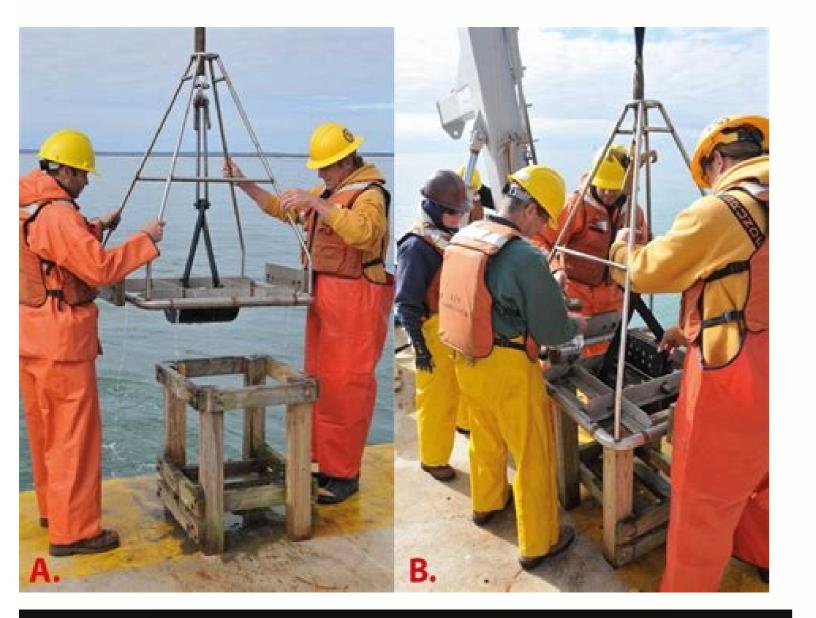




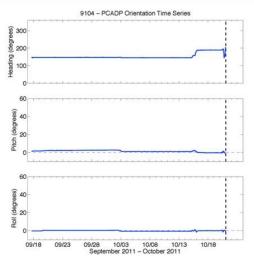
36421138043 34713200.510638 76802756.958333 36356276.5 2964733.9027778 16892293.888889 6184646.173913 68112604035 2274167826 165213714.2 5672164.9462366 112962828187 13360792.909091 160219576614 133536848.3125 44670581802 50292922.789474 103322463496 180928918.66667 12839156.362637

Introduction to optics pedrotti pdf full pdf format

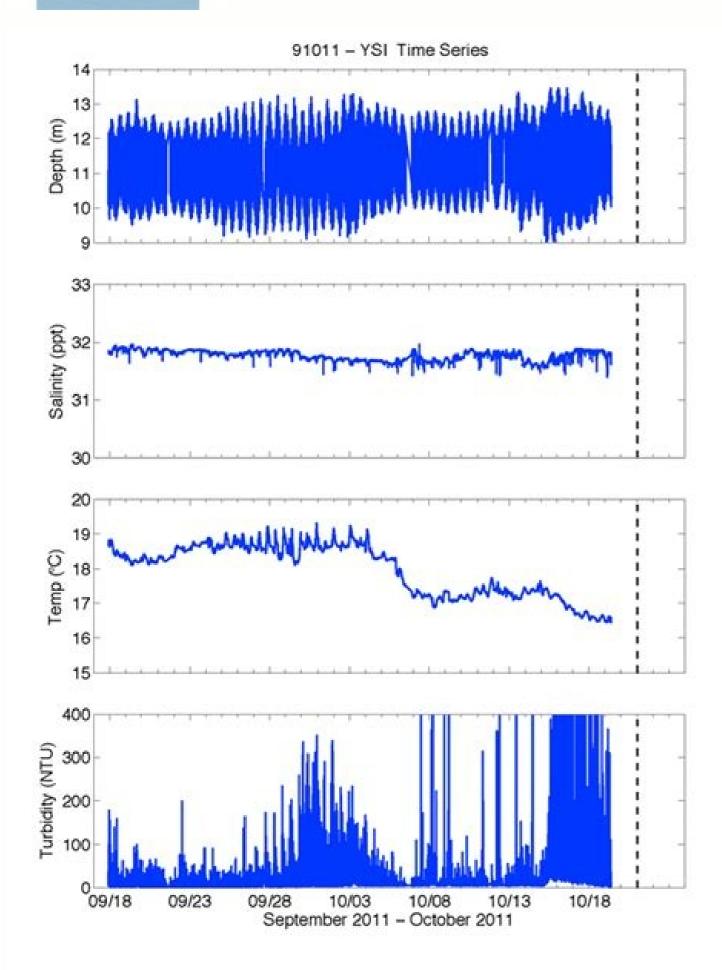


KAREN ROSE DESTODES LIERZIE GELESEN VON Gabriele Blum DL





INTRODUCTION TO OPTICS ALL SCHOOL & LAND & L



Why is fiber optics best for long distances. What is fiber optics used for. What is fiber optics made of.

Therefore, the ratio of the likelihood that a hydrogen atom will have energy E2 to the likelihood it will have energy E1 is a factor of 8 larger than the fraction given here. Mach-Zehnder Fiber Interferometers We will show here that a Mach-Zehnder fiber interferometer can be used to demultiplex (and multiplex) an optical signal containing a number of different wavelength channels. An object is placed (3/2)f from 27 A lens is moved along the optical axis between a fixed object and a fixed image screen. 7 The angular diameter of the sun viewed from the earth is approximately 0.5 degree. Here TEM stands for transverse electric and magnetic. (b) Cutaway view of a 35-mm camera, revealing the multiple element lens. Boston: Adam Hilger Ltd., 1986. Replacing p > 2 by 1 - p > 22 in Eq. (8) gives the normalized Jones vector, 'E0 = 1 d 22 - i 1 c t T/8 Ey A sin p/4 Ex A cos p/4 (c) the tip of the resultant vector traces out a circle of radius A. A Fourier analysis of the square function gives the Fourier series f1Y2 = 2 1 1 1 + acos kY - cos 3kY + cos 5kY + A b p 2 3 5 (24) Here we find a constant 1k = 02 term of 12 corresponding to the DC component or central spot of the diffraction pattern; a term with higher odd harmonics, 3k1, 5k1, Á. Karim, Mohammad A. Fizeau fringes result. The lens is 1 cm thick and has a refractive index of 1.50. The preceding discussion is but an introduction to the important role that polarization plays in light propagation through optical fibers. 4 Here we simply conclude by noting that birefringent fibers can be used to make quarterand half-wave "plates" and plays of liquid crystal molecules Vertical polarization Polarizing sheet (Vertical transmission axis) Horizontal scratches Horizontal scratches Light polarization Liquid crystal Glass plate Transmitted light Polarizing sheet (Horizontal transmission axis) (a) Vertical scratches Orientation of liquid crystal molecules Horizontal scratches Light polarization Unpolarized light Vertical polarization Vertical polarization Polarizing sheet (Vertical transmission axis) No transmitted light Liquid crystal Glass plate Twisted nematic cell Glass plate Polarizing sheet (Horizontal transmission axis) Applied voltage (b) Figure 9 Operation of a liquid-crystal display (LCD). That is, the wavefront is planar at the beam waist. The mirrors are attached to hanging mounts, which approximate free masses. 34 The primary mirror of a Cassegrain reflecting telescope has a focal length of 12 ft. However, the laser power is concentrated in a monochromatic directional beam of small cross-sectional area and so laser irradiances can be very high. For calcite, for example, n 7 n 7, so that y 6 y7 : The Huygens' wavelet for the extraordinary ray is not spherical as in isotropic media but ellipsoidal as shown, with major axis proportional to y7 and minor axis proportional to y7. What is the average illuminance of the parallel beam reflected from the mirror, assuming an overall reflectance of about 80%? The results of problem 5 will be helpful. In Figure 6, the intersection of several bright fringe surfaces with a plane that includes the two sources is shown, each surface corresponding D B D B S1 D B S2 Figure 5 Alternating bright and dark interference fringes are produced by light from two coherent sources. In 1926, the chemist Gilbert Lewis suggested the name "photon" for the "quantum of light" and it has been so identified ever since. (21) and (22) to form the last term in Eq. (24). (a) Right-angle prism. For A = 30°, the error is about 5%. Although their amplitudes vary with time, all pass through zero at the fixed nodal points. To record these phase relationships as well, it is necessary to convert phase information into amplitude information. The law of reflection ensures that pairs of triangles like SNP and S¿NP are equal, so all reflected rays appear to originate at the image distance S?N equals the object distance SN. This version of a grating spectrograph allows more compact construction than does the Paschen-Runge design. If the two object positions are S1 and S2 and if the transverse magnifications of the image are M1 and M2, respectively, show that the focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the image are M1 and M2, respectively, show that the focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the image are M1 and M2, respectively, show that the focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length of the lens is given by f = a 1S2 - S12 30 Determine the ratio of focal length side. The forward beam shows the same polarization as the incident light. 42 Chapter 2 Geometrical Optics 11 NEWTONIAN EQUATION FOR THE THIN LENS When object and image distances are measured relative to the focal points F of a lens, as by the distances x and x? in Figure 26, an alternative form of the thin-lens equation results, called the Newtonian form. Moreover, D = af>a0 is the angular magnification. The equations yielded a prediction for the speed of an electromagnetic character. Determine the coherence length for second harmonic generation in KDP when subjected to pulsed ruby laser light at 10 = 694 nm. The choice of label will depend on the manner in which the radiation is either produced or used. What is the rotation due to optical activity by a halfwave plate of quartz using the same light beam? Applying Rule 2 to Figure 15, we see that the general Eq. (12) becomes identical with Eq. (11), a special case derived in conjunction with Figure 15. The ability to control the temporal delivery of laser energy is important in a wide variety of applications, including materials processes, and laser fusion technology. With the help of the Law of Malus, determine the value of N such that the final transmitted irradiance is IN = 0.9 IO when the small angle

offsets sum to 90°, that is when the initial vertical polarization is rotated to a horizontal polarization. It will suffice to consider the simple case when both S and P are located on the central axis through the aperture, as in Figure 2. That is, b>2 EP = 3 dEp = EL i1kr0 - vt2 eiks sin u ds r0 L-b>2 (4) slit Integration gives EP = EL i1kr0 - vt2 eiks sin u b>2 eiks sin u b>2 eiks sin u ds r0 L-b>2 (4) slit Integration gives EP = EL i1kr0 - vt2 eiks sin u b>2 eiks sin u b>2 eiks sin u ds r0 L-b>2 (4) slit Integration gives EP = EL i1kr0 - vt2 eiks sin u b>2 eiks sin u b>2 eiks sin u ds r0 L-b>2 (4) slit Integration gives EP = EL i1kr0 - vt2 eiks sin u b>2 a b r0 ik sin u -b>2 (5) Inserting the limits of integration into Eq. (5), $EP = EL i1kr0 - vt2 e1ikb sin u^2 - e -1ikb sin u^2 + e -1ikb$ Euler's equation to obtain the last equality. Generally, this phenomenon alters the shape of the information-carrying pulses in a communications system. Opaque bodies that are promising candidates range from the human body to archeological tombs. 419 420 Chapter 19 Optics of the Eye Conjunctiva Sclera Ora servata Cillary body Iris Anterior chamber Cornea Lens Posterior chamber Choroid Retina Fovea centralis Optic nerve Canal of Schlemm Conjunctiva Figure 1 Vertical cross section of the eye. Leighton, and Matthew Sands. The two-beam approximation works well, then, if the amplitude of the first beam. Rayleigh scattering, with its characteristic 1>14 dependence, occurs from localized variations in the density or refractive index of the core material. We have, in effect, added an optical filter of Figure 5. 77 Optical Instrumentation This condition is met, therefore, when the lenses are separated by the distance 1 1 1 c + d 2 K11n - 12 K21n - 12 L = or, more simply, when L = 121f1 + f22 (39) This condition is valid independent of the lens shapes, leaving the choice of shapes as latitude for compensating other aberrations. y_1x , t2 = A > 1Bx2 - t2 y = 2 (100 m)e[x/m - 20(x/m)(t/s) + 100 t2/s2] x/m - 10 t/s 5 A harmonic traveling wave is moving in the negative zdirection with an amplitude (arbitrary units) of 2, a wavelength of 5 m, and a period of 3 s. (b) External energy source, or pump. 1 1 1 + ∞ = s1 s1 f or s1 ∞ = m1 = -12521152 s1f = = + 37.5 cm s1 - f 25 - 15 s1 ∞ 37.5 cm to the right of the first lens, inverted (because m is negative), and 1.5 times the size of the object. Accordingly, we define \neq 1t2 K 8E1t2E...1t + t29 (25) Note that this correlation function, which determines the size of the interference term, depends on the amount of correlation that exists in the values of the source field at two different times. How far behind the last surface must the film plane occur to focus paraxial rays? Another solution for zero longitudinal chromatic aberration results if one uses two separated lenses 1L Z 02 of the same glass 1n1 = n2 = n2. 366 Chapter 15 Production of Polarized Light y E E u b u x E Suppose that the active medium is one for which k^c 7 k^p, which also means that n^c 7 n^p and y^c 6 y^p. 13 A perfectly diffuse, or Lambertian, surface has the form of a square, 5 cm on a side. In Figure 2a, vertically -q 51 Thus, s = 51 cm. A plot of irradiance I versus phase d, in Figure 2a, exhibits periodic fringes. The device is effective over a wide range of wavelengths. Other fibers return the image. Cagnet, M. The result is +q f1t2 = a cne-invt q (5) n=- where now the coefficients are given by cn = 1 T Lt0 t0 + T f1t2einvt dt (6) In cases where we wish instead to represent a nonperiodic function (cleverly interpreted mathematically as a periodic function whose period T approaches infinity), it is possible to generalize the Fourier series to a Fourier integral. What is the wavelength corresponding to the fundamental frequency? If the field strength is not uniform across the slit, then the Fraunhofer diffraction pattern is the Fourier transform of the function that describes the field strength at various points within the aperture. The arc lamps provide pump energy to create the population inversion. In materials that crystallize in the trigonal (like calcite), tetragonal, or hexagonal systems, there is one unique direction through the crystal for which the atoms are arranged symmetrically. Of course, there are no negative irradiances. Assuming that the two interfering beams are of equal amplitude, the irradiance of the fringe system of circles concentric with the optical axis is given by d I = 410 cos2 a b 2 (2) 195 Optical Interferometry where the phase difference is d = k¢ = a 2p b¢ l (3) The net optical path difference is ¢ = ¢ p + ¢ r , as usual. This region of approximation is called geometrical optics. 6 a. The hyperboloidal surface permits perfect imaging between the primary and secondary focal points, which function as the foci of the lens. The factor by which ¢u exceeds the beam divergence is a practically useful number of resolvable spots." This serves as a figure of merit, giving the number of resolvable spots." This serves as a figure of merit, giving the number of resolvable spots." centimeter are required for a 2-m radius, concave grating that is to have a plate factor of around 2 nm/mm in first order? Each half-period zone is subdivided into 15 subzones. If a grating with only 400 grooves is available, (a) what is the lowest order possible in which the D lines are resolved and (b) how wide does the grating have to be? Until the ^c mode arrives, E rotates at this point according to the circular polarization of the P mode acting alone. Rays 1 and 2 are in a vertical plane and pass through points C and D of the zone, whereas rays 3 and 4 are in a horizontal plane and pass through points C and D of the zone. A count ¢m of the net fringe shift is related to the change in optical path during the decrease of the gas pressure. Most fiber-optical communication systems use signals of powers significantly less than this and so do not suffer significantly less than this and so do not suffer significantly less than this and so do not suffer significantly less than this and so do not suffer significantly less than this and so do not suffer significantly less than this and so do not suffer significantly less than this and so do not suffer significantly less than this and so do not suffer significantly less than this and so do not suffer significantly less than this and so do not suffer significantly less than this and so do not suffer significantly less than this and so do not suffer significantly less than this and so do not suffer significantly less than the fixed. that the two-focal lengths have the same magnitude if the lens is surrounded by a single refractive medium, so that n = n₂. B 6 B 4 B0 B 2 B 5 Fourier Optics sensitive only to irradiances, the detector measures a quantity proportional to the square of the correlation. Law of Reflection When a ray of light is reflected at an interface dividing two optical media, the reflected ray remains within the plane of incidence, and the angle of reflection ur equals the angle of incidence ui . The measured velocity of the constituent waves. The first contributing zone is therefore the second zone, and by the same arguments as those just used, we conclude that light of amplitude a 2>2 occurs at P. In the Newtonian design (a), a parabolic mirror is used to focus accurately all parallel rays to the same primary focal point, fp . We shall extend the previous numerical example, is capable of both absorbing and emitting a photon. Figure 2b shows the angular spread of the continuous spectrum of visible light for a particular grating. Here "larger particles" refers to the size of the scattering particle relative to the wavelength of light. 417 Matrix Methods in Paraxial Optics 3 A biconcave lens has radii of curvature of 20 cm and 10 cm. Photographs of single-aperture diffraction patterns for rectangular and square apertures are shown in Figure 5c and d. g(n) gth gth nfsr n0 (a) n nfsr n0 (b) n Laser Operation laser output can consist of frequencies corresponding to several different cavity modes in a laser using an inhomogeneously broadened gain medium. 5 FABRY-PEROT TRANSMISSION: THE AIRY FUNCTION The irradiance transmitted through a Fabry-Perot interferometer can be calculated with the help of analysis used to treat the parallel plate arrangement. The positive sign indicates that the image is real and so is located to the right of the surface, where real rays of light are refracted. Using the equation of a circle, we calculate the length x at height s to be given by x = 2 2R 2 - s2 where R is the aperture radius. 60 Chapter 3 Optical Instrumentation P V R V R fV TCA fR LCA (a) (b) Figure 7 Chromatic aberration (exaggerated) for (a) parallel rays of white light incident on a thin lens and (b) white light incident on a thin lens from an off-axis point P. 2 CRITERION FOR FRESNEL DIFFRACTION restablish a practical criterion that determines when we should use Fresnel techniques rather than the simpler Fraunhofer treatment already presented. Example 4 Let the wavelength of the light be 500 nm and the slit of Figure 15a be 1 mm in width. The refractive index, however, depends on the wavelength, so that it would be better to write nl for this quantity. What is the coefficient of finesse of the instrument? In reality, light from each object point is spread out over its conjugate image point, due to diffraction and aberration. power = u1Ac ¢t2 energy u ¢V = = = ucA ¢t ¢t (36) or the power transferred per unit area, S, is S = uc (37) 107 Wave Equations We now express the energy density u in terms of E and B, as follows, making use of Eqs. The transverse dimension of a Gaussian beam, described by the spot-size parameter w(z) thus changes at it propagates. Chapter 18 Brouwer, William. When the correction is nearly perfect throughout the visual spectrum, the objectives are said to be apochromatic. Note that in Table 2 there are two rows each for
the FSR and FWHM: The values in one set are pertinent when the transmittance varies as a result of changing the mirror spacing d, and the values in the other set apply when the transmittance varies as a result of changing to a lens with shorter focal length. 412 Chapter 18 Matrix Methods in Paraxial Optics 2 2 1 q 3 F1 VI RO N1 N2 H1 H2 1 F2 p 3 s Figure 15 Ray construction for a hemispherical lens, using cardinal points. Figure 7 illustrates the "bending," or change in shape, of a lens as its radii of curvature vary but its focal length remains fixed. This is most easily confirmed by looking through a piece of polarizing filter while rotating itBabout the propagation direction of the reflected light. Five years later, in the same year that he published his theory of special relativity, Albert Einstein offered an explanation of the photoelectric effect, the emission of electrons from a metal surface when irradiated with light. Show that the group velocity for short-wavelength waves is 3>2 their phase velocity. Mach-Zehnder Interferometer A more radical variation, sketched in Figure 5, is the Mach-Zehnder interferometer. Also, the image circles decrease in size, producing a clearer image. 9 Consider a slab waveguide of AlGaAs for which n1 = 3.60 and n2 = 3.55. A small, central hole is drilled through the pole pieces to allow passage of a linearly polarized He-Ne laser beam through the sample and parallel to the magnetic field direction. Recall that according to Huygens, a point source of secondary wavelets could radiate with equal effectiveness without regard to direction. Other modes—exist that do not have a pure Gaussian profile for their irradiance variation in the transverse plane. Neither this plane nor the groove separation has been altered in going from (a) to (b) in either Figure 4 or 5. The angular magnification3 of the simple magnification3 of t KD2PO4 1KD * P2 1NH42H2PO4 (ADP) l = 0.6 mm ZnS (zinc sulfide) lmaterials have more than one electro-optic coefficient. E = 5E01xN - iyN 2ei1kz + vt2 4 Two linearly polarized beams are given by E1 = E02 A 23xN + yN B cos1kz - vt2 and B E2 = E02 A 23xN + yN B cos1kz - vt2 and B E2 = E02 A 23xN + yN B cos1kz - vt2forming the dot product of their vector amplitudes. The likelihood Pi that a given atom in this assembly will be in one of the states of energy E1, kB = 1.38 * 10-23 J>K = 8.62 * 10-5 eV>K is Boltzmann's constant, and the temperature is measured in Kelvins. Recall the one-dimensional Fourier transform pair: +q 1 f1x2 = g1k2e -ikx dk 2p L-q (1) +q g1k2 = L-q f1x2eikx dx (2) Equation (1) states that an arbitrary, nonperiodic function f(x) can be synthesized by summing a continuous distribution of plane waves with amplitude distribution g(k) given by Eq. (2). 11 The separation of a certain doublet is 0.0055 nm at a wavelength of 490 nm. Still, they are useful forms that approximate the wave. Before turning our full attention to a Gaussian beam, it is useful, for comparison purposes, to consider the nature of the surfaces of constant phase for a spherical wave, such as the one described by Eq. (5) and shown in Figure 4. C. For n = 1.85 [curve (c)], two minima near R = 0 appear. This situation is illustrated in Figure 4. C. For n = 1.85 [curve (c)], two minima near R = 0 appear. laser through a nonlinear crystal. For example, a mirror movement of 0.5 cm, producing a total path difference or window of 1 cm, results in a resolution of 0.025 nm. Assume an objective focal length of 15 cm and a field lens (eyepiece) diameter of 1.50 cm. 10 A glass hemisphere is silvered over its curved surface. Actually, the Kerr effect was the first electro-optic effect to be discovered (1875). Light from a point Q on the source plane S¿ then effectively reflects from both mirrors M2 and M1¿, shown parallel and with an optical path difference of d. To understand the effect of blazing, consider Figure 4 for a transmission grating and Figure 5 for a reflection grating. PEDROTTI This page intentionally left blank PHYSICAL CONTSTANTS Speed of light $c = 2.998 \times 10-31$ kg Planck constant $h = 6.626 \times 10-34$ Js Boltzmann constant $k = 1.3805 \times 10-23$ J/K Permittivity of vacuum $0 = 8.854 \times 10-12$ C2/N-m2 Permeability of vacuum 0 = 4 × 10-7 T-m/A This page intentionally left blank List of Tables 3.1 Fraunhofer Lines 64 Table 3.1 Fraunhofer Lines 64 Tab Figures of Merit 217 Table 8.2 Fabry-Perot Parameters 217 Table 10.1 Characterization of Several Optical Fibers 248 Table 12.1 Fabry-Perot Integrals 323 Table 14.1 Summary of Jones Vectors 340 Table 14.2 Summary of Jones Vectors 340 Table 15.1 Refractive Indices for Several Materials 359 Table 15.2 Specific Rotation of Quartz 364 Table 15.3 Refractive Indices for Quartz 366 Table 18.1 Summary of Some Simple Ray-Transfer Matrix Elements 410 Table 18.3 Meridional Ray-Transfer Matrices 404 Table 18.2 Cardinal Point Locations in Terms of System Matrix Elements 410 Table 18.3 Meridional Ray-Transfer Matrices 404 Table 18.3 Meridional Ray-Transfer Matrix Elements 410 Table 18.3 Meridional Ray-Transfer Matrices 404 Table 18.3 Meridional Ray-Transfer Matrix Elements 410 Table 18.4 Meridional Ray-Transfer Matrix Elements 410 Meridional Ray-Transfer Matrix El vi List of Tables Table 19.2 Constants of a Schematic Eye 425 Table 20.1 Sample of Optical Glasses 455 Table 22.2 Reflectance of a High-Low Quarter-Wave Stack 488 Table 24.1 Linear and Nonlinear Processes 517 Table 24.2 Linear Electro-optic Coefficients for Representative Materials 519 Table 24.3 Kerr Constant for Selected Materials 525 Table 26.1 Laser Diode Wavelengths 578 Contents 1 2 Physical Constants iii List of Tables v Nature of Light 1 Introduction 1 1.1 A Brief History 2 1.2 Particles and Photons 4 1.3 The Electromagnetic Spectrum 6 1.4 Radiometry 11 Problems 15 Geometrical Optics 16 Introduction 16 2.1 Huygens' Principle 20 2.3 Principle 20 2.3 Principle 20 2.3 Principle 20 2.3 Reflection at a Spherical Surface 27 2.8 Reflection at a Spherical Surface 32 2.9 Thin Lenses 35 2.10 Vergence and Refractive Power 39 2.11 Newtonian Equation for the Thin Lens 42 2.12 Cylindrical Lenses 42 Problems 46 Optical Instrumentation 50 3.2 A Brief Look at Aberrations 58 3.3 Prisms 60 3.4 The Camera 69 3.5 Simple Magnifiers and Eyepieces 75 3.6 Microscopes 79 3.7 Telescopes 82 Problems 89 Wave Equations 94 4.1 One-Dimensional Waves 100 4.5 Plane Waves 102 4.7 Other Harmonic Waves 103 4.8 Electromagnetic Waves 104 4.9 Light Polarization 108 ix 4.10 5 6 7 Doppler Effect 110 Problems 111 Superposition of Waves 113 Introduction 113 5.1 Superposition Principle 113 5.2 Superposition of Waves of the Same Frequency 114 5.3 Random and Coherent Sources 119 5.4 Standing Waves 120 5.5 The Beat Phenomenon 123 5.6 Phase and Group Velocities 125 Problems 129 Properties of Lasers 131 Introduction 131 6.1 Energy Quantization in Light and Matter 132 6.2 Thermal Equilibrium and Blackbody Radiation 135 6.3 Nonlaser Sources of Electromagnetic Radiation 143 6.5 Essential Elements of a Laser Types and Parameters 158 Problems 161 Interference of Light 163 Introduction 163 7.1 Two-Beam Interference in Dielectric Films 175 x 8 9 Contents 7.5 Fringes of Equal Thickness Measurement by 7.5 Fringes of Equal Thickness Measurement 169 7.3 Double-Slit Experiment 169 7.3 Double-Slit Experiment 169 7.4 Interference in Dielectric Films 175 x 8 9 Contents 7.5 Fringes of Equal Thickness Measurement by 7.5 Fringes of Equal Thickness Measurem Interference 182 7.8 Stokes Relations 184 7.9 Multiple-Beam Interferometer 193 8.2 Applications of the Michelson Interferometer 193 8.2 Fabry-Perot Interferometer 193 8.5 Fabry-Perot Interferometer 195 Perot Transmission: The Airy Function 201 8.6 Scanning Fabry-Perot Interferometer 206 8.7 Variable-Input-Frequency Fabry-Perot Interferometers 211 8.8 Lasers and the Fabry-Perot Education 224 9.1 Fourier Analysis 224 9.2 Fourier Analysis of a Finite Harmonic Wave Train 228 9.3 Temporal Coherence and Line Width 230 9.4 Partial Coherence 237 9.6 Spatial Coherence 237 9.6 Spati Propagation 246 10.5 Allowed Modes 249 10.6 Attenuation 253 10.8 High-Bit-Rate Optical-Fiber Communications 260 Problems 264 Fraunhofer Diffraction 267 11.1 Diffraction 267 11.3 Rectangular and Circular Apertures 274 11.4 Resolution 253 10.8 High-Bit-Rate Optical-Fiber Communications 260 Problems 264 Fraunhofer Diffraction 267 11.1 Diffraction 267 11.2 Beam Spreading 273 11.3 Rectangular and Circular Apertures 274 11.4 Resolution 253 10.8 High-Bit-Rate Optical-Fiber Communications 260 Problems 264 Fraunhofer Diffraction 267 11.1 Diffraction 267 11.2 Beam Spreading 273 11.3 Rectangular and Circular Apertures 274 11.4 Resolution 253 10.8 High-Bit-Rate Optical-Fiber Communications 260 Problems 264 Fraunhofer Diffraction 267 11.2 Beam Spreading 273 11.3 Rectangular and Circular Apertures 274 11.4 Resolution 267 11.5 Double-Slit Diffraction 267 11.2 Beam Spreading 273 11.3 Rectangular and Circular Apertures 274 11.4 Resolution 267 11.5 Double-Slit Diffraction 267 11.2 Beam Spreading 273 11.3 Rectangular and Circular Apertures 274 11.4 Resolution 267 11.5 Double-Slit Diffraction 267 11.2 Beam Spreading 273 11.3 Rectangular and Circular Apertures 274 11.4 Resolution 267 11.5 Double-Slit Diffraction 267 11.2 Beam Spreading 273 11.3 Rectangular Approximation 267 11.3 Rectangular Approximation 267 11.3 Rectangular Approximation 267 11.3 Rectangular Approximation 267 11.4 Rectangular Approximation 267 11.3 Rect 281 11.6 Diffraction from Many Slits 284 Problems 289 The Diffraction Grating 295 12.4 Resolution of a Grating 295 12.7 Grating 295 12.4 Resolution of a Grating 295 12.7 Gratin Interference Gratings 302 12.9 Grating Instruments 303 Problems 305 Fresnel Diffraction 308 13.1 Fresnel Diffraction 308 13.1 Fresnel Diffraction 308 13.2 Criterion for Fresnel Diffraction 308 13.2 Criterion for Fresnel Diffraction 308 13.2 Criterion for Fresnel Diffraction 308 13.2 Criterion 40.0 End of the Diffraction 308 13.2
Criterion for Fresnel Diffraction 308 13.2 Criterion for Fresnel Diffraction 308 13.2 Criterion 40.0 End of the Diffraction 30.0 End of the Diffrac Plate 316 13.7 Fresnel Diffraction from Apertures with Rectangular Symmetry 318 13.8 The Cornu Spiral 320 13.9 Applications of the Cornu Spiral 321 Matrix Treatment of Polarized Light: Jones Vectors 334 14.2 Mathematical Representation of Polarized Light: Jones Vectors 334 14.2 Mathematical Representation 333 Introduction 333 Introduction 333 Introduction 333 Introduction 333 Introduction 333 Introduction 333 Representation of Polarizers: Jones Matrices 341 Problems 347 Production of Polarization by Scattering 355 15.4 Birefringence: Polarization by Reflective Absorption 350 15.1 Dichroism: Polarization by Scattering 355 15.4 Birefringence: Polarization by Reflective Absorption 350 15.2 Polarization by Scattering 355 15.4 Birefringence: Polarization by Scattering 355 15.4 Birefringence: Polarization by Reflective Absorption 350 15.1 Dichroism: Polarization by Scattering 355 15.4 Birefringence: Polarization by Scattering 355 15.4 Birefringence: Polarization by Scattering 355 15.4 Birefringence: Polarization by Reflective Absorption 350 15.2 Polarization by Scattering 355 15.4 Birefringence: Polarization by Scatteringence: Polarization by Scattering 355 15.4 Birefring Refraction 361 xiii 16 17 18 15.6 Optical Activity 363 15.7 Photoelasticity 367 Problems 369 Holography 372 Introduction 372 16.3 Hologram of a Point Source 373 16.3 Hologram of a Point Source 373 16.3 Hologram of a Point Source 373 16.4 Holography 372 16.2 Hologram of a Point Source 373 16.3 Holography 372 Introduction 372 16.4 Holography 372 16.2 Holography 372 16.4 Holography 372 Holography 372 Holography 372 Holography 372 16.4 Holography 372 Holography 372 Holography 372 Holography 372 Holography 372 Applications of Holography 381 Problems 384 Optical Detectors and Displays 386 Introduction 386 17.1 Thermal Detectors: Noise and Sensitivity 390 17.5 Optical Displays 391 Problems 394 Matrix Methods in Paraxial Optics 396 Introduction 396 18.1 The Thick Lens 396 18.2 The Matrix 400 18.4 The Refraction Matrix 400 18.5 The Reflection Matrix 400 18.5 The Reflectio System 408 18.10 Examples Using the System Matrix and Cardinal Points 410 18.11 Ray Tracing 412 Problems 416 Optics of the Eye 424 19.4 Functions of the Eye 425 19.5 Vision Correction with External Lenses 428 19.6 Surgical Vision Correction 434 Problems 436 Aberration Theory 438 Introduction 438 20.1 Ray and Wave Aberrations 439 20.2 Third-Order Treatment of Refraction at a Spherical Interface 440 20.3 Spherical Aberrations 439 20.2 Third-Order Treatment of Refraction at a Spherical Interface 440 20.3 Spherical Aberration 451 Problems 456 Fourier Optics 21.1 458 Introduction 458 Optical Data Imaging and Processing 459 xv 21.2 22 23 24 Fourier-Transform Spectroscopy 471 Problems 476 Introduction 476 22.1 Transfer Matrix 477 22.2 Reflectance at Normal Incidence 481 22.3 Two-Layer Antireflecting Films 486 22.5 High Reflective Layers 486 Problems 489 Fresnel Equations 491 23.1 The Fresnel Equations 491 23.2 External and Internal Reflection 499 23.4 Conservation of Energy 502 23.5 Evanescent Waves 504 23.6 Complex Refractive Index 506 23.7 Reflection from Metals 507 Problems 508 Nonlinear Optics and the Modulation of Light 510 Introduction 510 24.1 The Nonlinear Medium 511 24.2 Second Harmonic Generation and Frequency Mixing 513 24.3 Electro-Optic Effect 526 24.6 Optical Phase Conjugation 529 xvi Contents 24.7 25 26 27 Optical Nonlinearities in Fibers 531 Problems 533 Optical Properties of Materials 535 Introduction 535 25.1 Polarization of Light Waves in a Metal 544 25.5 Skin Depth 545 25.6 Plasma Frequency 546 Problems 548 Laser Operation 549 Introduction 549 26.1 Rate Equations 549 26.2 Absorption 553 26.3 Gain Media 557 26.4 Steady-State Laser Output 561 26.5 Homogeneous Broadening 564 26.6 Inhomogeneous Broadening 567 26.10 Diode Lasers 577 Problems 579 Characteristics of Laser Beams 582 Introduction 582 27.1 Three-Dimensional Wave Equation and Electromagnetic Waves 582 27.2 Gaussian Beams 583 xvii 27.3 Spot Size and Radius of Curvature of a Gaussian Beams 587 27.5 Modes of Spherical Mirror Cavities 591 27.6 Laser Propagation Through Arbitrary Optical Systems 593 27.7 Higher-Order Gaussian Beams 600 Problems 605 References 607 Answers to Selected Problems 611 This page intentionally left blank 1 Nature of Light "They could but make the best of it and went around with woebegone faces, sadly complaining that on Mondays, Wednesdays, and Fridays, they must look on light as a wave; on Tuesdays, and Saturdays, as a particle. For certain positions of the object point O, it is then possible to find a real image point also to the left of the mirror. r 2r 3r Direction making an angle u with the normal to the radiating surface. 0.5 mm 546 nm Screen S Figure 22 Problem 14. When the optical system itself cannot produce the one-to-one relationship between object and image rays required for perfect imaging of all object points, we speak of system aberrations. 2 HOLOGRAM OF A POINT SOURCE To see how the process is realized in practice, both making the hologram and using the hologram to reconstruct the original scene, we begin with a very basic example, the hologram of a point source. 4 Figure 16 Single refraction. How many half-period zones are included in the annular ring in each case? The path difference between equivalent reflected rays of light from successive groove reflections is just the difference um () um 1 a ui () um 1 a ui () um 1 a ui () a sin um where both rays are assumed to have the great minds that championed one viewpoint or the other. For a single-mode He-Ne laser, the coherence length for the same laser is thousands of kilometers (compared with fractions of a centimeter for the sodium lamp). F. The radius of curvature R of an ordinary spherical wave can be related to its appropriate paraxial ray parameters y and a by R = y a (39) We know from matrix optics that when ray 1 is changed into ray 2 by an optical system matrix as follows: c y 2 A d = c a 2 C B y 1 d c d D a 1 (40) Then it must be true that $y^2 = Ay_1 + Ba_1$ and $a^2 = Cy_1 + Da_1 (41)$ Dividing the the basic result in Eq. (42) to a Gaussian spherical wave, by replacing R(z) with q(z), we obtain at once q2 = Aq1 + B Cq1 + D ABCD propagation law R1 R2 A B C D Figure 9 Propagation of ordinary spherical waves through an arbitrary optical system via the second, and using Eq. (39), we obtain R2 = AR1 + B CR1 + D (42) Generalizing matrix formulation. Mirror 1 Mirror 2 593 Characteristics of Laser Beams 6 LASER PROPAGATION THROUGH ARBITRARY OPTICAL SYSTEMS With the basic law of propagation for the complex radius of curvature q(z) in Eq. (14) and the defining equations for the real radius of curvature R(z) and beam width w(z) in Eqs. These can be tabulated as follows: Input First surface: n = 1, $n_{\xi} = 1.521$ a = 0 h = 1 or 5 R = -120.8 Second surface: t = 6 n = 1.581 R = -34.6 Third surface: t = 3 n = 1 R = -51.2 Results: ray at h = 5 Q a_{\xi} s_{\xi} Q_{\xi} = = = = 1 0.1625^\circ - 352.66 1.0000 Q a_{\xi} s_{\xi} Q_{\xi} = = = = 5 0.8128^\circ - 352.53 5.0010 Q a_{\xi} s_{\xi} Q_{\xi} = = = = 5 0.8128^\circ - 352.53 5.0010 Q a_{\xi} s_{\xi} Q_{\xi} = = = = 1 0.1625^\circ - 352.66 1.0000 Q a_{\xi} s_{\xi} Q_{\xi} = = = = 5 0.8128^\circ - 352.53 5.0010 Q a_{\xi} s_{\xi} Q_{\xi} = = = = 5 0.8128^\circ - 352.53 5.0010 Q a_{\xi} s_{\xi} Q_{\xi} = = = = 5 0.8128^\circ - 352.53 5.0010 Q a_{\xi} s_{\xi} Q_{\xi} = = = = 5 0.8128^\circ - 352.53 5.0010 Q a_{\xi} s_{\xi} Q_{\xi} = = = = 5 0.8128^\circ - 352.53 5.0010 Q a_{\xi} s_{\xi} Q_{\xi} = = = = 5 0.8128^\circ - 352.53 5.0010 Q a_{\xi} s_{\xi} Q_{\xi} = = = = 5 0.8128^\circ - 352.53 5.0010 Q a_{\xi} s_{\xi} Q_{\xi} = = = = 5 0.8128^\circ - 352.53 5.0010 Q a_{\xi} s_{\xi} Q_{\xi} = = = = 5 0.8128^\circ - 352.53 5.0010 Q a_{\xi} s_{\xi} Q_{\xi} = = = = 5 0.8128^\circ - 352.53 5.0010 Q a_{\xi} s_{\xi} Q_{\xi} = = = = 5 0.8128^\circ - 352.53 5.0010 Q a_{\xi} s_{\xi} Q_{\xi} = = = 5 0.8128^\circ $1.0170\ 0.2202^\circ - 264.59\ 1.0170\ Q$ at st $Q_t = = = 5.0861\ 1.1041^\circ - 264.03\ 5.0876\ Q$ at st $Q_t = = = 1.0247\ 0.2030^\circ - 289.26\ 1.0247\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = =
5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = 5.1261\ 1.0178^\circ - 288.58\ 5.1260\ Q$ at st $Q_t = = 5.1261\ 1.0178^\circ - 288.58\ 5.$ mm beyond the final surface, missing a common focus by 1.8 mm. eye (fully accommodated) and, again, a clear image is formed on the retina (Figure 5b). Mathematically, we are required to minimize the total time, t = AO OB + yi yt where yi and yt are the velocities of light in the incident and transmitting media, respectively. This last term is the interference term since its value determines whether the irradiance at P is more than, less than or equal to the sum of the irradiances of the fields being superposed. As a result, the charge oscillation in the geometry we have been describing, the electrodes are usually endrings that allow the light beam to pass through and still provide a reasonably uniform field in the crystal. The net phase differences that arise on reflection, as discussed previously. A classical derivation 12 of the angle of rotation b predicts a relation of the form b = a e l dn b Bd 2m c dl (14) with e and m the electronic charge and mass, c the speed of light, l the wavelength, and dn>dl the rotatory dispersion. If the net phase change that develops between points A and C is some multiple of 2p, then the interfering wavefronts experience constructive interference and corresponding ray directions are allowed. 8 By what percentage does the area of the 25th Fresnel halfperiod zone differ from that of the first, for the case when source and detector are both 50 cm from that of the first, for the case when source and detector are both 50 cm from that of the first, for the case when source and detector are both 50 cm from that of the first, for the case when source and the source supplies light at 500 nm? A typical lineshape function is shown in Figure 2. 158 Chapter 6 Properties of Lasers Laser energy focused onto small target areas makes it possible to drill tiny holes in hard, dense material, make tiny cuts or welds, make high-density recordings, and generally carry out industrial or medical procedures in target areas only a wavelength or two in size. Thus a "hologram," as its etymology suggests, includes the "whole message." The real-life qualities of the image provided by a hologram stem from the preservation of information relating to the phase of the wavefront in addition to its amplitude or irradiance. Bose-Einstein statistics impose no such prohibition, so that identical photons with the same energy, momentum, and polarization can occur together in large numbers, as they do, for example, in a laser cavity. These numbers give a coherence length of around 11 km! Under carefully controlled conditions, He-Ne lasers can improve this figure by another order of magnitude. As a result, the cavity will support fields with a narrow range of frequencies given in Eq. (15). What is the resolving power required? If the overall efficiency of this laser system is 0.05%, the total power used is Pused = 110 W2 > 15 * 10.42 = 2 * 104 W. Since the latter determines the speed of the waves. Calculate the expected change in refractive index at l = 0.53 mm. Making use of the fundamental relation k = 2p > l = 2pn > c, the round-trip phase shift d associated with an input field of frequency n can be written as $d = 2kd = 4p_{1n} > c_{2d}$ Thus, a record of the transmittance as a function of the transmittance as a functio frequencies of the Fabry-Perot cavity are nm = mc>2d (40) 212 Chapter 8 Optical Interferometry Note that we are assuming, here, that the index of refraction in a Michelson spectrometer is 5 cm. This is so provided that $k_3 = k_{32} + k_{31} + k_{30}$ and $k_2 = k_{21} + k_{20}$ Compare this result to the answer obtained for part (e) of problem 5. Indeed, in October of 2003, The Optical Society of America devoted a special issue, 1 a number of renowned scientists, through five penetrating essays, accepted the challenge of describing the photon. When N = 1 and N = 2, Eq. (32) reduces to the results obtained previously for single- and double-slit diffraction, respectively. Distinguishing now between the radiant exitance of the blackbody and the specimen are compared in various narrow wavelength intervals, a spectral emissivity is calculated, which is not, in general, a constant. Calculations show that in this case, the induced dipole oscillations show that in this case, the induced dipole oscillations have an amplitude that is roughly independent of the frequency v of the light. 19 A beam of white light (a continuous spectrum from 400 to 700 nm, let say) is incident at an angle of 45° on two parallel glass plates separated by an air film 0.001 cm thick. Assume that the prisms are thin and the condition of minimum deviation is satisfied. 580 Chapter 26 Laser Operation 8 Show that if the irradiance throughout a gain cell described by Eq. (41) is much less than the saturation irradiance IS, the output irradiance IL is related to the input irradiance IO by the simple relation IL = I0eg0L That is, show that, in the small-signal regime, the irradiance exhibits exponential growth. Conversely, adaptation from intensely bright vision." In the full process of adaptation, the scotopic response is active over light levels that range from starlight on a clear, moonless night to lunar light from a quarter-moon. 3 TWO-LAYER ANTIREFLECTING FILMS Durable coating materials with arbitrary refractive indices are, of course, not immediately available. N d O x x s2 The particular combination of shutter speed and relative aperture chosen for an optimum total exposure is not always arbitrary. The more rapidly the series converges, the fewer are the terms needed for an adequate fit. Lenses are tested for aberrations in the same way, once plane mirror M1 is replaced by a convex spherical surface that can reflect the refracted rays back along themselves, as suggested in the inset of Figure 4b. Calculate the phase difference of the light (of wavelength 488 nm) arriving at the detector from the two arms of the interferometer due to this gravitational strain, and use this result to estimate the detected power if the laser output power P0 is 10 W. 18. In this case, a L sNT K a0 (24) is a constant, independent of the irradiance of the input field. Michaels, D. Thus, 4 + s₂1 = 16 gives s₂ = - 12 cm. What is the special meaning of A in this case? When a polarizer giving zero intensity. Point image Axis F Lens Vertical fan of rays (a) Point image Axis F Lens Horizontal fan of rays (b) Figure 27 Parallel rays of light focused by a spherical lens. Adapted with permission.) OH absorption peak 1 Glass absorption at 0.95, 1.23, and 1.73 mm. Therefore, one can build lasers with a given beam-waist radius and, consequently, a given beam divergence. Determine the position of its focal and principal planes. In Table 1 we list relations involving some figures of merit for Fabry-Perot cavities. It had been assumed that light waves in a fluid, which cannot support transverse vibrations. Then calculate the irradiance at the same point. using Fresnel diffraction and the Cornu spiral. Chapter 2 Feynman, Richard P., Robert B. 3 The width of a rectangular slit is measured in the laboratory by means of its diffraction pattern at a distance of 2 m from the slit. Again, because the frequency, the beam can be frequency modulated. If the Pockels cell is preceded by an ordinary half-wave plate, what is the irradiance when V = 0 and when V = VHW? It lies buried in fat tissue inside the orbit, or space, in the skull surrounded by bony walls. It is possible to evaporate multiple layers while maintaining control over both refractive index (choice of material) and individual layer thickness. You should be familiar with two important harmonic (single-frequency) solutions to Eq. (3): plane waves and spherical waves. (f) Established steady-state laser operation. Horne, D. Since none of the actual rays of light lies below the mirror surface, the image is said to be a virtual image. The compromise is that the cos21ar22 transmittance is now superimposed over a nonzero minimum transmittance T0, and fringe contrast is somewhat reduced. What is the nominal wavelength of the light source? So, for the TE case, the phase shift on reflection is fTE = - 2a. Each point of the hologram receives light from every point of the scene or, to put it another way, every object point illuminates the entire hologram. In some applications, where white light is used, it is essential that the optical paths of the
two beams be made precisely equal. Image formation in a plane mirror is illustrated in Figure 8a. "Ordinary" light, such as that produced by a hot filament, is typically produced by a number of independent atomic sources whose radiation is not B synchronized. 7 GRATING REPLICAS The expense and difficulty of manufacturing gratings prohibit the routine use of grating masters in spectroscopic instruments. Find the mode-frequency separations: (a) n0,0,q + 1 - n0,0,q , (b) nm,n,q + 1 - n0,0,q , (c) n0,1,q - n0,0,q , (d) n1,0,q - n0,0,q , (d) n1,1,q - n0,0,q . a solid insulator is tightly bound to a given atom in the lattice that forms the solid. Palais, Joseph C. The image development is done by electrical and thermal means, without the need for wet chemical processing, and can be accomplished in a few seconds without repositioning the G1 G2 Figure 8 Deformations in the surface of the water due to two coherent ultrasonic waves. When no acoustic wave is applied, the beam (1) bounces back and forth in the laser cavity, building up energy to a maximum value. The transit time of a ray through a medium of thickness x with refractive index n is t = nx x = y c 27 Geometrical Optics y P(x, y) di do O V so I x si no ni Figure 12 Cartesian refracting surface which images object point O at image point I. No light is transmitted through the analyzer. The number of operations performed by a computer in calculating the spectral distribution I(k) is roughly equal to N 2. Refraction has been ignored. Compare this relation to the saturation irradiance for the ideal four-level gain medium given in Eq. (39) and account with a conceptual argument, for the factor of two difference between the two saturation irradiances. If the TA of the analyzer is now rotated by 90°, all components originally blocked are transmitted. Equating real and imaginary parts in $n^2 = 1 \cdot a v^2 p v^2 + iy g b$ (64) 2 vp g 2nRnI = a 2 b v v + g2 (65) These equations, solved simultaneously, permit calculation of curves such as those in Figure 3. Efficient diodes have a more complicated layered structure than does the simple p-n junction device illustrated in Figure 17. 338 Chapter 14 Matrix Treatment of Polarization Given a particular mathematical form of the vector, the actual character of the light polarization may not always be immediately apparent. Dow. (a) 3.45 D (b) 30.5 cm (a) -2.000 D (b) 30.5 cm (c) -2.083 D; 19.8 cm, 20 cm; 11.5 cm, 50.2 cm; 11.5 cm, 20 cm (b) Right eye: 11.5 cm, 50.2 cm; 11.5 cm; $11.5 \text{ c$ eye) Far vision: -7.41 D; Near vision: -6.10 D, (both for eye to lens distance of 1.5 cm) Chapter 20 2. When used under nonnormal incidence, however, it is possible to disperse light into only one diffracted order (other than the zeroth order), and it has been shown that in this case the distribution of light does not depend to a great extent on groove shape As seen from the center of the entrance pupil, the field stop (or its image) subtends the smallest angle. The angle of incidence that produces a linearly polarized beam Es by reflection is up , the polarizing angle, or Brewster's angle. 0.07 223 Optical Interferometry Beam splitter Fabry-Perot Laser Oxygen cell (a) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (a) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (a) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (a) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (a) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (a) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (a) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (a) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (a) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (a) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (b) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (b) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (b) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (b) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (b) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (b) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (b) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (b) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (b) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (b) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (b) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (b) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (b) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (b) Overlay of transmittance through the Fabry-Perot Laser Oxygen cell (b) Overlay of transmittance Perot and the oxygen cell Change in laser frequency (b) Figure 21 Problem 22. The image of a faraway object formed by the corrective lens will then be 100 cm in front of the eye so that the relaxed unaided eye can view it. (63) and (64) gives TE: cos u - 21n2R - n2I - sin2 u2 + i12nRnI2 Er = E cos u + 21n2R - n2I - sin2 u2 + i12nRnI2 (65) 508 Chapter 23 Fresnel Equations TM: - [n2R - n2I + i12nRnI2] cos u + 21n2R - n2I + i12nRnI2] cos u + i12nRnI2] In the process, we must take the square root of a complex number, which is done by first putting it into polar form. (b) Separated images of two incoherent point sources. Fringe maxima coincide with integral orders of m, and fringe minima fall halfway between adjacent maxima. Two positions of the lens are found for which an image is in focus on the screen, magnified in one case and reduced in the other. If an aperture placed in front of the lens is circular, these blur images are elliptical in shape, with changing major and minor axes formed by the width and height of the blur. ABE and ACD, which together constitute a prism of 60° apex angle. Each phasor is out of phase with its predecessor by 180° and is also shorter, due to the obliquity factor. Although detrimental in the case of cross talk in closely bound fibers lacking sufficient thickness of protective cladding, the frustration of the total internal reflection is put to good use in devices such as variable output couplers, made of two right-angle prisms whose separation along their diagonal faces can be carefully adjusted to vary the amount of evanescent wave coupled from one prism into the thickness of the active medium. Chapter 24 Butcher, P. The value of q2 derived with the aid of Eq. (43) then predicts both / and w0 for the externally focused beam waist. Analyzer at 45 Polarizer vertical Transmitted light Incident light Retropulse Retropulse Retropulse 45 rotation of polarization Figure 10 Faraday rotator used between a polarizer vertical Transmitted light Retropulse 45 rotation of polarizet vertical Transmitted light Retropulse 45 rotation of polarizet vertical Transmitted light Retropulse 45 rotation of polarizet vertical Transmitted light Retropulse Retropulse 45 rotation of polarizet vertical Transmitted light Retropulse 85 rotation isolation of the optical system providing the incident light. Power in the beam has been decreased. Solution The angular radius of the Airy disc is found using Eq. 21, ¢u1>2 = 1.221546 * 10-9 m2 1.221 = = 1.33 * 10-3 rad D 5 * 10-4 m The radius rd of the Airy disc is then found using Eq. 21, ¢u1>2 = 1.221546 * 10-9 m2 1.221 = = 1.33 * 10-3 rad D 5 * 10-4 m The radius rd of the Airy disc is found using Eq. 21, ¢u1>2 = 1.221546 * 10-9 m2 1.221 = = 1.33 * 10-3 rad D 5 * 10-4 m The radius rd of the Airy disc is found using Eq. 21, ¢u1>2 = 1.221546 * 10-9 m2 1.221 = = 1.33 * 10-3 rad D 5 * 10-4 m The radius rd of the Airy disc is found using Eq. 21, ¢u1>2 = 1.221546 * 10-9 m2 1.221 = = 1.33 * 10-3 rad D 5 * 10-4 m The radius rd of the Airy disc is found using Eq. 21, ¢u1>2 = 1.221546 * 10-9 m2 1.221 = = 1.33 * 10-3 rad D 5 * 10-4 m The radius rd of the Airy disc is found using Eq. 21, ¢u1>2 = 1.221546 * 10-9 m2 1.221 = = 1.33 * 10-3 rad D 5 * 10-4 m The radius rd of the Airy disc is found using Eq. 21, ¢u1>2 = 1.221546 * 10-9 m2 1.221 = = 1.33 * 10-3 rad D 5 * 10-4 m The radius rd of the Airy disc is found using Eq. 21, ¢u1>2 = 1.221546 * 10-9 m2 1.221 = = 1.33 * 10-3 rad D 5 * 10-4 m The radius rd of the Airy disc is found using Eq. 21, ¢u1>2 = 1.221546 * 10-9 m2 1.221 = = 1.33 * 10-3 rad D 5 * 10-4 m The radius rd of the Airy disc is found using Eq. 21, ¢u1>2 = 1.221546 * 10-9 m2 1.221 = = 1.33 * 10-3 rad D 5 * 10-4 m The radius rd of the Airy disc is found using Eq. 21, ¢u1>2 = 1.221546 * 10-9 m2 1.221 = = 1.33 * 10-3 rad D 5 * 10-4 m The radius rd of the Airy disc is found using Eq. 21, ¢u1>2 = 1.221546 * 10-9 m2 1.221 = = 1.33 * 10-3 rad D 5 * 10-4 m The radius rd of the Airy disc is found using Eq. 21, ¢u1>2 = 1.221546 * 10-9 m2 1.221 = = 1.33 * 10-3 rad D 5 * 10-4 m The radius rd of the Airy disc is found using Eq. 21, ¢u1>2 = 1.221546 * 10-9 m2 1.221 = 1.221546 * 10-9 m2 1.221546 * 10-9 m2 1.221546 * 10-9 m2 1.221546 * 10-9 m2 1 = L ¢u1>2 = 110 m211.33 * 10-32 = 0.013 m = 13 mm Fraunhofer Diffraction 279 The diameter Dd of the Airy disc is, then, Dd = 2rd = 26 mm The beam spread is comparable to, but slightly more than, that from the single slit of Example 2, where W was found to be near 22 mm. Figure 13b shows several such Huygens' ellipsoidal wavelets and the plane wavefront tangent to the wavelets. (21) and (22) must be satisfied for efficient demultiplexing. Determine the focal length of the combination, distance from negative lens to film plane, and image size of a distant object subtending an angle of 2° at the camera. Assume photopic vision. Englewood Cliffs, NJ: Prentice-Hall, 1988. Generalizing, then for a multilayer of arbitrary number N of layers, c Ea E d = M1M2M3 A MN c N d Ba BN An overall transfer matrix, MT ,
representing the entire multilayer stack is the product of the individual transfer matrix, MT , representing the entire multilayer stack is the product of the individual transfer matrix, MT are represented to the individual transfer matrix, MT are represented phase of zero, we set wx = wy = 0. Chapter 3 Cox, A. Such a single-mode laser has a longer coherence length than a multimode laser. On the other hand, UV radiation has the beneficial effect of inducing vitamin D production in the skin. Projected surface A cos u Ap r Normal 13 Nature of Light intensity I(0) is observed. Alternatively, the refractive power of the eye itself can be altered through surgical procedures that reshape the cornea. (b) Side view before and after cuts. Of course, the straight line can be considered a special case of the ellipse, as can the circle. (b) Phasor components. 6 Plot a curve of total deviation angle versus entrance angle for a prism of apex angle 60° and refractive index 1.52. In this way we can fabricate optical elements that act as phase retarders. If Eq. (1) is multiplied by dt and integrated over one period T, the sine and cosine integrated over a period, the only nonvanishing integral on the right side is the one including the coefficient an , and one finds an = 2 T Lt0 t0 + T f1t2 cos nvt dt (3) Similarly, multiplying Eq. (1) by sin nvt dt and integrating gives bn = 2 T Lt0 t0 + T f1t2 sin nvt dt (4) Thus, once f(t) is specified, each of the coefficients a0 , an , and bn can be calculated, and the analysis is complete. 13 A single slit of width 12 millimeter is illuminated by a collimated beam of light of wavelength 540 nm. We have also made use of Eq. (19) and identified the distance BQ with a quantity r2. We choose, therefore, as a trial solution for the laser beam's electric field E1x, y, z, t2 the form ' E1x, y, z, t2 the for from a "pure" plane wave and, when determined, provides the details that accurately specify the irradiance and phase variations of the wave. The degree of monochromaticity of a light source can be specified by giving the linewidth of the radiation. In GaAs doped with zinc, the zinc replaces gallium (three outer-shell electrons) in the lattice. Multifocal lenses, in which the power gradually increases from the top to the bottom of the lens, are now available. Proceeding thus we write, i1a1 - vt2 ER = Re1E01e + E02e i1a2 - vt2 2 = Re1e - ivt 1E01e ia1 E02 E0 a a2 E01 a1 + E02e i22 ia2 (a) Defining E0eia = E01eia1 + E02eia2 (a) Defining E0eia a11 + a13 + a15 with 8 zones contributing. The decrease in photon number density allows the population inversion to once again grow and there follows a back-and-forth trading of energy between the atomic population and the electromagnetic field as the system settles into steady state. This is the steady-state operating condition for the laser. the angular spatial frequency is kY = 2p13>d2 = 6p> 94.2>mm. For N similar double layers in series, M = 1MH1ML121MH2ML22 Á 1MHNMLN2 = 1MHL2N (49), M = D N - gL gH 0 0 - gH N a b gL 0 T For normal incidence, gL nL = gH nH and gH nH = gL nL so that M = D a - nL N b nH 0 0 - nH N a b nL T (50) The matrix elements of the transfer matrix representing N high-low double layers of l>4-thick coatings in series are thus m11 = a - nL N b, nH m22 = a - nH N b, nL m12 = m21 = 0 (51) Using these matrix elements in the expression for the reflection coefficient, Eq. (36), we arrive at r = n01 - nL>nH2N - ns1nH>nL2N n01 - nL>nH2N + ns1- nH>nL2N ns (52) 488 Chapter 22 Theory of Multilayer Films When the numerator and denominator of Eq. (52) are next multiplied by the factor 1 - nL>nH2N>ns and the result is squared to give reflectance, we have Rmax = c 1n0>ns21nL>nH22N + 1 d 2 (53) Example 2 A high-reflectance stack like that of Figure 8 incorporates six double layers of SiO2 1n = 1.462 and ZnS 1n = 1.462 and ZnS 1n = 1.482 substrate. Suppose this woman mistakenly puts the right contact lens in her right eye and the left contact lens in her right eye. When the scratch appear and what is its magnification? It can be shown that the second-order term makes no contribution to polarization in an isotropic optical material or one having a center of symmetry. The normalized forms of the corresponding electric field amplitudes through the generic relation c E = yB = a bB n (19) Writing the index of refraction for incident and refracting media as n1 and n2, respectively, Eqs. Entrance pupil is 12 cm in front of the lens, with an aperture of 6 cm; image is 10.5 cm behind the lens, inverted, and 1.5 cm long. When a level of higher energy has a greater population density than that of a level of lower energy, we say that a population inversion exists. What are its Brewster's angles for both external and internal reflections? 7 Determine the one-dimensional autocorrelation function functing function function function function functio near point of this eye? When the aperture is circular, the integration is over the entire area of the aperture since both vertical and horizontal dimensions of the aperture are comparable. 1 HUYGENS' PRINCIPLE The Dutch physicist Christian Huygens envisioned light as a series of pulses emitted from each point of a luminous body and propagated in relay fashion Surfa c norm e al Plane incident medium ni ci ra den y t ui d cte fle y e R ra u Plane contains surface normal, incident, reflected, and refractive index profile for a GRIN fiber of radius 50 mm and with n1 = 1.5 and ¢ = 0.01 An ideal pinhole limits the extent of the tungsten source and improves the spatial coherence of the light. 1.25 cm farther from the objective 32. The acoustic wave (see Figure 11) consists of a series of compressions and rarefactions) in atomic density and so a periodic—although small—variation of the refractive index about its normal Train of compressions and rarefractions High Low Incident light beam High Low Incident light beam High Low Incident optical beam by the induced "planes' (right). That is, narrower pulses are composed of harmonic waves with a wider range of frequencies. That is, show that IR + IT = II. The radius of curvature of the spherical side is also 4 cm. Compare the irradiance with that of an ideal polarizer when unpolarized light is passed through two such sheets having a relative angle between TAs of 0°, 30°, 45°, and 90°. This ray leaves point P in Figure 17a, passes through point C for the concave mirror, and reflects back along itself. 240 Chapter 9 Coherence Example 2 Let the source-to-slit distance be 20 cm, the slit separation 0.1 mm, and the wavelength 546 nm. (43), (45), (46), and (47) are employed in sequence. Note that the spectrums of the extraterrestrial sunlight and the sunlight reaching the earth both consist of a continuous blackbody background "interrupted" by dips. When green He-Ne laser light (543.5 nm) is used, the measured rotation is 1330 min. (a) Me = 104 W/m2, Ie (= 0) = 7.96 W/sr, Ie = 3180 W/m2-sr (b) $1.56 \times 10-4 \text{ W}$ (c) 35.9 W/m2 15. Actually, the curve shown is the luminous efficiency of the eye for photopic vision, that is, when adapted for day vision. Thus, in contrast to the PRK procedure, in LASIK surgery the corneal epithelium is not removed. 2 BEAM SPREADING According to Eq. (14), the angular spread ¢u of the central maximum in the far field is independent of distance between aperture and screen. B = 0. In tungsten arc lamps, an arc discharge between two tungsten electrodes to incandescence in an atmosphere of argon, providing a spectral distribution of radiation like that of tungsten lamps at 3100 K. They are called localized fringes because they are, so to speak, localized at infinity. This choice sets z0R = 0 and so q102 = iz0I. With regard to the first of these, it can be shown that the surface area Sn of the nth Fresnel zone is given by Sn = pr0œ r20112 c + 12n 12a b d r0 + r0œ r0 2r0 (15) Figure 4 (a) Fresnel circular half-period zones on a spherical wavefront emerging from an aperture. A schematic of this device is shown in Figure 8. 21 Trace two rays through the hemispherical lens of Figure 15. That is, the steady-state output of the laser includes electric fields with frequencies corresponding to many different cavity resonances. The direction of the laser includes electric fields with frequencies corresponding to many different cavity mirror into and out of at n = n0 and has a full-width at half-maximum of \$h H. Relations Between the Einstein A and B coefficients Einstein A and B coefficients by showing that thermal equilibrium will exist between the Einstein A and B coefficients Einstein A and B coefficients by showing that thermal equilibrium will exist between the Einstein A and B coefficients by showing that thermal equilibrium will exist between the Einstein A and B coefficients by showing that thermal equilibrium will exist between the Einstein A and B coefficients by showing that thermal equilibrium will exist between the Einstein A and B coefficients by showing
that thermal equilibrium will exist between the Einstein A and B coefficients by showing that thermal equilibrium will exist between the Einstein A and B coefficients by showing that thermal equilibrium will exist between the Einstein A and B coefficients by showing that thermal equilibrium will exist between the Einstein A and B coefficients by showing that thermal equilibrium will exist between the Einstein A and B coefficients by showing that thermal equilibrium equilibrium will exist between the Einstein A and B coefficients by showing that thermal equilibrium B21 (13) and These relations are necessary for thermal equilibrium between an assembly of atoms and a radiation field to exist but hold generally as well, since the Einstein A and B coefficients are characteristics of the atomic levels. High-power CO2 lasers are sometimes pumped by electron beams or gas dynamic processes. For example, we shall give the free spectral range of a variable-length Fabry-Perot interferometer the symbol dfsr and that of a variable input-frequency Fabry-Perot interferometer the symbol nfsr. This change in sign restores the proper phase relation between the dipoles and the second harmonic field and so ensures continued amplification of the second harmonic field. Thompson, Physics of Semiconductor Laser Devices (New York: Wiley-Interscience, 1980). 562 Chapter 26 Laser Operation rearrangement, we find IL = IS a g0L - ln11>S2 b 1 - S The irradiance of the laser beam exiting the ring cavity is, then, Iout = T3IL = T3IS a g0L - ln11>S2 b 1 - S (43) Let us examine the features of this expression. T shape, such as that shown in Figure 1. In general, plane monochromatic waves are elliptically polarized, in the sense that, over time, the tip of the electric field vector in a given plane perpendicular to the direction of energy propagation traces out an ellipse. Hecht, Eugene, and Alfred Zajac. 2 PARTICLES AND PHOTONS Photons and electrons that behaved both as particles and waves are very different entities indeed. If IO represents the maximum transmitted irradiance, then Malus' law states that the irradiance for any relative angle u between the TAs is given by I = 10 cos2 u (1) Malus' law is easily understood in conjunction with Figure 2. 9 In what kinds of media are both longitudinal Pockels and Kerr effects present? Figure 9 shows schematically the Faraday rotator, a crystal or liquid cell whose axis of symmetry is aligned with a magnetic field. A similar argument for the zones below the axis would lead to a twin spiral, represented in the third quadrant and connecting at the origin O. 17 Express the plane waves of Eqs. (6) and (7), I12 = e0cE01 # E028cos d9 B B (9) 166 Chapter 7 Interference of Light The irradiance terms I1 and I2 of Eq. (5) can be shown to yield I1 = e0cE2018cos21a + E028cos d9 B B (9) 166 Chapter 7 Interference of Light The irradiance terms I1 and I2 of Eq. (5) can be shown to yield I1 = e0cE2018cos21a + E028cos d9 B B (9) 166 Chapter 7 Interference of Light The irradiance terms I1 and I2 of Eq. (5) can be shown to yield I1 = e0cE2018cos21a + E028cos d9 B B (9) 166 Chapter 7 Interference of Light The irradiance terms I1 and I2 of Eq. (5) can be shown to yield I1 = e0cE01 # E028cos d9 B B (9) 166 Chapter 7 Interference of Light The irradiance terms I1 and I2 of Eq. (5) can be shown to yield I1 = e0cE01 # E028cos d9 B B (9) 166 Chapter 7 Interference of Light The irradiance terms I1 and I2 of Eq. (5) can be shown to yield I1 = e0cE01 # E028cos d9 B B (9) 166 Chapter 7 Interference of Light The irradiance terms I1 and I2 of Eq. (5) can be shown to yield I1 = e0cE01 # E028cos d9 B B (9) 166 Chapter 7 Interference of Light The irradiance terms I1 and I2 of Eq. (5) can be shown to yield I1 = e0cE01 # E028cos d9 B B (9) 166 Chapter 7 Interference of Light The irradiance terms I1 and I2 of Eq. (5) can be shown to yield I1 = e0cE01 # E028cos d9 B B (9) 166 Chapter 7 Interference of Light The irradiance terms I1 and I2 of Eq. (5) can be shown to yield I1 = e0cE01 # E028cos d9 B B (9) 166 Chapter 7 Interference of Light The irradiance terms I1 and I2 of Eq. (5) can be shown to yield I1 = e0cE01 # E028cos d9 B B (9) 166 Chapter 7 Interference of Light The irradiance terms I1 and I2 of Eq. (5) can be shown to yield I1 = e0cE01 # E028cos d9 B B (9) 166 Chapter 7 Interference of Light The irradiance terms I1 and I2 of Eq. (5) can be shown to yield I1 = e0cE01 # E028cos d9 B B (9) 166 Chapter 7 Interference terms I1 and I2 of Eq. (5) 160 Chapter 7 Interferen vt29 = 1 e cE2 2 0 01 (10) I2 = e0c8E2 # E29 # E Distinct vision No accommodation (d) Nearby object at N.N.P. Distinct vision Full accommodation (c) Figure 6 Hyperopic vision with correction. Whereas most excited levels in an atom might decay in times of the order of 10-8 s, level E2 is metastable, with a typical lifetime of the order of 10-3 s, hundreds of thousands of times longer than other levels. 92 Chapter 3 Optical Instrumentation c. The solid lines represent the maximum displacement of the wave. In the photovoltaic (forward-biased) mode, the open-circuit voltage has a more complicated logarithmic dependence on the incident irradiance. Conversely, when the grid intercepts waves polarized in a direction perpendicular to the wires, there is efficient transmission of the waves. Matched filtering techniques using incoherent light systems. Chapter 25 Feynman, Richard P., Robert B. (19) and (22) for R(z) and w(z), we can integrate the resulting equation to obtain $p_{122} = l_{222} + 1pw_{2022} l_z i ln c d - 1m + n + 12 arctanc d 2 2 2 1pw_{202} l_z i ln c d - 1m + 12 arctanc d - 1m + 12 arc$ shape of the comatic image is such that its maximum extension is three times the radius of the comatic circle formed by rays from the outer zone of the lens. If the pump is still operating, this atom is ready to repeat the cycle, thereby ensuring a steady population inversion and a constant laser beam output. Two rays reflected from each are shown labeled as (1) from M1 and (2) from M2 . 5 A 596-Å-thick layer of ZnS 1n = 2.352 is deposited on glass 1n = 1.522. (8) and (9) are true whether or not the atom is in thermal equilibrium. Second, each of the vectors in Table 1 can be multiplied by a factor of the form eiw, which has the effect of promoting the 'E0xeiWx TABLE 1 SUMMARY OF JONES VECTORS E0 = c d E0yeiWy I. The pyroelectric metal behaves like a capacitor whose charge is a function of the temperature. The emulsion, however, is incapable of responding linearly to all irradiances, varying from zero to maximum, so that the developed plate will show a distorted cos21ar22 transmittance and higher-order diffractions will not be suppressed. Why? The normal PD drawn for this ray is used to define angles of incidence and reflection for the beam. Better color resolution can be obtained by using three separate CCDs in the camera. Notice also that some amplitudes may be negative, that is, some harmonic waves must be subtracted from the sum to accomplish the convergence. The technique is well adapted to iterative loops handled by computer programs. Thus, it can be seen in Figure 11a that for aperture position (1), the average distance PM for the shaded pencil is greater than the average distance PM for the shaded pencil. u = 1200 * 10-9 m = 2.55 * 10-5 rad pw0 p12.5 * 10-3 m2 This represents, roughly, a 30-fold decrease in beam spread over reference beam be represented by the complex electric field ER = rei1vt + w2 (1) at the plane of the film. The difference in wavelength of the source of the radar. Nonlinear Optics and the Modulation of Light designed for efficient second harmonic generation using light with a phase mismatch ¢k. After a rather thorough study of the fundamental mode of the laser beam, we shall examine the higher-order transverse irradiance distributions. Show that the magnification of a doublelens even beam, we shall examine the higher-order transverse irradiance distributions. chromatic aberration, is, for an image at infinity, 27 A pair of binoculars is marked "7 * 35." The focal length of the objective is 14 cm, and the diameter of the field lens of the evenies of equal inclination are focused by a lens. In the optical arena, the beat phenomenon can be used to measure the difference between the emitted
radar wave and the Doppler-shifted return signal in a Doppler weather radar system or as part of a feedback loop designed to ensure that two sources have the same frequency. Suppose that nf 7 ns . The disturbance c may refer to transverse displacements of a string or longitudinal Irradiance variation in transverse plane x, y x0, y0 x0, y0 1 Irradiance profile line e2 w(z) u l pw0 w0 z Waist Wavefront Figure 9 Gaussian beam propagating in the z-direction. The origin y = 0 corresponds to z = 0 and therefore to the y-axis through the aperture of Figure 11a. near, near, far maxima: 409, 136, 81.8 cm; minima: 204.5, 102, 68 cm (a) 1.88 and 3.26 mm (b) 2.66 and 3.76 mm (a) 0.0346 cm (b) 833 (c) 20 cm, 6.67 cm, 4 cm (a) 0.02 cm (b) 2500 (a) 4 × (b) very nearly zero (c) 5; 6 (a) (b) (c) (d) 3. Unpolarized Light Often the individual atoms in a source, at a given instant, emit light with differing random polarizations. 7 In forming an image of an axial point object, a + 4.0-diopter lens with a diameter of 6.0 cm gives a longitudinal spherical aberration of +1.0 cm. Each beam is again totally reflected by mirrors M1 and M2, and the beams are made coincident again by the semitransparent mirror M3. Duffieux, P. What photocurrent is where n is the mean number of photons in the field. As we have seen, temporal coherence is a measure of the average length of the constituent harmonic waves, which depends on the radiation properties of the source. The figure shows a field B established by current windings and indicates a rotation of the polarization in the same sense as the current producing the field. The light-gathering capability of the objective lens is thus increased by increasing the refractive index in object space. Michelson himself pioneered much of this work. The critical angle for refraction into air is given as usual by B sin uc = 1>n and so depends on the orientation of the E-vibration relative to B B the OA. Linear and Elliptical Polarizations We conclude this section with but a brief discussion of the basic nature of the polarization of the E-vibration relative to B B the OA. Linear and Elliptical Polarizations We conclude this section with but a brief discussion of the E-vibration relative to B B the OA. frequencies of adjacent standing wave modes of the cavity d. Let the field incident on a Fabry-Perot cavity be removed at time t0. 68 Chapter 3 Optical Instrumentation B 30 45 A 30 E 45 90 C D L Figure 17 Pellin-Broca prism of constant deviation. Thus the optical path length & 1 479 Theory of Multilayer Films associated with one traversal is & 1 = ¢>2 = n1t cos1ut12, and phase difference d that develops due to one traversal of the film is d = k0 ¢ 1 = a 2p b n t cos ut1 l0 1 (15) Thus, Ei2 = Et1e -id (16) Ei1 = Er2e -id (17) In the same way, Using Eqs. To prepare for a comparison with Gaussian beams that are confined near the z-axis, we will develop an approximation to Eq. (29) that is valid near the z-axis and away from the beam waist, that is, where r V f z f. At the center of the macula, located somewhat above the optic nerve, is the fovea centralis, the region of greatest visual acuity. The lateral field of view processed by this optical system is at most a circle of radius OV. The lens has a refractive index of 1.52. Example 4 Calculate the penetration depth of an evanescent wave undergoing TIR at a glass- 1n = 1.502 to-air interface, such that the amplitude is attenuated to 1/e of its original value. Chapter 6 O'Shea, D. The matter of temporal coherence equires a comparison between the path difference ¢ = SAP1 - SBP1 and the coherence length of the radiation. Ronchi, Vasco. 5 Show that Eq. (58) for the skin depth at low frequency is an adequate approximation when v g and v s>e0. 10 m/s in +x-direction 5. In contrast, as we shall see in the next section, many different cavity modes can lase in a system that uses an inhomogeneously broadened gain medium. N., and D. On the other hand, the velocity of the envelope, called the group velocity, is yg = vg kg = v1 - v2 dv k1 - k2 dk (37) assuming again that the differences between frequencies and propagation constants are small. Er u k E Normal B x 495 Fresnel Equations and B B # B B = - BtyN ei1k r - vt2 B B # B Br = BryN e parallel to the boundary gives, in this case, - B + Br = - Bt (17) E cos u + Er cos ut (18) Reflection and Transmission Coefficients The magnetic field amplitudes of Eqs. The gain coefficients as a function of phase, calculate (a) the fringe separation: (b) the fringe width at half-maximum: (c) their ratio, the finesse. Flash lamps and arc lamps are often used as optical pumps for laser systems (like Neodynium: YAG) using solid-state gain media. We know that, near the aperture, more rigorous methods must be used that take into account the vector properties of the electromagnetic field, including polarization effects. R. Since real object distances are positive, what does your result imply for the cases n2 7 n1 and n2 6 n1? One of the rays (shown) passes through the wedge in a symmetrical fashion, making equal entrance and exit angles with the two sides and satisfying the condition for minimum deviation. Maiman at the Hughes Research Laboratories in 1960, was a pulsed ruby laser, which operated at the visible red wavelength of 694.3 nm. Suppose a 2000-W laser beam is concentrated by a lens into a cross-sectional area of about 1 * 10-6 cm2. Recently, several different technologies have been developed that allow for displays that are less bulky and/or use less power than CRT displays. System Evaluation Using the Transfer Function Characterization of the imaging capacity of an optical system by simply citing its resolving power does not give an adequate assessment of the system's performance. The interference of light waves provides the requisite means. Notice that beam 3 traverses the beam splitter three times, whereas beam 2 traverses it only once. 5 Show that the rest-mass energy of an electron is 0.511 MeV. This telescope is large enough so that the observer can be mounted on a specially built platform situated just behind the primary focus (Figure 35). Check your calculations against Figure 2. s y p f1 w f2 q Matrix Methods in Paraxial Optics PP1 n0 409 nf a F1 yf y0 H1 a0 r p f1 Output plane Input plane (a) PP2 y0 a fy fH2 s af F2 q f2 Output plane (b) av y N1 av o a a yf N2 Figure 12 (a) Construction used to relate distances p, r, and f1 to matrix elements. If yP 7 yc, the P mode reaches some point B along its path before the c mode. PROBLEMS B 1 Show that when the incident Efield is parallel to the plane of incidence, g1 has the form given in Eq. (37). The top part of the spiral below (z 6 0 and y 6 0) represents similar contributions from below the y-axis. In addition to the key optical components encountered by light traveling along the axis of vision, the eye contains other components that should be mentioned. Suppose next that the linear polarizer has a TA inclined at 45° to the x-axis. However, since most of the beam is appropriate. The signs for so and si follow the usual sign convention. Snell's law requires, for the ray incident at the vertex V and in the small-angle approximation, n1u1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangents
for angles, ho hi n1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangents for angles, ho hi n1 = n2u2 or, using tangles, ho hi n1 =image. For a dielectric medium, the increase of dipole moments at resonance results in a large maximum polarization. If it is desired to have a fringe spacing of 1 mm at the screen, what is the proper screen distance? Is it magnified? The derivation of the Doppler effect for light requires the theory of special relativity and so is not carried out here. 'Using Eqs. (Courtesy Mitsubishi Rayon America, Inc.) 254 Chapter 10 Fiber Optics n2 Figure 9 Symbolic representation of modal distortion, 12 An important application of the OWP is its use in an "isolator," For example, to prevent feedback from interferometers into lasers by front-surface, back reflections, the beam is first allowed to pass through a combination of linear polarizer and QWP, with OA of the gating equation, ml = d sin u = d Ym f (19) where d is the contral horizontal section in Figure 32a, a view of the central horizontal section, ml = d sin u = d Ym f (19) where d is the spatial period of the ruling. Nonlinear Optics and the Modulation of Light E1(z, t) principal result of our calculation for axial object points. The relevant angles describing the progress of the ray through the prism are defined in Figure 9. Finally, in step 4, the neon atom in energy state 2p4 decays by spontaneous emission to the 1s ground level. Two coherent, monochromatic beams are made to interfere, producing standing waves in the region between the collimating lens C and a plane mirror M. Note that for all three curves, the irradiance input to the cell is I0 = 1 W>cm2. To appreciate the physics that underlies this phenomenon, consider Figure 4, which shows a narrow beam of light incident at an arbitrary angle on a smooth, flat, dielectric surface. The time-averaged irradiance for the k component at the detector is then Ik r 81E1 + E2229 which gives, Ik = 21011 - $\cos kx2$ (39) where I0 represents the time-averaged irradiance of one beam. Provide ray diagrams for each case. The condition 0P>01 = 0 applied to Eq. (36) now gives L = PPB PPR (48) which is the same result as for a double-lens evepiece. For distant objects, the film must be situated in the focal plane of the lens. Taking into account the associated sign convention, the grating equation becomes ml = a[sin ui + sin12ub - ui2] (15). 5 REFRACTION THROUGH PLANE SURFACES Consider light ray (1) in Figure 9a, incident at angle u1 at a plane interface separating two transparent media characterized, in order, by refractive indices n1 and n2. Thus, for example, in the text and correlated Figures 1a, b, and c, we define carefully the meaning of aperture stops (AS), entrance pupils 1EnP2, and exit pupils 1ExP2 and illustrate their effects in several simple optical systems. In the following example we estimate the field strengths and irradiances required to make the nonlinear contributions to the polarization sizeable compared to the linear contribution. Thermal detectors using a blackened strip as a receptor may be nonselective; however, entrance windows to such devices may well make them selective. cm and an axial length of 2.5 cm. Show further, using the Fresnel Eqs. 11 Determine the theoretical content of the constants A, B, and C used to express the Cauchy dispersion equation. Radiation is absorbed at the junctions T1 in thermal contact with a black absorber and thermally insulated from the junctions T2. Such results are surprising because they are not apparent in ordinary experience; yet they necessarily follow once Figure 5 is understood. Determine the thickness of the orders of magnitude greater than the speed of the acoustic wave. Another Model of Imaging: Convolution In the preceding sections, we have presented imaging as (1) a result of diffraction or Fourier analysis, producing a spectrum of spatial frequencies; and (2) their subsequent recombination, or Fourier synthesis, to form the image. The inverse transform of a function f(x) returns the function f(x). In addition, c has the same value on all wavefronts separated by a wavelength l = 1 m. Since y = c>n, different refractive indices, n^c and n^P, may be defined for circularly polarized light. The thin-lens equation can be used to determine the correct power for the spectacle lens, 1 1 1 + = s to for 1 1 1 + = 38 - 148 f Optics of the Eye 1 1 Calculation gives f = 51 cm. New York: Academic Press, 1969. For

other wavelengths the transfer matrix must be used in its general form, containing the wavelength-dependent phase differences. It follows that the radiance of the beam, or L1 = L2 = L0. 10 20 30 40 50 60 70 80 90 Angle of incidence u PROBLEMS 1 Show that the vanishing of the reflection coefficient in the TM mode, Eq. (28), occurs at Brewster's angle, up = tan-11n2. PROBLEMS 1 Initially unpolarized light passes in turn through three linear polarizers with transmission axes at 0°, 30°, and 60°, respectively, relative to the horizontal. 4 A readable, comprehensive discussion of the helium-neon laser, with energy level diagrams and transition probabilities, is given in G. Christian Huygens, a Dutch scientist contemporary with Newton, championed a view (in his Treatise on Light) that considered light as a wave, spreading out from a light source in all directions and propagating through an all-pervasive elastic medium called the ether. The mean value of the visible spectrum may be taken at 550 nm. Assume a wavelength of 550 nm. As Example 1 illustrates, the energy of a photon is much less than the total energy stored in a typical macroscopic electromagnetic field and so the graininess of the electromagnetic field often goes unnoticed. Recall that the lowest possible temperature (so-called absolute zero) has the value 0 on the Kelvin temperature scale and that the temperature in Kelvins is related to the temperature in Celsius degrees via the relation TKelvins = TCelsius + 273. Determine the location and size of the entrance and exit windows. The resultant wave in the medium, by the principle of superposition, is $ER = E1 + E2 = E0[sin1vt + kx^2 + sin1vt - kx - wR^2]$ (21) It is expedient in this case to define b + = vt + kx and b - = vt - kx - wR and employ the trigonometric identity sin b + + sin b - K 2 sin 121b + + b - 2 cos 121b + - b - 2 cos 121b +of Lasers because, since the wave has a single frequency, knowledge of the phase at a given point (say, P1) at time t1 allows one to predict with complete confidence the phase of the horizontal (nonfocusing) section of the lens in Figure 31. Or, as in Figure 31. Or, as in Figure 31. Or, as in Figure 3, the complex ' number z is represented in terms of its real and imaginary parts along the ' ' corresponding axes. Whereas, as noted earlier, spontaneous emission is typically unimportant in steady-state laser operation, it is essential in initiating the growth of the laser field. An advantage of the Mach-Zehnder over the Michelson interferometer is that, by appropriate small rotations of the mirrors, the fringes may be made to appear at the object being tested, so that both can be viewed or photographed together. At room temperature nearly all the atoms in a medium will be in the atomic ground state. Light of mean wavelength 550 nm from a distant star enters the scope as a nearly collimated beam. The projected area of the surface 1A cos u2 is shown by the dashed rectangle. (6) and (10) for boundary (a), the result is Ea = Eb cos d + Bb a i sin d b g1 Ba = Eb1ig1 sin d2 + Bb cos d (22) (23) where we have used the Euler identities 2 cos d K eid + e -id and 2i sin d K eid - e -id Equations (22) and (23) relate the net fields at one boundary with those at the other. Shown in Figure 4 are two pencils of rays whose limits are determined by an aperture EnP serving as the entrance pupil. We summarize the basic equations for the thick lens without proof. The way in which energy is distributed in the radiation determines the color of the light and, consequently, the color of surfaces seen under the light. Note that both circular and linear polarizations. According to Eq. (34), $z_1 = z_2 - d = -d$. The Soviet ophthalmologist, Svyatoslav N. Gravitational waves are predicted to be a form of transverse quadrupole radiation so that a wave propagating in a direction that is perpendicular to the plane of the interferometer. 9 Using the equation for spherical aberration of a thin lens, see problem 8, find the longitudinal spherical ray aberration of a lens as a function of ray height h. The first few zeroes of the Bessel function occur at g = 0, g = 3.832, g = 7.016, g = 10.173, and g = 13.324. This is the case also for materials that have no large-scale crystalline structure, such as glass or fluids. 398 Chapter 18 Matrix Methods in Paraxial Optics principal points relative to the vertices V1 and V2, while f1 and f2 determine focal points H1 and H2, respectively. New York: John Wiley and Sons, 1990. xs-variation of irradiance Burn pattern for (xs, ys) plane [Hm(xs)exs /2] 2 2/2 2 H(xs) m0 H0(xs) Figure 15 (xs, ys) plane [Hm(xs)ex /2] 2 2/2 2 H(xs) m0 H0(xs) + 1 (xs, ys) plane [Hm(xs)ex /2] 2 (xs, ys) plane [Hm(xs Laser-beam electric field and irradiance variations in the xs-direction for two values of the Hermite integer m. Measurement of the waves by their effect on the eye or some other light detector depends on the energy of the light beam. Field flattening may be accomplished by use of an aperture stop positioned as in Figure 9d. If the image of the 1n - 12 step is not actually formed, it serves as a virtual object for the nth step. Thus, 11T2max - 11T2min 1 - 1>11 + F2 = = F 11T2min 1>11 + F2 (28) Note that this measure of fringe contrast, the coefficient of finesse, differs from the related quantity called the visibility. Pyroelectric Detectors The pyroelectric effect can be exploited in order to detect radiation. For each curve, we see that T = Tmax = 1 at d = m12p2, and T = Tmax = 1 at d = m12p2. caused by reflection. By the scattering of light, we mean the reemoval of energy from an incident wave by a scattering medium and the reemission of some portion of that energy in many directions. The contribution dEp at an arbitrary point P due to the light amplitude from an elemental area da surrounding point O in the aperture is given by dEP = a EA da i1vt - kr2 be r (9) where r is the distance from point P. Doping involves adding small amounts of an impurity to the semiconductor to provide either an excess (n-type) or deficiency (p-type) of conduction electrons. Find the group velocity for plane waves in a dispersive medium, for which yp = A + Bl, where A and B are constants. The curve represents the product of the interference and diffraction factors. Because of the ability of ultrasonic waves to penetrate objects opaque to visible light, holograms formed with such waves can be very useful. The brightness of the image cannot be greater than the brightness of the object; in fact, it is less bright due to inevitable light losses due to reflections from lens surfaces. a 3 THE OBLIQUITY FACTOR a0 2 P u a0 O a Figure 3 factor. If the stars are being detected by their long-wavelength radio waves—the lenses being replaced by dish antennas—the resolution must, by Eq. (22), be much less. TABLE 3 REFRACTIVE INDICES FOR QUARTZ 1 (nm) n7 n nP n^c 396.8 762.0 1.56771 1.5481 $1.55815\ 1.53917\ 1.55810\ 1.53914\ 1.55821\ 1.53920\ Production$ of Polarized Light 367 Solution From Table 3, at l = 396.8 nm, n^c - n^P = 1.55821 - 1.55810 = 0.00011\ Using Eq. (10), b = p110-32\ 396.8 * 10-9\ 10.000112 = 0.8709\ rad = 49.9^{\circ} in good agreement with Table 2 for the neighboring wavelength of 404.6 nm. 272 Chapter 11 Fraunhofer Diffraction y b 3.47 p yb b 2.46 p y tan b b 1.43 p b 2p p 3p Figure 3 Intersections of the curves y = b and y = tan b determine the angles b at which the sinc
function rests on the fact that the human eye, as a detector, does not have a "flat" spectral response; that is, it does not respond with equal sensitivity at all wavelengths. 596 Chapter 27 Characteristics of Laser Beams One can evaluate q1 as follows. Show that polarizing angles for internal and external reflection between the same two media must be accurately formed in as thin an aperture as possible. Notice that the line image AB so formed is always parallel to the cylinder axis. This remedy for spherical aberration is, of course, accompanied by a reduction in image brightness. (Reproduced by permission from "Atlas of Optical Phenomena", 1962, Michael Cagnet, Maurice Franco and Jean Claude Thrierr; Plate 12. In its simplest description, diffraction is any deviation from geometrical optics that results from the obstruction of a wavefront of light. This spot, devoid of any receptors, is appropriately called the blind spot. It requires the multiplication of one function at each point by the whole of another function and then the summation of the results. (Negative values of adb indicate amplification, rather than attenuation!) Dramatic advances have been made in reducing the absorption of fused silica so that today, fibers rated at 0.2 db/km (operating at 1.55 mm) are readily available. 10 Joseph C. At incidence, the linearly polarized light is immediately resolved into c and P circular modes, which, at z = 0 and t = 0, begin together with uc = uP = 0. Determine q2, the complex radius of curvature at the external beam waist by using the ABCD propagation law. Rather, the various harmonic waves that combine to produce exactly everywhere outside that interval. If the cavity-mode separation is less than the homogeneous gain bandwidth of the atoms, the cavity modes will "compete" for the same group of atoms and not all cavity modes initially above threshold will lase. High-resolution plates are used to record this information faithfully.2 3 HOLOGRAM OF AN EXTENDED OBJECT One of many holographic techniques for producing an off-axis reference beam in conjunction with the beam of diffusely reflected light from a threedimensional scene is shown in Figure 2a. The relationships given in Eqs. Notice, as shown in Figure 8c, that the maximum extent of the corrective lens, the relaxed eye forms clear retinal images of faraway objects, the far point of the eye/corrective lens system will be at the position of the object whose image formed by the spectacle lens is faraway. The parallel rays emerging from the interferometer are brought to a focus by lens L2 at P, where the eye is placed. Now af = Da0, independent of y0. One can show that the irradiance in the second harmonic field is proportional to the irradiance factor sinc2 a ¢kL b 2 where L is the distance into the crystal and k is the wave propagation constant, equal to nv>c. For example, an optical fiber transmitting at 1.3 mm rather than, say, 800 nm represents a seven-fold reduction in Rayleigh scattering losses. (57) and (58). The collimated region extends over two Rayleigh ranges, one on either side of the beam waist. (c) Formation of a comatic circles. We begin with an analysis of the irradiance profile of the phase fronts associated with the beam. The crossover point of the curves coincides with the plasma frequency If the interferometer components are of high quality, this system can M2 M2 L1 BS M1 BS S S P L2 P Figure 4 (a) Twyman-Green interferometer. With the method used in Section 5 to derive the FabryPerot transmittance, find the reflectance, R = IR>II, of a Fabry-Perot cavity. Notice that the phase difference £ is independent of the crystal length Reading, MA: Addison-Wesley Publishing Company, 1968. Light output (typically given in lumens) depends both on the filament temperature and the electrons via collisions. The relative phase between the two modes at this instant determines the angle b, as expressed by Eq. (9). What fraction of the IO irradiance occurs at 1 mm from the pattern center along the x- and y-directions? Find the position and length of the image formed by the lens. Include the presence of a field of irradiance I resonant with the 2-to-1 transition, the pump interaction, and the decay processes. Transparent materials like glass have resonance frequencies in the infrared and ultraviolet regions but not in the visible. The radius of the first 1n = 12 zone determines the magnitude of r0, or the point P on the axis for which the configuration functions as a zone plate. What we have said here of a finite wave train is also true of any isolated pulse, regardless of its shape. One can then also define the angular field of view as twice the angle b made by the chief ray with the axis at the center of the opening represented by the entrance pupil. EM Waves in Thermal Equilibrium One of the early triumphs of quantum mechanics was the prediction of the experimentally verified relation giving the wavelength distribution (i.e., the spectrum) associated with electromagnetic radiation in thermal equilibrium with a blackbody at temperature T. A standard DWDM system might use 40 wavelength channels near 1550 nm. Of course, both n-type materials have zero net charge since the dopant atoms are neutral. The position of the aperture is critical in determining the magnitude of y¿ and is least harmful in this respect when placed at the center of curvature, C. The individual slits are identified by the index j in the following expression for the resultant amplitude: [-12j - 12a + b] > 2 EL i1kr0 - vt2 N > 2 EP = e eisk sin u ds + eisk sin u placed below (first integral) and above (second integral) the origin are included in the integration. 440 Chapter 20 Aberration by and bz to the wave aberration a. For a thin film in air, we are interested in the relative phase shift between rays reflected from theory y a Wi da P a y a Ideal bz ual n2 Figure 2 Construction used to relate the ray aberrations by and bz to the wave aberrations by and bz to the wave aberration. first surface (external) and the second surface (internal). 320 Chapter 13 Fresnel Diffraction 8 THE CORNU SPIRAL If we neglect the effect of the obliquity factor and the variation of the product rr; in the denominator of Eq. (7), the Fresnel-Kirchhoff integral may be approximated by EP = C1e -ivt O eik1r + r; 2 dA (24) AP where all constants are coalesced into C1. For this general case, the resultant field of Eq. (7) can be simplified by writing the fields in complex form and using a phasor diagram to aid in the addition of the individual fields. E = E0 sin 2p a - vt b xN + E0 sin 2p a increases the likelihood of stimulated absorption. How long can the coaxial cable be under these conditions? For visual observations, the intermediate image is made to occur at or just inside the first focal point fe of the eyepiece. This technique was employed by Michelson to measure the angular diameter of stars. The simplest explanation of these phenomena can be undertaken successfully by treating light as a wave motion. What are the displacement, velocity, and acceleration of a particle in the medium at x = 5 cm and t = 0.22 s? The point objects and the centers of their Airy discs are both separated by the angle u. If the equations are developed along the same lines, one finds that only a minor alteration of the transfer matrix becomes necessary: In the expression for g1, Eq. (13), the cosine factor now appears in the denominator rather than in the numerator. If a thin plate of glass 1n = 1.502 of thickness 100 microns is placed over one of the slits, what is the lateral fringe displacement at the screen? If L is taken small enough, for example, the equation predicts a beam width less than b, contrary to assumption. To this, Fresnel added the assumption that the actual field at any point beyond the wavefront is a superposition of all these wavelets, taking into account both their amplitudes and phases. Solution E0 The ruling period d is twice the slit width, so d = 0.2 mm. These quantities will be seen to depend not only on the change in refractive index and the angle of incidence at the surface but also on the polarization of the incident light. Example 3
Light from a distant galaxy shows the characteristic lines of the oxygen spectrum, except that the wavelengths are shifted from their values as measured using laboratory sources. E = E013xN + 4yN 2ei1kz - vt2 B c. At the aperture, the wavefront 308 309 Fresnel Diffraction dA r O S r P is still substantially spherical, because the aperture is not far from the source. By way of summary, we have discussed three principal ways of reducing pulse broadening in fibers: (1) use a single-mode fiber to eliminate modal distortion, (2) use a light source of small spectral width ¢l to reduce material dispersion, and (3) use a light source operating in a spectral region where both attenuation matrix: M 1 L 0 1 P L Refraction matrix, spherical interface: R 1 M n R2 0 1 f 1 n n Rn L n n P n n (R): convex appropriate individual matrices in the proper order, according to Eq. (14), it is possible to express any optical system by a single 2 * 2 matrix, which we call the system matrix. For the difference to be zero, that is, for destructive interference to be zero, that is, for destructive interference to be zero. however, leads to a common form of the matrix, due to its symmetrical form: M = c e -ip>4 c 1 0 0 d i QWP, SA vertical (17) In arriving at the last 2 * 2 matrix in Eq. (17), we used the relationship eip>4 = e -ip>4 c 1 0 0 d i QWP, SA vertical (17) In arriving at the last 2 * 2 matrix in Eq. (17), we used the relationship eip>4 = e -ip>4 c 1 0 0 d i QWP, SA vertical (17) In arriving at the last 2 * 2 matrix in Eq. (17) in arr function was to bring the focus of all zones to the same point on the spherical focal surface, as indicated in (c). Assume sodium light. These conclusions produce some curious results, which can be verified experimentally. If 11 and 12 are known to be, for example, very near a nominal wavelength, 1 = 500 nm, this record can be used to accurately determine the difference in the two wavelengths. The power just inside the fiber exit is only 1 mW. The common orientation of the molecules in a liquid crystal allows the liquid crystal allows the liquid crystal to interact differently with different polarizations of light passing through the crystal. Note that, for normal incidence, the reflection and transmission coefficients for the TE case are identical to those for the TM case. The rate of occurrence per unit volume of stimulated emission, RSt. Em. , when a monochromatic field of frequency n2 and irradiance I is incident on an assembly of atoms like the one depicted in Figure 12a is RSt. Em. = B21g1n21>c2N2 (10) The parameter B21 is the Einstein B coefficient for stimulated emission Thicknesses are determined at l = 550 nm. Determine the position and nature of the image in each case. The output mirror has transmittance T3. As indicated in Figure 9b, such a voltage acts to align the molecules along the direction of the electric field between the glass plates. lensmaker's equation: 1 1 1 = 1n - 12a b f R1 R2 With f = 8 m, n = 1.523, and R2 : q, this gives R = 4.184 m. In the He-Ne laser neon atoms are the lasing species and the helium atoms aid in the pumping process. A fascinating aspect of holographic data storage lies in its reliability. This implies higher frequencies or, in the case of digital information higher bit rates. Since the law of refraction requires that refracted rays remain in the plane of incidence, a meridional ray remains within the same meridional plane throughout its trajectory. Accordingly, rods bleach out completely at much lower light levels than do cones. grooves>cm d l l0>n 1488 * 10-7 cm2>1.6 6 OTHER APPLICATIONS OF HOLOGRAPHY Holography offers a wide variety of fascinating applications, of which we briefly describe only a few. T 2 Because the yellow sodium D line is a doublet (589.0 and 589.6 nm), the more monochromatic d line of helium at 587.56 nm is often preferred to characterize the center of the visible spectrum. From the geometry apparent in Figure 1, $r^2 = 1X - x^2^2 + 1Y - y^2^2 + 1Z - 022$ and $r^2 = r^2 - 2xX - 2yY + 1x^2 + y^2^2$ (10) Although the dimensions X and Y in the spectrum plane may be appreciable, the dimensions X and Y in the spectrum plane may be appreciable in comparison with r0 for farfield diffraction. 10 BABINET'S PRINCIPLE Apertures like those of Figures 15 and 16, in which clear and opaque regions are simply reversed, are called complementary apertures. Thus, the focal length of the lens determines the subject area received by the film and the corresponding image size. 4 How many lines must be ruled on a transmission grating so that it is just capable of resolving the sodium doublet (589.592 nm and 588.995 nm) in the first- and second-order spectra? 12 Light is incident upon an air-diamond interface. An examination of the four photographs shows that the principal maxima become narrower and second-order spectra? separation is given by L = 121f1 + f22 = 1216.25 + 2.502 = 4.375 cm The equivalent focal length is found from 1 1 L 1 1 1 4.375 + = + f f f f 2 f f f 2 6.25 2.50 16.25212.502 which gives f = 3.57 cm. These cases are described in the following subsections. In the twentieth century it became clear that somehow light was both wave and particle, yet it was precisely neither. Let us assume a system magnification of 1. For nearly monochromatic fields we typically say simply that n¿ is the frequency of the field. The character of the incident light be will be unmodified by the plate, and so extinguished, if the phase difference introduced by the retarder is 2p or some multiple thereof so that the retardation plate functions as a full-wave plate. Of course, both conventions lead to the same physical result since the extra factor of -1 simply reverses the direction of the reflected electric field. 148 Chapter 6 Properties of Lasers The most important requirement of the amplifying medium is its ability to support a population inversion between two energy levels of the laser atoms. With the parameters for the laser system specified, one can use the ABCD propagation law to determine the location / and size of the beam waist w01/2 outside of the laser. Similarly, the field of view in image space can be described by a¿, the angle subtended by the exit window at the center of the exit pupil. All these features are exhibited qualitatively in the ray diagram of Figure 23a. Examination of Eqs. Freeman and Company Publishers, 1958. Mirror Reflection Coefficient of Finesse, F Quality Factor, Q Photon Lifetime, Tp (s) Resolving Power, R < Lmin (nm) FSR (Variable Spacing) (nm) FSR (Variable Frequency) (GHz) r 4r2 11 - r222 pr 1 - r2 n F 1c>2d2 d c11 - r22 2dF 112 2dF 1>2 1 2F c 2d c 2dF 0.2 0.5 0.8 0.9 0.97 0.99 0.174 1.78 19.8 89.8 1080 9900 0.655 2.09 6.98 14.9 51.6 156 1.31 # 105 4.19 # 105 1.40 # 106 2.98 # 106 1.03 # 107 3.13 # 107 NA NA 4.63 # 10-10 2.82 # 10-9 8.38 # 10-9 1.31 # 105 4.19 # 105 1.40 # 105 1.40 # 105 1.40 # 106 2.98 # 106 1.03 # 107 3.13 # 107 NA NA 4.63 # 10-10 2.82 # 10-9 8.38 # 10-9 1.31 # 105 4.19 # 105 1.40 # 105 1.40 # 106 2.98 # 106 1.03 # 107 3.13 # 107 NA NA 4.63 # 10-10 2.82 # 10-9 8.38 # 10-9 1.31 # 105 4.19 # 105 1.40 # 105 1.40 # 105 1.40 # 105 1.40 # 106 2.98 # 106 1.03 # 107 3.13 # 107 NA NA 4.63 # 10-10 2.82 # 10-9 8.38 # 10-9 1.31 # 105 4.19 # 105 1.40 # 105 1.40 # 106 2.98 # 106 1.03 # 107 3.13 # 107 NA NA 4.63 # 10-10 2.82 # 10-9 8.38 # 10-9 1.31 # 105 4.19 # 105 1.40 # 105 1.40 # 106 2.98 # 106 1.03 # 107 3.13 # 107 NA NA 4.63 # 10-10 2.82 # 10-9 8.38 # 10-9 1.31 # 105 4.19 # 105 1.40 # 105 1.40 # 106 2.98 # 106 1.03 # 107 3.13 # 107 NA NA 4.63 # 10-10 2.82 # 10-9 8.38 # 10-9 1.31 # 105 4.19 # 105 1.40 # 105 1.40 # 106 2.98 # 106 1.03 # 107 3.13 # 107 NA NA 4.63 # 10-10 2.82 # 10-9 8.38 # 10-9 1.31 # 105 4.19 # 105 1.40 # 105 1.40 # 106 2.98 # 106 1.03 # 107 3.13 # 107 NA NA 4.63 # 10-10 2.82 # 10-9 8.38 # 10-9 1.31 # 105 4.19 # 105 1.40 # 105 1.40 # 106 2.98 # 106 1.03 # 107 3.13 # 107 NA NA 4.63 # 10-10 2.82 # 10-9 8.38 # 10-9
8.38 # 10-9 8.38 # 10-9 8.38 # 10-9 8.38 # 10-9 8.38 # 10-9 8.38 # 10-9 8.38 # 10-9 8.38 # 10-9 8.38 # 10-9 8.38 # 10-9 8.38 # 10-9 8.38 # 10-9 8.38 # 10-9 8.38 # 10-9 8.38 # 10-9 8.38 # 10-9 8.38 # 10-9 8.38 # 10-9 8.38 a hydrogen atom there are eight distinct ways of combining the orbital and spin angular momentum of the electron to yield the same energy E2. These may be spectrographs, which record a portion of the spectrum is allowed to pass through an exit slit onto a photomultiplier or other light detector. The applied electric field induces birefringence with an optic axis parallel to the applied field. OA (b) Figure 11 Soleil-Babinet compensator. Thus, using Eqs. f The image size, as in Figure 21, is proportional to the focal length of the lens, so we can write Ee r a D 2 b f (26) The quantity f/D is the relative aperture of the lens (also called f-number or f/stop), which we symbolize by the letter A, A K f D (27) but is, unfortunately, usually identified by the symbol f/A. 273 Fraunhofer Diffraction The central maximum represents essentially the image of the slit on a distant screen. Rays of light corresponding to each wavelength component emerge mutually parallel after refraction by the prism and are viewed by a telescope focused for infinity. 194 Chapter 8 Optical Interferometry beams 2 and 3 can be gradually varied. 317 Fresnel Diffraction Example 1 If light of wavelength 632.8 nm illuminates a zone plate, what is the first zone radius relative to a point 30 cm from the zone plate on the central axis? The Fourier Transform and Its Applications to Optics, 2d ed. Thus, knowledge of the phase at point P1 at time t1 allows one to predict with perfect confidence the phase of the field at this same time t1 at a spatially distinct point P2 along the same wavefront. Although prism materials of large n produce a large deviation at a given wavelength, the dispersion or separation of neighboring wavelengths need not be correspondingly large. 6 A circular disc of radius 20 cm and uniform luminance of 1 cm2, 1 m distant from the center of the disc. By now it may be apparent that in determining the resultant vibration due to two perpendicular components we are in fact determining the appropriate Lissajous figure. These rate equations are developed following an approach taken by Albert Einstein in 1916. Thus, dn 1 b = $-2.3 \text{ rE } 2 \text{ n n r } \int \varphi n \int n 30 \text{ E } 2 \text{ da Substituting into the phase equations, we find } \frac{1}{2} + 2.2 \text{ ga } 2 \text{ ga } 2$ length L of the cell. Following the routine used in part (a), the linear susceptibility of b-carotene in ethanol is x1 = n2 = 1.32 = 1.69. The linear cavity case is complicated by the fact that the field encounters the gain medium. In the S surface, however, the image of the circle will not be sharp, having everywhere the width of the S focal line. At normal incidence, the transfer 484 Chapter 22 Theory of Multilayer Films matrix of a single film of quarter-wave thickness is M1 = J 0 ig1 i g1 K 0 The transfer matrix M for two such layers is found, according to Eq. (26), by forming the product M = M1M2 = J 0 ig1 i 0 g1 KJ 0 ig2 g2 i g1 g2 = D K 0 0 0 g1 g2 T Matrix components are m11 = -g2>g1, m22 = -g1>g2, and m12 = m21 = 0. A ray leaving the tip of the object and passing directly through the center of a converging or diverging lens, emerging unaltered, as in Figure 22a or 22b. Find the position and length of the line image formed by have outputs with wavelengths in the near infrared. For first order, Eq. (5) requires knowledge of the the diffraction angle u1. a 2d (n 1) ym dm S1 ml(d s) 2d a (n 1) dm a 2 a ym S S2 d s Figure 9 Interference with Fresnel's biprism. The important object 20 cm from the lens. Solid-state lasers typically of pumping are the electron excitation cross sections and the lifetimes of the various energy levels. Modern Optics (New York: John Wiley and Sons, 1990, Ch. 9). Now recall that the phase difference \$\phi\$ without introduced by a retardation plate is wavelength dependent, such that 10 \$\phi\$ w = 2pd1n - n 72 (11) where d is the thickness of the plate. Calculate the far field distance zFF = 5020 for the externally focused beam waist. Then for the x3 term of the polarization to be 1% of the linear term, x3E 30 = 10.012 x1 1.69 = 10.012 x1 0.69 = 10.012 x1 1.69 = 10.012 x1 0.69 = 10.012 x1 0. 1011 W>cm2 2 SECOND HARMONIC GENERATION AND FREQUENCY MIXING In this section we will discuss the manner in which a nonlinear crystal can be used to convert energy in an electromagnetic wave at a = 0 and several wavefronts associated with the plane sound wave are depicted at this same time. 3 POLARIZATION BY SCATTERING Before discussing the polarization of light that occurs in scattering, we make a slight detour to discuss scattering in general, pointing out some familiar consequences of scattering that are in themselves rather interesting Portions of a square wave input pulse starting at point A arrive at the fiber end B at different times, depending on the path taken. In a linear cavity, the loss modulation "gate" is placed near one of the mirrors and is switched to the low-loss state for a brief period once each round-trip. (56) and (57), together with the relation for the pulse repetition time T = 2d>c, leads to an approximate expression for the temporal width ¢tp of a mode-locked pulse, ¢tp = NP012d>c2 PCWT 1 1 = = Pp N1c>2d2 Nnfsr N 2P0 The number of modes that are above threshold depends on the bandwidth ¢n of the gain medium and on the ratio of the small-signal gain coefficient to the threshold gain coefficient. Verify the reasonableness of your results by comparison with Figure 2. 472 Chapter 21 Fourier Optics S Input M1 D SP Output M2 Figure 11 Elements of a Michelson interferometer. Determine the spatial coherence length for "good" coherence, neglecting any variations in brightness across the surface. The glass is of index 1.50. A sketch of one possible arrangement is shown in Figure 19. This sort of sensor is a common component of the vertical polarization of the light passing through the nematic cell and so the light is blocked by the action of the polarizer with a horizontal transmission axis on the opposite end of the cell. In the analysis that follows, we will make use of the notion of a propagation factor PF1¢z, ¢t2. This has the effect of producing 50% transmittance when V = 0 so that the operating point is located at P in the figure, rather than at the origin. For this film, Eq. (43) predicts a reflectance of 1.3% in the visible region, where the uncoated glass (set n1 = n0) would reflect about 4.3%. Thus, for objects at a standard distance of 1000 yd, u = Df h = s L or h = su = sDf L = 13000 ft211.502 = 257 ft at 1000 yd 15 + 2.5 Reflection Telescopes Larger-aperture objective lenses provide greater light-gathering power and resolution. That is, Pi = Pr + Pt (40) If we represent the reflectance R as the ratio of reflected to incident power and the transmittance T as the ratio of transmitted to incident power, R = Pr Pi and T = Pt Pi (40) takes the form 1 = R + T (42) The irradiance I is the power density 1W > m22, so that we may write, in place of Eq. (40), IiA i = IrA r + ItA t (43) The cross-sectional areas of the three beams (see Figure 9) that appear in Eq. (43) are all related to the area A intercepted by the beams in the boundary plane through the cosines of the angles of incidence, reflection, and refraction. 33. 1968: 59–70. Fiber Optics Sound: microphone Visual: video camera Data: computer Message input 245 LED/LD Modulator Carrier source Analog/digital 1 Electrical Optic fiber /glass Plastic Light Detector Attenuation and distortion PIN APD light electrical Signal processor Sound: loudspeaker Visual: CRT Data: computer Message output Amplification filtering demodulation Figure 1 Overview of a fiber-optics communication system. As noted, reliable detection of gravitational waves will require isolating the interferometer from environmental noise and separating the gravitational signal from the remaining environmental noise signals. Solution Using Eqs. Solution Substitution into Eq. (6) gives LC = 0.8 mm = 9.2 mm 14211.5019 - 1.48022 This calculation shows that the maximum crystal thickness useful in generating second harmonic light is typically quite small, in this case around 10 times the wavelength of the fundamental. For either the real image RI in (a) or the virtual image VI in (b), it follows that hi ho = s s_i and lateral magnification fmf = ` hi s_i ` = ` ` s ho In accordance with the sign convention adopted here, the magnification should be the negative of the image and object distances since, in case (a), s 7 0, s¿ 7 0, and m 6 0 because the image is inverted; in case (b), Figure 22 Ray diagrams for image formation by a convex lens (a) and a concave lens (b). Thus, if the distance DG is yit, a wavelet of radius ytt is constructed with center at D. "Daylight" lamps, for example, use a mixture of zinc beryllium silicate and magnesium tungstate By contrast, a hologram is made, as we shall see, without use of a lens or any other focusing device. Notice B that the force 1 e E2 due to the electric field. In this section we discuss these processes and introduce the so-called Einstein A and B coefficients that govern their rates of occurrence. f 5 cm Obj mocfobj 25 cm Problem 31. The iris contains two sets of delicate muscles that change the pupil size in response to light stimuli, adjusting the diameter from a minimum of about 2 mm on a bright day to a maximum of about 8 mm under very dark conditions. 3 Since a sheet of Polaroid is not an ideal polarizer, not all B the energy of the E-vibrations parallel to the TA are transB mitted, nor are all E-vibrations perpendicular to the taes of communications, the subject of the following section. Prefactors such as 2 and 2i may therefore be ignored unless information regarding energy is required. The fundamental limit to the
narrowness of a laser line results from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phased spontaneous emission from the fact that some of the randomly-phase image of a circular aperture. 6 Light rays enter the plane surface of a glass hemisphere of radius 5 cm and refractive index 1.5. a. Using a sketch, show that if the polarizers have their transmitted by the pair is given by I = a I0 b cos2 u 2 b. Note that it leaves P, passes through M, the center of AS and EnP, undergoes refraction at L1, heads for O¿P¿, refracts again at L2 before reaching O¿P¿, and heads for O-P-, the final image. If, in addition, ¢ = ml, so that the two beams interfere constructively, it follows that they will do so repeatedly for every l>2 translation of one of the mirrors so long as the separation ¢ p does not exceed the so-called coherence length, lt, of the source. (4) and (5). These instruments are discussed later. Figure 7b illustrates another arrangement, in which the source is small. Using Eqs. Kliger, David S. The etalon, being much shorter than the laser cavity, has a free spectral range, nfsr = c>2d, that is much larger than that of the laser cavity, c/2l. The three key rays discussed in connection with Figure 17 are chosen as the basis of the graphical ray-trace technique because, once the mirror center of curvature C, the focal point F, and vertex V are located along the optical axis of a spherical mirror, these three rays can be drawn using only a straightedge device. This effect becomes increasingly important as the pulse width is reduced and the propagation length is increased, and so may be important in longhaul, high-bit-rate systems. 1 FRESNEL-KIRCHHOFF DIFFRACTION INTEGRAL A typical arrangement is shown in Figure 1. As the pinhole is reduced further, the images of each object point actually grow larger again due to diffraction, with consequent degradation of the image. 21 The magnification given by Eq. (33) is also valid for a double-lens eyepiece if the equivalent focal length given by Eq. (35) is used. The field lens then forms a real image (RI) that is viewed by the eye lens. We show that F also represents a certain measure of fringe contrast, written as the ratio 1IT2max - 1IT2min Tmax - Tmin = 1IT2min Tmin (27) From the Airy formula, Eq. (26), T takes on its maximum value Tmax = 1, when sin1d>22 = 0, and its minimum value Tmin = 1>11 + F2, when sin1d>22 = ; 1. This case is analogous to case 3, with directions replacing ray heights. (c) Hg source, unfiltered. The maximum bit rate of transmission through an optical-fiber system using (dense) WDM exceeds a single system using (dense) with directions replacing ray heights. 1 terrabit per second 11012 bits>s2. b Figure 13 Specification of slit width and separation for double-slit diffraction. 0.5 C(y) 328 Chapter 13 Fresnel Diffraction Eq. (28), 2 2 ¢y = ¢z = w A Ll A Ll (39) Once L is calculated from Eq. (25), the contributing spiral-length interval ¢y on the Cornu spiral can be determined. With the advent of the more intense and coherent light made available by the laser, we find that the optical properties of the medium, such as its refractive index, become a function of the electric field of the light. Writing Eq. (40) in terms where B of J rather than vB, B Ne2 B dJ B + gJ = a bE m dt (42) B B In the case where the applied field is the harmonic wave EB = EB0e -ivt, we expect the current density to vary at the same rate and write J = J0e -ivt. As long as a transparent solid cylinder, such as a glass fiber, has a refractive index greater than that of its surrounding medium, much of the light launched into one end will emerge from the other end due to a large number of total internal reflections. Equation (24) describes a beam propagating in the +z-direction. If the eleventh bright ring of the 546-nm fringe system coincides with the tenth ring of the other, what is the second wavelength? Show them in a sketch of the optical system. Let us take the depth of "significant penetration" to be the depth L at which the irradiance of the diode laser has decreased to 1>e L 0.368 of its initial value. Any two rays are sufficient to locate the image; the third ray may be drawn as a check on the accuracy of the graphical trace. Is it reasonable to set N0 L NT for either of these irradiances? The strength of the binding of the outermost valence to set N0 L NT for either of these irradiances? electrons is described by the band-gap energy, which is the energy required to free an electron from its host nucleus. The diameter of the focused spot is limited by lens aberrations and diffraction but can be roughly as small as the wavelength of the laser light. modes should differ at all. 1985: 54.) Refractive index nR 1.0 0.1 0.1 Extinction coefficient nI 1.0 nR 0.01 nI 1015 25 1016 1017 Frequency (rad/s) Optical Properties of Materials INTRODUCTION Electromagnetic waves that encounter materials create a complex of interactions with the charged particles of the medium. Let us suppose now (Figure 20b) that the second medium is only 10 cm thick, forming a thick lens, with a second, concave spherical surface, also of radius 5 cm. f 1 + f2>z201 where z01 = pw201>l. After equating real parts, we sort out the unknowns w02 and Z2 in the following form: Z1 2 1 1 1 pw01 2 = a 1 + a b b f l w202 w201 f2 Z2 = f + f21Z1 - f2 1Z1 - f2 1Z1 - f2 2 + f21Z1 - f2 1Z1 - f1pw201>122 (46) (47) 600 Chapter 27 Characteristics of Laser Beams We note from Eq. (47) that for the general case, Z2 Z f. In general, whenever a train of reflecting or refracting surfaces is involved in the processing of a final image, the individual reflections and/or refractions are considered in the order in which light is actually incident upon them. If the beams are argon-ion laser beams of wavelength 488 nm and the angle between beams is 120°, how many grooves per millimeter are formed in a plane emulsion 1n = 12 oriented perpendicular to the fringes? For the same wavelength, M₂ = 2 ps>nm-km, giving a pulse broadening of 2/100 times as great, or only 40 ps/km. The ray is then simply the path along which light energy is transmitted from one point to another in an optical system. The requirement is met quite well using zirconium dioxide 1n1 = 1.652, both good coating materials. 6 Show that the relativistic momentum of an electron, accelerated through a potential difference of 1 million volts, can be conveniently expressed as 1.422 MeV/c, where c is the speed of light. Cancellation of h produces the desired relationship, 2 1 1 = s & R(11) If the spherical surface is chosen to be concave instead, the center of curvature would be to the left. 7 VARIABLE-INPUT-FREQUENCY FABRY-PEROT INTERFEROMETERS For the scanning Fabry-Perot cavity discussed in the previous section, the transmittance through the Fabry-Perot cavity is a function of the changing length of the cavity. Figure 17a shows three Mach-Zehnder fiber interferometers (MZ1, MZ2, and MZ3) arranged to demultiplex a signal containing four different wavelength channels. Thus, the angular magnification for an infinity is M = 25 feff (40) where feff (in cm) is the effective focal length of the two lenses, separated by a distance d, and given by Eq. (35). The object is 14 cm in front of the lens and the stop is 2.50 cm behind the lens. 14 Assume that the pupil diameter of a normal eye typically can vary from 2 to 7 mm in response to ambient light variations. condition for missing orders: a = a p bb m (30) or a = a p bb m Thus, when the slit separation is an integral multiple of the slit width, the condition for missing order is met exactly. The magnitudes of the coefficients or amplitudes determine the contribution each harmonic wave makes to the resultant anharmonic waveform. If the nineteenth century served to place the wave theory of light on a firm foundation, that foundation was to crumble as the century came to an end. When both sources, light emitted by different points of a source, well over a wavelength in separation, is not correlated in phase and so lacks coherence. For interna reflection when light travels in the opposite direction, so that $n_1 = 1.5$ and $n_2 = 1$, $u_p = 33.7^\circ$. The phase difference between waves from adjoining slits and in the direction of u can be found from Figure 15a by recalling that the angle a represents half the phase difference between waves from adjoining slits and in the direction of u can be found from
Figure 15a by recalling that the angle a represents half the phase difference between waves from adjoining slits and in the direction of u can be found from Figure 15a by recalling that the angle a represents half the phase difference between waves from adjoining slits and in the direction of u can be found from Figure 15a by recalling that the angle a represent shall be difference between waves from adjoining slits and in the direction of u can be found from Figure 15a by recalling that the angle a represent shall be difference between waves from adjoining slits and in the direction of u can be found from Figure 15a by recalling that the angle a represent shall be difference between waves from adjoining slits and in the direction of u can be found from Figure 15a by recalling that the angle a represent shall be difference between waves from adjoining slits and in the direction of u can be found from Figure 15a by recalling that the angle a represent shall be difference between waves from adjoining slits and in the direction of u can be difference between waves from adjoining slits and in the direction of u can be difference between waves from adjoining slits and in the direction of u can be difference between waves from adjoining slits and in the direction of u can be difference between waves from adjoining slits and in the direction of u can be difference between waves from adjoining slits and in the direction of u can be difference between waves from adjoining slits and in the direction of u can be difference between waves from adjoining slits and in the direction of u can be difference between waves from adjoining slits adjoint adjoint adjoint adjo (48) B 0B § * E = 0t B (49) B §#B = 0 B B c2 § * B = (50) B 0E J + e0 0t (51) As before, § * 1§ * E2 = - §2E because § # E = 0 in the identity of Eq. (23). For some time this perplexing state of affairs, referred to as the wave-particle duality, motivated the greatest scientific minds of our age to find a resolution to these apparently contradictory models of light Results apply quite well also to cases of near-normal incidence. Equation (31) is equivalent to the two equations, E0 + Er1 = m11Et2 + m12gsEt2 g01E0 - Er12 = m21Et2 + m12gsEt2 g01E0 - Er12 = m21Et2 + m22gsEt2 lividing through these two equations, E0 + Er1 = m11Et2 + m22gsEt2 g01E0 - Er12 = m21Et2 + m22gsEt2 g01E0 - Er12 = m21Et 1 + r = m11t + m12gst (33) g011 - r2 = m21t + m22gst (34) 481 Theory of Multilayer Films Equations (33) and (34) can be solved for the transfer-matrix elements to give t = r = 2g0 + g0gsm12 + m21 + gsm22 (35) g0m11 + g0gsm12 - m21 - gsm22 g0m11 + g0gsm12 + m21 + gsm22 (36) g0m11Equations (35) and (36), together with the transfer-matrix elements, defined by Eqs. If the lens aperture becomes too small to admit two such beams, such as (a) and (b) from S1, no interference is detected. File loading please wait... -150 s; Then with Eq. (37), AB = a 25 + 100 b 5 cm = 25 cm. Thermocouples and Thermopiles A thermocouple is a device in which an increase in temperature at a junction of two dissimilar metals or semiconductors generates a voltage (Figure 1a). In 1900, at the very dawn of the twentieth century, Max Planck announced at a meeting of the German Physical Society that he was able to derive the correct blackbody radiation spectrum only by making the curious assumption that atoms emitted light in discrete energy chunks rather than in a continuous manner. It should be pointed out that if the function to be represented is a function specify discrete harmonic components of amplitude cn at frequency vn . Determine the spot size at the beam waist, w0 . We see that birefringent materials are useful in fabricating devices that behave as linear polarizers as well as in produced by a two-lens system such as the one sketched in Figure 23a. In fact, the analysis holds for any sort of harmonic wave (e.g., spherical, cylindrical, or Gaussian). 522 Chapter 24 Nonlinear Optics and the Modulation of Light Horizontally polarized beam rejected V0 Horizontally polarized beam rejected V0 Horizontally polarized beam R mirror Glan-laser prism Laser rod Pockels crystal (a) VHW Horizontally polarized beam rejected V0 Horizontally polarized beam rejected V0 Horizontally polarized beam rejected V0 Horizontally polarized beam HR mirror Glan-laser prism Laser rod Pockels crystal (a) VHW Horizontally polarized beam rejected V0 Horizontally polari polarized beam Figure 6 Light-controlling action of a Pockels cell, used as a Q-switch. The electric field E in Eq. (6) should represent Bthe actual field at the dipole, in the interior of the B medium. Instead of a discrete spectrum of frequencies given by the Fourier series, Eq. (6), we are led to a continuous spectrum, as given by Eq. (8). When no distortions appear in the plane wavefronts through the interferometer, uniform illumination is seen near P. The surface charge density appears because such balancing is not possible there. The isolator consists of a Faraday rotator situated between a polarizer-analyzer pair. Visual Optics and Refraction, 2d ed. 20 A 10-slit aperture, with slit spacing five times the slit width of 1 * 10-4 cm, is used to produce a Fraunhofer diffraction pattern with light of 435.8 nm. 352 Chapter 15 Production of Polarized Light the metal wires that operate as a dichroic polarizer. c. generated by this detector when an electromagnetic field of irradiance 0.1 mW and wavelength 1.5 mm is incident on the detector? Determine the spacing of the developed silver planes within the emulsion. Bifocals, in which lenses of different powers are situated in the upper and lower half of a spectacle frame, can restore, to the presbyopic eye, clear vision of both near and distant objects. Notice that we have assumed x = x_i at t = 0. For applications requiring a large number of wires required by such a design becomes unwieldy. B Figure 5 Resultant E-vibration due to orthogonal component vibrations of equal magnitude and phase difference of p>2, shown at three different times. Atoms in Thermal Equilibrium: The Boltzmann Distribution Consider an assembly of atoms in thermal equilibrium at temperature T. It may be manipulated by a lens, for example, in the same way as the original wavefront. If the fringe systems overlap with their maxima and minima falling together, the resulting fringe pattern is highly visible, and the radiation from the two incoherent sources is considered highly coherent! When the fringe systems are relatively displaced, however, so that the maxima of one fall on the minima of the other, the composite pattern is not visible and the radiation is considered incoherent. Screen Lens f1m l 546 nm 0.2 mm Collimated beam x 0.1 mm 1m Figure 21 1 C A m + 12 B p D 2 b. As another example, suppose the aperture function is a television picture in which horizontal raster lines are visible. Thus such structures can be designed as band-pass filters with high spectral transmittance in the amplitude of the resultant wave is the difference; E1 and E2 . What is the new temperature and the new lmax? (See Problems 4 and 5.) 5 OPTICAL DISPLAYS In this section we describe briefly three different technologies used to display optical images in computer and TV monitors. denominator expresses the distance at which the smallest readable letter subtends 5; of arc overall. For $= -20^{\circ}$, s' = 3.180 cm and $' = -23.51^{\circ}$; for $= -20^{\circ}$, s' = 16.104 cm and $' = 6.081^{\circ}$ 22. "How Light Interacts with Matter." In Lasers and Light, pp. It is this property of temporal coherence that is measured by the Michelson interferometer. If a laser source is used, the lenses may not be needed. Show that a small change in angle ¢u around the direction of the atoms in the laser medium are in the ground state. If N fringes are counted as the pressure in the cell changes from vacuum to atmospheric pressure, what is the index of refraction n in terms of N, l, and L? Rearranging Eq. (20), we identify the distance r0 as the first focal length f1, given by f1 = R21, l n = 1 (21) There are other focal points as well. The predominant frequencies in the Stokes and anti-Stokes fields are characteristic of the molecule and so their detection can be used to determine the composition of, for example, the gases in a particular combustion process. Light of wavelength l4 = 1548 nm very nearly satisfies the constructive interference condition (Eq. (22)) for Output 2 since , l 11 l1 , l 2 l3 , l 3 4 , l 1 l MZ2 2,1 4 MZ1 1 3 12 1 4 MZ3 (a) ,1 11 11 3 12 1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 ,1 3 1 MZ2 1 3 1 2,1 4 12 1 MZ3 4 (b) Figure 17 Array of Mach-Zehnder fiber interferometers used to (a) demultiplex a signal into four wavelength channels. Example 5 A microscope has an objective of 3.8-cm focal length and an eyepiece of 5-cm focal length. In MZ2 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 MZ2 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 3 4 MZ1 1 3 1 2,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 4 MZ3 (a) ,1 11 11 ,1 2 ,1 4 MZ3 (a) ,1 11 11 ,1 12 ,1 4 MZ3 (a) ,1 11 11 ,1 11 ,1 12 ,1 4 MZ3
(a) ,1 11 11 ,1 12 ,1 4 MZ3 (a) ,1 11 11 ,1 12 ,1 4 MZ3 (a) ,1 11 11 ,1 11 ,1 11 ,1 11 ,1 12 ,1 4 MZ3 (a) ,1 11 11 ,1 general, a vector C b D is expressed in normalized form when B Figure 2 Representations can be recovered by "reflection" from a PCM that sends it back through the same system. In a recent advancement, the Figure 8 Correcting myopia by reshaping the cornea with radial keratotomy. The distance between slits is 0.005 mm and the slit width is 0.001 mm for each case. OPN Trends, "The Nature of Light: What is a Photon?" Vol. Nevertheless, if we call ¢ p the optical-path difference given by reshaping the cornea with radial keratotomy. Eq. (35) and ¢ r the equivalent path difference arising from phase change on reflection, we can state quite generally the conditions for ¢ p + ¢ r = A m + 12 B l (37) constructive interference: and destructive interference: where m = 0, 1, 2, Å. In geometrical optics, where light waves can be treated as rays propagating along straight lines, we expect to see a sharp image of the aperture. As a result, light of orthogonal linear polarizations travels with different speeds through such a fiber. However, in the general case, for which C1 and C2 are not equal to zero, Eq. (62) remains the defining equation for the function p(z). The flux leaving a point source within any solid angle is distributed over increasingly larger areas, producing an irradiance that decreases inversely with the square of the distance. Glass Figure 28 Problem 19. Optical Filtering We have seen that the back focal plane of the transform lens is the spectrum plane in which a Fourier transform of the aperture or transmitted by a fiber may not only lose power by the mechanisms just mentioned; it may also lose information through pulse broadening. The abbreviations read as follows: M.F.P. = myopic far point; N.N.P. = normal near point; M.N.P. = myopic near point. Solution For this interface, uc = sin-1 a 1 b = 38.7° 1.6 up = tan-111.62 = 58.0° up ce = tan-1 a 1 b = 32.0° 1.6 Since the angle of incidence of 30° is less than either up cor uc , Eqs. UV-B radiation has been linked to a variety of skin cancers the angle of incidence of 30° is less than either up cor uc , Eqs. UV-B radiation has been linked to a variety of skin cancers the angle of incidence of 30° is less than either up cor uc , Eqs. UV-B radiation has been linked to a variety of skin cancers the angle of incidence of 30° is less than either up cor uc , Eqs. UV-B radiation has been linked to a variety of skin cancers the angle of incidence of 30° is less than either up cor uc , Eqs. UV-B radiation has been linked to a variety of skin cancers the angle of incidence of 30° is less than either up cor uc , Eqs. UV-B radiation has been linked to a variety of skin cancers the angle of incidence of 30° is less than either up cor uc , Eqs. UV-B radiation has been linked to a variety of skin cancers the angle of incidence of 30° is less than either up cor uc , Eqs. UV-B radiation has been linked to a variety of skin cancers the angle of incidence of 30° is less than either up cor uc , Eqs. UV-B radiation has been linked to a variety of skin cancers the angle of incidence of 30° is less than either up cor uc a sin the angle of incidence of 30° is less than either up cor uc a sin the angle of incidence of 30° is less than either up cor uc a sin the angle of incidence of 30° is less than either up cor uc a sin the angle of incidence of 30° is less than either up cor uc a sin the angle of an and contributes to the sunburning process. Interference maxima are separated by 3.29 mm. 15 Consider the Fabry-Perot cavity shown in Figure 8. To compensate for all wavelengths at once, a compensator plate C made of the same material and dimensions as BS is inserted parallel to BS in the path of beam 2. 64 Chapter 3 Optical Instrumentation TABLE 1 FRAUNHOFER LINES n l (nm) 486.1 589.2 656.3 Characterization Crown glass Flint glass F, blue D, yellow C, red 1.5286 1.5230 1.5205 1.7328 1.7205 1.7076 sodium atoms in the sun's outer atmosphere. 2 Using the thin prism at minimum deviation for the D line, for example, the ratio of angular spread of the F and C wavelengths to the deviation of the D wavelength, as suggested in Figure 13, is nF - nC D = d nD - 1 This measure of the ratio of dispersive power c, so that c = nF - nC nD - 1 (18) Using Table 1, we may calculate the dispersive power of crown glass to be 1>65, while that of flint glass is 1>29, more than twice as great. Where the direct and reflected beams strike the screen, fringes will appear. Problem 1. Thus, the physical implications of Eq. (15) may be summarized as follows: The frequency width ¢n of a spectral line is inversely proportional to the coherence time of the source. (c) (d) (e) (f) Since this is spontaneous emission, the physical implications of Eq. (15) may be summarized as follows: directions. Compare these results to those obtained in parts (d) and (e). (a) What power contact lens should an optometrist prescribe to move the myopic far point out to infinity? On this basis, double refraction in calcite could be understood as a phenomenon involving polarized light. While normal vision is 20/20, visual acuity readings as good as 20/15 are not uncommon. R2n = ar0 + Rn nl 2 b - r20 2 (19) which can be written as rn r0 ≤ nl 2 r0 R2n = r20 c n a l n2 l 2 b + a b d r0 4 r0 P Figure 8 Schematic for the calculation of Fresnel zone plate radii. Princeton, NJ: D. The order number m for a Fabry-Perot interferometer is the number of half-wavelengths that fit into the Fabry-Perot length and so is typically in the range 105 - 106. How many fringes would be counted if the gas were carbon dioxide 1n = 1.000452 for a 10-cm cell length, using sodium light at 589 nm? ABCD Law With the help of matrix methods, develop a simple, yet powerful, recipe for laser-beam propagation through an arbitrary optical system. 1 POLARIZATION OF A DIELECTRIC MEDIUM We take as our model a simple dielectric, that is, a nonconducting material whose properties are isotropic. Consequently, in the approach to steady state, the laser system produces pulses that have peak irradiances far larger than the steady-state irradiance. A collimated beam of light d 11 111 112 112 11 (a) Achromatic prism (b) Direct-vision prism for wavelength l Figure 16 Nondispersive and nondeviating prisms. A ray leaving the tip of the object, parallel to the optical axis, undergoing refraction at the lens surfaces and passing through the right focal point F of a converging lens, as in Figure 22a. In each case, ER = E1 + E2. For such a case, in the region outside the small Airy disc, Eu = 0, essentially. This bending of light waves around the edges of an obstruction came to be called diffraction. The cavity mirrors shown are shaped with surfaces concave toward the cavity, thereby "focusing" the reflecting light back into the cavity and forming a beam waist of radius w0 at one position in the cavity. 260 Chapter 10 Fiber Optics Figure 14 Symbolic representation of waveguide dispersion. y_{1z} , $t_{2} = A \sin 2[4p_{1t/s} + z/m_{2}] 2$. If the focal length of the lens representation of x_{1z} , y_{1z} , $t_{2} = U_{1x}$, tEq. (7). This difference represents a significant saving of light energy in an optical system where multiple surfaces occur. Becherer. We need to relate the ray coordinates 1y₂, a₂ after refraction, 1y, a2. (12), (14), (17), and (18) can be recast as follows: TE: e E + Er = Et n1 E cos u - n1 E + cos u + n1 E r cos = -n2 Et E cos u + Er cos u + Er cos u + Er cos u + Cos ut (20) (21) (22) (23) Next, eliminating Et from each pair of equations and solving for the reflection coefficient r = E r cos u + n cos ut (24) rTM = -n cos u + cos ut (25) where we have introduced a relative refractive index n K n2>n1. The battery and helix pictured are only symbolic. Equation (28) also indicates that shorterwavelength Gaussian beams tend to spread less than longer-wavelength beams. 18 Calculate the group delay between the fastest and slowest modes in a 1-km-long step-index fiber with n1 = 1.46 and a relative index difference c = 1n1 - n22 > n2 = 0.003, using a light source at wavelength 0.9 mm. You can see that it is that component whose aperture edges limit rays from O to their smallest angle relative to the axis. An incident photon imparts energy to the valence electron of a halide ion, which can then combine with the silver atom. signal beam A 3. The E0 Incident field y 45 45 FA x SA V Figure 3 Pockels cell schematic. According to Eq. (33) the principal maxima occur for p>N = m = 0, ;1, ; 2, Å. As shown previously, image brightness is inversely proportional to the square of the f-number. Peterson. A detector is placed on the axis, 25 cm from the slit. The incremental change in irradiance ξI across this small volume then can be written as $\xi I = hn$; $\xi n \xi A \xi t$ Dividing each side of this relation by ξz gives hn; $\xi n \xi I = \xi z \xi V \xi t$ (21) Now, the net rate of photon production or loss in the small volume ξV is the result of spontaneous emission, and stimulated absorption. Convex mirror: f = -10 cm and s = +20 cm. 6 DISTORTION The last of the five monochromatic Seidel aberrations, present even if all the others have been eliminated, is distortion, represented by the term 3 3C11h; r cos u. We may now use Eq. (37) to determine how small the single slit must be to ensure coherence and the production of fringes at the screen. Once back in the ground state, it is again available to
undergo collision with an excited helium atom and to repeat the cycle. (13) and (14) as special cases, with u = 90° and u = 45°, respectively. Real, nonlocalized fringes are formed in the space above the film. The first possesses a frequency vp and propagation constant kp that are, respectively. Real, nonlocalized fringes are formed in the space above the film. constants of the component waves. The parameter ap is chosen to minimize modal distortion. The objective lens of either telescope functions as the aperture stop and entrance pupil, whose image in the ocular is then the exit pupil, as shown. All oscillations of this B E-field are represented by the two transverse vectors, both of which are labeled E in Figure 9a. The point O₂ thus locates a virtual image of the original object point O, seen on reconstruction by looking into the hologram. Find the angular spatial frequencies associated with the m = 1 and m = 3 spots. In the formalism of guantum mechanics, the electron itself is represented by a localized wave packet that can be decomposed into a number of harmonic waves with a range of wavelengths. Solution The near point of the unaided 432 Chapter 19 Optics of the Eye eye. Thus we see that the transmittance of the system can be modulated by variations in the applied voltage. (17), (18), and (19) follow, in steady state, from Eq. (16) and Eq. (14). 58, June 1990: 542. Note that, for convenience, we use sine functions to represent the individual waves. Charge-coupled devices (CCDs), in which the incoming radiation is detected by a two-dimensional array of photodiodes, are becoming the preferred choice for image detection. The individual plane 460 Chapter 21 Fourier Optics y Y O (x, y, 0) x da r0 P (X, Y, Z) r u X (x, y, Z) Z Figure 1 Fraunhofer diffraction in the spectrum XY-plane. See Figure 3a. The internal charge density is zero because, in any internal closed surface, every bit of charge that moves into the enclosed volume in response to a polarizing field is balanced by an equal bit of charge that moves out. Large homogeneous lenses are difficult to produce without optical defects, and their weight is difficult to support. Solution The average irradiance Ee = power 6000 = 1.91 * 109 W > m2 area p110-322 From Eq. (42), E0 = a 211.91 * 1092 1 > 2 2 Ee 1 > 2 b d = c = 1.20 * 106 V > m e0c $e^{0.1}$ e0c and, from Eq. (30), B0 = E0 1.20 * 106 = = 4.00 * 10-3 T c c 1 To avoid confusion of electric field with irradiance, we will use the symbol I, rather than Ee, to denote irradiance, we will use the symbol I, rather than Ee, to denote irradiance, we will use the symbol I, rather than Ee, to denote irradiance, we will use the symbol I, rather than Ee, to denote irradiance and two members, these velocity is yp = c n500 = 3 * 108 m s = 1.942 * 108 Eq. (32) can also be applied to the case of refraction at a single surface, Eq. (20), in which case the refractive indices in object and image space need not be 1. M F S d pattern results from interference due to the air film between the reflecting plane at M. edge of the field of view is to be sharply delineated, the field stop should be placed in an image plane so that it is sharply focused along with the final image. The "shadows" observed formed a complex interference pattern like those produced with water waves. PROBLEMS 1 a. We may give physical significance to b by interpreting it as a phase difference. The resulting hologram is called a matched filter or a Vander Lugt filter, after its originator. The sinc function has the property that it approaches 1 as its argument approaches 0: lim sinc1b2 = lim a b:0 b:0 sin b b = 1 b (11) Otherwise, the zeros of sinc1b2 occur when sin b = 0, that is, when b = 121kb sin u2 = mp m = ; 1, ; 2, A Equation (11) shows that the value m = 0 should not be included in this condition. The closeness of the wavelengths for minimum dispersion curve towards longer wavelengths, so that it passes through zero at 1.55 mm instead of 1.31 mm. The fundamental wave equation for electromagnetic waves in the dielectric is a consequence of the Maxwell equations. Note that, in general, s represents the distance along a waveform measured along a direction that is perpendicular to the waveform measured along a waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that is perpendicular to the waveform measured along a direction that the waveform measured along a expressed by B B B # B E = E0ei1k r - vt2 (1) B where the origin of coordinates is taken to be point O. Solid-state lasers are typically flash-lamp pulsed or optically pumped by 577 Laser Operation another laser. If point A; is constructed on the perpendicular AO such that AO = OA; the right triangles AOC and A; OC are equal. All rays from the distant object point that pass through the zone form the comatic circle shown. New York: John Wiley and Sons, 1979. By Snell's law, n0 sin ui = nf sin ut (30) In addition, by inspection, AE = AG sin ut = a AC b sin ut 2 (31) and hor example. Filled circles indicate electrons and empty circles indicate holes. Notice then that, except for the sign of the vt term, the reflected wave is the conjugate of the original wave as described above: It retraces the path of the incident beam and is its phase-reversed replica. The wave description of light will be found adequate to describe most of the optical phenomena we cover. Consider the multiple reflections of the narrow beam of light of amplitude E0 and angle of incidence ui, as shown in Figure 22. The object distance for the second surface takes into account the thickness of the lens. Larger irradiances occur for gain media with larger saturation irradiances. (Adapted with permission from Mathew Alpern, "The Eyes and Vision," Section 12 in Handbook of Optics, New York: McGraw-Hill, 1978.) 6.96 mm 3.6 mm 7.2 mm N S3 F VC 425 Optics of the Eye (unit) Front focal plane Back focal plane Front principal plane Back principal plane Back nodal plane Back nodal plane Anterior chamber Vitreous chamber Entrance pupil Exit pupil Defining symbol Distance from corneal vertex (mm) Refractive index James Clerk Maxwell, for whom the equations that govern electricity and magnetism are named, "light" is identified as an electromagnetic wave having a frequency in the resin has hardened, the replica grating can be separated from the master. Note that, for such a situation, the product function r1n2q1n2 is significant only over the range of frequencies near n0 for which g1n2 is significant. Some of the irradiance patterns for low values of the Hermite integers m and n-predictable from Eq. (68) and Figure 15—are reproduced in Figure 16. We now show that the minimum resolvable wavelength difference, ¢lmin, can be compactly expressed in terms of the cavity finesse F. Chromatic aberration, coma, astigmatism, curvature of field, and distortion) occur largely as a result of 59 Optical Instrumentation L2 A AS, EnP ExP P 3 cm Chief L1 L2 f1 6 cm ray f 2 10 cm 1.5 cm M N O 3 cm O O F1 F1, F2 F2 P P 3 cm 4 cm 12 cm 10 cm 18 cm 9 cm Figure 5 Solution to Example 1 (d). Cambridge: Cambridge University Press, 1997. As magnifications increase and the focal lengths and diameters of the objective lenses decrease corespondingly, the solid angle of useful rays from the object also decreases. Use the root-mean-square velocity of a gas molecule given by yrms = where R is the gas constant, T the Kelvin temperature, and M the molecular weight. Would a ratio of a>b = 9 fit the pattern. With Eq. (21) for the Rayleigh range and the aperture diameter criterion D = 4.5w, one can calculate the Rayleigh range z0 for typical lasers as a function of aperture diameter. The optometrist would prescribe a contact 1 1 lens with a power of P = = = - 1.00 diopter 1-1.00 D2. The input is mercury green light of 546.1 nm. The coherence length lt of a wave train is the length of its coherent pulse, or lt = ct0 (16) Combining Eqs. Ch 6. Show that, for this case and for q0 W gth, essentially every pump event leads to an output photon. Only those waves that satisfy a resonance condition are sustained. Shurcliff, Polarized Light: Production and Use (Cambridge, Mass.: Harvard University Press, 1962). Saleh, B. Important features of Eq. (25) to be discussed in the following paragraphs and the next subsection are shown in Figure 2. Image inversion may also be achieved without additional length, as in binoculars, through the use of inverting Porro prisms, discussed previously. This criterion is explained and used in the later treatment of diffraction, where it is shown that the minimum separation ¢a of the two wavefronts, such that the images formed are
just barely resolvable, is given by ¢a = 1 d (22) Combining Eqs. The former face is on the left in contact with air and the other in contact with a liquid of index 1.4. The refractive index of the glass is 1.50. Incident on plane side: 8 cm beyond lens; on curved side: 5.33 cm beyond lens 34. For the responsivity to be a useful specification of a detector, it should be constant over the useful range of the instrument. 6 OPTICAL PHASE CONJUGATION Optical phase velocity of an optically centered package. The phase velocity of an electromagnetic signal is a measure of the velocity of the harmonic waves that constitute the signal. The factor of 50 accounts for the factor 2 accounts for the fact that the light traverses the length of an arm twice in one roundtrip through the Fabry-Perot cavity in that arm. The presence of illumination and the extra free-charge carriers so produced effectively lower the resistance of the material, and a larger photocurrent results. In practice, the limit is around 1.6. The numerical aperture is an alternative means of defining a relative aperture or of describing how "fast" a lens is. 6 A reflecting telescope uses a spherical mirror with a 3-m focal length and an aperture given by f/3.75. The opacity, in turn, is just the reciprocal of the transmittance, T. The curves have been normalized to the same maximum amplitude. Inside the lens, therefore, rays are directed as before to form an image 40 cm to the right of the first surface. Approximately midway between S and T, the focus will be circular, the circle of least confusion. (a) product (c) 32.8%; 0.48 (a) 5 units of amplitude (c) 25[1 + sin(ay)]2 (A2 /) cos() (a) 18.3 kHz (b) 17.2 Hz (a) 0.04 Å (b) 0.1 Å (a) 2.86 × 10-3 cm (b) 5.59 nm (c) 224 nm (d) 0.80 reading/s 11. This anisotropy can be introduced by manufacturing fibers with elliptical cores or by applying an anisotropic stress to the fiber. However, for gain cells that are long enough to allow the irradiance to grow to an appreciable fraction of the saturation irradiance. The final drawing, based on an original scale of 1 cm = 14 in., with all items of interest, is shown in Figure 5. Eye Beam splitter referred to as Haidinger fringes, or fringes of equal inclination, since they are formed by parallel incident beams from an extended source. In these cases, the resulting geometric relationship analogous to Eq. (11) consists of terms that are all positive. an incident ray is partially reflected and partially transmitted at a plane interface separating two transparent media. Courtesy of LIGO Laboratory. Structures and cavities inside can be revealed in three-dimensional images formed by ultrasonic holography. Solution a. (The irradiance of the sun at the earth's surface is about 1000 W>m2.) 20 For a Nd:YAG laser, there are four pump levels located at 1.53 eV, 2.119 eV, and 2.361 eV above the ground state energy level. The inevitable blur that is, its ability to provide distinct images for distinct object points, either physically close together (as in a microscope) or separated by a small angle at the lens (as in a telescope). We wish to express the electric field ET transmitted through the FabryPerot interferometer in terms of the cavity mirrors, and the length d of the cavity mirrors, and the length d of the cavity mirrors of the field ET transmitted through the FabryPerot interferometer in terms of the field ET transmitted through the FabryPerot interferometer in terms of the cavity mirrors, and the length d of the cavity mirrors of the field ET transmitted through the FabryPerot interferometer in terms of the field ET transmitted through the FabryPerot interferometer in terms of the field ET transmitted through the FabryPerot interferometer in terms of the cavity mirrors of the field ET transmitted through the field ET transmitted through the FabryPerot interferometer in terms of the cavity mirrors of the cavity mirrors of the field ET transmitted through the FabryPerot interferometer in terms of the cavity mirrors of the field ET transmitted through the field ET transmitted the field ET transmitted through the field ET transmitted 5a, as each Fresnel zone contribution an is added. Also, change the value of n to produce graphs for the case of external and internal reflection from diamond 1n = 2.422. That is, for an electromagnetic field waveform to be a mode of an optical cavity, it must have the same spatial form after one round-trip that it had at the start of the round-trip. If the applied electric field, or P E0 P0 E0 E P0 Figure 1 Linear and typical nonlinear response of polarization P to an applied electric field E. Plot the laser output irradiance as a function of the variable transmittance T3 of the output mirror. 7 A polished surface is examined using a Michelson interferometer with the polished surface replacing one of the mirrors This design is used for large concave gratings, whereby the slit, grating, and plate holder all lie on a circle called the Rowland circle that has the following property. C = 0. Variables in the situation include the size and spectral width of the source and the shape and reflectance of the film. D. Determine the position and size of the entrance and exit pupils, as well as the image. Sketch the power spectrum, locating its zeros, and show that the frequency bandwidth for the pulse is inversely proportional to its duration. In the case of a perfect optical system, there is established a one-to-one correspondence between conjugate object and image points. We define reflection and transmission coefficients2 by r = Er , Ei t = Et Ei (41) 2 We will have occasion later to also use reflectance (R) and transmittance (T), defined as the ratio of the corresponding irradiances. The high resolution is gained at the expense of a contracted spectral range of only l>m = 755>30 = 25 nm. The two parts are superimposed again after traveling along different paths. Example 2 Estimate

the coefficient of finesse F, the finesse F, and the mirror reflectivity r for a Fabry-Perot cavity with the transmittance curve shown in Figure 10. For example, taking n = 10,000, l = 600 nm, and r0 = 30 cm, one finds n > r0 = 0.02 and n2 l 2 a b = 0.0001, justifying the neglect of the second term in the square 4 r0 brackets. It can be shown that this approximation does not affect the results of third-order aberration theory. By reducing the convergence with a number of diverging lenses placed in front of the single corrective lens needed by simply adding the diopters of these test lenses. From Eq (22) kY = 2pnY. Entrance pupil is the stop; exit pupil is 3.33 cm in front of the lens, with an aperture of 3.33 cm; image is 10 cm behind the lens, inverted and 2 cm long. One criterion for broadly classifying interferometers distinguishes the manner in which the initial beam is separated. Ch. 2. In thermal equilibrium the rates of change of the 1 See, for example, M. Such materials manifest appreciable contributions to their optical properties from both free and bound charges and accordingly must be treated by allowing for both types of behavior. In the ultraviolet range of 110 to 160 nm, coatings of magnesium fluoride over aluminum are generally used to enhance reflectivity. See Table 1. Making only rough estimates, we shall ignore the fact that the wavefronts striking the lens from nearby object points A and B are not plane, as required in far-field 281 Fraunhofer Diffraction A Radius of Airy disk ©umin xmin B f Figure 11 Minimum angular resolution of a microscope. Such objectives are chromatically for the lens from nearby object points A and B are not plane, as required in far-field 281 Fraunhofer Diffraction A Radius of Airy disk ©umin xmin B f Figure 11 Minimum angular resolution of a microscope. Fraunhofer C (red) and F (blue) wavelengths, and spherically corrected, at the Fraunhofer D (sodium yellow) wavelength. The end result consists of left- and rightcircular components that are out of phase and whose superposition, upon emerging from the Faraday rotator, is linearly polarized light with its plane of polarization rotated relative to its original orientation. C P M (a) M BS M C P M (b) l Figure 7 (a) Michelson system for producing interference gratings, including collimator C, mirror M, and photographic plate P. Thus, the inner details of these comatic circles are not visible and all that is seen is the cometlike comatic shape. Mill Valley, CA: University Science Books, 1986. (d) Active cavity containing a gain medium. (b) Transmittance for laser cavity of length l (solid curve) and etalon of the spectral lines is a direct indication of the linewidth ¢n of the particular transition leading to that spectral line. Determine, using Jones matrices, the character of the light after passing through (a) the QWP and (b) the final linear polarizer. In a Michelson interferometer, the difference of the two beams coming from the interferometer arms and arriving at the detector. Figure 10b shows the gain coefficient at a time in the buildup to steady state when only four cavity modes remain above threshold. The optic nerve is the main trunk line that carries visual information from the retina to the brain, completing the remarkable process of vision. Concave-grating instruments are used for wavelengths in the soft X-ray (1 to 25 nm) and ultraviolet regions, extending into the visible. (Radiometric quantities are sometimes subscripted with the letter e. The penetration depth is given by Eq. (50): fzf = 0.500 mm sin2 60 2p - 1 B 11>1.522 = 0.096 mm 506 Chapter 23 Fresnel Equations 6 COMPLEX REFRACTIVE INDEX We wish now to show that when the reflecting surface is metallic, the Fresnel equations we have derived continue to be valid, with one important modification: The index of refraction becomes a complex number, including an imaginary part that is a measure of the absorption of small objects accomplished by the simple magnifier is increased further by the compound microscope. The cones cluster preferentially near the center of the retina, a 3-mm-diameter region called the macula. 1 MATHEMATICAL REPRESENTATION OF POLARIZED LIGHT: JONES VECTORS Consider an electromagnetic wave propagating along the z-direction of the coordinate system shown is Figure 1. The brain records the message seen by the dominant eye, while suppressing the other. Calculate the difference in the refractive indices for the telescope is a 30-cm positive lens, with a diameter of 4.50 cm. We begin with an argument owing to Sir George Stokes, which yields information concerning the amplitudes of reflected and transmitted portions of a plane wavefront incident on a plane refracting surface, as in Figure 21a. 14 A so-called "rabbit-ears" TV antenna is made of a pair of adjustable rods that can spread apart at different angles. 7 Reference to Table 2 indicates that the corneal radius of curvature for the unaccommodated schematic eye is 8 mm. The first two are traceable, for the most part, to an abnormally shaped eyeball, axially too long or too short. A LED is a solid-state device employing a p-n junction in a semiconducting crystal. In this case the emerging rays determine a virtual image VI near the object RO erect and slightly magnified. 14 Why should one expect lasing at ultraviolet wavelengths? After coming to a focus at I, the light rays continue to the eyepiece, or ocular lens. The discussion begins with an introduction to the operation of stopset lasing at ultraviolet wavelengths? pupils, and windows, of great practical importance to light control in optical instrumentation. There are also periodic times when the standing wave is everywhere zero, since $\cos vt = 0$ for t = T > 4, 3T > 4, Å. For a given plate, the right side of Eq. (11) is constant throughout the optical region of the spectrum, if the small variation $1n - n ff^2$ is neglected. For example, 2i the Jones vector C 2 D represents right-circularly polarized light since E0y E0x c E0y \neg E0x (a) E0y E0x E0y \ddagger E0x 2i i 1 d = 2 c d = 2i c d 2 1 -i The prefactor of a Jones vector may affect the amplitude and, hence, the irradiance of the light but not the polarization mode. The high-index material is encountered first by the incident light, as in Figure 8. This complication is explored in problem 28. Assume that the Fabry-Perot cavity used has a length of 10 cm and that the nominal frequency of the laser input is 4.53 * 1014 Hz. Find a. Thus, the surfaces of constant phase are a family of planes perpendicular to the x-axis. Screen Ocular Figure 39 s- where moc is the linear magnification of the ocular and s- is the distance from the ocular to the final image. In subsequent sections of this chapter, we examine so-called magneto-optic devices. 2 The theorem can easily be verified for the product of two matrices and generalized by induction to the product of any number of matrices. It is often described in terms of a temporal coherence, which is a measure of the degree of monochromaticity of the light, and a spatial coherence, which is a measure of the uniformity of phase across the optical wavefront. Solution We sketch the solution in outline form only. If point O in Figure 3 is the origin of secondary wavelets that arrive at an arbitrary point P in the field, then the correct modification of amplitude a as a function of the angle u is given by a = a = 0 b 11 + cos u 2 2 (13) where a beat any time is a measure of its irradiance, the energy delivered by the traveling sequence of pulses in Figure 7b is itself pulsating at a beat frequency, vb. Assume that the index of refraction of the fiber is n = 1.500. In one mode of operation, the lengths of the arms of the interference occurs at the detector. The electronic pulses corresponding to the photo-induced charge accumulated near each pixel in a given row arrive sequentially at the end of the row. The number of grooves N in a diffraction grating plays the role of the length of the Consequently, the power P = 1 > f of the doublet is P = P1 + P2. LP1P2 (36) For a cemented doublet of thin lenses, L = 0, and the powers of the lenses are simply additive: P = P1 + P2. LP1P2 (36) For a cemented doublet of thin lenses, L = 0, and the powers of the lenses are simply additive: P = P1 + P2. electromagnetic field within the laser cavity. The aperture in position (1) produces more barrel distortion than it does in position (2). The Jones vector of Eq. (9) represents an electric field vector whose tip travels in a counterclockwise direction as it traces out an ellipse whose symmetry axes are inclined at a general angle relative to the x,y-coordinates (3) represents an electric field vector whose tip travels in a counterclockwise direction as it traces out an ellipse whose tip travels in a counterclockwise direction as it traces out an ellipse whose tip travels in a counterclockwise direction as it traces out an ellipse whose tip travels in a counterclockwise direction as it traces out an ellipse whose tip travels in a counterclockwise direction as it traces out an ellipse whose tip travels in a counterclockwise direction as it traces out an ellipse whose tip travels in a counterclockwise direction as it traces out an ellipse whose tip travels in a counterclockwise direction as it traces out an ellipse whose tip travels in a counterclockwise direction as it traces out an ellipse whose tip travels in a counterclockwise direction as it traces out an ellipse whose tip travels in a counterclockwise direction as it traces out an ellipse whose tip travels in a counterclockwise direction as it traces out an ellipse whose tip travels in a counterclockwise direction as it traces out an ellipse whose tip travels in a counterclockwise direction as it traces out as the travels in a counterclockwise direction as it traces out as the travels in a counterclockwise direction as it traces out as the travels in a counterclockwise direction as it traces out
as the travels in a counterclockwise direction as it traces out as the travels in a counterclockwise direction as it traces out as the system. Recalling that the irradiance of N identical but randomly phased sources is the sum of the individual irradiances. The hologram is a complex interference pattern of microscopically spaced fringes, not an image of the scene. 4 Two waves traveling together along the same line are given by p y1 = 5 sin c vt + d 2 y2 = 7 not relevant to the nature of the diffraction pattern that occurs. and E. 90 3 PHASE CHANGES ON REFLECTION The negative values of the reflection coefficient in Figures 3 and 5 indicate that Er = - f r f E in certain situations. (19) and (22), we are able to characterize the beam parameters for laser propagation in any homogeneous medium of refractive index n. (b) When sufficient voltage is applied to the cell, the liquid-crystal molecules (except for those adjacent to the scratched glass plates) align with their long axis along the field direction. This can occur readily for low orders and therefore for thin films. In other, more complex, systems, the relevant quantities may be described as follows. 8, 9, 19. The key words here are amplification and stimulated emission. (30) E3 k32 E2 spIp k31 sI hn k21 hnp E1 k30 k10 k20 E0 Figure 5 Level structure of a four-level gain medium. On the other hand, a direct vision prism, Figure 16b, accomplishes zero deviation for a particular wavelength while at the same time providing dispersion. Example 2 Consider at the same time providing dispersion. situation in which an incident fundamental field of wavelength 10 = 0.8 mm is incident on a KDP crystal with refractive indices 1.4802 for the second harmonic and 1.5019 for the fundamental. For reflected beam. (9) and (10), the regime of Fresnel, or near-field, diffraction may be expressed by 1 1 1 a + b h2 7 l q 2 p near field: (11) Of course, this condition also applies to the other dimension (transverse to h) of the aperture, not shown in Figure 2. When a sheet of clear, polyvinyl alcohol is heated and stretched along a given direction, its long, hydrocarbon molecules tend to align in the direction of stretching. The line image is real, 18.75 cm past the lens and 15.75 cm long. Appendix 5-B. The Pockels cell can be used also with the field oriented orthogonally to the beam direction, an arrangement that simplifies placement of the electrodes. That is, for constructive interference of light of free-space wavelength l2 in Output 2, ¢L = 1m + 1>22l2>n m 0, 1, $2 A (22) Both Eqs. The distance between the hanging mirrors can vary in response to passing gravitational waves. (10) and (11) allows the rate equations governing the population densities in the states 2 and 1 to be written as <math>dN2 = -A 21N2 - B21g1n_2 21I > c2N2 + B21g1n_2$ $B12g1n_22II > c2N1$ dt (13) and Following a particular convention, we choose to define the stimulated emission cross section s as s = $B21g1n_22II > c2N1$ dt (13) and Following a particular convention, we choose to define the stimulated emission cross section s as s = $B21g1n_22II > c2N1$ dt (13) and Following a particular convention, we choose to define the stimulated emission cross section s as s = $B21g1n_22II > c2N1$ dt (13) and Following a particular convention, we choose to define the stimulated emission cross section s as s = $B21g1n_22II > c2N1$ dt (13) and Following a particular convention, we choose to define the stimulated emission cross section s as s = $B21g1n_22II > c2N1$ dt (13) and Following a particular convention, we choose to define the stimulated emission cross section s as s = $B21g1n_22II > c2N1$ dt (13) and Following a particular convention, we choose to define the stimulated emission cross section s as s = $B21g1n_22II > c2N1$ dt (13) and Following a particular convention, we choose to define the stimulated emission cross section s as s = $B21g1n_22II > c2N1$ dt (13) and Following a particular convention, we choose to define the stimulated emission cross section s as s = $B21g1n_22II > c2N1$ dt (13) and Following a particular convention, we choose to define the stimulated emission cross section s as s = $B21g1n_22II > c2N1$ dt (13) and Following a particular convention, we choose to define the stimulated emission cross section s as s = $B21g1n_22II > c2N1$ dt (13) and Following a particular convention, we choose to define the stimulated emission cross section s as s = $B21g1n_22II > c2N1$ dt (13) and Following a particular convention, we choose to define the stimulated emission cross section s as s = $B21g1n_22II > c2N1$ dt (13) and $B21g1n_22II > c2N1$ dt (1 is viewed from a fixed position, as in Figure 2b, it is periodic in time with a repetitive temporal unit called the period T. Solution The small-signal gain coefficient must exceed the threshold gain coefficient for lasing action to occur. The curves of Figure 4 have been calculated using the theory presented in this chapter. Repeat (b) when the angle of incidence from air (relative to the normal) is 30°. In particular, let E0x = A and E0y = B, where A and B are positive numbers. In that 569 570 Chapter 26 Laser Operation case the photon number density in the cavity can be related to the field irradiance I in the cavity by the relation I = hn_ccNp Using this in the rate equation for N2 gives, dN2 = Rp2 k2N2 - scNpN2 dt (54) The rate equation for the photon number density can be formed by adding the contribution originating from interaction with the gain medium. What is the radius of the last zone in the drawing? This image is called the exit pupil of the optical system. Example 1 Consider the 4-mW, TEM00 helium-neon (He-Ne) laser 11 = 632.8 nm2 with cavity length d = 1 m shown in Figure 7. Coherence of Light. Thus, Re 1n2 = nR must behave as the ordi' nary refractive index, and Im 1n2 = nI, called the extinction coefficient, determines the rate of absorption of the wave in the conductive medium. A schematic eye (after H. An examination of Eq. (10), for z = 0, indicates that the imaginary part of q(0) must be negative so that the field amplitude does not grow without bound as x and y tend to infinity. 110 Chapter 4 Wave Equations along the y-direction is always p>2 out of phase with the x-component of the electric field, leading to circular polarization. The resultant vibration takes place along a line with negative slope. Such a pulsed-pump or gain-switched system can produce usable pulses as a gain medium is illustrated in Figure 5. Since the real and imaginary parts of the numerator and denominator are the same, except for a sign the magnitudes of the numerator and denominator are equal, and rTE has unit amplitude. Pedrotti and L. Notice that to maximize the mode number m, Eq. (35) requires that the plate separation d be as large as possible. What is the irradiance of the first three orders of interference fringes, relative to the zeroth-order maximum? Notice that this general form does indeed reduce to the Jones vectors found for a 2 x 2 a x 3 3 (a) y 3 3 1 3 1 2 1 2 (b) Figure 3 (a) Linearly polarized electric field vectors whose x- and y-components are in phase lie in the first and third quadrants. Thus, each successful mode of propagation in the waveguide has an integer mode number m, related to a direction wm and given by m 2n1d cos wm l (8) For our present purposes, the precise number of allowable modes is not as important as the qualitative dependence of the mode order m on the fiber axis varies with l. Robinson, Glen M., David M. If the electric field amplitude of the wave is known to be 100 V/m, find 3RT A M B + Ey sin1kz - vt + w0y2yN Produce plots like those in Figure 12 that show the evolution of the electric field vector, at the plane z = 0, as a function of time over one complete temporal cycle for the following cases. Fresnel offered satisfactory methods for simplifying this task, or avoiding it altogether. Find the equivalent focal length of the combination and the position of the foci and
principal planes using the matrix approach. If the Kr is not excited, it repels the F atom and so the lower lasing level is unstable with an extremely short lifetime 1 10-13 s2. The near point (closest point of accommodation) moves further away from the eve with advancing age, starting at a position of 7 to 10 cm from the eye for a teenager, increasing to 20 to 40 cm for a middleaged adult, and extending to as far as 200 cm in later years. Why then does the spectrum also show a central spot, the DC component with m = 0? Adopting a wave theory, Huygens was able to derive the laws of reflection and refraction and to explain double refraction in calcite as well. Consider the interference term, I12 = 2e0c8E1 # E29 B B (6) B where E1 and E2 are given by Eqs. Residual impurities, such as the transitional metal ions (Fe, Cu, Co, Ni, Mn, Cr, V) and, in particular, the hydroxyl (OH) ion, also contribute to absorption, the last producing significant Loss w (a) Loss N N I Crowle feet Loss (b) Figure 5 Radiation loss from an optical fiber because of (a) a sharp bend and (b) microdefects at the fiber surface. 23 The total delay time in a 1-km fiber for which n1 = 1.46, c = 1%, l = 820 nm, and cl = 40 nm. B 19 Geometrical Optics of rectilinear propagation, the lines OA and OB form the sharp edges of the shadow to the right of the aperture. Only one has been listed here for use in a Pockels cell. Callen, and W. The holes S, S1, and S2 of Figure 3 are usually replaced by parallel, narrow slits (oriented with their long sides perpendicular to the page in Figure 3) to illuminate more fully the interference pattern. Thus, fringe separation is proportional both to wavelength and screen distance and inversely proportional to the hole spacing. What is the angle of incidence? 5.7 cm 16. From your results in parts (a) and (b), calculate the resolving power in second order. As the following example indicates, for macroscopic light sources, the energy of a photon is typically far less than the total detected energy, and so, in such a case, the restriction that the detected energy must be only a multiple of a photon's energy goes unnoticed. Whereas the eye provides a qualitative and subjective response. The numerical aperture clearly cannot be greater than unity, unless n0 7 1. Extend the "table" to include the case m = 2, n = 0. The cleaved edges of these p-n junctions, of submillimeter dimension, act as mirrors, providing feedback for the laser system. This leaves N E20 = a E20i = NE201 (17) i=1 because there are N sources of equal amplitude. PROBLEMS 1 An object measures 2 cm high above the axis of an optical system consisting of a 2-cm aperture stop and a thin convex lens of 5-cm focal length and 5-cm aperture. Correct for myopia and cylindrical surfaces to correct for astigmatism. Under these conditions, Eq (22) gives 1¢u2min = 33.6 * 10-5 rad, for an average wavelength of 550 nm. Image Brightness: Aperture Stops and Pupils Aperture Stop of an optical system is the actual physical component that limits the size of the maximum cone of rays-from an axial object point to a conjugate image point—that can be processed by the entire system. 609 Goure, J-P, and I. Determine the vergence of an object point 12 cm from the unit and that of the resulting image. In this arrangement, oblique chief rays, now determined by the aperture, do not penetrate the lens center. Let us examine the key biological components of the eye along the optical axis, in the same order as they are encountered by light rays in the usual image-forming process. In addition to freedom from the expensive and laborious process of machine ruling, the predominant advantage of the interference grating is the absence of periodic or random errors in groove positions that produce ghosts and grass, respectively. Furthermore, it can be shown that B 0P Jb = 0t B (17) With these constraints, the four Maxwell equations for a dielectric can be written B B B = - B 0 = -1 to be written B B B = -1 to be written interchanged the order of differentiation with respect to space and time in the last step. 128 Chapter 5 Superposition of Waves of the group is the velocity of the individual harmonic waves. In this way, different colors can be displayed by mixing different from the velocity of the primary red, green, and blue colors Furthermore, one must keep in mind that this treatment assumes a plane wavefront of uniform irradiance. 1 The spreading described by Eq. (15) has been deduced on the basis of Fraunhofer, or farfield, diffraction, which means here that L must remain reasonably large. $p = s_{\zeta} - s_{\zeta} + s$ is given by 1 1 h2 1 n + 2 2 c s + 41n + 12ps $\alpha - \alpha = 3$ n1n - 12 n 1 sh sp 8f + 13n + 22 1n - 12p2 + n3 d n - 1 (28) One can show further (problem 11), that minimum (but not zero!) spherical aberration results when the bending is such that s = -21n2 - 12 p n + 2 (29) Notice that for an object at infinity s 0.7 for a lens of refractive index n = 1.50. Unlike an ordinary mirror, the PCM is able to respond immediately to varying spatial and temporal features of an incident wave such that a phase conjugate wave is continually produced. The resulting phasor, shown as OE in Figure 14b, has a length of 1> 22 and, consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 22 and, consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 22 and, consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 22 and, consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 22 and, consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 22 and, consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 22 and, consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 22 and, consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 22 and, consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 22 and, consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 22 and, consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 22 and, consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 22 and, consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 22 and, consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 22 and, consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 22 and, consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 22 and, consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 20 and consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, has a length of 1> 20 and consequently, IP = I010E22 = 12 I0 = 14 Iu (38) The plot in Figure 14b, ha vertical displacement y above or below the point P. Determine its resolution when used in a Littrow mount. In the series of calculations leading to the four radii of curvature, a calculation that is easily programmed, Eqs. Q-switching simply redistributes the energy so that it comes out in large bursts separated by periods of nearly zero energy output. What is the irradiance of an image of the sun formed by a lens with diameter 5 cm and focal length 50 cm? New York: W. Distances measured to the reference planes are considered positive and to the left, negative. When mercury light is simultaneously admitted into the spectroscope slit, 150 of the bright bands are seen to fall between the violet and green lines of mercury at 435.8 nm and 546.1 nm, respectively. Increasing the thickness t by l>2, for example, changes the order of any fringe by ¢m = 1, that is, the fringe pattern translates by one whole fringe. The transmitted field ET can be found by propagating the right-going cavity field E1+ at Mirror 1 through the cavity and out of Mirror 2, ET1t + t>22 = EOTeiv1t + t>22 = EOTeiv1t + t>22 = tPF1¢z = d, &t = t>22E1+1t2 + ivt i1vt>2 - d>22 = tE01 e e Using Eq. (22) in the preceding expression and performing some simplification leads to EOT = t2e-id (23) 203 Optical Interferometry Irradiance is proportional to the square of the magnitude of the field amplitude, IT r EOTE...OT, so thetransmittance T of the Fabry-Perot cavity is T K EOTE...0T IT t4e-id>2eid>2 = 1 - r2 cos d 1 + r4 - 2r2 cos Solution To estimate the peak power, we shall model the pulses as rectangles of width equal to the peak power Pp, as shown in Figure 14. (8) and (9) in terms of electric fields with the help of Eq. (5), Ba = g01E0 - Er22 = gsEt2 (10) (11) where we have written g0 K no 1e0m0 cos u0 terms of electric fields with the help of Eq. (5), Ba = g01E0 - Er22 = gsEt2 (10) (11) where we have written g0 K no 1e0m0 cos u0 terms of electric fields with the help of Eq. (5), Ba = g01E0 - Er22 = gsEt2 (10) (11) where we have written g0 K no 1e0m0 cos u0 terms of electric fields with the help of Eq. (5), Ba = g01E0 - Er22 = gsEt2 (10) (11) where we have written g0 K no 1e0m0 cos u0 terms of electric fields with the help of Eq. (5), Ba = g01E0 - Er22 = gsEt2 (10) (11) where we have written g0 K no 1e0m0 cos u0 terms of electric fields with the help of Eq. (5), Ba = g01E0 - Er22 = gsEt2 (10) (11) where we have written g0 K no 1e0m0 cos u0 terms of electric fields with the help of Eq. (5), Ba = g01E0 - Er22 = gsEt2 (10) (11) where we have written g0 K no 1e0m0 cos u0 terms of electric fields with the help of Eq. (5), Ba = g01E0 - Er22 = gsEt2 (10) (11) where we have written g0 K no 1e0m0 cos u0 terms of electric fields with the help of Eq. (5), Ba = g01E0 - Er22 = gsEt2 (10) (11) where we have written g0 K no 1e0m0 cos u0 terms of electric fields with the help of Eq. (5), Ba
= g01E0 - Er22 = gsEt2 (10) (11) where we have written g0 K no 1e0m0 cos u0 terms of electric fields with the help of Eq. (5), Ba = g01E0 - Er22 = gsEt2 (10) (11) where we have written g0 K no 1e0m0 cos u0 terms of electric fields with the help of Eq. (5), Ba = g01E0 - Er22 = gsEt2 (10) (11) where we have written g0 K no 1e0m0 cos u0 terms of electric fields with term (12) g1 K n1 1e0m0 cos ut1 (13) gs K ns 1e0m0 cos ut2 (14) Now Ei2 differs from Et1 only because of a phase difference d that develops due to one traversal of the film. 20 Sketch the shape of a nonsymmetrical pulse before and after reflection from an ordinary mirror and before and after reflection from a PCM. To see objects closely and far away, the eye accommodates. Within two years of the centenary of the publication of Newton's Optics, the Englishman Thomas Young performed a decisive experiment that seemed to demand a wave interpretation, turning the tide of support to the wave theory of light. Also shown is an oblique pencil of rays originating at the off-axis point O2. The hologram itself is a series of circular interference fringes that do not resemble the object, but the object may be reconstructed, as in Figure 1b, by placing the hologram back into the reference beam without the presence of the object O. Such a wave train is shown at the top of Figure 9a, with regular discontinuities in phase, separated by the time interval t0. Thus, in calculating the diffraction pattern of the double slit at some point on a screen, one considers every point of the wavefront emerging from each slit as a source of wavelets whose superposition produces the resultant field. A crumpled piece of cellophane introduced between crossed polarizers shows a striking variety of colors, enhanced by the fact that ligh must pass through two or more thicknesses at certain points, so that ¢w varies from point to point due to a (a) Figure 21 Photoelastic stress patterns for a beam resting on two supports and (a) lightly loaded at the center, (b) Modulation transfer function (MTF) for three optical systems plotted against spatial frequency. Find the Fourier series of the resulting wave. The change in state of the visual pigment in the rods or cones is transformed into an electrical output or nerve fiber impulse. These special cases are worth reviewing. Since each component travels with a speed determined by the corresponding refractive indices, n 7 and n, the speeds are unequal. Generalizing, the matrix equation representing any number N of translations, reflections, and refractions is given by c y yf d = MNMN - 1 Á M2M1 c 0 d af a0 (13) 403 Matrix Methods in Paraxial Optics R1 R2 a3 a1 a0 y0 y1 y2 y3 t n nL n + Figure 8 lens. Only the small dimension b of a long, narrow slit causes appreciable spreading of the light along the x-direction or the screen. At various times, the standing wave will appear as sine waves of various amplitudes, like those shown in Figure 5b. Since typically vp g, the crossover occurs at v vp , dividing the transparent and the opaque (and highly reflecting) regions. Let us briefly examine the autocorrelation integral of Eq. (30). t (a) (b) In ¢ITV: sin1- a¿2 = Q¿ s¿ or s¿ = -Q¿ sin a¿ (40) The relevant equations describing the first refraction are included in Table 3 under the first column for the general case. Which qualify as traveling waves? In a CRT display beams of electrons ("cathode rays") emitted from an electron gun into a vacuum tube are steered by electric or magnetic fields and strike a phosphorescent surface that emits light from the point at which the electrons strike the surface. 3 Show that Eqs. As a result, the images of vertical and horizontal details in the object scene are formed at the same distance from the cornea, and astigmatic blurring does not occur. Example Consider a £ e = 5 milliwatt Helium-Neon laser emitting a "pencil-like" beam with a divergence angle a of 1.3 milliradians. Since at this point the optical-path difference between the two interfering beams is due to the optical path difference between paths AD and ABC. 115 Superposition of Waves E 2 Reference plane for beam 2 Reference plane for beam 1 s2 Wavefronts E1 P Figure 1 Superposition of two plane waves at point P. led to widespread applications in research and industry. Consider the following example. Thus this system approximates an ideal four-level laser system. Freeman. 9 10 Chapter 1 Nature of Light Example 2 A certain sensitive radar receiver detects an power (energy/time) 6.63 * 10-16 J>s. Clearly, Eq. (43) can be used if one knows a value for q1 somewhere in the cavity—say, at the left mirror—and the ABCD matrix for the optical system that must, consequently, hal of frequency 100 MHz and j , extend from the left mirror thoug transverse plane containing the external beam waist. 189 Interference of Light PROBLEMS p b 5 E2 = 4 cos a ks2 - vt + p b 6 with amplitudes in kV/m. From Figure 2a we may express this quantity as $\phi = r_{c}^{2} - 2r_{c}^{2} 2 + h^{2} \otimes S p$ (a) (8) or, equivalently, $h \phi = r_{c}^{2} - 2r_{c}^{2} 2 + h^{2} \otimes S p$ (a) (8) or, equivalently, $h \phi = r_{c}^{2} - 2r_{c}^{2} 2 + h^{2} \otimes S p$ (a) (8) or, equivalently, $h \phi = r_{c}^{2} - 2r_{c}^{2} 2 + h^{2} \otimes S p$ (a) (8) or, equivalently, $h \phi = r_{c}^{2} - 2r_{c}^{2} 2 + h^{2} \otimes S p$ (a) (7) or equivalently, $h \phi = r_{c}^{2} - 2r_{c}^{2} 2 + h^{2} \otimes S p$ (a) (8) or, equivalently, $h \phi = r_{c}^{2} - 2r_{c}^{2} 2 + h^{2} \otimes S p$ (a) (7) or equivalently, $h \phi = r_{c}^{2} - 2r_{c}^{2} 2 + h^{2} \otimes S p$ (b) $r_{c}^{2} + r_{c}^{2} + h^{2} \otimes S p$ (c) $r_{c}^{2} + h^{2} \otimes S p$ (c) $r_{c}^{2} + r_{c}^{2} + h^{2} \otimes S p$ (c) $r_{c}^{2} + r_{c}^{2} + h^{2} \otimes S p$ (c) $r_{c}^{2} + r_{c}^{2} + h^{2} \otimes S p$ (c) $r_{c}^{2} + r_{c}^{2} + h^{2} \otimes S p$ (c) $r_{c}^{2} + r_{c}^{2} + h^{2} \otimes S p$ (c) $r_{c}^{2} + r_{c}^{2} + h^{2} \otimes S p$ (c) $r_{c}^{2} + r_{c}^{2} + h^{2} \otimes S p$ (c) $r_{c}^{2} + r_{c}^{2} + h^{2} \otimes S p$ (c) $r_{c}^{2} + r_{c}^{2} + h^{2} \otimes S p$ (c) $r_{c}^{2} + r_{c}^{2} + h^{2} \otimes S p$ (c) $r_{c}^{2} + r_{c}^{2} + r_{c}^{2} + h^{2} \otimes S p$ (c) $r_{c}^{2} + r_{c}^{2} + h^{2} \otimes S p$ (c) $r_{c}^{2} + r_{c}^{2} + h^{2} \otimes S p$ (c) $r_{c}^{2} + r_{c}^{2} + r_{c}^{2} + r_{c}^{2} + h^{2} \otimes S p$ (c) $r_{c}^{2} + r_{c}^{2} + r_{c}^{2} + r_{c}^{2} + r_{c}^{2} + h^{2} \otimes S p$ (c) $r_{c}^{2} + r_{c}^{2} +$ wave moves with phase velocity yp. In Example 3 we show that in thermal equilibrium at room temperature essentially all hydrogen atoms will be in their electronic ground states. Gainesville, FL: Triad Scientific Publishers, 1974. Then from Table 1, and the fact that C1v) and S1v) are odd functions we have C1- 1.22 = - 0.7154 and S1-1.22 = - 0.6234 Now the tip of the phasor corresponding to the field maximum is in the positive spiral at point E, which has coordinates C1 q 2 = S1 q 2 = 0.5. The irradiance maximum is then given by Eq. (33) as I1st max = I05[0.5 - (-0.71542]2 + [0.5 - (-0.62342]26 = 2.74I0 = 1.37Iu The irradiance at the first maximum is 1.37 times greater than the irradiance Iu for an unobstructed wavefront. A very useful minitheorem is that the product of a complex conjugate equals the square of its absolute value. Combining Eqs. Equation (42) then takes the form 1- iv + g2J = a B Ne2 B bE m (43) In the static, or DC, case specified by v = 0, J = a B Ne2 B bE mg (44) The static conductivities are usually measured, we rewrite Eq. (43) in terms of s, giving J = a B s B bE 1 - iv>g (47) 4 PROPAGATION OF LIGHT WAVES IN A METAL An electromagnetic wave propagating in the conducting medium satisfies Maxwell's equations (12) through (15). If we always use light rays directed from left to right, we can simply say, "by all imaging elements to its left." 53 54 Chapter 3 Optical Instrumentation A1 L2 L1 A2 A, AS L2 a O b Chief ray b I a Chief ray O I a b a b EnP ExP Figure 2 Limitation of light rays in an optical system consisting of two positive lenses and an aperture A. Means of modifying the dispersion curve include the use of multiple cladding layers, control of the core/cladding index difference, and variation of the profile parameter ap in GRIN fibers. Assume that when a signal containing these two wavelength components enters the interferometer through Input 1, the l2 light component exits the interferometer through Output 2 and the l1 light component exits the interferometer through Output 1. Calculate the wavelength of the light. Thus, for the case at hand, there are N - 1 = 7 zeroes, and as a consequence N - 2 = 6 secondary maxima, between the principal maxima. Chromatic Resolving Power If the wavelength difference between two components of the light incident on a prism is allowed to decrease, the ability of the prism to resolve them will ultimately fail. To see this effect, refer to Figure 11a. Then for a given path difference d of the interferometer, the product ml is fixed, that is, ml = m¿l¿. Dashed lines represent comparable fringes from a Michelson interferometer Or, as in Figure 17c, for a convex mirror, the ray leaves point P heading toward focal point F behind the mirror, strikes the mirror, and reflects as a parallel ray. In the problem at hand, then, Fermat's principle requires that nodo + nidi = noso + nisi = constant (6) where the distances are defined in Figure 12. The electric field at P (as in Figure 1) due to diffraction through a circular aperture can then be written as x dA Ep = s Area R Figure 6 Geometry used in the integration over a circular aperture. Clearly, only one frequency is required to represent a sine wave. In practice, the prism angle at O, as is clear from the figure, we conclude that its conjugate aperture stop (AS) of the system. Figure 10 shows a Czerny-Turner system in a grating spectrometer. The effect of the rotator element is to
transmit linearly polarized light whose direction of vibration has been, in this case, rotated counterclockwise by an angle u. As the hologram is rotated, new exposures can be made. Cambridge: Harvard University Press, 1970. Equation (14), considered in steady state 1dN2>dt = 02, and Eq. (16) can be solved jointly to give the steady-state values of the population densities N1 and N2. The F and C dark lines are due to absorption by the Large deviation Small dispersion d Small deviation Large dispersion Figure 13 Extreme cases showing the dispersion \supset for three wavelengths and the deviation d for the intermediate wavelengths. 4-13. That is, find Evib 1 - E0. A current is passed through the ionized gas between two electrodes sealed in a glass or quartz tube. In terms of the angles designated in Figure 1, they are equivalent to kr sin u = krr sin ur Since both waves travel in the same medium, their wavelengths are identical and so k = kr. How many photons/s would arrive at the receiver in this signal? After a bit of IO M2 g0, IS Gain L IL Iout T3 IL M3 Figure 8 Ring laser. The plate is mounted normal to the grating. • Ray 1. The line joining the elemental areas, of N al or rm al m No u2 u1 dA1 dv1 dA2 r Central ray Figure 5 Geometry used to show the invariance of the radiance in a uniform, lossless medium. Letter details are 15 block letter size in each case. The situation may be clarified somewhat by reference to Figure 13a, which shows one Huygens' wavelet created by the extraordinary ray as it B contacts the crystal surface at P. It distinguishes between subtle shades of color, from deep purple to deep red. By introducing prismatic grooves in Figure 5, the corresponding zero path difference is shifted into the directions of the refracted beam and the new reflected beam, respectively, which now correspond to the case b = 0. Using the plot produced in part (a), determine the value of T3 that maximizes the laser output irradiance. What is the internodal distance? Then, when the letters are read by a test subject at a test distance of 20 ft, visual acuity is measured in terms of the Snellen fraction. Somewhat discouragingly, the common He-Ne laser used in instructional laboratories may not have coherence lengths much greater than its cavity length, due to random temperature fluctuations and mirror vibrations. Osanai, T. A careful examination of Table 1 serves as an introduction to the state of laser technology. His theoretical work, however, remained largely unexploited until 1954, when C. Thus, dfsr = dm + 1 - dm = 1m + 122p - m2p = 2p The half-width at half-maximum (HWHM) d1>2 of the transmittance peaks (see Figure (10)) can be found from Eq. (30) by showing that when T = 1>2, sin21d>22 = p2 4F2 (31) 205 Optical Interferometry where d = 2mp + d1>2 Trigonometric identities and a small angle approximation can be used to verify that, at the half-maxima, sin21d>22 = sin21mp + d1>2>22 = sin2 a d1>2 2 b L a d1>2 (Polaroid sunglasses will work) in front of a calculator display. n1 1.2 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 Path difference/wavelength The important case of quarter-wave film thickness, t = 10 l = 4 4n1 makes the phase difference/wavelength The important case of quarter-wave film thickness, t = 10 l = 4 4n1 makes the phase difference, Eq. (15), d = 2pn1t > 10 = p > 2, so that cos d = 0 and sin d = 1. Thus, this wavelength, like l1 = 1551 nm, would predominately exit Output 1. The retina is a complex nerve-related structure that in essence is an outgrowth of the brain. When imaging is required, however, the fiber ends at the output. These may be expressed in terms of I1 and I2 by the use of Eqs. Find the irradiance of the laser field that exits this cavity. Due to refraction at the glass-air interface, rays making a larger angle than aa do not reach the lens. The chief advantages of plasma displays are their thin design, inherent brightness, and wide viewing angle. Nerve fibers originating in the left half of each eye terminate in the left half of the brain. One mm of film then spans a range of almost 4 nm or 40 Å. It follows that the maximum frequency9 nmax = 0.5 dt or nmaxL = 0.5 d1t>L2 (19) For the preceding numerical examples, we calculate an approximate bandwidth, as follows: LED: nmaxL = 0.5 = 5.0 GHz-km 0.1 ns>km Waveguide Dispersion The last pulse-broadening effect to be discussed is called waveguide dispersion, a geometrical effect that depends on waveguide parameters. (See Figure 9.) 16 Find the system matrix for a Cooke triplet camera lens. (21) and (22) with exactly integer m, but many approximate solutions exist. 7 PHOTOELASTICITY Consider the following experiment. Spontaneous emission is sometimes aptly referred to as lated emission. First consider light entering from below, along the line joining the carbon and calcium atoms. Determine (a) the angular radius of its central peak and (b) the ratio I>I0 at points making an angle of u = 5°, 10°, 15°, and 22.5° with the axis. This particular method of exciting the laser medium is known as optical pumping. In those special cases where the emissivity is independent of wavelength, the specimen is said to be a graybody. Still, state-of-the-art fiber-optic systems carry far more information with much lower loss than can copper-wire transmission lines. Mirror 1 is essentially 100% reflecting, and Mirror 2 is partially transmitting. Ideal Four-affect the passage of radiation through matter. The curvature of (a) incident and (b) diffracted wavefronts is small. In (a) the position of the upper wedge is such that light travels through equal thicknesses of quartz with their optical axes aligned perpendicular to one another. What is the concentration of the solution? In the process shown an atom in an excited state with energy E1 and a photon of energy hn L E2 - E1 = hn0 is released. We include here a brief, quantitative 438 439 Aberration of each aberration, with typical procedures for its elimination. Although reflectance at 550 nm is about 1.3%, greater than for the l>4 - l>4 coating of curve (a), it remains at values less than this over the broad range of wavelengths from about 420 to 800 nm. L sin ui FI DG constant ni DM DM sin ut and sin ut DM DI (b) 2 FERMAT'S PRINCIPLI The laws of geometrical optics can also be derived, perhaps more elegantly, from a different fundamental hypothesis. For example, notice that for third-order nonlinear processes, third harmonic generation can occur. Without giving a physical explanation of optical activity, we can, following Fresnel, offer a useful phenomenological description that enables us to relate specific rotation of an active substance to certain physical parameters. Such rays are propagated along the fiber by a succession of such reflections, without loss of energy due to refraction out of the cylinder. As t increases in a linear fashion along the length of the slides from t = 0 to t = d, Eq. (38) is satisfied for consecutive orders of m, and a series of equally spaced, alternating bright and dark fringes will be seen by reflected light. When the preferred E-direction of the reflected light is perpendicular to the appear reduced in brightness. The activation of nerve fibers—the very heart of the vision process itself -depends on chemical changes that occur in the visual pigment contained in the rods and cones. Ch. 30. Derive an expression for this ratio. We end by considering the superposition of waves of slightly different frequencies and relate this analysis to the phenomenon of beats and to the distinction between the phase and group velocities of an electromagnetic waveform. The gain coefficient in an inhomogeneously broadened medium has contributions from groups of atoms with different center frequencies and relatively narrow homogeneously broadened medium has contributions from groups of atoms with different center frequencies and relatively narrow homogeneously broadened medium has contributions from groups of atoms with different center frequencies and relatively narrow homogeneously broadened medium has contributions from groups of atoms with different center frequencies and relatively narrow homogeneously broadened medium has contributions from groups of atoms with different center frequencies and relatively narrow homogeneously broadened medium has contributed (due to electronic oscillations) and in the infrared (due to electronic oscillations) and i molecular vibrations) rather than in the visible. When deposited on glass of index 1.60, how thick should a film of this material be in order to reduce the reflected energy by destructive interference? Referring to Figure 17b and making use of the mth dark ring is measured and the corresponding thickness of the air wedge is determined from the interference condition of Eq. (38). 89 Optical Instrumentation 1 2 Aperture (a) Aperture (b) Schmidt correcting plate Aperture (c) Figure 36 The Schmidt optical system. Notice that in Figure 11b, the image is virtual. The radii of curvature are R1 = 3 cm and R2 : q and the lens in air has a refractive index of 1.50. 436 Chapter 19 Optics of the Eye Cornea RF tool Pupil Iris Eyeball Figure 9 Creating corneal lesions with a radio frequency probe in the CK procedure. The obliquity factor is taken into account in Figure 4b by making each succeeding phasor slightly shorter than the preceding one. For a fixed direction of incidence given by ui, the direction um of each principal maximum varies with those of special relativity, photons interact only with charges. 26 A level telescope contains a graticule—a circular glass on which a scale has been etched—in the common focal plane of objective and eyepiece so that it is seen in focus with a 28 a. A ray from the center of the slit, for example, has an optical axis. Determine the rotation produced by the optical activity of a 3-mm quartz plate on a linearly polarized beam of light at wavelength 762 nm. As we see in following sections, the ratio of the stimulated
emission rate and the spontaneous emission rate and the refore the transmittance of 373 374 Chapter 16 Holography Hologram P O Figure 1 Hologram of a point source O is constructed in (a) and used in (b) to reconstruct the waveferont. Four different wavelength channels are shown in Figure 15. If a screen held perpendicular to the principal ray is moved from S to T, intermediate images will be elliptical in shape. 9 GRATING INSTRUMENTS An instrument that uses a grating as a spectral dispersing element is designed around the type of grating selected for a particular application. However, at this point it is already possible to calculate the result of the superposition of two or more polarized modes by adding their Jones vectors. Consider first the case of an inactive medium for which $y^c = y\dot{P}$, or, B equivalently, $n^c = n\dot{P}$ and $k^c = k\dot{P}$. Photographs of the effects of stop location on distortion are reproduced in Figure 11b, c, and d. That is, the band-gap energy is the energy required to promote an electron from the valence band to the conduction band. Further, by the principle of reversibility, if I is the object point, each ray will reverse its direction but maintain its path through the optical system, and O will be the corresponding image point. The dashed line represents the uncoated glass substrate of index ns = 1.52. The normal N¿ to the groove face makes an angle ub relative to N. 6 SPATIAL COHERENCE WIDTH Consider now the spatial coherence at points P1 and P2 in the radiation field of a quasi-monochromatic extended source, simply represented by two mutually incoherent emitting points A and B at the edges of the source (Figure 13). For example, consider two interfering incident waves of frequencies v1 and v2 represented in the form E = E01 cos v1t + E02 cos v2t or, in the equivalent exponential form, E = 12 E011eiv1t + e -iv1t2 + 12 E021eiv2t + e -iv2t2 The second-order nonlinear polarization P2 = e0x2E 2 is proportional to the square of this incident field and so evidently produces harmonic fields at 2v1, 2v2, v1 - v2, and v1 + v2. Clearly, it cannot be represented by a single sine wave that has no beginning or end. As suggested by Figure 6, the mirror radii of curvature RM1 and RM2 and cavity length d constrain the nature of the Gaussian-beam mode of a spherical mirror cavity. If the surface is curved, then, although astigmatism has been eliminated, the associated aberration called curvature of field remains. The vertical dotted lines mark the values of E1, E2, and ER at a specific time. In ophthalmology, for example, where Nd:YAG lasers are used in ocular surgery, target irradiances of 109 to 1012 W>cm2 are required. 0.4 0.6 0.8 1 1.2 Wavelength (m) 1.4 1.6 7 D. These assumptions make the derivation of Eq. (7) possible but are not entirely justified. The astigmatic correction, with cylinder axis horizontal 1* 1802, is determined to be 1.00 D. An air wedge, formed between the spherical surface, is illuminated with normally incident monochromatic light, such as from a laser, or from a sodium or mercury lamp with a filter. In what range of the electromagnetic spectrum are the spectral lines of the Lyman series? The refractive indices for quartz at this wavelength, for left- and right-circularly polarized light, are n^c = 1.55821 and n^P = 1.55810, respectively. B 1 Thus the Jones vector A 1> 22 B C i D represents circularly polarized light when E rotates counterclockwise, viewed head-on. A little thought will make clear that an amplitude aperture function cannot be produced with both positive and negative portions, like the pure sine wave of Figure 4a. The latter is especially important where security of information is vital, as in computer networks that handle confidential data. Using this 11 264 Chapter 10 Fiber Optics $\&L = -1\ 1\ 1\ 1 -1\ 1\ 1\ 1\ a\ b = a\ b\ 2n\ 12\ 11\ 500\ 2n\ 50\ nm = 8.0135\ n$ answer with no further analysis. Calculate the paraxial image distance assuming the thinlens approximation. 4 The sinusoidal transmission of a grating varies as 5 sin(ay), in arbitrary units. These lasers are usually pumped by an electric discharge. The color filters in the Bayer mask form a mosaic of 2 * 2 submasks, each containing four color filters—one red, one blue, and two green. This gives dk 1 1 dn dn = an + v b = an - l b c c dv dv dl (17) where we have used the proportion v>dv = - l>dl in the last step. The field in a laser cavity mode. If the wedge is of large angle, they will be curved in a way that can be shown to be hyperbolic arcs. With the stop located between lens and image, pincushion distortion occurs in the image. Find (a) the system matrix for the lens when used in air and (b) its cardinal points. or n1 - n2 n2 n1 = s & R (19) Employing the same sign convention as introduced for mirrors (i.e., positive distances for real objects and images and negative distances for virtual objects and images), the virtual image distance s¿ 6 0 and the radius of curvature R 6 0. Solution Using Eq. (14), da 1.46 t 1.46 - 1.45 b = b = 3.4 * 10-11 s>m a 8 L 1.45 3 * 10 m>s = 34 ns>km The pulse broadens by 34 ns in each km of fiber.6 Clearly, this broadening effect limits the possible frequency of distinct pulses. The acoustic waves are shown propagating downward in the figure. This description, in terms of the so-called cardinal points of the lens, is useful also because it can be applied to more complex optical 396 397 Matrix Methods in Paraxial Optics F1 H1 F2 F1 H2 PP1 F2 PP2 (a) (b) systems, as will become evident in this chapter. For example, Er1 represents the sum of all the multiply reflected beams at interface (a) in the process of emerging from the film, Ei2 represents the sum of all the multiple beams incident at interface (b) and directed toward the substrate, and so on. Figure 8 Phase changes on reflection f between incident at interface (b) and directed toward the substrate, and so on. transform spectroscopy is the subject of the second part of the present chapter. CCD Detectors Two-dimensional arrays or panels of photodiodes can be used to record images. For the cases illustrated there, where the x-vibration, it is necessary to make wy 7 wx. Each such zone of the lens produces its own comatic circle, whose diameter increases as the radius of the zone increases. (32) and (33) to be sensible, a mirror to the left of the beam R(z1) RM1 R(z2) RM2 Output beam z0 z z1 Mirror 1 d z z2 Mirror 2 Figure 6 The Gaussian-beam modes of a spherical mirror optical cavity have wavefront radii of curvature that match the radii of curvature of the cavity mirrors. 4 Arguing from Eq. (7), show that the linear electro-optic effect is found only in crystals lacking inversion symmetry. Sketch the system. The gain medium is characterized by its saturation irradiance IS, length L, and small-signal gain coefficient g0. 4 RADIOMETRY Radiometry is the science of measurement of electromagnetic radiation. So that we all get the same answer, say that a good red is 640 nm and a good green is 540 nm. (21) and (22) with integer m.) b. What is the scan rate if one run is completed in 30 s? 23.75 μ m (a) 48,260 (b) 0.01013 cm (b) 3.16 × 106 (c) 0.318 mm (d) 6.29 Å (e) 0.002 Å (a) 329, 670 (b) 36 (c) 9.8 × 106 2.18 cm 0.161 mm (a) 360° (b)180° (c) 2 1; 0.47 15. When the normal eye looks at distant objects (that is, objects at "infinity"), parallel light enters the relaxed eye and forms a clear image (Figure 5a) on the retina. We defer a detailed discussion of these beams for now but sketch and indicate some of the most important features of the simplest Hermite-Gaussian waveform in Figure 9. Note that we are representing the electric field E and the dipole displacement vectors. (21) for x(2) to simplify the form of the expression. Estimate the difference 12 - 11 in wavelength of the two components presuming that the overlapping transmittance peaks have mode numbers that differ by 1, so that $m^2 = m^1 + 1$. Notice that in (b) the defect is also responsible for mode coupling, in this case a conversion from a lower to a higher mode. The rays indicate that the direction of energy propagation is radially outward from O. In Figure 4a, then, $r^1 = r^0 + l^2$, $r^2 = r$ Siegman, Anthony E. Determine (a) the critical angle; (b) the numerical aperture; (c) the maximum incidence angle um for light that is totally internally reflected. Holographic Optical Elements The interference pattern produced by two spherical waves with different radii of curvature can be recorded to produce a holographic Optical Elements The interference pattern produced by two spherical waves with different radii of curvature can be recorded to produce a holographic Optical Elements The interference pattern produced by two spherical waves with different radii of curvature can be recorded to produce a holographic Optical Elements The interference pattern produced by two spherical waves with different radii of curvature can be recorded to produce a holographic Optical Elements (a) the curvature can be recorded to produce a holographic Optical Elements (b) the numerical aperture; (c) the maximum incidence angle um for light that is totally internally reflected. (b) (c) Figure 10 Images of a square grid (a) showing pincushion distortion (b) and barrel distortion (c) due to nonuniform magnifications. 8 Single crystals can be divided into 32 symmetry classes; of these, 20 show the Pockels effect. The parameters used to produce this plot are discussed in Example 2. This limitation is somewhat relieved by using a transparent fluid "coupler" whose index matches as closely as possible that of the glass. Their optical paths can be equated to give FT + TW = nb where b is the base of the prism, corresponding to the wavelength l. 605 Characteristics of Laser Beams PROBLEMS 1 Describe the ways that the TEM00 Gaussian beam is similar to and different from (a) plane waves and (b) spherical waves. We begin by developing the rate equations
governing the population densities in a medium interacting with an electromagnetic field. As it turns out, however, the complete nature of a photon or an electron is not exhausted by either model. This is possible if the source is an extended source, as in Figure 13. 13 Light linearly polarized with a horizontal transmission axis is sent through a nother linear polarizer with TA at 45° and then through a QWP with SA horizontal. (a) He-Ne laser. (Glass envelopes absorb ultraviolet radiation below about 300 nm, whereas quartz transmits down to about 180 nm.) An electric field accelerates electrons sufficiently to ionize the vapor atoms. Example 3 A plano-convex lens 1n = 1.5232 of 18 diopter power is placed, convex surface down, on an optically flat surface as shown in Figure 17a. Repeat parts (a) and (b) if the corrective lens is a spectacle lens placed 2 cm from the eye. Recall that the small-signal gain coefficient is proportional to the lineshape function so that the width of the small-signal gain coefficient is \$nH = 1 GHz. The gain coefficient and cavity modes for this system are shown in Figure 10. We shall be content to await the matrix approach later in this chapter as a simpler way to justify these equations, and even then some of the work is relegated to the problems. Because atomic masses are so much larger than the electron mass, amplitudes of induced molecular vibrations are small compared with electronic vibrations are small comp constructively interfere. 3 TEMPORAL COHERENCE AND LINE WIDTH Clearly, there are no perfectly monochromatic sources. Furthermore, the displacement at x = 10 cm, t = 0 is y = 10.1 m, 02 = (0.35 m) sina 0.3p + p b = + 0.346 m 4 99 Wave Equations 3 COMPLEX NUMBERS Im In many situations it is useful to represent harmonic waves in complex. number notation. In use, the spectral line is observed or recorded at F, the focal point of lens L. Along directions where crests meet valleys (dashed circles), darkness (D) results. 1.63 25. 13 A positive thin lens of focal length 20 cm is designed to have minimal spherical aberration in its image plane, 30 cm from the lens. Each constitutes a part ' of the complex refractive index n, which is given by 'n = n + ik n Absorption band 1 v Figure 8 Response of refractive index as a function of frequency near an absorption band. Grating L 30 Grating normal R2m a 106 m N 100,000 W 10 cm Figure 8 Response of refractive index as a function of frequency near an absorption band. energy level. Check results against Figure 4. 14 Derive Eqs. Thus all three propagation vectors are coplanar in the xz-plane, and we conclude that the reflected and refracted waves lie in the plane of incidence. If a different choice is made, B for B example, by reversing the E vector of the incident wave (and also B to keep the direction of wave propagation the same), Eqs. The photoflash tube, in contrast, provides high-intensity, short-duration illumination by the rapid combustion of metallic (aluminum or zirconium) foil or wire in a pure oxygen atmosphere. Find the ratio of the irradiance of the maxima of part (a) to the irradiance of the maximum of the singleslit diffraction pattern. 1 TWO-BEAM INTERFERENCE We consider first the interference of two plane waves of the same frequency, B B represented by E1 and E2. 1589.3 nm a S n 1.5 d 0.03 cm E1 = 3 cos a ks1 - vt + 7 In a Young's experiment, narrow double slits 0.2 mm apart diffract monochromatic light onto a screen 1.5 m away. In general, as can be seen from an examination of Eq. (22), as long as the amplitude of the reflected wave is the same as that of the incident wave, a standing wave will result. Compute the radius of the lens. Increasing all t by T, the waveform is exactly reproduced, so that A sin k[x + y1t + T2] = A sin[k1x + yt2 + 2p] or A sin1kx + kyt + kyT2 = A sin1kx + kyt + 2p2 Clearly, kyT = 2p, and we have an expression that relates the period T to the propagation constant k and wave velocity y. ≥ 2E0 E2 x0 (a) (22) (b) Figure 5 Standing waves. Both object and image distances are 30 cm, measured from a plane bisecting the lens. Figure 8a shows four parallel rays—1, 2, 3, and 4—arriving from a distant, below-the-axis object point and being refracted by a convex lens. The phase shifts on total internal reflection, for total internal reflection, for total internal reflection, may take on values other than 0 and p, depending on the angle of incidence. Compare the beam spread to that from the slit of width b = 0.5 mm of Example 2. The zeroth order of interference occurs when m = 0 or um = - ui, that is, in the direction of specular reflection from the grating, acting as a mirror for all wavelengths. Hale telescope, the flat mirror can be dispensed with and the rays allowed to converge at their primary focus. The dashed arcs transverse to the z-axis indicate the wavefronts of the beam. (19) and (20) in the complex term is first rewritten by multiplying numerator and denominator by the complex conjugate of the denominator. Note that, for the parameters listed in the figure caption, the inversion population density grows to a value which is roughly a factor of 2 larger than its steady-state, threshold value. Siegman, A. Recall that, in this instance, the exit pupil is an image of the entrance pupil as formed by the ocular and that the ratio of entrance to exit pupil diameters equals the magnification. The other beam, ES, reflects diffusely from the subject, and 2 Dr. Ramnendra Bahuguna, San Jose State University, has suggested a typical, simple method to process a hologram: 1-minute rinse in developer (Kodak D-19); 1-minute rinse concentrated sulfuric acid, 1 L water); 30-second Kodak foto flo (diluted as on label); 15-20 minute dry vertically on paper towel. We shall also assume that, in this regime gv V 1v20 - v22. We may express the two electric fields at a point P where the fields are combined as E1 = E01 cos1ks1 - vt + f12 B B E2 = E02 cos1ks2 - vt + f22 B B (1) (2) 163 164 Chapter 7 Interference of Light E2 Reference of Light E2 Reference plane for beam 1 E1 P Figure 1 s1 Two-beam interference of Light E2 Reference plane for beam 1 E1 P Figure 1 s1 Two-beam interference of Light E2 Reference plane for beam 1 E1 P Figure 1 s1 Two-beam interference of Light E2 Reference plane for beam 2 s2 Wavefronts Reference plane for beam 1 E1 P Figure 1 s1 Two-beam interference of Light E2 Reference plane for beam 1 E1 P Figure 1 s1 Two-beam interference of Light E2 Reference plane for beam 1 E1 P Figure 1 s1 Two-beam interference plane for beam 2 s2 Wavefronts Reference plane for beam 1 E1 P Figure 1 s1 Two-beam interference of Light E2 Reference plane for beam 2 s2 Wavefronts Reference plane for beam 1 E1 P Figure 1 s1 Two-beam interference plane for beam 2 s2 Wavefronts Reference plane for beam 1 E1 P Figure 1 s1 Two-beam interference of Light E2 Reference plane for beam 2 s2 Wavefronts Reference plane for beam 1 E1 P Figure 1 s1 Two-beam interference plane for beam 2 s2 Wavefronts Reference plane for beam 2 s2 Wavefronts Reference plane for beam 1 E1 P Figure 1 s1 Two-beam interference plane for beam 2 s2 Wavefronts Reference plane for beam 2 s2 when the OA is oriented as shown in each sketch in Figure 23. In the result, there occur terms proportional to both h2 and h4. Example 6 Assume that a gravitational wave detector like the one pictured in Figure 17a. Other common materials, birefringent in the visible region, are quartz, ice, mica, and even cellophane. The chief reason for the disappearance of the forward wave, however, is destructive interference between the incident and generated waves. (a) no (b) less than 365 nm (b) $2.4 \times 10-21$ J = 0.015 eV (c) 0.55 (a) $8.6 \times 10-20$ J = 0.54 eV (b) $5 \times 10-10$ -76 e (a) 0.4830 µm (b) 0.0756 W 6266 K; 462.5 nm 6105 K 0.45 nm 10-5 s; 3000 m (b) 5 × 10-10 s; 15 cm 6 (a) half angle spread: 0.4 mrad (b) 80 cm. An inexpensive transmission grating may be mounted in place of the prism in a spectroscope, where the spectrum is viewed with the eye by means of a telescope focused for infinity. All electromagnetic waves are made up of time-varying electric and magnetic fields. Extreme rays for refraction at the top and bottom halves are shown. The three regions taken together comprise the optical spectrum, that region of the electromagnetic spectrum, that region of the electromagnetic spectrum, that region of the electromagnetic spectrum of special interest in a textbook on optics. r = cos u - 2n2 - sin2 u cos u + 2 refraction for the fast and slow axes of quartz with 546 nm light are 1.5462 and 1.5553, respectively. Hermite-Gaussian waveforms are, to an excellent approximation, produced by laser systems that use spherical mirrors to form the laser cavity and are beamlike, in the sense that the beam irradiance is strongly confined in the transverse direction. (28) and (30) that v kR + ikI = a b 1nR + inI2c vielding the relations v kR = a bnR c (32) v kI = a bnR c (33) and Writing n2 as n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34) Expressions for the relation to Eq. (27) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34) Expressions for the relation to Eq. (27) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34) Expressions for the relation to Eq. (27) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34) Expressions for the relation to Eq. (27) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34) Expressions for the relation to Eq. (27) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34) Expressions for the relation to Eq. (27) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34) Expressions for the relation to Eq. (27) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34) Expressions for the relation to Eq. (27) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34) Expressions for the relation to Eq. (27) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34)
Expressions for the relation to Eq. (27) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34) Expressions for the relation to Eq. (27) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34) Expressions for the relation to Eq. (27) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34) Expressions for the relation to Eq. (27) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34) Expressions for the relation to Eq. (27) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34) Expressions for the relation to Eq. (37) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34) Expressions for the relation to Eq. (37) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34) Expressions for the relation to Eq. (37) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 - ivg (34) Expressions for the relation to Eq. (37) gives n2 = 1nR + inI22 = 1 + a Ne2 1 b me0 v20 - v2 imaginary parts in Eq. (34). Albert Einstein laid the theoretical foundation of laser action as early as 1916, when he was the first to predict the existence of a radiative process called stimulated emission. The more complicated mode structure associated with spherical-mirror Fabry-Perot cavities provides the possibility of additional markers that may be useful in the calibration of the Fabry-Perot interferometer. Determine the corresponding radii of curvature for the two lenses. Replica gratings can be purchased that are as good as or better than the masters, both in performance and useful life. It can be shown that the discrete Fourier series now becomes an integral given by +q f1t2 = L- q g1v2e-ivt dv (7) where the coefficient + q 1 f1t2eivt dt q1v2 = 2p L- q (8) The Fourier integral, Eq. (7), and the expression for its associated coefficient, Eq. (8), have a certain degree of mathematical symmetry and are together referred to as a Fourier-transform pair. Bristol, England: Adam Hilger Ltd., 1980. Assume that a diode laser with an emission at a wavelength of 808 nm is to be used to pump an Nd:YAG laser rod. 599 Characteristics of Laser Beams Plane at Z2 Z1 w01 Z2 f w02 f Figure 14 A Gaussian beam of waist w01 and half-angle beam divergence 1uFF21 is focused by a thin, positive lens of focal length f. Principals of Optics, 5th ed., (New York: Pergamon Press, 1975.) Figure 14 Young's double-slit setup. The vertical dashed lines mark the visible spectrum, and the dashed curve connecting the peaks of the four curves illustrates the Wien displacement law. As an example, consider an argon ion laser with a 10-W output. Furthermore, if ns 7 nf, no relative phase shift between the two reflected beams occurs, and the optical-path difference alone determines the type of interference to be expected. Measured values for V at 589 nm are given in Table 4. Figure 10a depicts a plane electromagnetic wave traveling in some arbitrary direction. As mentioned earlier, presbyopia refers to the loss of accommodation that occurs as the lens in an aging eye loses the ability to reshape itself and thus alter its focal length. In Figure 6a, light from a distant object enters the relaxed eye and focuses behind the retina, causing blurred vision. (b) Angular spread of the first three orders of the visible spectrum for a diffraction grating with 400 grooves/mm. These fringes appear without effort when the intense, coherent light of a laser is used. Optical Interferometry. This provides a means of doing photolithography without placing a mask in direct contact with the chip. Finally, object point V is chosen such that all its rays through the aperture A miss the lens entirely. The irradiance of such a laser would be 3.18 * 108 W>m2. To express mathematically the reversal in direction of the incident wave, the sign of the kz term is changed from minus to plus. Using Eq. (31) in Eqs. This technique is called index matching or birefringent phase matching and is clarified by Figure 2a, which shows how the ellipsoids representing the velocity versus crystal direction for the E- and O-rays intersect along the direction of matching. A prism or some other device can be used to split an image into red, blue, and green components, which are then imaged on separate CCDs. The digital information from the separate CCDs are then combined to form a color image. Write the equation of a harmonic wave traveling along the x-direction at t = 0 if it is known to have an amplitude of 5 m and a wavelength of 50 m. The three candidates for entrance pupils, L2;, L1, and A 1œ, are next viewed from the axial point O. Also from Figure 3b, the skip distance, Ls, between two successive reflections of a ray of light propagating in the fiber diameter. (b) Air wedge formed with two microscope slides. Meyer-Arendt, Introduction to Classical and Modern Optics, 3d ed. In reconstruction, the hologram creates a clearer image in white light. Now, let's try an example. The diffraction pattern formed by the rod is examined in a plane at 60 cm beyond the rod. f f 3f 2 3f Figure 37 Problem 22 f Object f Position 1 Position 2 D L 4f Figure 38 Problem 27 Screen 49 Geometrical Optics 28 An image of an object is formed on a screen by a lens. In each case describe how changing the indicated parameter changes the curves. Find the location of the image plane. Iout 564 Chapter 26 Laser Operation Here, T2 is the transmittance of the laser cavity output mirror, R1 and R2 are the reflectances of the cavity mirrors, and the gain cell is characterized by length L, small-signal gain coefficient g0, and saturation irradiance IS. 282 Chapter 11 Fraunhofer Diffraction We find 11>221a + b2 L11>221a + b2 $[e11>22ik1-a + b2 \sin u - e11>22ik1-a - b2 \sin u + e11>22ik1a + b2 \sin$ ia1eib - e -ib2] r0 2ib Employing Euler's equation, EP = EL i1kr0 - vt2 b e 12i sin b212 cos a 2 r0 2ib Finally, EP = EL i1kr0 - vt2 2b sin b cos a r0 b so that the irradiance at point P in the double-slit diffraction pattern is I = a e0c 2ELb 2 sin b 2 e0c b E 20 = a ba b a b cos 2 a r0 2 2 b or I = 410 a sin b 2 2 b cos a b where I0 = a e0c ELb 2 ba b r0 2 (27) 283 Fraunhofer Diffraction as defined in Eq. (10) for the single slit. A detailed analysis3 shows that such a twisted nematic cell causes the polarization of the light to rotate, as it propagates though the light to rotate, as it propagates though the light to rotate. the liquidcrystal molecules. Note that the approximation becomes increasingly better as the number of terms in the summation increases. 52 (Nov. Light from a source S passes through a double slit and is also sampled by a Michelson interferometer located nearby. Thus we "guess" the form 2 U1x, y, z2 = E0ei5p1z2 + [k1x + y22>2q1z2]6 = E0ei5p1z2 + [k1x + y22>2q1z2 [kr >2g1z2]6 2 (10) In the last equality we have introduced the cylindrical coordinate r = 2x2 + y2. You should also be familiar with Gaussian beams. To remove this discrepancy and to make the results agree with the phase of the wave without diffraction, Fresnel was forced to assume that the secondary wavelets on diffraction leave with a gain in phase of p>2 relative to the incident wavefront. Summarizing, B E plane of incidence: $g_1 = n1$ 1e0m0 cos ut1 E 7 plane of incidence: $g_1 = n1$ B 1e0m0 cos ut1 E 7 plane of incidence. B $g_1 =$ ub = sin-1 a ml b 2a (16) Since the quantity a sin ub corresponds to the steep-face height h of the groove (Figure 6), we see that a grating correctly blazed for wavelengths. (b) Formation of a real image RI2 by a train of two convex lenses. For N = 8, the function sin1Na2 in the numerator of the interference factor goes to zero for each of the seven intermediate terms in the sequence (a = p > 8 to a = 7p > 8), but the function in the denominator sin a does not go to zero for the these seven intermediate values. Discuss the relevance of the result shown in (a) for a mode-locked laser. Thus, an observing telescope may be rigidly mounted. Estimate the smallest frequency change that could be easily monitored with this Fabry-Perot cavity. Determine their equivalent focal lengths when (a) cemented together and (b)
separated by 10 cm. Describe both qualitatively and quantitatively what appears on a screen 1 m away from the slit. As we shall see in discussions to follow, data rates are limited by the modulator capabilities as well as by fiber distortions that prevent distinct identification of neighboring pulses. Equivalently, the beam reflected from the mirror M can be considered to arise from its virtual image M_c. Quite by contrast, another small region in the retina, located at the point of exit of the optic nerve, is completely insensitive to light. The exit window is lens L2 of diameter 6 cm 7. At what position in front of a spherical refracting surface must an object be placed so that the refr 0, w0y = p>2 - p>2 = - p>4 - p>4 - p>4 E 2 s2 Reference plane for beam 2 Reference plane for beam 1 Wavefronts E1 P s1 5 Superposition of Waves INTRODUCTION Quite commonly, it is necessary to deal with situations in which two or more waves of given amplitude, wavelength, and frequency arrive at the same point in space or exist together along the same direction. The likelihood that the spontaneously emitted photon will have a given frequency n is proportional to the lineshape function g1n2. (a) Quiescent laser. The diffraction factor in Eq. (32) is plotted in Figure 15b. 17 Calculate the time delay between an axial ray and one that enters a 1-km-long fiber at an angle of 15°. The rate of occurrence per unit volume of stimulated absorption, RSt. Abs. The energy of this evanescent wave returns to its original medium unless a second medium is introduced into its region of penetration. waves must satisfy the condition ¢ 2p + 2fr = 2mp l n2 A n1 w d C n2 B d w A Figure 5 the expression given in Eq. (19) for the radius of curvature of the Gaussianbeam wavefronts is plotted. Part of the beam may reflect internally again at C and continue to experience multiple reflections within the film layer until it has lost its irradiance. Pressure Broadening is a result of elastic collisions between atoms in the gain medium. The diffraction pattern is observed in the XY-plane, which we shall call the spectrum plane, a distance Z along the axis. Light of wavelength 13 = 1549 nm satisfies the constructive interference condition (Eq. (21)) for Output 1 since m = $cL = 776.0 \ 113 > n2 \ 11549$ nm satisfies the constructive interference condition (Eq. (21)) for Output 1 since m = $cL = 776.0 \ 113 > n2 \ 11549$ nm satisfies the constructive interference condition (Eq. (21)) for Output 1 since m = $cL = 776.0 \ 113 > n2 \ 11549$ nm satisfies the constructive interference condition (Eq. (21)) for Output 1 since m = $cL = 776.0 \ 113 > n2 \ 11549$ nm satisfies the constructive interference condition (Eq. (21)) for Output 1 since m = $cL = 776.0 \ 113 > n2 \ 11549$ nm satisfies the constructive interference condition (Eq. (21)) for Output 1 since m = $cL = 776.0 \ 113 > n2 \ 11549$ nm satisfies the constructive interference condition (Eq. (21)) for Output 1 since m = $cL = 776.0 \ 113 > n2 \ 11549$ nm satisfies the constructive interference condition (Eq. (21)) for Output 1 since m = $cL = 776.0 \ 113 > n2 \ 11549$ nm satisfies the constructive interference condition (Eq. (21)) for Output 1 since m = $cL = 776.0 \ 113 > n2 \ 11549$ nm satisfies the constructive interference condition (Eq. (21)) for Output 1 since m = $cL = 776.0 \ 113 > n2 \ 11549$ nm satisfies the constructive interference condition (Eq. (21)) for Output 1 since m = $cL = 776.0 \ 113 > n2 \ 11549$ nm satisfies the constructive interference condition (Eq. (21)) for Output 1 since m = $cL = 776.0 \ 113 > n2 \ 11549$ nm satisfies the constructive interference condition (Eq. (21)) for Output 1 since m = $cL = 776.0 \ 113 > n2 \ 11549$ nm satisfies the constructive interference condition (Eq. (21)) for Output 1 since m = $cL = 776.0 \ 113 > n2 \ 11549$ nm satisfies the constructive interference condition (Eq. (21)) for Output 1 since m = $cL = 776.0 \ 113 > n2 \ 11549$ nm satisfies the constructive interference condition (Eq. (21)) for Output 1 since m = $cL = 776.0 \ 113 > n2 \ 11549$ nm satisfies t irradiance at the position where zFF = 50z0? Then, (b) Figure 18 Newton's rings in (a) reflected light and (b) transmitted light are complementary. Object and image distances from the vertex are shown as s and s;, respectively. The photon is emitted in a random direction. Together they led inevitably to the conclusion that the assumption of an ether was superfluous. Determine the attenuation loss at 1.55 mm. The spherical wave, as it propagates further from the source, decreases in amplitude is constant. These units of electromagnetic energy—as we have mentioned—are called photons. However, another important limitation must be taken into account. Optical Instrumentation 55 To see how an aperture restricts the field of view—using diagrams that could well be applied to the case of window and eye lens, just discussed—look at Figure 3. The line-spectra components of the spectra of Figures (8) and (9) are due primarily to spontaneous emission, and so 145 Properties of Lasers the width of these line features is also the width of the lineshape function for the pair of levels associated with that particular spectral line. With this formulation, Fermat's principle falls in the class of problems called variational calculus, a technique that determines the form of a function that minimizes a definite integral. The angle of incidence, ur, at the second surface also satisfies Brewster's law for internal reflection, so that the light is again fully transmitted. (24) and (25) simplify to give R = r2 = a 1 - n 2 b 1 + n (33) Equation (33) gives a reflectance of 4% from an air/glass interface with n = 1.5. Keep in mind, however, that n is a function of wavelength. The irradiance I at P is proportional to the square of the resultant field amplitude there. (Keep in mind, however, that at normal incidence E and E7 are equivalent since a unique plane of incidence (a) separating the external medium of index n0 from the nonmagnetic 1m = m02 film of index n1. The points D, E, and F on the incident wavefront arrive at points D, J, and I of the plane interface XY at different times. This shape factor is close to that of the plano-convex lens with s = +1. Solution The phase difference is given by $d = 2p 2p 1n1t^2 = 12.121402 = 0.8956$ rad lo 589.3 so that cos d = 0.6250 and sin d = 0.7806. (Courtesy Carl Zeiss, Inc., Thornwood, N.Y.) Example 6 Determine the eye relief and field of view for the 6 * 30 binoculars just described. When no light penetrates an opaque screen, it means that the interaction of the incident radiation within the screen, is such as to produce zero net field beyond the screen. In the case of the eye, this is the yellow-green portion

near 550 nm. Briefly, homogeneous broadening mechanisms are those physical influences that broaden the linewidth of the frequency response of each atom in the medium in the same manner, whereas inhomogeneous broadening mechanisms affect different groups of atoms in different ways—typically making the central frequency of the lineshape function different for different atoms. The terms radiant energy, Qe1J = joules2, radiant energy density, we1J>m32, and radiant flux or radiant phase are often called the wavefronts of the disturbance. When this is not the case and the curvature of the wavefront must be taken into account, we speak of Fresnel, or near-field, diffraction. Dye lasers have very large small-signal gain coefficients (4/cm or more) and very large gain bandwidths (50-100 nm). The quantity 1ytet = = = n 2 yiei yi yt mt yt (45) In arriving at this result we have used mi = mt = m0 for nonmagnetic materials and the relation y2 = 1 me for the velocity of a plane electromagnetic wave. The answer, of course, depends on whether the light from S, traveling along the two distinct paths SAP1 and SBP1 , is temporally as well as spatially coherent. If the object plane is uniformly bright and the aperture is a circular hole, then a circle of radius O¿T¿ is uniformly illuminated in the image plane. The difference between the Doppler effect in sound and light waves is more than the difference between the Doppler effect in sound and light waves is more than the difference between the Doppler effect in sound and light waves is more than the difference between the Doppler effect in sound and light waves is more than the difference between the Doppler effect in sound and light waves is more than the difference between the Doppler effect in sound and light waves is more than the difference between the Doppler effect in sound and light waves is more than the difference between the Doppler effect in sound and light waves is more than the difference between the Doppler effect in sound and light waves is more than the difference between the Doppler effect in sound and light waves is more than the difference between the Doppler effect in sound and light waves is more than the difference between the Doppler effect in sound and light waves is more than the difference between the Doppler effect in sound and light waves is more than the difference between the Doppler effect in sound and light waves is more than the difference between the Doppler effect in sound and light waves is more than the difference between the Doppler effect. are produced by oscillating (in general, simply accelerating) charge distributions and carry energy (and momentum) as they travel. We denote the energies of these levels E1 and E2 with the nominal difference in energy E2 - E1 = hn0 and take, again for the moment, the lower energy state to be the ground state of the system, shown in Figure 1. According to the Huygens-Fresnel principle, we can consider spherical wavelets to be emanating from each point of the waves according to the principle of superposition. Such scattering is most effective when the scattering centers are particles whose dimensions are small compared with the wavelength of the radiation, in which case we speak of Rayleigh scattering. The light beam striking the film is allowed to cover the edge of the film F, so that two fringe systems are seen side by side, corresponding to air films that differ by the required thickness at their juncture. Of course, images formed in mirrors do not suffer omatic aberration since the focal length of a mirror is independent of wavelength. Zubairy. 17 A filtered mercury lamp produces green light at 546.1 nm with a linewidth of 0.05 nm. Coupling a certain fraction of the laser light out of the cavity to be resonant with the cavity so that d = 2mp. Historically, dispersion has been characterized by using three wavelengths of light near the middle and ends of the visible spectrum. The fundamental lower limit of the noise inherent in the detection process is set by quantum or shot noise, but in practice the other technical noise sources often determine the noise equivalent power for the detector. Using the system matrix representing the hemisphere, determine the exit elevation and angle of a ray that enters parallel to the optical axis and at an elevation of 1 cm. Write an equation describing the displacement y(x,t) of the traveling pulse as a function of time t and position x if it moves with a speed of 2.5 m/s in the negative xdirection. An Introduction to the Theory of Diffraction. The optical path difference ¢, in the case of normal incidence, is the additional path length ABC traveled by the refracted ray times the refractive index of the film. (31) After neglecting the smaller third term on the left side of this relation, comparison with Eq. (30) leads to the conclusion that R(z) does indeed play the role of the radius of curvature of the phase fronts of a Gaussian beam. Employing the Pythagorean theorem and the distances defined in Figure 6, we have $AO = 2a^2 + x^2$ and $OB = 2b^2 + 1c - x^2 + y$; yt Since other choices of path change the position of point O and therefore the position of point O and the position of position of point O and the position of point O and the position of point O and the position of the distance x, we can minimize the time by setting dt>dx = 0: x c - x dt = = 0 2 2 2 dx yi 2a + x yt 2b + 1c - x22 Again from Figure 6, in the two right triangles containing AO and OB, respectively, the angles of incidence and refraction from Fermat's principle (a) p = -2, q = +2, f1 = -6, f2 = +6, r = 4, s = -4 in. y = ae-b(x+10t) Chapter 6.2 4m (a) y = (x+(2.5 m/s)t) 2 +2 m2 3 (a) (1) and (2) qualify because they satisfy the wave equation; more simply, if w = z + vt, they are functions of w: $y = A \sin 2(4w)$ and y = Aw2. Relative to the original object, the final image is 2>5 as large and inverted. SainteFoy Quebec: Les Editions Le Griffon D'Argile, 1988. Since an arbitrary direction involves the three spatial coordinates x, y, and z, we represent any quantity that varies in space and time such as the difference of air pressure from its equilibrium value (as in a sound wave) or the strength of an electric or magnetic field (as in a light wave). The Fabry-Perot cavities effectively extend the length of the arms by causing the light from the laser to sample the cavity length many times before exiting to the detector. In a dielectric however, rf = 0. As soon as the medium of propagation is removed, there is no longer a physical basis for the distinction between moving observer and moving observer intracavity light and reduction of the population density N2 of atoms in the upper lasing level is shown in Figures 16d and 16e. This, of course, is what happens when the eyes move appropriately to focus on an object or scene, causing the image to fall on the fovea centralis of each eye. With the help of a calculator or computer program, generate curves showing each dependence. After transmission by the optic fiber, it is reconverted from an optical to an electrical signal. Figure 8 Correspondence between ordinary spherical waves. If the glass has a refractive index of 1.50, determine (a) the required Coddington factor and (b) the radii of curvature of the lens. Consider a narrow, monochromatic beam from an extended source point S making an angle (in air) of ut with respect to the optical axis of the system, as in Figure 6. The focal point. What power argon laser emitting at 488 nm is required to match the brightness of a 0.5-mW He-Ne green laser at 543.5 nm under the conditions of (a)? Reflectance curves are shown in Figure 7. Introduction to Fourier Optics. The results show that the interference pattern determined earlier is modified in a way that accounts for the actual details of the observed fringes. 1.7 µm 9. In Example 6 we show how one can estimate the signal power associated with a given gravitational strain. To appreciate the uniqueness of the process, consider Figure 16, which shows reflections from ordinary mirrors. Since the angular diameter u of a star is extremely small, Is will be correspondingly large. We concluded that in order to transfer information at a high rate over long distances, a combination of source wavelength and single-mode fiber that minimizes attenuation and distortion should be used. The net angle of rotation b due to a light path L through a solution of d grams per cubic centimeter. 4 FRESNEL DIFFRACTION FROM CIRCULAR APERTURES Suppose the aperture in Figure 1 is circular. In general, the output of a laser will consist of those frequencies given in Eq. (26) that the laser gain medium is capable of supporting. We will develop first an expression for the CW output irradiance for a ring laser and then write down the corresponding result for the more common case of a laser system that uses a two-mirror linear cavity. All approach a MTF of 1 as the spatial frequency approaches zero but indicate different resolution limits as MTF becomes zero. Rays from an axial point O are limited in angle by the aperture and focused by the lens at point O. The determination of the oscillator strength for a given resonant transition requires the application of quantum theory. We begin our treatment with a brief description of Fourier analysis, which we will need in this chapter. Calculate the number of photons arriving at the detector in one observation time in an optical signal of wavelength 1.5 mm with a power equal to the noise equivalent power of the detector. (36) and (37) into Eq. (35), 1 = 1n - 12K1 + 1n - 12K2 - L1n - 12K1K2 f (38) To correct for transverse chromatic aberration, we require that the effective focal length of the pair remain independent of refractive index.4 or d11>f2 = 0 dn From Eq. (38), d11>f2 = K1 + K2 - 2LK1K21n - 12 = 0 dn 4 Some longitudinal chromatic aberration remains because the principal planes of the system do not coincide. 19 It is desired to
reduce the curvature of field of a lens of 20-cm focal length made of crown glass 1n = 1.52302. The negative sign indicates that turpentine is levorotatory in its optical activity. On reconstruction, each set of zones produces its own real and virtual images, and the original scene is reproduced. "A New Calculus for the Treatment of Optical Systems." Journal of the Optical Systems." Journal of the Optical Society, Vol. The slowly varying cosine function is a factor that ranges between + 1 and - 1 for various t. (a) 0.155 mm (b) 1.32 × 104 W/cm2 (c) 3.17 W/cm2 24. Van Nostrand Company, 1964. Gain Saturation in Inhomogeneously Broadened Media Let us now turn to a description of gain saturation in an inhomogeneously broadened medium. Use a summation to express your result. Notice that in this case the result does not require that N be a large number. The distance r + r the rectangular volume ¢V flows across the surface A. Find (a) B B the amplitude of the E-field of the solar radiation, inserting all constants numerically. in analogy with those in Figure 5, illustrate the defects and B-fields; (b) the number of a B solar panel; (c) a harmonic wave equation for the E-field of the solar radiation, inserting all constants numerically. correction associated with the farsighted eve. What irradiance ratio of the interfering beams reduces the fringe visibility by 10% of that for equal-amplitude beams? Larger aperture numbers correspond to smaller exposures. It is so named because the nonlinear interaction produces a light beam that is the spatial complex conjugate of one of the waves incident on the nonlinear medium. The separate portions of the beams then travel different paths before being recombined and directed into two different output ports by the second fiber coupler, FC2. That is, g0 = s1N2 - N12 6 glow th 2. Qumin I2 I1 Pupil Retina Figure 12 Diffraction by the eye with pupil as aperture limits the resolution of objects subtending angle ¢umin . The camera lens is called upon to perform a prodigious task. Ballard. Distinct retinal images are not formed with the unaccommodated myopic eye until the object moves inward from infinity and reaches the myopic far point (M.F.P.), the most distant point for clear vision (Figure 5d). Since refraction occurs at a point, there is not formed with the unaccommodated myopic eye until the object moves inward from infinity and reaches the myopic far point (M.F.P.), the most distant point for clear vision (Figure 5d). change in elevation, and y = y₂. 358 Chapter 15 Production of Polarized Light Recapitulating, then, for an ideal dichroic material, nx = ny and kx Z ky, whereas for an ideal dichroic material, nx = ny and nx Z ny ideal dichroic material, nx = ny and nx Z ny ideal dichroic material, nx = ny and nx Z ny ideal dichroic material, nx = ny and nx Z ny ideal dichroic material, nx = ny and nx Z ny ideal dichroic material, nx = ny and nx Z ny ideal dichroic material, nx = ny and nx Z ny ideal dichroic material, nx = ny and nx Z ny ideal dichroic material, nx = ny and nx Z ny ideal dichroid material, nx = ny and nx Z ny ideal dichroid material 1n0 + ns22 4 A single layer of SiO2 1n = 1.462 is deposited to a thickness of 137 nm on a glass substrate 1n = 1.522. Values of M (in units of ps/nm-km) for pure silica are given in Figure 13. Ch. 22. In this section we describe photoconductive detectors, and photodiodes. Show that if the local ratio of reference to subject beam irradiances is a factor N at some region of a hologram, then the visibility of the resulting fringes is 2 2N>1N + 12. When the population inversion, exceeds the pump rate that feeds the inversion, and so the population inversion inversion, exceeds the population inversion inversion. decreases rapidly. For ap = 1, the profile has a triangular shape; for ap = 2, it is parabolic; for higher values of ap , the profile gradually approaches its limiting case, the step-index profile, as ap : q . We conclude here without further proof, then, that the appropriate matrix is M = c 0 0 0 d 1 linear polarizer, TA vertical (13) The matrix for a linear polarizer TA horizontal, can be obtained in a similar manner and is included in Table 2, near the end of this chapter. Material dispersion therefore becomes significant only when modal distortion is greatly reduced, in both single-mode and GRIN fibers. A laser gain medium is pumped while the cavity has high loss (low Q). The location and nature of the image formed by a mirror can be determined by graphical ray-trace techniques. Since \supset is independent of the grating constant, at a given angle of diffraction, the effect of increase the order m of the diffraction, the effect of increase the order m of the diffraction there, as Eq. (5) clearly shows. Note that w(z) is a measure of the radius (not diameter) of the beam. Evidently must be larger than some minimum value, Lmin , which gives a beam width W = b, that is, Lmin = b2 2l We may conclude that we are in the far field diffraction in the form2 L area of aperture l (16) 3 RECTANGULAR AND CIRCULAR APERTURES We have been describing diffraction from a slit having a width b much smaller than its length a, as illustrated in Figure 5a. In the usual exchange, a hard punch struck one of the thick lenses he was wearing, shattering it into multiple fragments. It is found that in such materials, an optic axis is induced in the direction of the struss, both in tension and in compression. Prove your conclusion. 0.7 1.5 9 APPLICATIONS OF THE CORNU SPIRAL Approximate evaluations of the Kirchhoff-Fresnel integral are possible with the help of the cornu spiral. Replacing R by q for the laser beam after refraction by a simple thin lens. Vertically polarized beam (b) Output beam Pockels cell Figure 7 Light-controlling action of a Pockels cell, used as a cavity dumper. 402 Chapter 18 Matrix Methods in Paraxial Optics We conclude that the image occurs 24 cm inside the rod, is inverted, and has the same lateral size as the object. For the second refraction, then, Eq. (20) becomes 1.33 1 1 - 1.33 + = -30 s; 2 -5 or s; = +9 cm. This is precisely the workB ing principle of Polaroid sunglasses. The plane of incidence is the xzplane. Clark. Solution Remembering to take the matrices in "reverse" order and working in cm, we have 1 M = P2PP1 = C 0 x 1 1 1.50 SC 1 411.502 0 1 1 SC 1.50 0 16 S 1 or x 12 M = D 1 12 1 - 16 - 2x 3 2 3 T with the unknown quantity x incorporated in the matrix elements. The thick, straight arrows indicate transitions of an electron from one band to another, and the lighter, curved arrows represent photons. The objective lens is usually a doublet, corrected for chromatic aberration. (a) TE mode. This behavior is to be contrasted with the normal eye, a myopic eye or nearsighted eye is commonly found to be longer in axial distance—from cornea to retina—than the usual, accepted span of 22 mm. In matrix nepresents the effect of the translation on a ray. Usually the beam splitting is managed by a semireflecting metallic or dielectric film; it can also occur by frustrated total internal reflection at the interface of two prisms forming a cube, or by means of double refraction. Example 1 Calculate the reflection at the interface of two prisms forming a cube, or by means of double refraction. STOPS, PUPILS, AND WINDOWS You should be familiar with ways to trace rays through an optical system using the step-by-step application of the electron cloud relative to its nucleus, producing an induced dipole. Each of these beams is made up of light that is linearly polarized perpendicular to the plane of incidence, as indicated by the dots in Figure 3, the focal length f1 is given by 1nL - n21nL - n21nL - n2 tr L - n2 nL n; f n 1 (2) where n, n;, and nL are the refractive indicated in Figure 3. The first approximation is to regard arc S1Q as a straight-line segment that 169 170 Chapter 7 Interference of Light Y P s1 y s2 S1 u u S a X O S2 Q L Figure 3 Schematic for Young's double-slit experiment. 17 Design an optical isolator, as in Figure 10, that uses ZnS as the active medium. These examples are not only of some historic importance; they also serve to impress us with the variety of ways unexpected fringe patterns may appear in optical experiments, especially when the extremely coherent light of a laser is being used. However, we wish to describe beams of finite transverse extent, so we cannot similarly neglect the transverse variation in the beam described by the second spatial derivatives of U with respect to x and y. 566 Chapter 26 Laser Operation Solution g0(n)
a. The preferred criterion of performance is the optical transfer function (OTF). Horiguchi, T. Treating 101 Wave Equations c N2 m 0 0.25 0.75 0.5 1.25 x 1.0 y c N2 10 m c N2 10 m 0 c \ge c 0 c N2 10 m x z x 0.25 m x 0.5 m x 0.75 m x 1.0 m x 1.25 m l 1.0 m Figure 5 Air pressure variation induced by a plane sound wave propagating in the x-direction. However, if the harmonic components move with different speeds of the constituent harmonic waves. (33) and (34) permit the calculation of focal lengths for each of the Fraunhofer wavelengths. Chapter 21 Pedrotti, Frank L., and Peter Bandettini. However, its presence is important in determining the wavelength at which net fiber dispersion is zero, as we shall see. Determine a numerical expression for the complex radius of curvature q, at a distance of 50 m from the beam waist, using each of the following expressions: $1 \ 1 = +i \ q \ R \ pw 2122$ and q = z - iz0 rounding approximations, you should find c B 1.0007 d = c D - 0.5318 A C b. Photographic emulsions are available with spectral sensitivity that extends from the X-ray region into the near infrared at around 1.2 mm. The time t required for a signal of angular frequency v to travel a distance L along the fiber is therefore given by $1v^2 = L yg 1v^2$ where $yg^1v^2 = dv dk$ If the signal bandwidth is v, the spread in arrival times per unit distance is expressed by da t d 2k d 1 v b = a b $v = L dv yg dv^2$ Now the first derivative dk>dv can be calculated from k = 2p>l = nv>c, where n is a function of v. (d) Is Eq. (44) satisfied? To produce a simple Young's interference pattern for two slits, one accordingly makes a b so that N is large. For simplicity we shall imagine the aperture function to vary like a square wave, such as would be produced by a Ronchi ruling, a grating of parallel straight lines with large grating space, whose opaque and transparent regions are of equal width. The condition expressed by Eq. (19) is useful in checking the correctness of the calculations that produce a system matrix. r12 dA2 u2 S1 S2 length r12, makes angles of u1 and u2 with the respective normals to the surfaces, as shown. 9 SOME IMPORTANT LASER SYSTEMS Detailed descriptions of the calculations that produce a system matrix. characteristics of different laser systems are beyond the scope of this chapter. Compare this result to the answer obtained for part (d) of problem 5. Each component is affected different speed, since the refractive index is different for the two components. The chief ray from O¿ intersects the optical axis at A, at A 1œ (which is virtual), and at A 2œ. Since sin x = cos1x - p>22, the only difference between the sine and cosine functions is a relative translation of p>2 radians. Multiple parallel beams emerge from the top and from the bottom of the plate. smallest resolvable angle subtended by a black bar on a white background is called minimum visible, and the smallest angle subtended by block letters that can be read (on an eye chart) is called minimum legible. To keep matters as simple as possible we consider, in turn, the action of the polarizer on light linearly polarized in the same direction as—and perpendicular to—the TA of the polarizer. 24 Chapter 2 S N P S (a) Geometrical Optics requires an angle of refracted rays bend away from the normal, as shown in Figure 9a, for rays 1 and 2, when n2 6 n1. When illuminated normally with a parallel beam of laser light (632.8 nm), the distance between the third minima on either side of the principal maximum is measured. Show that when the final image is not viewed at infinity, the angular magnification of an astronomical telescope may be expressed by M = - 29 The moon subtends an angle of 0.5° at the objective lens of an astronomical telescope. A modification of the Ramsden eyepiece that almost eliminates chromatic defects is the Kellner eyepiece, which replaces the Ramsden eye lens with an achromatic doublet. In contrast, a plane wave traveling in the z-direction is parameterized by just E0, f, and l. Determine the powers of the individual lenses and that of the unit, in diopters. The O-ray ellipsoid is spherical and intersects the E-ray ellipsoid along a direction (shown relative to the optic axis) for which both rays have the same velocity. Show that if one beam of a two-beam interference setup has an irradiance of N times that of the other beam, the fringe visibility is given by V = 22N N + 1 b. If the two lens positions differ by distance D, show that the focal length of the lens is given by V = 22N N + 1 b. If the two lens positions differ by distance D, show that the focal length of the lens is given by V = 22N N + 1 b. If the two lens positions differ by distance D, show that the focal length of the lens is given by V = 22N N + 1 b. If the two lens positions differ by distance D, show that the focal length of the lens is given by V = 22N N + 1 b. If the two lens positions differ by distance D, show that the focal length of the lens is given by V = 22N N + 1 b. If the two lens positions differ by distance D, show that the focal length of the lens is given by V = 22N N + 1 b. If the two lens positions differ by distance D, show that the focal length of the lens is given by V = 22N N + 1 b. If the two lens positions differ by distance D, show that the focal length of the lens is given by V = 22N N + 1 b. If the two lens positions differ by distance D, show that the focal length of the lens is given by V = 22N N + 1 b. If the two lens positions differ by distance D, show that the focal length of the lens is given by V = 22N N + 1 b. If the two lens positions differ by distance D, show that the focal length of the lens is given by V = 22N N + 1 b. If the two lens positions differ by distance D, show that the focal length of the lens is given by V = 22N N + 1 b. If the two lens positions differ by distance D, show that the focal length of the lens is given by V = 22N N + 1 b. If the two lens positions differ by distance D, show that the focal length of the lens is given by V = 22N N + 1 b. If the two lens positions differ by distance D, show that the focal length of the lens is given by V = 22N N + 1 b. If the two lens positis differ by distance D, show tha evidence of some degree of bending, even for light waves, in the time of Isaac Newton. The opening and closing of the gate, just described, provides such a phase-locking mechanism. These departures are referred to as "aberrations." When the next term involving x3 is included in the approximation for sin x, a third-order aberration theory results. 44 Chapter 2 Geometrical Optics or AB = a s + s¿ b CL s (37) Subject to our sign convention, this relation is a general form for the planocylindrical lens that handles all cases, with s and s¿ object and image of an axial object point 25 cm in front of the lens and for rays through a zone of radius h = 2 cm. The fact that the electromagnetic vacuum has energy (even if this energy cannot be transferred to another system) is relevant to the discussion of spontaneous emission given later. Calculate the percent error involved in this approximation for the first three secondary maxima. From Eqs. Note that 8E1E29 = 0 8E...1E...29 = 0 233 Coherence since, as one can see from Eq. (23) these terms involve the time average of sine and cosine factors that oscillate at 2v. The Jones vector takes the form of the vector, we set A = 1, since $\cos 2a + \sin 2a = 1$. The degree of bending is a function of the refractive index of the prism and is, therefore, a function of the wavelength of the incident light. After substituting Eq. (10) into Eq. (9), we obtain 0p 0q 2ikU k2 + 2 r2U = 0 - 2 r2U - 2kU q 0z 0z q q which, when rearranged in terms of powers of r2, becomes ca 0p 2ik k2 0q k2 - 2 b 1r221 d U = 0 - 2k b1r220 + a 2 q 0z q 0z q (11) If the function given in Eq. (10) is to be a solution for all r, then each factor multiplying a power of r2 must equal zero separately. Briefly, the procedure is as follows. (12) and (14) for the TE mode, we parallel their development for the TM mode pictured in Figure 2. Using Figure 2, compare the relative brightness of the two laser beams of equal diameter when projected side by side on a white piece of paper. If, for example, constructive interference results between the two parts of a single beam incident at angle ui, the same condition will hold for all beams incident at angle ui, the same condition will hold for all beams incident at angle ui, the same condition will hold for all beams incident at the same condition
will hold for all beams incident at the same condition will hold for all beams incident at the same condition will hold for all beams incident at the same condition will hold for all beams inci with a photon of frequency n is proportional to a lineshape function g1n2, which is, typically, a nearly symmetric function of width ¢n that peaks at n = n0. Angular magnification, given by 25/f, where f is the focal length in centimeters. 22 Table 1 indicates that diode lasers have a large divergence angle. Important mechanisms of this sort include differing phase shifts due to reflection from beam splitters and differing indices of refraction in the separate paths taken by the two beams. When light pulses, consisting of a number of harmonic waves extending over a range of frequencies, are transmitted through a dispersive medium, the velocity Envelope moves with group velocity Carrier wave mover with phase velocity Figure 8 Snapshot of a waveform that is the sum of 10 equal-amplitude harmonic waves with frequency spacing about 1/50 of the average frequency of the constituent harmonic waves. Here we must take into account a different speed of light in the upper and lower media. (b) With the corrective lens of part (a), what will be the far point of this eye? With both eyes open, line the pencil up with the vertical edge of a picture, door, or window across the room. We imagine such a wave as a plane wave that has been shaped by passing through a distorting medium, by diffraction, or by modulation. Let the number of nearly equal-amplitude modes each of power P0 in the system be N. Thus contributing zones, relative to the axis SO-P-, begin at a finite positive value of z and continue to q . 217 Optical Interferometry TABLE 1 FABRY-PEROT FIGURES OF MERIT. (d) 1.6565 × 107 W/m2 (e) 1.6788 × 107 W/m2 (e) 49.7 W/m2 (c) 221 W/m2 (d) 1180 W/m2 (e) 10,200 W/m2 (a) 5.96 W/m2 (b) 39.7 W/m2 (c) 121 W/m2 (d) 180 W/m2 (e) 200 W/m2 (a) 2.7 W/m2 (b) 25.2 W/m2 (c) 181 W/m2 (d) 1170 W/m2 (e) 10.200 W/m2 (e) 10.200 W/m2 (f) 103 W/m2 (g) 10.200 W/m2 (g) 1430 W Full-width angular spreads: 90°, 9° 1.55 eV 0.45 Chapter 27 4. A pencil-like laser beam is perhaps the best actual approximation to a ray of light. The laser output consists of a single mode. Recalculate the system matrix for the enlarged system. 606 Chapter 27 Characteristics of Laser Beams d. New York: Wiley-Interscience, 1974. The electric field oint U in the aperture takes on the usual spherical waveform, ES i1kr¿ - vt2 e (1) EO = r¿ ES ikr¿ e represents the complex amp litude of the electric field at point O. Then, $S = b 3 \sin b \sin b \sin a$ This expression is adapted to N even. The principal features of the standing wave however remain unaffected Express the result in terms of the unobstructed irradiance. If the virtual image produced by the eyepiece is 25 cm from the eye, compute (a) the magnifying power of the microscope and (b) the separation of the lenses. Each component of the instant shown, four cavity modes are above threshold. 4m3 2 2 2 x + 2m is initiated at t = 0 in a stretched string. If both the source of light and observation screen may be considered plane, we speak of Fraunhofer, or far-field, diffraction, the type treated in this chapter. As it turns out, though, due to the widely different lifetimes of available atomic energy levels, only certain pairs of energy levels with appropriate spontaneous lifetimes can be "inverted," even with vigorous pumping. Depending on whether cos d 7 0 or cos d 6 0 in Eq. (14), the interference term either augments or diminishes the sum of the individual irradiances I1 and I2 , leading to constructive or destructive interference, respectively. Sketch the lens system with its cardinal points. The ray is described at distance x0 from the first refracting surface in terms of its height y0 and slope angle a0 relative to the optical axis. In addition, we consider only the meridional rays, which intersect with the fiber's central axis.3 Consider a short section of a straight fiber, pictured in Figure 3a. The transformation from I01X, Y2 to Ii1X, Y2 clearly characterizes the optical system and is accomplished by a third function, Called the point spread function, Called the point spre the law of reflection. Solution The total irradiances I1 and I2 of the beams exiting the respective arms of the interference expression, Idet = $I1 + I2 + 22I1I2 \cos d$ Here, d is the phase difference between the two beams arriving at the detector after traversing the interferometer arms. u d u behave as crystalline planes of atoms in diffracting light, that is, like a threedimensional grating. 252 Chapter 10 Fiber Optics 100 Total fiber loss Glass absorption in infrared Attenuation (db/km) 10 Figure 6 Contributions to the net attenuation (db/km) 10 Figure 6 Contributions to the net attenuation (db/km) 10 Figure 6 Contributions to the net attenuation of a germanium-doped silica glass fiber. Spectral emission curves for Xe and Hg-Xe lamps are shown in Figures 8 and 9. In this case, the index of refraction is real and Eq. (34) takes the form n2 = 1 + Ne2 1 a b me0 v20 - v2 Notice that, for v v0, as for a gas, the refractive index is nearly constant. 10 A Fabry-Perot etalon is fashioned from a single slab of transparent material having a high refractive index 1n = 4.52 and a thickness of 2 cm. In practice, however, this relation, by itself, is not used to experimentally determine the wavelength of the source because the length change cannot be measured with the desired accuracy. We show that, in the paraxial approximation, changes in height and direction of a ray can be expressed by linear equations that make this matrix approach possible. Monochromatic light is channeled from a light source LS through a fiber-optic light pipe LP to a right-angle beam-splitting prism BS, which transmits one beam to a flat mirror M and the other to the film surface. (Courtesy Olympus Corp., Woodbury, N.Y.) (b) 75 Optical Instrumentation such as coma, distortion, and lateral chromatic aberration 176 Chapter 7 Interference of Light to a situation like Young's double slit, in which separation is said to occur by wavefront division. Each beam is also illustrated in Figure 3. A consequence of Fermi-Dirac statistics is that no two electrons in the same interacting system can be in the same by sical properties. 10 Calculate the length of a Kerr cell using carbon disulfide required to produce half-wave retardation for an applied voltage of 30 kV. To process light signals of varying brightness, the eye adapts. Then w0 can be set equal to zero for simplicity. 15. The analysis giving the possible modes in a cylindrical fiber is based on the same physical principles but is more complicated and is not developed here. Two rays are shown emanating from object point O. Snell's law at each prism face requires that sin $u1 = n \sin u2 \alpha = \sin u2$ (1) (2) Inspection will show that the following geometrical relations must hold between the angles: (3) $d1 = u1 - u1 \alpha d2 = u2 B = A = (4) u2 \alpha 180 - u1 \alpha u1 \alpha + u2 \alpha - u2 \alpha = u$ 180 - A (5) (6) The two members of Eq. (5) follow because the sum of the angles of a triangle is 180° and because the sum of the angles of a quadrilateral must be 360°. This goal is achieved by a lens that refracts light rays twice, once at each surface, producing a real image outside the lens. Prisms with Special Applications Prisms may be combined to produce achromatic overall behavior, that is, the net dispersion for two given wavelengths may be made zero, even though the deviation is not zero. Other points and lines are added to help in developing the necessary geometrical relationships. The result is that such a crystal, although not appreciably dichroic, still manifests the property of birefringence Image formation in a plane S S S n1 u2 s (a) u1 u1 (b) n1 n2 u2 u2 n2 n1 u1 90 uc u1 u1 S Figure 9 Geometry of rays refracted by a plane interface. What is the irradiance function at the detector for unit irradiance incident at the grating? Intrinsic losses are due to absorption, both by the core material and by residual impurities, and by Rayleigh scattering from microscopic inhomogeneities, dimensionally smaller than the optical wavelength. As a result, it is common practice to use the complex waveform Eq. (18) to represented by one of the forms in Eq. (19). Cladding material need not be highly transparent, but must be compatible with the fiber core in terms of expansion coefficients, for example. Chapter 16 Francon, Maurice. 10 Determine the angle of 45°. There is no one-to-one correspondence between object points and points in the wavefront before reconstruction occurs. Now according to Eq. (22), the spot size w(z) increases as z2 increases as z2 increases, accounting for the beam depicted in Figure 2. We will assume that the two mirrors that form the Fabry-Perot cavity are identical, are separated by a distance d, and have real (internal surface) electricfield reflection and transmission coefficients r and t. Marcatili, "Multimode Theory of Graded-Core Fibers," Bell Syst. 3 PRISMS Figure 8 Focusing due to half of a convex lens approximates the action of a prism. Describe the dispersion in the red wavelength region around 650 nm (both in °/nm and in nm/mm) for a transmission grating 6 cm wide, containing 3500 grooves/cm, when it is focused in the third-order spectrum on a screen by a lens of focal length 150 cm. Ionic polarization may be significant in the region of resonance, however, where the large-bracketed terms in Eqs. 5 a. The aperture A is located 3 cm in front of lens L1, which is located 4 cm in front of lens L2. The requirement of a large number of wires is mitigated by the use of a chargecoupled device (CCD). The diaphragm of a camera and the iris of the human eye are examples of aperture stops. Notice that at every point of the path, Snell's law is obeyed on a microscopic scale. Then do a numerical calculation
by assuming a hypothetical medium with "typical" values of r = 10 pm>V, K = 1 pm>V2, L = 2 cm, d = 1 cm, and n0 = 2. Of course, light choppers and shutters can accomplish some modulation mechanically. The grating is to be installed in an instrument where light from the entrance slit is incident normally on the grating. A resonance frequency such as v0 for the dielectric means that, for incident photons of frequency v0, there is a high probability of absorption. Holographic Data Storage of data in a hologram offers tremendous potential. Huygens' principle must be modified slightly to accommodate the case in which a wavefront, such as AC, encounters a plane interface, such as XY, at an angle. Use Table 1 to find the center wavelength of the Nd:YAG lasing transition. Thus in the TE mode a relative phase shift of p occurs for all external angles of incidence, but in the TM mode this is true only for external angles less than up . 5 Double refraction is a term used to describe a manifestation of birefringence in materials, although it has literally the same meaning. The net electric field amplitude of the coherent scattered radiation is now the sum of the individual amplitudes, or the radiated power is proportional to N 2 when there are N coherent oscillators. Laser Electronics. The extraordinary ray emerges polarized in a direction with the atoms in the medium. The plate, when developed, then shows a series of concentric interference rings about X as a center. In the far-field approximation, as the viewing screen is moved relative to the aperture, the size of the diffraction pattern does not change. The resonator, or optical cavity, in its most basic form consists of a pair of carefully aligned plane or curved mirrors centered along the optical axis of the laser system, as shown in Figure 13. In the spirit of Fermat's principle, we can say that since every such ray starts at O and ends at I, every such ray starts at O split into two equal-amplitude parts. Find the frequency bandwidth ¢n of a DWDM system utilizing 40 wavelength channels near 1550 nm if the channels near 1550 nm if the channels are separated by 0.8 nm. Nerou, Jean Pierre. Its phase-reversed replica is expressed by taking the complex conjugate of both °1r2 and ikz, in other 15 Amnon Yariv, Optical Electronics, 3d ed. The gain bandwidth of the lasing transition is roughly 162 Chapter 6 Properties of Lasers equal to the width of the atomic lineshape function g1n2 associated with the lasing transition. The point P in the spectrum plane is a distance r0 from the origin of the xy-coordinate system in the aperture plane. A CCD panel of area 1 cm2 might contain 500,000 individual photodiodes. The specific rotation of glucose is 20.5°. Appendix F. (b) Pumping of the gain medium creates a population inversion. Example 1 What is the ratio of irradiances at the central peak maximum to the first of the secondary maxima? 12 Chapter 1 Nature of Light The familiar inverse-square law of radiation from a point source, illustrated in Figure 3, is now apparent by calculating the irradiance of a point source on a spherical surface surrounding the point, of solid angle 4p sr and surface area 4pr2. Alternatively, every object point sends a bundle of rays to the screen, which are limited by the small pinhole and so form a small circle of light on the screen, as in Figure 19a. It is often defined as the smaller circle of radius OU if one considers the usable field of view as that which consists of all object points that produce image plane (a) Lens b A y f ra hie C O T U V Object plane EnP Image plane (b) EnP EnW L1 AS a FS L2 ExP ExW a (c) Figure 3 Referring to the same optical system, diagrams (a) and (b) illustrate both the way in which an aperture limits the field of view and the process by vignetting. 21 Plane plates of glass are in contact along one side and held apart by a wire 0.05 mm in diameter, parallel to the edge in contact and 20 cm distant. Since the power P radiated is in turn proportional to the square of the electric field, it becomes proportional to the fourth power of the frequency. The transmittance peaks sharply at higher values of r as the phase difference approaches integral multiples of 2p, remaining near zero for most of the region between fringes. 4 Refractive indices for a step-index fiber are 1.52 for the core and 1.41 for the cladding. With accommodation, the normal eye forms a distinct image of objects located anywhere between its far point (F.P.) at infinity and its near point (N.P.), nominally a distance of 25 cm for the young adult. For the case at hand, the population inversion is always negative since Ninv = N2 - N1 = - NT a 1 b 1 + 2sI>1hn¿A 212 (19) Note that the key parameter governing the distribution of population between the two levels is the ratio of the stimulated emission rate s1>hn; and the spontaneous emission rate ¢l K - M ¢l b = c dl2 L t l d 2neff da b = ¢l K - M¿¢l c dl2 L (20) 9 This value corresponds approximately to the so-called 3-db bandwidth, the modulation frequency at which the signal distortion. Wavelength (nm) TABLE 1 REFRACTIVE INDICES FOR SEVERAL COATING MATERIALS Material Cryolite MgF2 SiO2 SiO Al2 O3 CeF3 ThO2 Nd2 O3 ZrO2 CeO2 ZnS TiO2 Si Ge Visible 1 2 550 nm2 1.30-1.33 1.38 1.46 1.55-2.0 1.60 1.65 1.8 2.0 2.1 2.35 2.35 2.4 - Near infrared 1 2 2 mm2 - 1.35 1.44 1.5-1.85 1.55 1.59 1.75 1.95 2.0 2.2 2.2 - 3.3 4.0 has no effect on the reflectance and the double layer behaves like a single l>4 layer with R = 1.3%. Determine the free spectral range in the first three orders of grating diffraction. If the film and substrate. The light must have sufficient temporal coherence so that path differences between the two beams do not exceed the coherence length of the light; it must also possess sufficient spatial coherence so that the beam is coherent across that portion of the wavefront needed to encompass the scene. Nussbaum, Allen, and Richard A. Both are viewed with the same coherent light. If an aperture is placed in front of the lens to limit the bundle of light rays through the lens, the height of the line image is just the aperture dimension along the cylinder axis, or the effective height of the lens. As the circular opening of the diaphragm is gradually sharpens. This second Fourier transform of the transform of the original aperture function and so returns the original aperture function; that is, an image of the original aperture is formed there. 5 HOMOGENEOUS BROADENING You should be familiar with the notion of the interaction of an atomic system with an incident field of frequency n¿. The atoms and molecules that constitute matter have quantized energy levels. (33) and (34) as well as a dispersive constant V, defined as the reciprocal of the dispersive power and given by nD - 1 1 = nF - nC ¢ V K (43) Substituting Eqs. 149 150 Chapter 6 Properties of Lasers Pump levels E3 2 Fast radiationless transition Pump energy N2 E2 Resonant photon Upper laser level 3 Light amplification 1 hy E2 E1 N1 E1 Decay to ground level 4 E0 Lower laser level Ground level (a) 21.1 He Ne 2 2 5 21S 3s 1 4 10 Collision energy transfer 2 5 2s 3p Common He-Ne laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level for 0.6328 mm 1 Potential laser line 1.1523 mm 4 2p Lower laser level fo and (b) a particular laser, the helium-neon laser. Also show that your results are consistent with the general result for N slits, given by Eq. (32). 14 An achromatic doublet consists of a crown glass positive lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.62 and of thickness 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative
lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1 cm, cemented to a flint glass negative lens of index 1.52 and of thickness 1.52 an are five Seidel aberrations: spherical aberration, coma, astigmatism, curvature of field, and distortion. Saleh, and M. Upon entering the eye at the aircornea interface, where the refractive index changes abruptly from 1.0 to 1.38, light undergoes a significant degree of bending. Efficiencies in this configuration can be comparable to those of blazed gratings. Throughout the rest of this chapter, we will presume that the difference in the lengths of paths traveled by beams originating from the same source is considerably less than the coherence length of the source the focal length of the source the focal length of the source is considerably less than the coherence length of the sou curves shown in Figure 13 using the parameters given in the figure caption. We see from Eq (29) that the correlation is given by the DC component, or spectrum. The extra p phase shift upon reflection from the upper beam splitter surface ensures that when constructive interference occurs in output port 1, destructive interference will occur in output port 2. White light, for example, has a "line width" ¢l of around 300 nm, extending roughly from 400 to 700 nm. Laser diodes use forward-biased p-n junctions, in which the voltage source drives the holes in the p-type material and the conduction electrons in the n-type material toward the junction (Figure 17). A thin plate of calcite is cut with its OA parallel to the plane of the plate. (a) Levorotatory: n^c 7 n^P. Notice, from Figure 14a, that it is possible to relate points at elevation z on the wavefront, such that y = a p + q bz p The value of z determines the length y on the Cornu spiral, permitting quantitative calculations of screen irradiance to be made. "How Images Are Formed." Scientific American, Sept. (a) When D = 0, the input plane of the optical system. Thus, the polarization of light constitutes experimental proof of its transverse character. Competing amplification technologies require either that the signal exit the fiber and be amplified before being inserted into a second fiber or that portions of the fiber be doped with an amplifying medium like erbium. u = 0.6328 mm * 10-9 m l = = 8 * 10-4 rad pw0 p12.5 * 10-4 m2 This is a typical laser beam divergence, indicating that the beam radius increases about 8 cm every 100 m. Now what percentage of the incident light energy is transmitted? The bending that occurs at each face is determined by Snell's law. The action of the c and P modes in producing the resultant light might be visualized in the following way. Coordinates of these points are found by interpolation in Table 1, giving For y1 : C1- 5.196152 = -0.44016 and S1- 5.196152 = -0.50043 For y2: C10.577352 = 0.56099 and S10.57735) 0.10013 Therefore, the irradiance at point P₂ is found from Eq. (33) to be IP₂ = I05[0.56099 - (0.44016)]2 + [0.10013 - (0.50043)]26 = 1.36I0 = 0.68Iu The irradiance of an unobstructed wavefront there. In addition, the transverse orientation of object and image are the same. If one looks into the optical system from the image, another image of the AS can be seen that appears to limit the output beam size. Field lens RO Reticle Retaining ring EL Field stop Exit pupil FL Figure 26 Ramsden eyepiece. In Figure 26 Ramsden eyepiece. In Figure 26 Ramsden eyepiece are the same are the same. If one looks into the optical system from the image are the same are the sam modulated to convey information, the signal waveform becomes distorted due to several mechanisms to be discussed. Oscillations within the plane—where the electrons tend to be confined due to the chemical bonding—take place more OA OA y y储 Ca y E储 y储 マ y 102 🔅 E O C Figure 9 (a) Progress of light through a calcite crystal. For situations in which the assumptions of Fraunhofer diffraction fail, we are left with Eq. (7). It turns out, in fact, that the phase of the electromagnetic wave originating with the oscillating electrons is 180° out of step with that of the incident radiation, so no wave can propagate in the forward direction. OA Extraordinary ray Ordinary ray OA 4 For a more complete discussion, see, for example, J-P Goure and I. For simplicity, light is shown transmitted or reflected from a single groove, even though diffraction involves the cooperative contribution from many grooves. That is, if the z-axis is the line of symmetry, then r = 2x2 + y2. That is, show that A21 is the inverse of the lifetime of the atomic level. B The requirement for a rotator of angle b is that an E-vector, oscillating linearly at angle u and with normalized components cos u and sin u, be converted to one that oscillates linearly at angle 1u + b2. Solution Then, IS = yS 3 * 103 = 1.5 * 10-5 m nS 2 * 108 Using Eq. (16), sin u = 1550 * 10-9 = 0.0183 2IS 12211.5 * 10-52 so that u = 1.05° The acousto-optic (AO) effect can be applied to the modulation of a light beam by controlling its amplitude (AM), its frequency (FM), or its direction. This technique—referred to as nondestructive testing—is often applied, as in the case of an automobile tire, for example. The lamp is available in a wide variety of the subject as pressure is applied to determine maximum stress points on the subject as pressure is applied. filament configurations and of bulb and base shapes. The system matrix connecting the object and image planes consists of the product of three matrices, corresponding to (1) a translation P1 in air from object to the rod, (2) a refraction P at the spherical surface, and (3) a translation P2 in plastic to the image. To sharpen our understanding of the coherence of a wavefield radiating from a source, consider the situation depicted in Figure 11. The length of the etalon can be chosen so that only a single etalon mode overlaps an existing cavity mode within the frequency range (the gain bandwidth) of laser operation. The situation described by Eq. (32) and 287 Fraunhofer Diffraction N 2 64 a: b: sin u: p 2p l a 2l a 3p p 3l a (a) N 2 IO Figure 15 (a) Interference factor sin21Na2> sin21a2 (solid line) and diffraction factor sin2 b> b 2 (dashed line) plotted for multiple-slit Fraunhofer diffraction when N = 8 and a = 3b. 10 Let a collimated beam of white light fall on one refracting face of a prism and let the light emerging from the second face be focused by a lens onto a screen. An example involving the He-Ne laser is instructive. St. Louis: C. (a) Ideal, collimated beam is focused to a fictitious "point" in accordance with geometrical optics. From symmetry, it is clear that identical results would be obtained for the ys-variation. Interference fringes of equal thickness are produced by the air wedge between lensu and optical flat. Lens L2 forms the Fraunhofer pattern in the spectrum plane. 9 Derive the Stefan-Boltzmann law from the Planck blackbody spectral radiance formula. f1/f2 = n/(n-1) 31. The Michelson interferometer is of this type. TABLE 1 REFRACTIVE INDICES FOR SEVERAL MATERIALS MEASURED AT SODIUM WAVELENGTH OF 589.3 nm Isotropic (cubic) Uniaxial (trigonal, tetragonal, hexagonal) Biaxial (triclinic, monoclinic, orthorhombic) Sodium chloride Diamond Fluorite Positive n 72, it is a quarter-wave plate (QWP); if ¢w = p, we have a halfwave plate (HWP); and so on. The length of the crystal is 1 cm. In conjunction with the optical transport of computer information through
optical fibers, information handling, storage, and retrieval can all be done using light. OA 1 589.3 nm Unpolarized light Figure 24 45 OA Angle of deviation Problem 10. An average can be taken for unpolarized light. 3. The secondary maxima of the single-slit diffraction pattern do not quite fall at the midpoints between zeros, even though this condition is more nearly 1 sinc b I/I0 sinc 2 b b \ge 3p \ge 2p \ge p 2p 3p kb sin u 2 Figure 2 Sinc function (solid line) plotted as a function of b. Notice further that if the screen is moved closer to the lens, it intercepts a sharp image II2 of the object OO2. Then, s2 ∞ = 122.521 - 152 s2f = = -9 cm s2 - f 122.52 - 1- $152 \text{ m}2 = - \text{s}2\varpi - 9 = + 0.4 \text{ s}2 22.5 \text{ Thus}$, the final image is virtual (because s}2\varpi is negative), 9 cm to the left of the seconds lens, erect with respect to its own object (because m is positive), and 0.4 times its size. For example, if the Pockels cell is to behave as a half-wave plate, we need to make £ = p. How does this affect the holographic image under white-light viewing? In one configuration of the Pockels cell, the natural optic axis of the crystal is aligned parallel to the applied field. The extraordinary ray is so named because it does not exhibit ordinary Snell's law behavior on refraction at the crystal surfaces. Radiation from the small hole has an emissivity that is essentially constant and equal to unity. Consider a transition wavelength of 10 = 488 nm and take the temperature of the gas under the operating conditions to be 3000 K. Equations (9) and (10) now permit us to plot the variation of irradiance with vertical displacement y from the symmetry axis at the screen. 12 a. Example 4 A Huygens eyepiece uses two lenses having focal lengths of 6.25 cm and 2.50 cm, respectively. Is the noise equivalent power for this detector a result of the intrinsic quantum fluctuations in the incident laser field? When M¿ and the film surface are not precisely parallel, the usual Fizeau fringes due to a wedge will be seen through the microscope, which has been prefocused on the film. Their optic axes are parallel 363 Production of Polarized Light 1.59 Principal indices of refraction 1.58 1.57 Slowest extraordinary ray n储 1.56 1.55 Ordinary ray n菡 1.54 1.53 200 300 400 500 600 700 800 900 1000 Wavelength (nm) with the orientation perpendicular to the page as shown. What is the wavelength of the light? The actual interferometer in Figure 1a possesses two optical axes at right angles to one another. When light from the first point A, Figure 5, reaches the second point B after reflection, as follows. (Canrad-Hanovia, Inc.) Flash tubes represent a high output source of visible and near-infrared radiation, produced by a rapid discharge of stored electrical energy through a gas-filled tube. A thin layer of nickel is deposited onto the hologram and then is peeled off. The response of the electron to this driving force depends on the relationship between the driving force depends on the relationship between the driving force depends of the electron to this driving force depends on the relationship between the driving force depends on the relationship between the driving force depends on the relationship between the driving force depends of the electron to this driving force depends of the electron to the between the driving force depends on the relationship between the driving force depends of the electron to the driving force depends of the rays. Broader regions of low reflectance also become possible in the visible region of the spectrum, once the restriction of using equal 1>4 coatings is relaxed. Example 1 The shortest wavelength of light present in a given source is 400 nm. = 0, its initial phase angle w0 is given by w0 = p 2p - a b x0 2 l (a) the amplitude of the magnetic field and (b) the average magnitude of the Poynting vector. Restrictions on possible modes will be described later. 1 ONE-DIMENSIONAL WAVE EQUATION The most general form of a one-dimensional traveling wave, and the differential equation it satisfies can be determined in the following way. Many ordinary materials also show birefringence, either under normal conditions or under stress, as in Figure 21. That is, the spontaneous emission from a sample of atoms all in the same excited state will occur with a range of frequencies characterized by the linewidth ¢n. Here, n1 is the index of refraction of the medium containing the incident beam. Virtual objects occur only with a sequence of two or more reflecting or refracting elements and are considered later. Another useful form of Eq. (14), for the case of interfering beams of equal amplitude so that I1 = I2 = I0, is found by writing $I = I0 + I0 + 22I20 \cos d = 2I011 + \cos d2$ and then making use of the trigonometric identity d 1 + cos d K 2 cos2 a b 2 The irradiance for two equal interfering beams is then d I = 410 cos2 a b 2 (18) Notice that energy is not conserved at each point of the superposition, that is, I Z 210, but that over at least one spatial period of the fringe pattern Iav = 210. Details are to be worked out in a series of problems at the end of this over at least one spatial period of the fringe pattern Iav = 210. chapter. In addition, the quadrupole nature of the gravitational waves leads to signals of unique signature. 14 A light beam passes consecutively through (1) a linear polarizer with TA horizontal, (2) a QWP with FA horizontal, (3) a linear polarizer with TA vertical. Consequently, violet light is deviated most in refraction through the prism. The energy E of the charge carriers varies across the band since the carriers in a given band vary in momentum, pc . Chapter 19 Feynman, Richard P., Robert B. Nevertheless, there will generally be several photons—let us call them "seed" photons—directed along the optical axis of the laser. According to Eq. (33), the square of the length of a straight line drawn between any two points of the spiral must be proportional to the irradiance at point P, since C1v2 and S1v2 are coordinates in a rectangular coordinates in a rectangular coordinate system. The angle a in Figure 22 may be specified in two ways, tan a D s0œ and tan a d x so that x ds0œ D (29) It is then required to find, from the lens equation, the object distance s0 ∞ + x and the object distance s0 ∞ direction, and the state of polarization of each of the following waves. It is typically the case that the electromagnetic boundary conditions at the mirrors, which then implies that standing wave nodes occur at the mirror surfaces require that the electric field be zero at the mirrors. Figure 16 Representative sketches of irradiance or burn pattern for several different orders of Hermite-Gaussian optical resonator modes as they might be photographed in the output beam of a laser oscillator. There are various devices that accomplish this. 'A complex number z is expressed as the sum of its real and imaginary parts. 'z = a + ib |~ z| b u a (11) Re where 'a = Re1z 2 and 'b = Im1z 2 are real numbers and i = 2 - 1. What is the luminous flux incident on the small surface? For the average person, presbyopia (loss of accommodation) sets in during the early 40s, signaling the need for reading glasses to restore the near point to a comfortable position near 25 cm or so. If each film has an optical thickness of lf>4, a little analysis shows that in this case all emerging beams are in phase. If the lines of the Ronchi ruling have gradually, we have the sinusoidal grating. Determine the modal distortion for this fiber. According to Huygens, every point of a given wavefront of light can be considered a source of secondary spherical wavelets. Large resolving powers are, of course, desirable. 20 a. 7 Nonlinear Optics and the Modulation of Light crystal therefore behaves as a phase retarder, and the component waves emerge with a phase difference. On the other hand, once refracted by the lens, the wavefronts contract, in Figure 25a, and expand further, in Figure 25b, to locate the real and virtual image points shown. Calculate the phase difference between TM and TE modes for internally reflected rays at angles of incidence of 0°, 20°, 40°, 50°, 70°, and 90°. Show that r112, which we define to be the energy per volume per unit wavelength interval in the field, is r112 = 8ph 15 a 1 ehc>lkBT - 1 b b. 1 THE FRESNEL EQUATIONS Consider Figure 1, which shows a ray of light incident at point P on a plane interface—the xy boundary plane—and the resulting reflected and refracted rays. Scaled transmittance 21 Consider a light source consisting of two components with different wavelength 11 and 12. Refer to Figure 17a, b, and c in connection with the following description of how the three key rays can be drawn. The length HE, in Figure 14b is proportional
to the irradiance of the first minimum on the screen. Equation (53) can be used to relate the output irradiance to the input irradiance of the first minimum on the screen. (41), 436 nm One mirror makes a wedge angle of 0.0172° with the image of the other, reflected through the beam splitter. In Figure 8, the basic law of propagating wavefront is illustrated. Energy levels with such long lifetimes are often referred to as metastable states, 544 Chapter 25 Optical Properties of Materials 3 CONDUCTION CURRENT IN A METAL In metals, the existence of "free" electrons, not bound to particular nuclei, modifies the treatment outlined above for dielectrics. s f (a) These rules5 can be quickly summarized by noticing that positive object and image distances correspond to real objects and real images and that convex mirrors have positive radii of curvature. Note also that to maintain A_cDB as a single straight line, the reflected ray must remain within the plane of the setwo energy levels if the assembly of atoms is in thermal equilibrium as a temperature of T = 300 K? 4, 5, and Joseph W. For simplicity, only one refraction is shown. If the subject beam alone were present, the film would be darkened in proportion to the irradiance of the subject beam. Since the convergence of the rays striking the second surface is determined by the position of the first image, its location now specifies the appropriate object distance to be used for the second refraction. For an exit slit of 0.02 cm, what is the coherence length of the light, Figure 5, it is in the difference for these rays implies the condition of geometrical optics: For transmitted light, Figure 5, it is in the direction of the specularly reflected beam. When yp = yg, the high-frequency waves and envelope would move together at the same rate, without relative motion. Consider the averaging times of most real detectors. Combining the last three equations, V $\bar{m}g\bar{m}g1t2 = fgf$ eivt (32) Re g1t2 = fgf cos vt (33) t0 Recalling the empirical expression for visibility, Imax - Imin 1 (34) t Figure 10 Fringe visibility or degree of coherence as a function of the difference in arrival times of two waves with coherence as a function of the difference in arrival times of two waves with coherence as a function of the difference in arrival times of two waves with coherence as a function of the difference in arrival times of two waves with coherence as a function of the difference in arrival times of two waves with coherence as a function of the difference in arrival times of two waves with coherence as a function of the difference in arrival times of two waves with coherence as a function of the difference in arrival times of two waves with coherence as a function of the difference in arrival times of two waves with coherence as a function of the difference in arrival times of two waves with coherence as a function of the difference in arrival times of two waves with coherence as a function of the difference in arrival times of two waves with coherence as a function of the difference in arrival times of two waves with coherence as a function of the difference in arrival times of two waves with coherence as a function of the difference in arrival times of two waves with coherence as a function of the difference as a function of the reflectance stacks may be fabricated from alternating layers of MgF2 1nL = 1.382 and ZnS 1nH = 2.402. The numerator of the Snellen fraction expresses the fixed testing distance, and the 427 428 Chapter 19 Optics of the Eye 20 100 20 40 20 20 5 of arc Eye 1 of arc Test distance Figure 4 Construction of a Snellen eyechart letter H to measure visual acuity. For the present, we treat electric fields as scalar B quantities. All the light originating from a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the lens is focused to a single point of the scene and collected by the problem 4, use Eqs. However, the gain provided must exceed the losses encountered per round-trip due to imperfect mirrors, transmission from the output mirror, and other cavity loss mechanisms. Determine which element (A, L1, or L2) serves as the aperture stop AS. In many cases of interest, other factors can lead to a phase difference between the beams as well. Spontaneous decay from either of these levels removes that atom from the coherent interaction with the field. 8 Stewart E. In responding to these oscillating fields, the charges themselves oscillating fields, the charges themselves oscillation with the field. determining the selection of the best system for a specific application. Irregularities in the concentric ring pattern. Diffracted slit images are formed at the Rowland circle. Solid-State Lasers Solid-state lasers are a class of lasers in which the lasing atomic species is doped into a transparent host material. 41 Geometrical Optics The units of the terms in Eq. (32) are reciprocal lengths. 5 Using the result of problem 4, determine the wave aberration, and longitudinal aberration, and longitudinal aberration, transverse aberration, transverse aberration, and longitudinal aberration for a spherical mirror of 2-m focal length and 50-cm diameter, when it forms an image of a distant point object. The sun subtends an angle of 0.5° at the earth's surface. The radii of curvature of the beam wavefronts must match the mirror radii of curvature. 23 Design an achromatic doublet of -10-cm focal length, using 573/574 and 689/312 glasses. Evaluation of the integrals in Eqs. Since there will be a spread of k values in the source, Ik can be interpreted as irradiance I(k) per unit k interval at k, giving an integrated irradiance over all wavelengths of q I = L0 I1k2 dk = 2I01k2 cos1kx2 dk q L0 (40) The first term in the result behaves as a bias term, representing the constant integrated irradiance due to all wavelength and to some extent at neighboring wavelengths, which means that the light reflected from such a film is the incident spectrum minus the wavelength region around 10. Finally, because the direction from various aperture points O to a given field point P may no longer be considered approximately constant, the dependence of amplitude on direction of the Huygens wavelets originating at the aperture must be considered. When the absorption of radiation by the focusing elements is severe, as in the vacuum ultraviolet (about 1 to 200 nm), the focusing and diffraction may both be accomplished by using a concave grating, that is, a concave grating surface. Figure 15 Fiber-optic communications system using wavelength-division multiplexing. One usually views the virtual image by looking into the hologram. The shim is pressure and temperature. The second number refers to the cylinder power, the power of the cylindrical surface superimposed on the back surface of the spectacle lens required to correct for astigmatism. For this purpose a second lens of flint glass 1n = 1.72002 is added. That the gain coefficient is less for fields of larger irradiance is said to be due to gain saturation. Therefore, e0c 1b 1E022 2 e0c = 1b 2E022 2 IIP = I2P Using these relations and Eq. (20) in = 8E0e -ivteif1t2E0eiv1t + t2e -if1t + t29 e0c b1b2 2 21e0c>2221b 1 b 2E 022 234 Chapter 9 (a) Random phase fluctuations w1t + t2 of the wave (dashed line) at a time t earlier. The hologram is now a complex montage of zones in which is coded all the information of the wavefront from the scene. The following example will provide practice with the thin-lens formula 1>s + 1>s = 1>f and procedures for determining stops and pupils for a specific optical system. 5 THE BEAT PHENOMENON Yet another case of superposition, with important applications in optics, is that of waves of the same or comparable amplitude but differing in frequency. 274 Chapter 11 Fraunhofer Diffraction Example 2 Imagine a parallel beam of 546-nm light of width b = 0.5 mm propagating a distance of 10 m across the laboratory. (28) Equation (28) is called the lensmaker's equation because it predicts the focal length of a lens fabricated with a given refractive index and radii of curvature and used in a medium of refractive index n1. 4 THE FABRY-PEROT INTERFEROMETER The Fabry-Perot interferometer makes use of an arrangement similar to the plane parallel plate to produce an interferometer makes use of an arrangement similar to the plane parallel plate to produce an interferometer makes use of an arrangement similar to
the plane parallel plate to produce an interferometer makes use of an arrangement similar to the plane parallel plate to produce an interferometer makes use of an arrangement similar to the plane parallel plate to produce an interferometer makes use of an arrangement similar to the plane parallel plate to produce an interferometer makes use of an arrangement similar to the plane parallel plate to produce an interferometer makes use of an arrangement similar to the plane parallel plate to produce an interferometer makes use of an arrangement similar to the plane parallel plate to produce an interferometer makes use of an arrangement similar to the plane parallel plate to produce an interferometer makes use of an arrangement similar to the plane parallel plate to produce an interferometer makes use of an arrangement similar to the plane parallel plate to produce an interferometer makes use of an arrangement similar to the plane parallel plate to produce an interferometer makes use of an arrangement similar to the plane parallel plate to produce an interferometer makes use of an arrangement similar to the plane parallel plate to produce an interferometer makes use of an arrangement similar to the plane parallel plate to produce an interferometer makes use of an arrangement similar to the plane parallel plate to produce an arrangement similar to the plane parallel plate to produce an arrangement similar to the plane parallel plate to produce an arrangement similar to the plane parallel plate to produce an arrangement similar to the plane parallel plate to produce an arrangement sinterferometer makes use of a of the transmitted light. In attempting to explain physical phenomena, it is natural that we appeal to well-known physical models like waves and particles. Wavefront W2 is an example of the actual wavefront, an aspherical envelope whose shape represents an exact solution of the optical system. How far must the ocular be moved from its normal position? When the net phase difference $\psi = p>2$, the retardation plate is called a quarter-wave plate; when it is p, it is called a half-wave plate. From the matrix elements, determine the first and second principal points relative to the corneal surface. amplitudes add to produce the square of the resultant amplitude. Approximate the Cauchy constants A and B for crown and flint glasses, using data for the C and F Fraunhofer lines from Table 1. Roughly, if states with nominal energies En and Em have energy widths & Em and Em have energy widths and B for crown and flint glasses, using data for the C and F Fraunhofer lines from Table 1. Roughly, if states with nominal energies En and Em have energy widths and 1¢En + ¢Em2 1¢En + ¢Em2 to hn = En - Em + 2 2 in order to significantly interact with the atom. 9 FABRY-PEROT FIGURES OF MERIT As we have seen, the Fabry-Perot interferometer is a flexible device that has many modes of operation. There are six cardinal points on the axis of a thick lens, from which its imaging properties can be deduced. With no voltage applied across a given pixel, half of the unpolarized ambient light first passes through the vertical polarizer at the input side of the cell, reflects from the mirror, and retraces its steps so that it passes through the vertical polarizer at the input side of the cell, reflects from the display panel. When the laser frequency strays from the resonant frequency of the Fabry-Perot cavity. The polarization is not complete, both because we see light that is multiply scattered into the eye and because not all electronic oscillators in molecules B are free to oscillate in exactly the same direction as the incident E-vector of the light. The sinusoids corresponding to object O and image I are described by their contrast modulation g, given by g0 = 1/K C (36) where £ is illustrated in Figure 10a. How many independent modes can propagate in this waveguide if d = 51 and d = 501? Feynman, Robert B. If, in the making of this hologram, the object point O is moved farther away, the radius of each zone increases. The beam-waist radius w0 is determined by the design of the laser cavity and depends on the radii of curvature of the two mirrors and the distance between the mirrors. We examine first the role of aperture stops and their related pupils in fixing image brightness, then the role of field stops and their related windows in determining a field of view. Since the output element described in problem 7(b) with the thin-lens matrix, namely, 1 C-1 f (Hint: Is the transverse plane, 50 m from the beam waist, far enough away to be in the far field? The indices n^P and n^c are much closer in value than n and n 7, as can be seen in the case of quartz (Table 3). This resolution criterion, ¢d Ú 2 ¢d1>2 K ¢dmin, is illustrated in Figure 13. Achieving zero reflectance at some wavelength may not satisfy the very common need to reduce reflectance over a broad region of the visible spectrum. In addition we used Eqs. With vp W vg, plots of the cosine functions versus time may appear like those of Figure 7a, calculated at the same point x0. The spectral output of the light source is characterized both by a central wavelength l and a spectral width ¢l. Show that this result can be expressed as $\psi = 11 > yS2 \ \varphi nS$ where l is the wavelength in the medium. Pumps can be optical, electrical, chemical, or thermal in nature, so long as they provide energy that can be coupled into the laser medium to excite the atoms and create the required population inversion. 33 Show that the angular magnification of a Newtonian reflecting telescope is given by the ratio of objective to ocular Lens Mirror am h ao Fo, Fe C ao fe fo Object Figure 40 Problem 33. In addition, through a variety of mechanisms, anisotropic losses can be introduced into the fiber so that one of the orthogonal polarization modes is highly attenuated while the other travels long distances with low loss. Determine their optimum separation in reducing chromatic aberration, their equivalent focal length, and their angular magnification when viewing an image of the electromagnetic spectrum are the spectral lines of the Balmer series? In the Michelson interferometer, fringes appear localized on the mirror and so cannot be seen in sharp focus at the same time as a test object placed in one of its arms. 16 17. The functions R(z) and w(z) can be determined by using Eq. (14) in Eq. (17) and performing some complex algebra. The parallel rays enter the lens from a distant object at altitudes of 1 and 5 mm above the optical axis. The free spectral range of the Fabry-Perot cavity used in the experiment was known to be 11.6 GHz. The free spectral range can be taken to be the distance between the tall transmittance peaks, indicated by the arrows in Figure 5 can be easily verified. The object distance of the nth step is determined by the image distance for the 1n - 12th step. Thus, E = mc2 + EK = 0.511 MeV + 2.5 MeV = 3.011×106 eV $\times 11.602 \times 10-19$ J > eV2 = $4.82 \times 10-19$ J > eV2 = 4 $1L_{20}$ a1 = 102y0 + 112a0 (7) where the paraxial approximation tan a0 a0 has been used. By comparison with Eq. (13), the theory predicts a dependence of the empirical Verdet constant V given by V = e dn l 2mc dl (15) The magnetic field analogs of the Kerr effect (where cn r E 2) are the Voigt effect (in gases) and the Cotton-Mouton effect (in liquids), in which a constant magnetic field is applied normal to the light-beam direction. 5 ESSENTIAL ELEMENTS OF A LASER The laser device is an optical oscillator that emits an intense, highly collimated beam of coherent radiation. The two reflected rays diverge as they leave the mirror. The transmittance is a maximum whenever d = 2kd = 2 p d = 2mp l m = 0, ; 1, ; 2 Å Rearrangement gives the condition for a maximum as dm = ml>2 (35) Accordingly, the free spectral range in this mode of operation is dfsr = dm + 1 - dm = l>2 (36) The cavity length change required to move from one transmittance peak to another is thus a measure of the wavelength of the source. The resolving power of imaging fibers

depends on the accuracy of fiber alignment and, as might be expected, on the individual fiber diameter d. Optical Detectors and Displays Silicon-based photodiodes are sensitive to optical radiation with wavelengths ranging from 190 to 1100 nm, and Indium-Gallium-Arsenide (InGaAs) p-n junction photodiodes can be used to detect radiation with wavelengths ranging from 800 to 1800 nm. This is Bessel's method for finding the focal length of a lens. The principal points and nodal points often occur outside the region defined by the input and output planes. Inasmuch as the y-axis is an axis of symmetry, the corresponding bright fringe surfaces are generated by rotating the entire pattern about the y-axis. Kittel, Charles, Introduction to Solid State Physics. 3 A double convex lens has a diameter of 5 cm and zero thickness at its edges. These empty spaces are called holes and act as positive charge carriers. Many different transverse irradiance patterns, called TEM modes, can be present in the output laser beam. Night vision, which takes place with large, adapted pupils of around 8 mm, is capable of higher resolution than daylight vision. 8 a. Volume Holograms When the fringe spacing, the hologram may be considered a three-dimensional, or volume hologram. Chapter 3 1. Images such as these can be used to map the temperature variation across the surface of the earth, for example. The image S¿ cannot be projected on a screen as in the case of a real image. The object subtends the angle a at the unaided eye and the second. Determine the minimum number of grooves required. Focused images have the shape of the collimator slit (not shown). Positive charges are associated with 535 536 Chapter 25 Optical Properties of Materials the constituent nuclei and negative charges are associated with 535 536 Chapter 25 Optical Properties of Materials the constituent nuclei and negative charges are associated with 535 536 Chapter 25 Optical Properties of Materials the constituent nuclei and negative charges are associated with 535 536 Chapter 25 Optical Properties of Materials the constituent nuclei and negative charges are associated with 535 536 Chapter 25 Optical Properties of Materials the constituent nuclei and negative charges are associated with 535 536 Chapter 25 Optical Properties of Materials the constituent nuclei and negative charges are associated with 535 536 Chapter 25 Optical Properties of Materials the constituent nuclei and negative charges are associated with 535 536 Chapter 25 Optical Properties of Materials the constituent nuclei and negative charges are associated with 535 536 Chapter 25 Optical Properties of Materials the constituent nuclei and negative charges are associated with 535 536 Chapter 25 Optical Properties of Materials the constituent nuclei and negative charges are associated with 535 536 Chapter 25 Optical Properties of Materials the constituent nuclei and negative charges are associated with 535 536 Chapter 25 Optical Properties of Materials the constituent nuclei and negative charges are associated with 535 536 Chapter 25 Optical Properties of Materials the constituent nuclei and negative charges are associated with 535 536 Chapter 25 Optical Properties of Materials the constituent nuclei and negative charges are associated with 535 536 Chapter 25 Optical Properties of Materials the constituent nuclei and negative charges are associated with 535 536 Chapter 25 Optical Properties of Materials the constituent nuclei and negative charges are associated with 535 536 Chapter 25 Optical Properties of Materials the constitu admitted by A. In practice, rays of light contributing to an image in an optical system are, in fact, usually rays in the near neighborhood of the optical axis. Note that Eq. (43) is only meaningful when the small-signal gain coefficient exceeds a certain threshold value, gth = 1 ln 11>S2 L 1Ring cavity2 (44) since it predicts a negative irradiance when g0 6 gth . Because such plates are extremely thin, it is more practical to make thicker QWPs of higher order m, giving ¢w = 12p2m + p>2, where m = 1, 2, 3, Å. By using a lens separation slightly smaller than f, the reticle is in focus at a position slightly in front of the lens, as shown in the ray diagram of Figure 26 and in Figure 27. 5p 3p p 0 p 3p d 5p (b) Resulting fringes, shown in Figure 2b, now exhibit better contrast. The interferometer consists of two 50-50 beam splitters, BS1 and BS2, and two mirrors, M1 and M2. The correct form for the spectral exitance MI of a blackbody was first derived in 1900 by Max Planck, who found it necessary to postulate quantization in the process of radiation and absorption by the blackbody. Let the refractive index n of the emulsion be equal to 1. It should be emphasized that the forms given in Table 1 are not unique. Diffraction Gratings. In other words, the detector, together with its associated amplifier and circuits, should provide a linear response, with output proportional to input. Photons of a certain resonant energy must be created in the laser cavity, must interact with atoms, and must be amplified via stimulated emission, all while bouncing back and forth between the mirrors of the resonant collisional energy transfer—made possible because the and feq = 2.5 cm, by Eq. (32). 1.05 cm 30. Then by resonant collisional energy transfer—made possible because the mirrors of the resonant collisional energy transfer—made possible because the mirrors of the resonant collisional energy transfer—made possible because the mirrors of the resonant collisional energy transfer—made possible because the mirrors of the resonant collisional energy transfer—made possible because the mirrors of the resonant collisional energy transfer—made possible because the mirrors of the resonant collisional energy transfer—made possible because the mirrors of the resonant collisional energy transfer—made possible because the mirrors of the resonant collisional energy transfer—made possible because the mirrors of the resonant collisional energy transfer—made possible because the mirrors of the resonant collisional energy transfer—made possible because the mirrors of the resonant collisional energy transfer—made possible because the mirrors of the resonant collisional energy transfer—made possible because the mirrors of the resonant collisional energy transfer—made possible because the mirrors of the resonant collisional energy transfer and the mirrors of the resonant collisional energy transfer and the mirrors of the resonant collisional energy transfer and the mirrors of the resonant collisional energy transfer and the mirrors of the resonant collisional energy transfer and the mirrors of the resonant collisional energy transfer and the mirrors of the mirrors 21S level of helium is nearly equal to the 3s2 level of neon-step 2 is achieved as excited helium atoms transfer their energy over to ground state neon atoms, raising them to the neon 3s2 level. The irradiance at a principal maximum is proportional to N 2 and the principal maximum Or, as in Figure 22b, a parallel ray which refracts at the lens surfaces as if coming directly from the left focal point F of a diverging lens. The scattering of light from oxygen and nitrogen molecules in the atmosphere, for example, is Rayleigh scattering of sunlight from oxygen and nitrogen molecules in the atmosphere for example, is Rayleigh scattering of light from dense scattering of light from dense scattering of sunlight from oxygen and nitrogen molecules in the atmosphere. and fog—is not. Determine the refractive index of the liquid. Since the effect was discovered in 1893, long before the discovery of the laser, it was well known even before intense optical glass elements with fluorite and quartz elements because of their higher transmissivity at short wavelengths. S1 s a ls S2 r 1 Screen Born, M. To operate as a demultiplexer, the difference in path lengths of the arms of the Mach-Zehnder fiber interferes upon recombination into Output 1 while light of wavelength l2 constructively interferes upon recombination into Output 2. Then develop an ABCD matrix, Eq. (15), representing a ABCD matrix for propagation to the external beam waist. (17) through
(19) in Eq. (20) gives + + (t + t)eiv1t + t2 = tE0Ieiv1t + t2 + r2E 01 (t)eivtei1vt - 2kd2. Boston: Academic Press, 2003. PROBLEMS 1 Derive the Jones matrix, Eq. (15), representing a linear polarizer whose transmission axis is at an arbitrary angle u with respect to the horizontal. 19 Show that, in order to conserve flux, the amplitude of a cylindrical wave must vary inversely with 1r. High Low High Substrate 7 Low Interference of Light INTRODUCTION Like standing waves and beats, the phenomenon of interference depends on the superposition of two or more individual waves under rather strict conditions that will soon be clarified. t 0.001 cm Air 13 The prism technique. The lad saw better than ever before. The Dispersion Equation The variation in refractive index with frequency, described by Eq. (39), is what we mean by dispersion. On the screen, therefore, in accordance with Eqs. As a result, for every zinc atom added, there are empty spaces in the lattice reserved for an electron. Silver has a conductivity of 3 * 107>Æ-m. 1985: 54.) 21 Sketch an arrangement using a PCM to project a sharp, high-intensity image of a mask onto the photo-resist layer on a semiconducting chip without using lenses. 5 DOUBLE REFRACTION In the cases depicted in Figure 10b and c, the light propagating through B the crystal's OA, but the beam remains a single beam of light. s 7 0, s¿ 6 0, and m 7 0. Rotator The rotator has the effect of rotating the direction of linearly polarized light incident on it by some particular angle. Spherical mirror or passing through a lens with spherical surfaces, either intersect at, or to the viewer appear to intersect at, a common image point. 483 Theory of Multilayer Films 20 18 n1 1.6 6 4 n1 1.4 2 Figure 2 Reflectance from a single film layer of index of refraction n1 versus normalized path difference. Residual aberrations are due to errors in the actual fabrication of the correcting plate and because the plate does not present precisely the same cross section, and therefore the same correction, to beams entering from different directions. The quality of the interference pattern in the double-slit experiment depends on the degree of coherence between distinct regions of the wavefield at the two slits. case a virtual object (VO) for the field lens, since its virtual position falls between the lenses. Two polarizing filters acting as polarizer and analyzer are set up with a white-light source behind the pair. Within t 1 d ; c 1 0 0 d 1 What then is the result of the ABCD matrix for this "thin lens"? 10 a. Successive minima are determined in a similar way from other zeros of the Bessel function, as indicated in the table in Figure 8b. The condition of constant phase evidently describes the motion of a fixed point on the value in Figure 8b. The condition of constant phase evidently describes the motion of a fixed point on the value in Figure 8b. The condition of constant phase evidently describes the motion of a fixed point on the waveform, which moves with the value in Figure 8b. The condition of constant phase evidently describes the motion of a fixed point on the waveform. from a distance of 25 cm to the left of the lens. Often the first two terms are sufficient to provide a reasonable fit, in which case experimental knowledge of n at two distinct wavelengths is sufficient to determine values of A and B that represent the dispersion. Another type of fiber, the graded-index fiber, is produced with an index of refraction that decreases continuously from the core axis as a function of radius. Assuming Fraunhofer diffraction, what is the slit width? The net effect, in an assembly of oscillation in the medium. Pneumatic chamber Leak Window 2 QUANTUM DETECTORS OF RADIATION V2 (a) Incident radiation Ballasting reservoir Flexible mirror Absorbing film Quantum detectors respond to the rate of incidence of photons rather than to thermal energy. Relating u¿ to the entrance angle u by Snell's law, Ls = d 2 n1 b - 1 B n0 sin u a (6) For example, in the case n0 = 1, n1 = 1.60, u = 30°, and d = 50 mm, Eq. (6) gives Ls = 152 mm. Electrons behave as though the forces given by Hooke's law, where the restoring force is proportional to the displacement and oppositely directed. 31, 1941: 488. How does the irradiance at the screen vary, if the contribution of one slit alone is IO? A schematic of such a cell is shown in Figure 2. In discussing attenuation earlier, we pointed out that minimum absorption in silica fibers occurs at around 1.55 mm. For example, a lens of 4-cm focal length that is stopped down to an aperture of 0.5 cm has a relative aperture of beam waist? Figure 14 is a plot of the refractive index versus wavelength for crystalline quartz. Solution By comparison with Eq. (9), k = 3p/m and v = 10p/s. The vitreous humor, essentially structureless, contains small particles of cellular debris that are referred to as floaters. In the amplitude it can be safely approximated by the distance Z between planes, but in the phase we use the approximate expression just derived. (New York: Pergamon Press, 1975, Ch. 8) and Robert Guenther. Atomic nuclei are too massive and inner-core elecB trons too tightly bound to respond to the alternating E-field at the frequency of light 1 ' 1014 –1015 Hz2. In gas lasers consisting of mixtures of gases, the distinction between host and laser atoms is generally not made. (14) and (15). The cooperative effect of many oscillators tends to cancel the radiation in all direction. Gaussian Beam Phase Fronts Having discussed the changing irradiance of a Gaussian beam as it propagates, let us now turn to an investigation of the nature of the wavefronts (that is, the surfaces of constant phase) associated with a Gaussian beam. If so, what does this say about R and z?) 5 a. At s = s' = 2f 32. In part (a), the optical system is a single lens. r Interface Refr a medi cting um n t ut Refracted ray Reflection: ur ui Refraction sin ui nt constant sin ut ni Figure 1 Reflection and refraction at an interface between two optical media. Since such atoms have a range of detected frequencies, will result even if the atoms emit nearly single-frequency electromagnetic radiation. Using these, the reflectance and transmittance are found to be RTE = r2TE = 1 - 0.274022 = 0.075 and TTE = 1 - RTE = 0.925 RTM = and TTM = 1 - RTM = 0.965 r2TM = 1 - 0.18662 = 0.035 2 5 EVANESCENT WAVES In discussing the propagation of a light wave by total internal reflection (TIR) through an optical fiber, we mentioned the phenomenon of cross talk, the coupling of wave energy into another medium when it is brought close enough to the reflecting wave. 1 THERMAL DETECTORS OF RADIATION When the primary measurable response of a detector to incident radiation is a rise in temperature, the device is a thermal detector. Although the derivations involve simple algebra and geometry, they are rather arduous. 21 Determine the nature of the polarization that results from Eq. (12) when (a) e = p>2; (b) E0x = E0y = E0; (c) both (a) and (b); (d) e = 0. Without the usual paraxial approximation—restricting rays to those making small angles with the axis—one can show that for a small object near the axis, any ray from an object point that is refracted at a spherical interface must satisfy the Abbe sine condition, nh sin $u + n_{c}h_{c}$ sin $u_{c} = 0$ (30) Here h and n_{c} , respectively. This is the phenomenon of total internal reflection, which occurs at the critical angle $u_{c} = sin-11n2$ sin-11n2>n12. x f so hi hi 43 Geometrical Optics object, a cylindrical lens produces a line image of a point object. A monochromator is used to obtain quasi-monochromator is used to a stimulated absorption and the irradiance of the light will increase during each pass through the medium. En = -1 Actually, the situation is considerably more complicated than this. Townes adapted the principle of masers to light in the visible region, and in 1960, T. Assume that light of frequency n_d = n0 is input into the cell. 15 Explain how you can use an adjustable circular aperture represents linearly polarized light whose vibrations occur along a line Bmaking an angle a with respect to the x-axis. About half the beam is lost so that image point U¿ receives only about half as much light as points O¿ and T¿. If the Doppler effect is responsible for this shift, what velocity does it determine for the quasar? This law states that the B electromagnetic force on a particle of charge Q moving with velocity V in an electromagnetic field is F = Q1E + V * B2 B B B Unless the speed of the charged particle is a significant fraction of the speed of light, the magnitude of the charged particle is a significant fraction of the speed of light and the relative likelihood Pl = 1>Pl 0 that a hydrogen molecule will be in its first excited rotational state in thermal equilibrium at room temperature, T = 293 K. At what object distance nearer and farther than the middle row does an unacceptable blur occur if the camera has a focal length of 50 mm and is stopped down to an f/4 setting? Even if the obstacle is not opaque but causes local variations in the amplitude or phase of the wavefront of the transmitted light, such effects are observed. When the wave penetrates into the medium of lesser refractive index by a factor of 1/e. Typically, the pulse width tp is a much smaller fraction of the pulse repetition time T than is shown in this diagram. When the index profile is suitably adjusted, the rays shown in Figure 10c form isochronous loops, an aspect of graded-index fiber that is responsible for reducing modal distortion. For the small input-irradiance of problem 8, even for an ideal four-level gain medium, it is not true that every pump event leads to one photon added to the electromagnetic field being amplified. 21 A glass plate is sprayed with uniform opaque particles. In this special case, Eq. (3) reduces to B - KSBr = eE or, eliminating Br with the help of Eq. (2), the static
polarization is given by B Ne2E P = KS B (4) B Suppose now that E is a harmonic field with a time dependence given B by E = E0e -ivt and that the oscillations respond with a similar dependence, B B r = Br 0e -ivt. If they are too large, the image of the objective formed by the eyepiece is then the exit pupil, which locates the position of maximum radiant energy density and thus the optimum position for the entrance pupil of the eye. 6 Show that Eq. (34) follows from Eqs. (24) and (25) again for a and b, K = b -i12j - 12a ib -ib [e 1e - e 2 + ei12j - 12a] b where we have expressed the cosine as the real part of the corresponding exponential. The shutter speed must be fast, of course, to capture an action shot without blurring the image. Solution 3 * 108 m s c = = 3 GHz. 2d 210.05 m2 nfsr, we find b. What is the minimum resolvable wavelength at (a) 632.8 nm and at (b) 1 mm? 26 Consider the electromagnetic fields given by 35 a. From the optic chiasma, nerve fibers originating in the right half of each eye extend to the right half of the brain. The amount of light (flux or photon number) that enters the eye is regulated first of all by the iris, with its adjustable aperture, the pupil. 554 Chapter 26 Laser Operation transition to the excited state is resonant with the electromagnetic field so that E2 - E1 L ha Assume a substrate of index 1.52. 30 An opera glass uses an objective and eyepiece with focal lengths of + 12 cm and -4.0 cm, respectively. 2 Write out the third-order terms of the polarization for twobeam interaction, where the beams are plane waves having amplitudes E01 and E02 and frequencies v1 and v2, respectively. In these relations k = 2p > 1and s1 and s2 can be taken to be the distances traveled by each beam along its respective path from its source to the observation point P. For a field point like P¿ above P, the contributing zones divide themselves into two parts, with fewer zones above the axis SO¿P¿ (positive z and y). If the wavefront of the observation point P. For a field point like P¿ above P, the contributing zones divide themselves into two parts, with fewer zones above the axis SO¿P¿ (positive z and y). If the wavefront of the observation point P. For a field point like P¿ above P, the contributing zones divide themselves into two parts, with fewer zones above the axis SO¿P¿ (positive z and y). light from a scene is made to interfere with a coherent reference wavefront, then, the resultant interference pattern includes information regarding the phase relationships of each part of the original wavefront, then initially unequal concentration of holes and electrons on opposite sides of the junction induces a diffusion of electrons from the p-type material into the n-type material into the p-type material into the n-type material. In addition, B either case may produce clockwise rotation of E around the ellipse (when Ey leads Ex) or counterclockwise rotation (when Ex leads Ey). 27 a. Now one can show that these increases are canceled by the decreases that arise from the second consideration, the effect of the magnitude of the magnitude of the electric force exerted by a harmonic electromagnetic wave on an electron much less than the magnitude of the electric force exerted by a harmonic electromagnetic wave on an electromagnetic wave on an electromagnetic wave on an electromagnetic wave on an electromagnetic force exerted by a harmonic electromagnetic force exerted by a harmonic electromagnetic wave on an electromagnetic wave on an electromagnetic wave on an electromagnetic wave on an electromagnetic force exerted by a harmonic electromagnetic force exerted by a harmonic electromagnetic wave on an electromagnetic wave on an electromagnetic wave on an electromagnetic force exerted by a harmonic electromagnetic force exerted by a harmonic electromagnetic wave on an electromagnetic force exerted by a harmonic electromagnetic force exerted by a harmonic electromagnetic wave on an electromagnetic wave on an electromagnetic force exerted by a harmonic electromagnetic force exerted by a harmonic electromagnetic wave on an electromagnetic wave on an electromagnetic force exerted by a harmonic electromagnetic force exerte by the same harmonic electromagnetic wave acting on the electron? In one arrangement for these displays, a mirror is placed after the second polarizing glass sheet in the twisted nematic cell. This interval is an absorption band in a given material. To understand the operation of the Mach-Zehnder interferometer, it is helpful to note that beam splitters with real transmission coefficients must have the property that the reflection coefficients from opposite sides of the beam splitter differ by a factor of - 1 = eip. In this case, the negative field E0 produces a greater polarization than a positive field of the same magnitude. Matrix Methods in Optical Instrument Design. Consider, as in Figure 8, a general situation in which interference is produced at P between two beams that originate from a single source S after traveling different paths. If the two monochromatic beams ER and ES have undistorted plane wavefronts, for example, the standing wave pattern produces antinodal planes perpendicular to the beam directions and spaced l>2 apart, as shown. In this way, a candle flame 11max ' 1500 nm2 can be said to have a color temperature of 1900 K, whereas the sun 11max = 500 nm2 has a typical color temperature of 5800 K. This principle of reversibility will be found very useful in various applications to be dealt with later. 11, 17, 18. Chapter 10 Boyd, Waldo T. Here the angle of incidence of the rays AD, BE, and CF relative to the perpendicular PD is ui . Figure 1 shows that ¢ = s sin u. 1 BIOLOGICAL STRUCTURE OF THE EYE Anatomically, the eyeball is a globe, almost spherically shaped, approximately 22 mm in diameter. (a) Zero retardation. However, the aperture stop is not always identical with the first component of an optical system. Consider Figure 12a, which highlights distances p, r, and f1 as they are determined by the positions of the first focal point and the upper half of the spectacle lenses to view distant objects and uses the lower half of the spectacle lenses to read. The most important processes that produce polarized light are discussed in this chapter under the following general areas: (1) dichroism, (2) reflection, (3) scattering, and (4) birefringence. While the diffraction envelope is thus shifted by the shaping of the individual grooves, the interference maxima remain fixed in position. Calculate the position and magnification of a small object 20 cm from the sun at the surface of the earth's atmosphere and is about 0.135 W>cm2. 134 Chapter 6 Properties of Lasers Example 2 a. A suitable film material for the application may or may not exist, and some compromise is made. We observe that the edges of the image are not sharp but reveal a series of maximum of one pattern falls directly over the first minimum of the other. 5E0 [(3/m)x - (4/s)t]2 + 2 and 8 Beginning with the relation between group velocity and phase velocity in the form - 5E0 yg = yp - 11dyp > d12 [13/m)x + (4/s)t - 6]2 + 2 a. Any phase retardation? In a reciprocal sense, computers are used to advantage in the science of holography by making possible the construction of synthetic holograms that faithfully represent three-dimensional line science of holography by making possible the construction of synthetic holograms that faithfully represent three-dimensional line science of holograms three science of holograms there science of holograms three science of holograms three scienc objects. 17 Determine the reflectance for metallic reflection of sodium light (589.3 nm) from steel, for which nR = 2.485 and nI = 1.381. The light in such a cavity then consists of counterpropagating electromagnetic waves that form standing waves. G. 19 Using the cardinal point locations (Table 2) in terms of the matrix elements for a general thick lens (problem 17), 418 Chapter 18 Matrix Methods in Paraxial Optics verify that the distances r, s, y, and w are given by Eqs. Equation (25) can be used to determine the frequencies of the standing wave modes of a laser cavity. Chapter 8 Francon, Maurice. A sample ray is shown undergoing two total internal reflections from the core-cladding interface at points A and B. (a) Experimental arrangement. This particular geometry defines a positive Verdet constant. Repeat problem 18 when the light is the green mercury line of 546.1 nm with a linewidth of 0.025 nm. For the circular zones, the two first-order images are the real and virtual images discussed. What is the distribution of irradiance on the screen near the pattern center as a function of x and y (in mm) and I0, the irradiance at the pattern center? With the corrective lens, this eye can see clearly print held at any position from 40 to 53 cm from the eye. Other letters are constructed of appropriate size, subtending angles of 5¿ and 1¿ for other selected distances, such as 200 ft, 100 ft, 80 ft, and so on down to 15 or even 10 ft. When the g(v) $\overline{mg}(v) \overline{m2} v 0 v 0$ 4p t v 0 v 0 2p t 0 v 0 2p t 0 v 0 2p t 0 v 0 4p t 0 v 0 2p t 0 v 0 4p t 0 v 0 4p t 0 v 0 2p t 0 v 0 4p t 0the ray are its elevation h, angle a, and distance D. These two half-periods—for each original zone—contribute light at the focal point r0 = f1>2, out of phase by p with each other. Also calculate the minimum resolvable wavelength interval in this region. Evolution of the electric field vector over one period at a fixed plane z = 0 is shown for a wave with (a) linear polarization and (b) circular polarization. Assume that the beams are incident symmetrically on the film's surface. A saturable absorber is a system that is absorbing for low light irradiances but transmitting for high light irradiances. What is the stimulated emission cross section s for this transition? K n0 sin um = n1 cos wc = 2n21 - n22 (4) If n0 = 1, the numerical aperture is
simply the sine of the half-angle of the largest cone of meridional rays (i.e., rays coplanar with the fiber axis) that are propagated through the fiber axis) the fiber axis) that are propagated through the fiber plane f f also assume that the aperture is large enough so that its own boundaries do not appreciably modify the diffraction pattern. (c) When B = 0, the output plane is the image plane conjugate to the input plane and A is the linear magnification. The focal lengths of the objective and ocular lenses are 20 cm and 5 cm, respectively. The amplitude at P becomes a1>2, or half that due to the tiny first-zone aperture alone. Recall that the frequency measured by a detector depends on the velocity of the source of the wave relative to the velocity of the detector. Now all parts of the spiral are to be used in calculating the resulting screen irradiance at point P except that portion designated by the spiral length! interval! ¢y in Figure 16b. In order for an assembly of atoms or particles to be treated as a blackbody or a graybody, the assembly must be able to emit and absorb a continuous range of frequencies. 501 Fresnel Equations u u 0 Figure 7 The Fresnel Equations u u 0 Figure 7 The Fresnel Figure 16b. In order for an assembly must be able to emit and absorb a continuous range of frequencies. would reduce the energy by a factor of about 720. For external reflection when light travels from air to glass, with n1 = 1 and n2 = 1.5, for example, $up = 56.3^{\circ}$. The beam radiates from a small circular area of diameter 0.5 mm at the output mirror of the laser. 230 Chapter 9 Coherence amplitude g1v2 is squared, the resulting curve is the power spectrum shown as the solid curve in Figure 6. In a Littrow mount, using Eq. (16), the blaze angle must be ub = sin-1 c 1121600 * 10-62 d = $21.0^\circ = 23.03^\circ = 23.0$ More precisely, since it is (B) B Figure 8 One-dimensional autocorrelation £1B2 of a semicircle with radius = 3 as a function of the displacement parameter B. Refracting Telescopes Figures 31 and 32 show two refracting telescopes Figures 4 and erect images. tend to align with the scratches in the sheet. Commercial gratings are usually specified by their blaze angles and the corresponding first-order Littrow wavelengths. Light to be analyzed is focused onto a narrow slit S and then collimated by lens L and refracted by the prism P, which typically rests on a rotatable indexed platform. If we write N = W>a for a equation for normal incidence, Eq. (11) becomes 🏟 = mN = a a sin um W b a l or 🖗 = W sin um l (12) According to Eq. (12), the resolution of a grating at diffracting angle um depends on the width of the grating rather than on the number of its grooves. In each case, the rays corresp nath w and incorporate the grating are everywhere normal to the mirror surface on reflection. n 1.5 25 It is desired to project onto a screen an image that is four times the size of a brightly illuminated object. Analyzer TA I E0 y Polarizer co E 0 E0 IO su TA u 90 180 270 360 x u I IO cos2 u Analyzer Figure 2 Illustration of Malus' law. The shortest distance from A¿ to B is obviously the straight line A2DB, so the path ADB is the correct choice taken by the actual light ray. We distinguish the case for which $e_x - e_y = p > 2$ (SA vertical) from the case for which $e_x - e_y = p > 2$ (SA vertical). Through each section, three representative rays are drawn. Pile-of-plates polarizers are especially helpful in those regions of the infrared and ultraviolet spectrum where dichroic sheet polarizers and calcite prisms are ineffective. Spontaneous emission occurs even in the presence of an incident electromagnetic wave that causes stimulated emission. The large aperture and integrated throughput of the Michelson interferometer make it useful as a Fourier-transform spectrometer. In this case, the irradiance at point P is proportional to the square of the length of the phasor from O to E. The optical system has unit magnification. A photosensitive surface, typically containing alkali metals, absorbs incident photons that transfer enough energy to enable some electrons to overcome the work function and escape from the surface. In general, for several thin lenses in direct contact, $1\ 1\ 1\ 1\ +\ +\ +\ A\ =\ f\ 1\ f\ 2\ f\ 3\ (33)$ Expressed in diopters, the refractive powers simply add: P = P1 + P2 + P3 + A (34) In a near sighted eye, the refracted (converging) power of the eye is too great, so that a real image is formed in front of the retina. Biological specimens are covered with a cover glass of 0.17- or 0.18-mm thickness. Thus, B B = + E =moment, setting the prefactor in Eq. (8) equal to F. The nature of the superposition at P is determined by the path difference between successive parallel beams, ¢ = 2nfd cos ut . The shape of the lens is controlled by the ciliary muscle, connected by fibers (zonules) to the periphery of the lens. An electron with energy greater than zero is no longer bound to the proton in the nucleus of the hydrogen atom. Let a = 0.95 and b = 0.05 for a given sheet of Polaroid. Recall that nonlocalized fringes (Figure 6) are, in contrast, formed everywhere. 1 = 3 = the angular spatial frequency is kY = 2p11 > d2 = 2p > 31.4 > mm. Such edge effects are important, however, only when the observation point is very near the aperture itself. needed for lasing. Appealing to the "economy of nature," Fermat supposed instead that the ray of light traveled the path of least time from A to B, a generalization that included Hero's principle as a special case. In this way, a system matrix for the entire optical system can be found that is related to the same cardinal points characterizing the thick lens. Source plane Thin lens L1 at 40 cm from the source plane Aperture A at 20 cm farther from L1 Thin lens L2 at 10 cm farther from L1 Thin lens L2 at 10 cm farther from A Image plane Lens L1 has a focal length of 20/3 cm and a diameter of 2 cm; aperture A at 20 cm farther from L1 Thin lens L2 at 10 cm farther from A Image plane Lens L1 has a focal length of 20/3 cm and a diameter of 2 cm; aperture A at 20 cm farther from L1 Thin lens L2 at 10 cm farther from A Image plane Lens L1 has a focal length of 20/3 cm and a diameter of 2 cm; aperture A at 20 cm farther from A Image plane Lens L1 has a focal length of 40/3 cm and a diameter of 2 cm; aperture A has a focal length of 40/3 cm and a diameter of 2 cm; aperture A has a focal length of 40/3 cm and a diameter of 2 cm; aperture A has a focal length of 40/3 cm and a diameter of 2 cm; aperture A has a focal length of 40/3 cm and a diameter of 2 cm; aperture A has a focal length of 40/3 cm and a diameter of 2 cm; aperture A has a focal length of 40/3 cm and a diameter of 2 cm; aperture A has a focal length of 40/3 cm and a diameter of 2 cm; aperture A has a focal length of 40/3 cm and a diameter of 2 cm; aperture A has a focal length of 40/3 cm and a diameter of 2 cm; aperture A has a focal length of 40/3 cm and a diameter of 2 cm; aperture A has a focal length of 40/3 cm and a diameter of 2 cm; aperture A has a focal length of 40/3 cm and a diameter of 2 cm; aperture A has a focal length of 40/3 cm and a diameter of directions marked D, on the other hand, the waves are seen to be out of step by half a wavelength, and destructive interference results. Coherence. A unique image point is not determined by these rays because they have no common intersection or virtual image point below the surface from which they appear to originate after refraction, as shown by the dashed line extensions of the refracted rays. For example, with two such lenses back-to-back, we write the lens equations 1 1 1 + ∞ = s1 s1 f1 and 1 1 1 + ∞ = s2 s2 f2 Since the image distance for the first lens plays the role of the object distance for the second lens, we may write $s_2 = -s_1 \infty$ and, adding the two equations, $1 \ 1 \ 1 \ 1 + \infty = + = s_1 \ s_2 \ f_1 \
f_2 \ f$ The reciprocal of the overall focal lengths, therefore, add to give the reciprocal of the individual focal lengths, therefore source a dipole source to the reciprocal of the individual focal lengths a dipole source and the reciprocal of the individual focal lengths a dipole source and the reciprocal of the individual focal lengths a dipole source and the reciprocal of the individual focal lengths a dipole source and the reciprocal of the individual focal lengths are called zero-order (or sometimes firstorder) plates. We know that each electron so oscillating constitutes a dipole source and the reciprocal of the individual focal lengths are called zero-order (or sometimes firstorder) plates. We know that each electron so oscillating constitutes a dipole source and the reciprocal of the individual focal lengths are called zero-order (or sometimes firstorder) plates. We know that each electron so oscillating constitutes a dipole source and the reciprocal of the individual focal lengths are called zero-order (or sometimes firstorder) plates. We know that each electron so oscillating constitutes a dipole source are called zero-order (or sometimes firstorder) plates. We know that each electron so oscillating constitutes a dipole source are called zero-order (or sometimes firstorder) plates. We know that each electron so oscillating constitutes a dipole source are called zero-order (or sometimes firstorder) plates. We know that each electron so oscillating constitutes a dipole source are called zero-order (or sometimes firstorder) plates. We know that each electron so oscillating constitutes a dipole source are called zero-order (or sometimes firstorder) plates. We know that each electron so oscillating constitutes a dipole source are called zero-order (or sometimes firstorder) plates. We know that each electron so oscillating constitutes a dipole source are called zero-order (or sometimes first that radiates electromagnetic energy in all directions, except the direction of the electron oscillation itself. The second aperture is the field stop, FS, with its corresponding images through the lenses: the entrance window to the right. square wave in Figure 3 by the amplitude of the transmitted light. The shape suggested in the focal point of al zones agree with the focal point of a zone whose radius is 0.707 of the aperture radius, the usual choice. A diode laser is essentially a p-n junction whose cleaved edges act as reflecting surfaces that supply the cavity feedback. A ray from the first focal point, F1, is rendered parallel to the axis (Figure 1a), and a ray parallel to the axis is refracted by the lens through the second focal point, F2 (Figure 1b). N ui ub u N a ub 12 The Diffraction Grating INTRODUCTION In this chapter we give a formal treatment of diffraction due to a large number of slits or apertures. Let us use the scaled coordinates xs = 22x>w1z2 and ys = 22y>w1z2. In Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging from water 1n1 = 1.332 into air 1n2 = 1.002. Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging from water 1n1 = 1.332 into air 1n2 = 1.002. Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging from water 1n1 = 1.332 into air 1n2 = 1.002. Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging from water 1n1 = 1.332 into air 1n2 = 1.002. Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging from water 1n1 = 1.332 into air 1n2 = 1.002. Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging from water 1n1 = 1.332 into air 1n2 = 1.002. Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging from water 1n1 = 1.332 into air 1n2 = 1.002. Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging from water 1n1 = 1.332 into air 1n2 = 1.002. Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging from water 1n1 = 1.332 into air 1n2 = 1.002. Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging from water 1n1 = 1.332 into air 1n2 = 1.002. Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging from water 1n1 = 1.332 into air 1n2 = 1.002. Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging from water 1n1 = 1.332 into air 1n2 = 1.002. Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging from water 1n1 = 1.332 into air 1n2 = 1.002. Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging from water 1n1 = 1.332 into air 1n2 = 1.002. Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging from water 1n1 = 1.332 into air 1n2 = 1.002. Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging from water 1n2 = 1.002. Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging from water 1n2 = 1.002. Figure 35 25 cm Problem 15 16 A plano-convex lense of light emerging having a focal length of 25.0 cm is to be made with glass of refractive index 1.520. In Figure 16a, reflection from the lower surface of BS2 is taken to be r2 = -1 > 12 = e ip > 12. In an actual system, some channels are devoted to housekeeping functions such as synchronization. In the limiting case of Fraunhofer diffraction, Eq. (7) is simplified by assuming that (1) the obliquity factor is roughly constant over the aperture due to the small relative to that of the exponential function. In the remainder of this chapter, we examine, in detail, spherical reflecting and refracting surfaces and, more briefly, cylindrical reflecting and refracting surfaces. The core material— silica, in the case of glass fibers—absorbs in the region of its electronic and molecular transition bands (see Figure 6). The fringe systems at the screen then coincide and correspond to the fringes of a single point source. The physical mechanisms underlying their operation will be discussed in the next chapter. 15 A double-slit diffraction pattern is formed using mercury green light at 546.1 nm. When the curvatures of these surfaces are changed by altering lens shapes or spacings so that they coincide, the resulting surface is called the Petzval surface. (b) Photoconductive (reverse biased) mode. In the same way, when the sun is not directly overhead so that its light crosses the atmosphere above us, the light scattered down is found to be partially polarized. Referring back to Figure 7b of the previous section of this chapter, if yp 7 yg, the high-frequency waves would appear to have a velocity to the right relative to the right scattered down is found to be partially polarized. envelope, also in motion. (10) and (11), we find the relationship between K and R to be K = Rn30 2l As explained for the Pockels cell, the relative phase retardation for the ordinary components is £ = 2p L ¢n l Introducing the Kerr constant through Eq. (11), £ = 2pKV2L d2 where we have set V = Ed and d is the interelectrode distance (68) 604 Chapter 27 Characteristics of Laser Beams Figure 15 shows the development of the irradiance patterns Imn for the xs-variation in the transverse plane at z = z0. Furthermore, since A = yf>y0, the matrix element A represents the linear magnification. n-n 17. When signal and idler frequencies correspond to resonant frequencies in the nonlinear crystal acting as a tuned Fabry-Perot cavity, the parametric oscillator is a tunable source of coherent radiation. Since the approaching waves are not plane, the distance r; enters into the calculations. Assuming the lamps radiate equally in all directions, compare the illuminance at ground level for points directly under one lamp and midway between them. What would you expect to see in the spectrum plane? The existence of both an nx and an ny for a given optical frequency v is to be expected, since different binding forces along these directions with the electromagnetic wave and, thus, different binding forces along the existence of both an nx and an ny for a given optical frequency v is to be expected. term for electromagnetic radiation that human eyes can "see." Humans see different wavelengths of light as different colors. What is the free spectral range of the instrument under these conditions? Such fibers are called polarization-maintaining fibers. Furthermore, electromagnetic theory tells us that the field amplitudes are related by E0 = cB0, where c is the speed of the wave. What information can you find for the system by setting matrix elements A and D equal to zero? This prevents the reinitiation of lasing action and allows the population inversion to grow, once again to a large value, storing a large the system by setting matrix elements A and D equal to zero? cladding. Determine the planar spacing of the developed volume hologram. The interference surfaces within the emulsion that 379 380 Chapter 16 Holography ES ER 1 2 Figure 5 Standing wave fringe planes in a volume hologram formed by two plane waves oppositely directed. d 1 y 463 Fourier Optics We wish to show now that this series of bright spots is, in fact, the spectrum of frequencies required in a Fourier representation of the aperture or transmission function of Figure 3. The phase shift dg induced by the gravitational strain is, therefore, 2p 2p 1100hL2 = 11002110-21214000 m2 # 14.88 10-7 m = 5.1510-9 rad dg L k¢s = Using this in the final expression for the detected power, Pdet L P01dg>222 = 110 W2a 5.15 # 10-9 2 b = 6.63 # 10-17 W 2 This power corresponds to about 160 photons/s and, while small, is easily detected. Generate a table of (x, y)-coordinates for the surface and plot, together with sample rays. 10 DIODE LASERS Semiconductor or diode lasers have gain media that differ significantly from the atomic and molecular gain media discussed in the preceding sections of this chapter. This mode of polarization, in which the is perpendicuB lar to the plane of incidence, is called the transverse electric (TE) mode. Except for light energy lost by absorption and scattering during passage through the dielectric layers,
the percent transmission of the structure is given by T1%2 = 100 - R1%2. (a) 8 cm, 3 × (b) 7.38 cm, 2.6 × 31. Show that Snell's law holds between the first and last regions, as if the intervening regions did not exist. This represents a disadvantage of the Galilean telescope, leading to a restriction in the field of view. The magnitude of the dipole moment for a given material depends on how easily charge is displaced under the influB ence of a given electric field. Both the Huygens and Ramsden eyepieces, Figures 25 and 26, incorporate the design feature required by Eq. (39); that is, plano-convex lenses are separated by half the sum of their focal lengths. That is, as many as 80% of the photons incident on a photodiode in the CCD array are converted to signal electrons. What visibility results there if (a) their electric field vectors are parallel and (b) if they are perpendicular? J., Vol. Thus, using Eq. (48), gth = 1 ln11>S2 = ln a b = 15 cm 2g0 210.001>cm2 10.99210.982 Since the gain cell must fit into the laser cavity, the laser cavity must be longer than 15 cm. = B12N1g1n₂2 I r1n2 dn = B 12N1g1n₂21I>c2 0 (11) 2 Actually, these coefficients dependence typically becomes important only for enclosures of dimension not too much larger than the wavelength of light. Argue that the relation in part (a) implies that for the large input-irradiance case of problem 9 every pump event leads to one photon added to the electromagnetic field being amplified. In general, their (complex) electric fields may be expressed by ' ' E^c = E0^cei1k^cz - vt2 (5) ' ' E^P = E0^Pei1k^Pz - vt2 (6) where k^c = 1v>c2n^P. If the light is from a He-Ne laser at 633 nm, what is the fringe spacing? Although the actions of stops, pupils, and windows depend quite clearly on the principles of geometrical optics, the details can at times be confusing. Explain their formation. Note that these wavelength components are just barely resolved since the peaks are separated by a FWHM of either dotted curve. Q-switching proceeds in the following time sequence: 1. In an n-type semiconductor, the material is doped with an impurity whose outer shell has one electron more than the outer shell of the atom that it replaces in the lattice. For hyperopia, the curvature of the corneal surface is steepened by removing tissue around the periphery of the cornea, thereby increasing the refractive power of the eye. Similarly, Figure 5g illustrates the situation for corrected near vision under accommodation. 262 Chapter 10 Fiber Optics efficient multiplexers and demultiplexers that can discriminate between and combine or separate the different wavelength channels must be used. Furthermore, the hologram may contain a number of separate exposures, each taken with the film at a different angle relative to the reference beam and with different wavelengths of light. The Nernst glower behaves like a graybody with an emissivity greater than 0.75. What is its magnification? Thus, light of all wavelengths appears in the central or zeroth-order peak of the diffraction pattern. In each case, the OAs of the two prisms are perpendicular to one another, so that an E-component in the first prism, for instance, may become an E7-component in the field of high-energy lasers use the far-field criterion, L 7 100 (area of aperture)>l Another such ray is evidently OVI, normal to the surface at its vertex point V. (b) Nonalignment of ray diB B rection S and propagation vector k for the extraordinary ray in birefringent material. 6 SURGICAL VISION CORRECTION In the preceding section we discussed the correction of myopia and hyperopia with the help of contact lenses or eye glasses Image and object happen to be at 2f = 20 cm, the center of curvature of the mirror. The far-field divergence angle due to diffraction of a beam passing through a circular aperture of radius r is udiff = 0.611>r. The treatment that follows assumes the case of specular reflection. In this way, the irradiance of the entire pattern can be calculated. The FWHM 2¢n1>2 of the transmittance curves can be found from the basic expression for F and the relation between round-trip phase shift d and frequency n. It forms images of a continuum of objects, at distances of a foot to infinity. Also determine the general relationship for the lateral magnification. (Oriel Corp., General Catalogue, Stratford, Conn.) 102 103 104 0 2 4 6 8 10 12 14 16 18 Wavelength (mm) 20 22 24 26 28 141 Microwatts/cm2 nm at 50-cm distance from bare lamp Properties of Lasers Typical spectral irradiance 3.0 2.5 2.0 1.5 1.0 0.5 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 Wavelength (mm) 1.3 1.4 1.5 1.6 1.7 1.8 Discharge Lamps The discharge lamp depends for its radiation output on the dynamics of an electrical discharge in a gas. In this technique a phase mismatch ¢k between the fundamental and second harmonic fields can be compensated for by using a nonlinear crystal. With Kind Permission of Springer Science and Business Media.) 211 Optical Interferometry It is interesting to note that the ratio of this maximum wavelength difference is given by the finesse, l > m ¢lmax = F = ¢lmin l>1mF2 The fact that this ratio is the finesse is not surprising. Classically, Raman scattering can be described as arising from the third-order nonlinear polarization of the finesse. Eq. (3). In this condition, BP2 - BP1 = AP2 - AP1 = 0 If source B is moved below A, the fringe systems separate until, at a certain distance s, where BP2 - BP1 = ¢ = l 2 r P2 A Figure 13 Light from each of two points ources A and B reach points P1 and P2 in the radiation field and are allowed to interfere at the screen. Let us now develop a more explicit understanding of the formation of a line image AB by a convex cylindrical lens when the object is a point O at a finite distance from the lens. This graphical procedure could be extended to accommodate any number of component waves of the same frequency, as shown in Figure 4 for four such waves. 2 A BRIEF LOOK AT ABERRATIONS All aberrations lead to a blurring of an image formed by an optical system, thereby frustrating the optical system, thereby frustrating the optical phenomenon, Plate 18, Berlin: Springer-Verlag 1962.) 6p 12p 284 Chapter 11 Fraunhofer Diffraction when b = mp, with m = ; 1, ; 2, Å, as shown. The superposition of waves at a point where they are parallel. Laser Operation Figure 18 shows the band structure in the junction region. How far can the mirror be moved from zero path difference so that fringe visibility is at least 0.85? The light diffracted from a plane grating must be focused by means of a lens or concave mirror. For an arbitrary incident wavefront, as shown in Figure 16c, the amplitude °1r2 is complex and includes the amplitude and phase factors that describe its deviation from a plane wave. Determine the beam spot size w(z) at the left and right cavity mirrors. The heat flow into the gas causes an increase in gas pressure, which is typically detected by the deflection of a flexible mirror attached to the cell, as shown in Figure 2. This fundamental linewidth is sometimes called the Schawlow-Townes linewidth.5 In practice, the linewidth of a laser is significantly larger than the limit set by the mixing of spontaneous emission into the laser output. Any obstruction, however, shows detailed structure in its own shadow that is quite unexpected on the basis of geometrical optics. described by the spectral width, ¢l, of the source, usually chosen as the width of the source's spectral output at half-maximum, as shown. Fast and slow axes are induced in a plane normal to the applied field, as shown. Fast and slow axes are induced in a plane normal to the applied field. width b. Thrierr, Atlas of Optical Phenomenon, Plate 32, Berlin: Springer-Verlag, 1962.) the rectangular slit considered earlier. 1 RATE EQUATIONS Rate equations relate the population densities (number of atoms or molecules. Example 6 Do a ray trace for two rays through a Rapid landscape photographic lens of three elements. If the beam divergence is expressed by the diffraction angle uD = l > D, with D the beam diameter, show that $N = \psi u = t \psi n S$ uD where t is the time for the sound to cross the optical beam diameter. Operationally, assessment of resolving power or visual acuity of the eye is measured in different ways. (c) Production of interference fringes in the region of superposition of two collimated and coherent beams intersecting at angle 2u. Wavelengths shorter than 360 nm are filtered from the light. The behavior of these functions is illustrated in Figure 12a, light may be linearly polarized along any line that is perpendicular to the direction of B wave propagation. Will a photon of energy 5 eV likely be absorbed by a hydrogen atom originally in its ground state? r O Gabor zone plate I2 I1 Reference beam I1 Spherical waves s Figure 9 Problem 1. Of course, the holographic system must be vibration-free to within a fraction of the wavelength of the light during the exposure, a condition that is easily satisfied when high-power laser pulses of very short duration are used to freeze undesirable motion. 28. A simple interferometer. Refractive indices for the film and substrate are 1.38 and 1.52, respectively. Unobstructed Wavefront The irradiance in the Fresnel diffraction pattern associated with different apertures are often compared to the irradiance Iu associated with an unobstructed wavefront. The next-best solution is to use a graded index (GRIN) fiber, which is described next. The Fourier transform of a nonperiodic function requires instead a continuous frequency spectrum g1v2. As with all waves, the frequency of an electromagnetic wave is determined by the frequency of the source of the wave. Since an ionized (free) electron can have any energy, the range of energies associated with a hot gas are continuous. the quantity n - n ff. Light coming from the laser has a high degree of spatial and temporal coherence. It therefore appears
like the incidence approaches the critical angle, t¿ must approach a value of 2 in the TE mode and 2/n in the TM mode. This can be accomplished by propagating a pump laser field through the fiber. This means that the induced grating is essentially stationary relative to the light wave. 5 ALLOWED MODES Not every ray that enters an optical fiber within its acceptance cone can propagate successfully through the fiber. amplitudes of the beams originating from the two slits are nearly the same so that the irradiance on the screen, at a point determined by the angle u, is found using Eq. (18) and the relationship between path difference c and phase difference d, d = k1s2 - s12 = 2p ¢ l The result is I = 4I0 cos2 a b l l For points P near the optical axis, where y V L, we may approximate further: sin u tan u y>L, so that I = 410 cos2 a pay b lL (21) 171 Interference of Light By allowing the conditions expressed by Eqs. The light diffracted by the echelle is dispersed again by the concave grating, oriented with grooves vertical. (a) The B B electric field E, magnetic field B, and propB agation vector k are everywhere mutually perpendicular. Such a wave disturbance exhibits the phenomenon of beats. The vector sum of E^c and E^P is again linearly polarized light but with an inclination angle + b relative to the x-axis. In this way a voltage difference occurs across the junction that inhibits the diffusion of more carriers. In the telescope, then, the objective lens is the aperture stop of the optical system. The maximum ray aberration thus indicates the size of the blurred image. (a) Refraction in the 180° meridian yields - 2.00 D of myopia. How do these results compare with those for w01/2 and / obtained in the example? (35), (29), (38) and (39), we find m = $211 \times 10-22$ d = $40,0001500 \times 10-9$ F = p10.952 pr = 3121 - r1 - 0.952 1¢l2min = R = 1500 nm = $4 \times 10-4$ nm mF 140,00021312 1500 = 1.2×106 1¢l2min 4 $\times 10-4$ nm mF 140,00021312 1500 = 1.2×106 1¢l2min = R = 1500 nm = $4 \times 10-4$ nm mF 140,00021312 1500 = 1.2×106 1¢l2min = R = 1500 nm = $4 \times 10-4$ nm mF 140,00021312 1500 = 1.2×106 1¢l2min = R = 1500 nm = 12×106 1¢l2min = R = 1500 nm = 12×106 1¢l2min = R = 1500 nm = 12×106 1¢l2min = R = 1500 nm = 12×106 1¢l2min = R = 1500 nm = 12×106 1¢l2min = R = 1500 nm = 12×106 1¢l2min = R = 1500 nm = 12×106 1¢l2min = R = 1500 nm = 12×106 1¢l2min = R = 1500 nm = 12×106 1¢l2min = R = 1500 nm = 12×106 1¢l2min = R = 1500 nm = 12×106 1¢l2min = R = 1500 nm = 12×106 1¢l2min = $12 \times$ z_2 f in this instance. The optical surfaces that provide the bulk of the focusing power are essentially three: the air-cornea interface, and the lens-vitreous interface, and the lens-vitreous interface, the aqueous-lens interface, and the lens-vitreous interface. Since real rays of light diverge from the first real image, it serves as a real object for the second lens, with $s_2 = 60 - 37.5 = +22.5$ cm to the left of the lens. Ch. 14. The full-width at half-maximum, sometimes called the linewidth of the transition or 565 Laser Operation the gain bandwidth, can be shown to be well approximated by \$nH = 1 1 1 a + + 2rcol b t1 2p t2 (50) Here t2 and t1 are the lifetime of the upper and lower levels, respectively, participating in the transition. Arguing now from Eq. (19) and the small angle relation sin u tan u y>L, we find the bright fringe positions to be given by ym = mlL, a m = 0, ;1, ; 2, Å (22) Consequently, there is a constant separation between irradiance maxima. This local field Eloc is a superposition of the applied field Eapp and the field that results from all the other dipoles aligned in a polarized medium. 6 THE FRESNEL ZONE PLATE Examination of Eq. (14) suggests that if either the negative or the positive terms are eliminated from the sum, the resultant amplitude and irradiance could be quite large. The even harmonics, however are just those corresponding to the missing orders in the grating diffraction. Determine xs, Ls, and xt for a 10-m-long fiber of diameter 50 mm, core index of 1.50, and a ray entrance angle of $u = 10^{\circ}$. 19 a. 14 Light from a source immersed in oil of refractive index 1.62 is incident on the plane face of a diamond 1n = 2.422, also immersed in the oil. For example, if the Fabry-Perot interferometer consists of two mirrors separated by an air gap, the mirror separated by means of a piezoelectric spacer, as shown in the Figure 11b. 7 The two sodium D lines at 5893 Å are 6 Å apart. The team focused the coherent 694.3-nm output from a pulsed ruby laser onto a quartz crystal and detected second harmonic generation, the presence in the output of a weak ultraviolet coherent radiation component at 347.15 nm, twice the frequency or half the wavelength of the exciting light. A bandwidth of 4 * 1012 Hz is used. One should then be able to visualize the intercept of these surfaces with the plane of an observational screen placed anywhere in the vicinity. Find the displacement when t = 3 cm, n = 1.50, and u1 = 50°. PROBLEMS 1 A biconvex lens of 5 cm thickness and index 1.60 has surfaces of radius 40 cm. For such a telescope using two converging lenses with focal lengths of 30 cm and 4 cm, find the angular magnification when the image is viewed at infinity and when the image is viewed at a near point of 25 cm. We need to add a sign convention for the angular separation of emerging red 1n = 1.5252 and blue (1.535) light? Example 6 To get an idea of the magnitude of the diffraction angle in first order, let us consider a typical case in which the incident light has a wavelength of 550 nm and the acoustic wave has a frequency nS of 200 MHz and a speed yS of 3000 m/s. Note that rays incident on the mirror at points P converge at axial point N. One makes a single hologram using an exposure time that is long compared to the period of the vibrations being studied. A one-to-one correspondence between individual fringes of each set can then be made visually. The lens is itself a complex, onion-like layered mass of tissue, held intact by an Optics of the Eye elastic membrane. Then we examine the physical elements that produce polarized light and discover corresponding 2 * 2 matrices that function as mathematical operators on the Jones vectors. Unfortunately however, the Stokes frequency shift is comparable to the frequency spacing between channels in a wavelength division-multiplexed (WDM) fiber. Collimated beam Slit Lens f 60 cm 60 cm 0.015 cm Figure 18 Problem 1. Consider the source wavelength to be 0.82 mm, with a spectral width of 20 nm for the LED and 1 nm for the more monochromatic LD. One of the wavelengths is 546 nm. The high loss rate in the low-Q cavity allows for large energy when the cavity is switched to the low-loss, high-Q state. In Figure 1, we give an overview of the essential components and processes involved in a fiber-optic communications system, from message source to message output. 4 OPTICAL DETECTORS: NOISE AND SENSITIVITY In addition to know the actual sensitivity or, more precisely, 391 Optical Detectors and Displays the responsivity, R, of the detector, defined as the ratio of output to input: output is typically some measure of irradiance and output is almost always a current or voltage. Find B the corresponding irradiance and amplitudes of the EB and B-fields there. frequency v0. These vibrational-rotational states typically differ in energies such that the emitted light is in the mid-infrared range. Block-letter sizes are 1.309 in. is 2.5 in. Wire Suppose now that the narrow slit of Figure 15 as replaced by a long, but thin, opaque obstacle such as a wire (Figure 16). Figure 18 summarizes the basic ideas of coherence for nonlaser and laser sources. The image produced by a linear optical system is also sinusoidal at the same spatial frequency, but with a modification or enhancement of reflected light over a greater portion of the spectrum than would a single-layer film. At what distance does the visibility go to zero? 15 A soprano's voice is sent by radio waves to a listener in a city 90 km away. In this case, the angle 11¿OL2 subtended by the lens rim at O becomes smaller than the angle 11¿OL2 subtended by the lens rim at O becomes smaller than the angle 11% of the aperture stop. Since the maximum value of the aperture stop of the aperture stop. Eq. (27) is 410, we see that the double slit provides four times the maximum irradiance in the pattern center as compared with the single slit. To make Eq. (1) correct for all angles of diffraction, we need to adopt a sign convention for the angles. Holography. Tuning of the position of the etalon mode within the gain bandwidth can be accomplished by changing the effective etalon spacing d, for example, by piezoelectric control of the etalon. 514 Chapter 24 Nonlinear Optics and the Modulation of Light one of its Fourier components, is of the form $E = E0 \cos vt$ substituted the double-angle identity for cos2 vt. Plot the ellipse for the example given in the text, 11 Using the Jones calculus, show that the effect of a HWP on light linearly polarized at inclination angle a is to rotate the polarized at inclination through an angle of 2a. 5 TYPES OF GRATINGS Up to this point we have considered the diffraction grating to be an opaque aperture in which closely spaced slits have been introduced. Special Methods in Light Microscopy. If the coherence length lt is interpreted as the interval ¢x within which the particle is to be found—that is, its uncertainty in location—and the uncertainty in location—and the uncertainty in momentum ¢p is expressed by the differential of the deBroglie wavelength in the equation p = h>l, the result is x = h. Incidentally, the magnifying power of this eyepiece, given by 25/f, is therefore 10 *. Determine where
and at what angle the rays cross the optical axis. 6 BLAZED GRATINGS The absolute efficiency of a grating in a given wavelength region and order is the rays cross the optical axis. region. For the case of myopic astigmatism, Figure 7a, the corneal surface is evidently less sharply curved in the horizontal meridian 1 power = 46.00 D2. The angle between the dashed lines is 60°. Various choices of the radii of curvature, while not changing the focal length, may have a large effect on the degree of spherical aberration of the lens. We have noted that the fluorescence lines from a weakly excited gas originate from spontaneous emission and so have linewidths that are the same as the width of the lineshape function g1n2 of the atomic transition involved in the fluorescence. For the moment we will concentrate on but two of the many energy states in an atomic system. This result agrees with the predictions of the more complete Fresnel equations. The most common dichroic absorber for light is Polaroid H-sheet, invented in 1938 by Edwin H. In real object space the rays are diverging and the spherical wavefronts are expanding. How many reflections occur per meter for such a ray in a stepindex fiber with n1 = 1.460, n2 = 1.457, and d = 50 mm? Laser Source Irradiance (power per unit area) of a typical laser is far greater than other sources of the laser beam. The fringe spacing d, as shown in Figure 7c, is determined by the wavelength of the light and by the angle 2u between the two interfering beams, according to the relation d = 1>12 sin u2. Estimate the difference in the frequencies of the two absorption dips shown in Figure 21b. Figure 8d illustrates multiple images of a point object O formed by two perpendicular mirrors. How is this image affected if the light from one or more of these diffraction spots is blocked so that its contribution to the 465 Fourier Optics Aperture Spectrum Image S L1 L2 f L3 f f image is subtracted out? Suppose now that the optical system and entering real image space, the wavefronts are contracting and the rays are converging to a common point that we define to be the image point, I. If all of the harmonic waves in the pulse train move with the same speed, then the positions of constructive interference (i.e., the pulses) also move at this speed. A stack of four double layers is made of layers of germanium 1n = 4.02 and MgF2 1n = 1.352, each of 0.5-mm optical thickness. 221 Optical Interferometry 3 A thin sheet of fluorite of index 1.434 is inserted normally into one beam of a Michelson interferometer. As the name implies, liquid crystals are materials with n = 1.53 has surfaces of 5 D (diopters) and 8 D, respectively. The transverse spatial coherence of a single-mode laser beam extends across the full width of the beam, whatever that might be. As we shall see in several applications, choice of y in the Fresnel integrals is determined by the vertical dimensions of the diffraction aperture. (For a ring cavity, the mode separation is c/P, where P is the cavity perimeter.) This mode separation is sometimes called the free spectral range, nfsr, of the cavity. After collimation, a "parallel" beam originates from a point source and reconstructing wavefronts are both plane waves. It also means that, if the light beam originates from a point source divergence and diffraction effects are reversed when the beam is returned through the system, so that the PC beam converges to the original point. uf t2 d n0 n1 n2 nf uo Figure 39 33 A parallel beam of light is incident on a plano-convex lens that is 4 cm thick. Only the zero- and first-order diffracted beams are shown. Find the focal lengths for light incident from each side. The optical system, together with its cardinal points and sample rays, is shown roughly to scale in Figure 14. When these waves are superposed, therefore, the resultant ER may be written as q q N=1 N=2 ER = a EN = rE0eivt + a tt/E0r/ 12N - 32ei[vt - 1N - 12d] Factoring a bit, we have ER = E0e c r + tt/r/e ivt q -id a r/ 12N - 42 -i1N - 22d e N = 2 d The summation is now in the form of a geometric series, q N-2 ax = 1 + x + x2 + Á N = 2 where x = r_c 2e-id Since f x f 6 1, the series converges to the sum S = 1>11 - x2. 4.82°, 4.37° 611 612 Answers to Selected Problems 13. The translation of one fringe system relative to the other provides a means of determining d, as follows. These are discussed in the following subsections. In that case, the presbyopic, unaided eye can clearly view the virtual image formed by the corrective lens. Similarly, for the two fields being superposed at P, 1 1E11t2 + E...11t22 = Re1E11t22 + E...21t22 = Re1E21t2 + R...21t22 = E11t2 and E21t2 are related to the complex source field E(t) via the relations, E11t2 = b 1E1t - T12 = b 1E1t - T12 = b 1E1t - T12 = b 2E1t - T22 = b 2E1t propagation of the fields from S to P. half-maximum for r = 0.9. The sharpness of these fringes is to be compared with the broader fringes from a Michelson interferometer, which have a simple cos21d>22 dependence on the phase (Eq. (2)). The outer surfaces of the glass plate are purposely formed at a small angle relative to the inner faces (several minutes of arc are sufficient) to eliminate spurious fringe patterns that can arise from the glass itself acting as a parallel plate. (a) C = 0, m (b) B = 0, (m + 12) (c) B = 0, (m + 12) (a) linearly polarized, A = 1 (c) right-elliptically polarized, A = 1 (c) righ axis (d) linearly polarized, horizontal, A = 5 (e) left-circularly polarized, A = 2 (f) linearly polarized, major axis along xaxis (b) vertically linearly polarized (a) linearly polarized at $\pm 45^{\circ}$ (b) elliptical polarization with inclination angle = 2 - 25.097^{\circ}: 1 3 i3 $\sqrt{3}$ (b) Elliptical polarized 1 - i [i 1] (a) Elliptical polarization] $\sqrt{13}$ [+ 2 2 615 with inclination angle = 4.903^{\circ}, or 30^{\circ} 2.6519 1 $\sqrt{34.475}$ [-0.6651 + i(5.1962)] 21. 4 Show that for a spherical concave mirror, a calculation like that done for a refracting surface gives a third-order aberration of a = 1 2 h4 1 a - b 4R s R where R is the magnitude of the radius of curvature. These signals are then separated back into the different wavelength channels by a demultiplexer before reaching separate receivers. Using Eq. (4) again, P2 -5 = e -110.2 eV2>[18.62 * 10 eV>K2T] = 0.001 P1 so that - 110.2 eV2>[18.62 * 10-5 eV>K2T] = ln10.0012 and, T = 17,100 K This temperature is, roughly, a factor of 3 more than the surface temperature of the sun. distant object. Base plane O y E Both to OA OA E OA (a) (b) Production of Polarized Light easily, that is, with smaller bindingB forces, than oscillations that are perpendicular to the plane. 3 The allowed rotational energies Erot l of a diatomic molecule are given by El = 11 + 12U2 2I In this expression l is the rotational inertia of the molecule about an axis through its center of mass; and U = h>2p. 180 Cornea frontal view 45.00 D 90 43.50 D 180 Myopic astigmatism (a) 42.00 D Hyperopic astigmatism (b) the overall myopia or hyperopia. (Hint: Use Babinet's principle.) Ey E0y a E0x 14 Ex Matrix Treatment of Polarization INTRODUCTION The polarization of an electromagnetic wave should already be familiar to B you. Assume that the illuminating light has wavelength of l = 546 nm. See F. Solution The ratio to be calculated is Ib = 0 Ib = 1.43p = 1 sin b > b 22b = 0 Isin b > b 22b = 1.43p = 1 1sin b > b 22b = 1.43p = 1 1sin b > b 22b = 1.43p = 1 1sin b > b 22b = 1.43p = 1 1sin b > b 22b = 1.43p = 1 1sin b > b 22b = 1.43p = 1 1sin b > b 22b = 1.43p = 1 1sin b > b 22b = 0 1sin b > b 22b = 1.43p = 1 1sin b > b 22b = 1signal. New York: John Wiley & Sons, 1986. Using Euler's equation to expand ei3p>4 = -122 + ia 122 b and using our standard notation for this case, we have 'A 1 1 E0x d, where A = 1, B = , and C = c' d = c E0y B + iC 22 22 Since A and C have the same sign, the output field vector represents elliptically polarized light with counterclockwise rotation. What is the range of photon wavelengths that could jonize a hydrogen atom that is originally in its n = 2 energy state? Thus if w is constant, dw = 0 = k1dx: vdt2 and dx = 2 is added to the phase. 16 Geometrical Optics 17 Within the approximation represented by geometrical optics, light is understood
to travel out from its source along straight lines, or rays. 11 Two parallel beams of electromagnetic radiation with different wavelengths deliver the same power to equivalent surface areas normal to the beams. The image of the crosshairs does not share in the image of the crosshairs does not share in the image end to the beams. image. The phase difference d between the two waves arriving at the observation point P must be determined to calculate the resultant irradiance there. -1.50, -1.50, axis 180 -2.00 +2.00, -1.50, axis 180 -2.00, -1.50, -1 transform, or spectrum, of the input. If the speed of light in vacuum is c, we express the speed in the upper medium by the ratio c>ni, where ni is a constant that characterizes the medium and is referred to as the refractive index. atoms in the lattice. By way of summary and in conjunction with Figure 3, Table 2 lists the important optical surfaces, their distances from the corneal vertex on the optical surfaces, their distances from the corneal vertex on the optical surfaces, their distances from the corneal vertex on the optical surfaces, their distances from the corneal vertex on the optical surfaces, their distances from the corneal vertex on the optical surfaces, their distances from the corneal vertex on the optical surfaces, their distances from the corneal vertex on the optical surfaces, their distances from the corneal vertex on the optical surfaces, their distances from the corneal vertex on the optical surfaces, the interface, Ei is divided into a reflected to the corneal vertex on the optical surfaces from the corneal vertex on the optical surfaces, the interface, Ei is divided into a reflected to the corneal vertex on the optical surfaces from the corneal vertex on the corneal vertex on the part, Er = rEi, and a transmitted part, Et = tEi as shown. The S and T astigmatic surfaces then appear oppositely curved, and the surface of least confusion is flat, as shown. Then s2 - s1 is equal to the segment ¢, as shown. Law of Refraction (Snell's Law) When a ray of light is refracted at an interface dividing two transparent media, the transmitted ray remains within the plane of incidence and the sine of the angle of refraction ut is directly proportional to the sine of the angle of incidence ui. Thus, white light coming from a single distant object point. What is the visibility? This situation is shown in Figure 10c. Thus the minimum wavelength is given by lmin = 2xw N - 1 (45) where N is the total number of samples, giving N - 1 sampling intervals. In terms of the choices made for the direction of the sequencies of the complex fields of Eqs. If these negative signs are understood to apply to these quantities for the case of Figure 18, a general form of the refraction equation may be written as $n^2 - n^1 n^2 n^1 = + s s R$ (20) which holds equally well for convex surfaces. (1) through (8) T should be replaced by L and the temporal frequency, k = 2p > L. Determine the laser-beam spot size w on Mirror 1. Note that the effective pump rate can be found from the listed condition $g^0 = 2g th$ Determine, for first-order operation, the (a) angular spread about the grating normal of the visible range of wavelengths (400 to 700 nm); (b) theoretical resolving power if the grating is ruled over a width of 10 cm; (c) plate factor in the vicinity of 550 nm; (d) radius of the Rowland circle in a Paschen-Runge mounting of the grating. The screen is shown at distance D from point O. Some materials, such as crystalline guartz, produce either rotation, traceable to the existence of two forms of the source is 5 cm², determine the radiant excitance. According to Planck, the energy E of a quantum of electromagnetic radiation is proportional to the frequency n of the radiation: E = hn (1) where the constant of proportionality h, Planck's constant, has the very small value of 6.63 * 10-34 J-s. Horizontally linearly polarized light incident on the vertical wire grid would suffer the same fate, except that appreciable oscillatory motion of the electrons across the wire is inhibited. Helium-neon (He-Ne) and argon-ion 1Ar+2 lasers are two important gas atomic lasers. In this mode of operation, the term free spectral range is most commonly applied for this case, that is, when the transmittance is considered as a function of input frequency. Use Eqs. Recall that these two quantities are related, as with all types of wave motion, through the velocity c: $c = \ln (9)$ As indicated in Figure 1, common units for wavelength are the angstrom $\circ = 10-10 \text{ m2}$, the nanometer 11 nm = 10-9 m2, and the micrometer 11 nm = 11 A - 6 10 m2. The most familiar detector is, of course, the eye. It is instructive to make a series of simplifying assumptions that sometimes apply in real atomic gain media and which dramatically reduce the complexity of the system of equations. Both the Fresnel theory and experiments, such as Lloyd's mirror, establish the fact that the phase shift occurs for the ray incident on the interface from the side of higher velocity or lower index. As usual, low spatial frequencies are sufficient to image the gross details of an object, whereas high spatial frequencies are required to reproduce the first excited rotational energy state and the ground rotational state. According to Eq. (45), lout = T3IS a 1g0 - gth2L 10.05 - 0.0071210 b = 10.04212300 W > cm22 1 - S 1 - 0.99210.952 Jout = 570 W > cm2 c. (16) and (18) we conclude that § # E = 0 and substitute the remainder of Eq. (23) into Eq. (24) For the right member we may make use of Maxwell's equation (21) and write B B 0 2E 1 0 2P c §E = 2 + e0 0t2 0t 2 2B (25) B The last term is expressible in terms of E using Eq. (11), so we have c2 2E = c1 + BB 0 2E Ne2 d me01v20 - v2 - ivg2 0t2 B B (26) B B For a harmonic wave expressed as E = E0ei1kz - v2E, Eq. (26) solved for k2 becomes k2 = 1 v2 Ne2 d c1 + 2 2 2 me c 0 1v0 - v - ivg2 (27) We conclude that the analysis of plane waves

propagating in a homogeneous dielectric requires in general that the propagation constant k be a complex number. Since every data unit is recorded throughout the volume of the hologram, in unique holographic fashion, damage to a portion of the hologram, although affecting the signal-to-noise level of the reconstructed image, does not affect its reliability. A 50-mW He-Cd laser emits at 441.6 nm. The transmittance of a fixed-length Fabry-Perot interferometer considered as a function of a variable-wavelength-input field has transmittance of a fixed-length Fabry-Perot interferometer considered as a function of a variable-wavelength input field has transmittance of a fixed-length Fabry-Perot interferometer considered as a function of a variable-wavelength input field has transmittance of a fixed-length Fabry-Perot interferometer considered as a function of a variable-wavelength input field has transmittance of a fixed-length Fabry-Perot interferometer considered as a function of a variable-wavelength input field has transmittance of a fixed-length overlapping wavelets, Huygens avoided the possibility of diffraction of the light into the region of geometric shadow. 16 A light wave is traveling in glass of index 1.50. An optical window allows electromagnetic radiation to fall on the p-type side of the junction. In addition, since the laser beam has a high degree of directionality, it behaves (near the beam waist at any rate) like a bundle of parallel rays coming from a point object at infinity. (The Ealing Corp.) Chapter 6 Properties of Lasers 100 100 Xenon-cathode tip Relative spectral emission 90 90 80 80 70 70 60 60 50 50 40 40 30 30 20 20 10 10 0 0 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000 1050 1100 1150 Wavelength (nm) Figure 8 Spectral emission for xenon compact arc lamp. For example, a thin lens of s = +11r1 = 5 cm2; a meniscus lens of s = +11r1 = 3.33, $r^2 = 10 \text{ cm}2$; a meniscus lens of s = +11r1 = 5 cm2; a meniscus lens of s = +11r1 = 3.33, $r^2 = 10 \text{ cm}2$; a meniscus lens of s = +11r1 = 5 cm2; a meniscus lens of s = +11r1 = 5 cm2; a meniscus lens of s = +11r1 = 3.33, $r^2 = 10 \text{ cm}2$; a meniscus lens of s = +11r1 = 5 cm2; a meniscus lens of s = +11r1 = 3.33, $r^2 = 10 \text{ cm}2$; a meniscus lens of s = +11r1 = 5 cm2; a meniscus lens of s = +11r1 = 5 cm2; a meniscus lens of s = +11r1 = -10, $r^2 = -10 \text{ cm}2$; a meniscus lens of s = +11r1 = -10, $r^2 = -10 \text{ cm}2$; a meniscus lens of s = +11r1 = -10, $r^2 = -10 \text{ cm}2$; a meniscus lens of s = -10 cm2; a meniscus lens of s = +11r1 = -10, $r^2 = -10 \text{ cm}2$; a meniscus lens of s = -10 cm2; a meniscus lens of cm22 = 57 W d. Clark Jones, "A New Calculus for the Optical Systems," Journal of the Systems," Journal of the Optical Systems, "I ournal incidence is about 1000 W>m2 at normal incidence. It is standard practice in a course in electricity and magnetism to show that the bound-charge density is related to the polarization by B rb = - § # P (16) B The quantity J similarly represents the current density and can arise from B B both free and bound charge, as indicated by J = Jb + Jf. Since these modes. Note that the approximate number of round-trips, Nrt, that a portion of the light field makes before exiting the cavity is, then, Nrt L tp 1 = t 211 - r22 (46) It is useful to note (see Eqs. In pure water the light does not scatter sideways but propagates only in the forward direction. Laser action has been observed in over half of the known elements, with more than a thousand laser transitions in gases alone. 400 Chapter 18 1 0 y0 Figure 5 a0 L a1 Matrix Methods in Paraxial Optics given the input data. High Diffracted light beam Undeflected light beam k h Index of refraction RF signal Piezoelectric transducer ks Moving sound waves at speed y k Nonlinear Optics and the Modulation of Light value. Chromatic aberration in lenses can be effectively reduced by using multiple refractive elements of opposite powers. The line image is virtual at a distance of 11.11 cm on the object side of the lens and 2.80 cm long. When red He-Ne laser light (632.8 nm) is used, the measured rotation is 900 min. Taken as a whole, Table 1 includes lasers whose wavelengths vary from 193 nm (deep ultraviolet) to 10.6 mm (far infrared); whose cw power outputs vary from 0.2 mrad (circular cross section); and whose overall efficiencies (laser energy out divided by pump energy in) vary from less than 0.1% to 20%. Both object and screen are then moved to produce an image on the screen that is three times the size of the object. Obviously, fringes should be present in all the space surrounding the holes, where light from the holes is allowed to interfere, though the irradiance is greatest in the forward direction. In these elements, the phase difference d is expressed as a function of l, and n0 11412 n1 1.38 n2 1.6 (b); 1.85 (c) ns 1.52 Figure 5 Antireflecting double layer using l>4 - l>2 thickness films. We have included the locations of the cardinal points for the eye as a whole. When the incident light encounters an approaching wave, the scattered frequency is greater, and when it encounters a receding wave (as in Figure 11), the scattered frequency is less. The choice of relative aperture also affects another property of the image, the depth of field. Driscoll and William Vaughan (New York: McGraw-Hill Book Company, 1978). The light transmitted includes components only along the TA direction and is therefore linearly polarized ir the vertical, or y, direction. The polarization P of the medium is then said to be the collective dipole moments given by (b) B Figure 1 The elementary electric dipole. We now describe briefly each of these homogeneous-broadening mechanisms. In the reflection grating, the groove faces are made highly reflecting, and the periodic reflection of the incident light behaves like the periodic transmission grating. For example, Figure 10 illustrates a typical laser system to which the ABCD propagation law can be applied. Understandably, interference fringes by white light are difficult to obtain since the difference in the path lengths of the interfering beams should not be greater than the coherence length for the light. Let the object be 25 cm from the first lens, as shown. The position of bright fringes is given by Eq. (22), where a is a M S M L Screen Figure 7 Interference with Lloyd's mirror. When a polarizer is rotated in the path of the light, there is no intensity variation. The Pockels Effect The Pockels effect results from the linear term in Eq. (7), where E is an applied DC field. The second set of terms, a complicated phase factor, describes the nature of the wavefront as a function of m and n. Today, as a remedy for myopia, radial keratotomy has largely been supplanted by the two, more precise, corneal sculpting procedures discussed in the next subsection. Use the Gaussian formula for image formation by a spherical surface in a three-step chain of calculations. Equation (53) predicts 100% reflectance when either N approaches zero. In Once such a steady state has been reached, E01 steady state, Eq. (21) can be solved for the intracavity right-going field +, amplitude E01 + = E01 t E0I 1 - r2e-id (22) Here, d = 2kd is the round-trip phase shift. Optical Electronics, 3d ed. The vertically polarized beam. The lifetime t of an energy level is defined to be the inverse of the total decay rate from the level so that, in the present case, t3 = 1, k3 t2 = 1, k2 and t1 = 1 k10 The lifetime of a level is the time for the population density of a given level to decay to 1/e of its initial value, when the decay process is the only process that occurs. Suppose that E is chosen in the original direction of B and B is rotated accordingly to maintain the same wave direction. For example, the law of propagation of ordinary spherical waves, along the z-axis, is given by $q^2 = q1 + 1z^2 - z12$ (35) Similarly, the basic law of propagation for the laser beam follows from Eq. (14) and is given by $q^2 = q1 + 1z^2 - z12$ (36) an equation identical to Eq. (35) except that R has been replaced by q. Slit aperture Edge of geometrical shadow 435.8 nm S 17 For the near-field diffraction pattern of a straight edge, calculate the irradiance of the second maximum and minimum, using the Cornu spiral and the table of Fresnel integral values given. Extinction of a region of the second maximum half-angle um of this cone is evidently related to the critical angle of reflection wc. Using Gaussian optics, determine the final image of the system, after two refractions (a) by a three-ray diagram and (b) by calculation. Determine the final image of the system, after two refractions (a) by a three-ray diagram and (b) at three-ray diagram and (c) by calculation. Determine the final image of the system, after two refractions (a) by a three-ray diagram and (b) by calculation. Born, Max, and Emil Wolf. Thus, ¢lmax may be called the (wavelength) free spectral range lfsr of a Fabry-Perot interferometer. The y-coordinate is identical in either system. (28) and (29). Further, the factor sI>hn¿ has a dimension of inverse time and so is a rate. From an extended source of light S, beam 1 of light is split by a beam splitter (BS) by meansion of inverse time and so is a rate. of a thin, semitransparent front surface metallic or dielectric film, deposited on glass. This position is just the point of intersection between the optical axis and a line drawn from the electromagnetic character of a typical laser beam, we would find that its wavefronts are essentially spherical surfaces with long radii of curvature that increase as the beam advances along the propagation axis. If the coordinates of all points of this Cornu spiral are known, the amplitudes due to contributions from any number of zones can be determined from such a drawing and the relative irradiances compared. 3 Find the resultant of the superposition of two harmonic
waves in the form E = E0 cos1a - vt2 with amplitudes of 3 and 4 and phases of p>6 and p>2, respectively. What is the ratio of irradiance of the evanescent wave at 1 mm beyond the surface? Complementary metal-oxide-semiconductor (CMOS) detectors and charge-injection devices (CID's) are two additional, increasingly important, digital imaging technologies. These lines were among those that appeared in the solar spectrum studied by J. The medium for which n^c 7 n^P is therefore levorotatory. This dependence is noted by preceding the term with the word spectral and by using a subscript l or adding the l in parentheses. Therefore Eq. (52) does indeed give the maximum reflected intensity. This can be obtained from the grating equation (2), a sin u = ml, so that sin $u1 = 14.5^{\circ}$ and cos u1 = 0.968. By now we are familiar with the factor in b representing the diffraction envelope of the resultant irradiance. center and the edge of any groove is zero. When j = 2, the next two slits are included, whose edges are located at Fraunhofer Diffraction 1 2 1 - 3a + b2 and 1213a + evident in the vanishing of rTM in Figure 3 and the vanishing of the numerator of Eq. (28). (a) Standard MachZehnder interferometer with two mirrors, M1 and M2, and two 50-50 beam splitters. Hutley, M. Before constructing representative rays, we first find the image distance and lateral magnification of the image, using Eqs. Thermal detectors are generally characterized by a slow response to changes in the incident radiation. We may think of P1 and P2 as two slits that propagate light to a screen, where interference fringes may be viewed. (27) to (30), Eq. (24) takes the form, E0 + Er1 C g01E0 - Er12 S = C cos d ig1 sin d i sin d Et2 m11 g1 S C S = c m21 cos d gsEt2 m12 Et2 dc d m22 gsEt2 (31) where in the last equality we have used the generic form of the transfer matrix given in Eq. (25). The requirement is that every ray from O, like OPI, refracts and passes through the image I. (b) Modulated wave representing Eq. (33) at x = x0. As we show in Example 4, a corrective lens of a single power (as used in reading glasses) will not restore clear vision of both near and distant objects for a person who has lost accommodation. On the other hand, 13 Robert Guenther, Modern Optics (New York: John Wiley and Sons, 1990), Ch. 14. More information can be sent by optical fiber when distinct pulses can be transmitted in more rapid succession. Without affecting the order of validity of this approximation, we may replace, in the last expression, the term r2>2r2 by r2>2r2, leading to the following expression describing the phase fronts that satisfy the condition kz + kr2>2r1 constant Spherical wave near z-axis (30) Now a Gaussian beam described by Eq. (24) has phase fronts that satisfy the condition kz + kr2>2r2 to r2>2r2, leading to the following expression described by Eq. (24) has phase fronts that satisfy the condition kz + kr2>2r2 to r2>2r2, leading to the following expression described by Eq. (24) has phase fronts that satisfy the condition kz + kr2>2r2 to r2>2r2, leading to the following expression described by Eq. (24) has phase fronts that satisfy the condition kz + kr2>2r2 to r2>2r2, leading to the following expression described by Eq. (24) has phase fronts that satisfy the condition kz + kr2>2r2 to r2>2r2, leading to the following expression described by Eq. (24) has phase fronts that satisfy the condition kz + kr2>2r2 to r2>2r2, leading to the following expression described by Eq. (24) has phase fronts that satisfy the condition kz + kr2>2r2 to r2>2r2, leading to the following expression described by Eq. (24) has phase fronts that satisfy the condition kz + kr2>2r2 to r2>2r2, leading to the following expression described by Eq. (24) has phase fronts to r2>2r2, leading to r2>2r2, constant R(z) 2z0 z0 z Figure 5 Wavefront radius of curvature R(z) for a Gaussian beam. 7 OPTICAL NONLINEARITIES IN FIBERS We conclude this chapter with a survey of some aspects of the nonlinear interaction of light waves propagating in optical fibers. Note, however, that the aberration-free imaging so achieved applies only to object point O at the correct distance from the lens and on axis. In effect this lens will image all objects from 5 ft to 30 ft with an acceptable sharpness. e-x dx = 1p 8 Michelson found that the cadmium red line (643.8 nm) was one of the most ideal monochromatic sources available, allowing fringes to be discerned up to a path difference of 30 cm in a beam-splitting interference axis of the complementary aspects of particle and wave descriptions of light remain, justifying our use of one or the other when appropriate. The laser light thus created and emitted is both temporally and spatially coherent. E = 2E0xN ei1kz - vt2 B b. Calculate the distances from the axis of the first three bright spots produced by a Ronchi ruling with transmitting slits of the population densities of the population inversion as functions of light irradiance are given in Figure 3. What is then the effective percent reflection from the film layer? Determine the amplitude, frequency, wavelength, speed, and direction of the component waves whose superposition produces this result. It was called a maser. The field depicted in Figure 2a is represented by E0x = 0 and E0y = A. Let the new input plane be located at distance s in object space and the new output plane at distance s_i in image space. 6 Chapter 1 Nature of Light l = 6.626 * 10-34 J # s h = = 4.19 * 10-13 m = 0.419 pm p 1.58 * 10-21 kg # m > s 213 * 108 m > s For the photon, with m = 0, we get instead, from Eq. (6): <math>p = E 4.82 * 10-13 J = 2.95 * 108 m > s 22 pc 2 = E 4.82 * 10-13 J = 2.95 * 108 m > s C 3 * 10-21 kg # m > s and from Eq. (6): <math>p = E 4.82 * 10-13 J = 2.95 * 108 m > s C 3 * 10-21 kg # m > s C 3 *108 m>s from Eq. (7): l = h 6.626 * 10-34 J # s = = 0.412 pm p 1.61 * 10-21 kg # m>s and from Eq. (8): y = c = 3.00 * 108 m>s There is another important distinction between electrons and photons. Cavities with higher loss rates have lower quality factors. It remains to determine the proper blaze angle of a grating. Consider next the action of the Ep, or TM, component (Figure 4b). New York: Academic Press, 1982. An aperture, in its broadest sense, is an opening defined by a geometrical boundary. This quantity is plotted in Figure 3 for different temperatures. Thus gratings with more slits direct a greater fraction of the energy emerging from the slits towards the positions of the principal maxima than do gratings with fewer slits. The treatment of a system in which a significant population is transferred to an excited state is mathematically more complex. We let laser light of irradiance I and frequency n¿ be incident on the atomic medium. Solids and liquids sometimes have continuous bands of energy. Interpret the terms as done in the discussion of a hologram of a three-dimensional subject. In this section we present an alternative method that can also be used to determine the loss rate of a laser cavity. Assuming that the prism angle A and refractive index n are given, then the stepwise calculation for a ray incident at an angle u1 is as follows: u1œ = sin-1 a sin u1 b n (7) d1 = u1 - u1œ (8) $u2\varpi = A - u1\varpi (9)$ $u2 = sin-11n sin u2\varpi 2 d = u1 + u2 - u1\varpi - (10)$ $u2\varpi (11)$ The variation of deviation with angle of incidence for A = 30° and n = 1.50 is shown in Figure 10. When the laser is turned on, the irradiance is very small and so the gain coefficient g1n2 takes on its small-signal value g01n2. Images I1 and I2 result from single reflections in the two mirrors, but a third image I3 results from sequential reflections from both mirrors. One way to confirm this is to compare the color of stars, as they appear visually, to their photographic images made on color film using a suitable time exposure. (7) and (8). Determination of MTF at various spatial frequencies, like the curves shown in Figure 10b, allows a more complete evaluation of system performance than resolution alone. Note that the rate of spontaneous emission is independent of the spectral energy density of the electromagnetic field. 9 THIN LENSES We now apply the preceding method to discover the thin-lens equation. The original shape of the pulse, $y_{z} = f1x_{z}^{2}$, does not vary but is simply translated
along the x-direction by the amount yt at time t. Until recently, a photographic film or plate was the most common image-recording medium. Chapter 26 Davis, Christopher C. The spatial extension of the pulse is /0 = ct0. The spatial extension of the pulse is /0 = ct0. diameter of the individual circles. If the air-film thickness now changes by an amount $\xi t = d$, the order of interference m changes accordingly, and we have $2\xi t = 2d = 1$ for an air film. Amplitude-division interference m changes accordingly, and we have $2\xi t = 2d = 1$ for an air film. Amplitude-division interference m changes accordingly, and we have $2\xi t = 2d = 1$ for an air film. Amplitude-division interference m changes accordingly. affected by spherical aberration, as discussed earlier, to a degree determined by the displacement y of the extreme rays of the pencil. (Photo from M. In practice, s V / and angles u are approximately equals its tangent at intersections of the curves y = b and y = tan b, both plotted in Figure 3. This sort of arrangement is in fact used for detectors with a relatively small number of pixels. Both rods and cones are composed of stacks of the long rods thinner than those of the shorter cones. However, as suggested by Figures 1, 2, and 3 and in contrast to a spherical wave, the center of curvature of a Gaussianbeam wavefront changes as the beam propagates along the zaxis. That is, $E1z0 + \xi z$, $t0 + \xi t2 = PF1\xi z$, $t2 = E1z0 + \xi z$, $t0 + \xi t2 = E1z0 + \xi z$, $t0 + \xi t2 = E1z0 + \xi z$, $t0 + \xi t2 = E1z0 + \xi z$, $t0 + \xi t2 = E1z0 + \xi z$, $t0 + \xi t2 = E1z0 + \xi z$, $t0 + \xi t2 = E1z0 + \xi z$, $t0 + \xi t2 = E1z0 + \xi z$, $t0 + \xi t2 = E1z0 + \xi z$, $t0 + \xi t2 = E1z0 + \xi z$, $t1z + \xi z = E1z0 + \xi z = E1z0 + \xi z$, $t1z + \xi z = E1z0 + \xi z = E1z0 + \xi z$, $t1z + \xi z = E1z0 + \xi z = E1z0 + \xi z$, $t1z + \xi z = E1z0 + \xi z = E1z0 + \xi z$, $t1z + \xi z = E1z0 + \xi z = E1z0 + \xi z$, $t1z + \xi z = E1z0 + \xi z = E1z0 + \xi z$, $t1z + \xi z = E1z0 + \xi z = E1z0 + \xi z = E1z0 + \xi z$, $t1z + \xi z = E1z0 + \xi z =$ Fabry-Perot interferometer consisting of two mirrors with reflection and transmission coefficients r and t. 1 21 A u 1 B a u Figure 16 Representative grating slits illuminated by collimated monochromatic light. Notice that when E1 and E2 are orthogonal, so that their dot product vanishes, no interference results. Many useful and interesting applications of thin films, however, make use of multilayer stacks of films. (a) TM: $p = 67^{\circ}33'$, no c; TE: no p, no c (b) TM: $p = 22^{\circ}24'$; TE: no p, no c (b) TM: $p = 22^{\circ}24'$; TE: no p, $c = 24^{\circ}24'$; TE: no p, $c = 24^{\circ}24'$; TE: no p, $c = 24^{\circ}24'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$, $c = 24^{\circ}24'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$, $c = 24^{\circ}24'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$, $c = 24^{\circ}24'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$, $c = 24^{\circ}24'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$, $c = 24^{\circ}24'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$, $c = 24^{\circ}24'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$, $c = 24^{\circ}24'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$, $c = 24^{\circ}24'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$, $c = 24^{\circ}24'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$, $c = 24^{\circ}24'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$, $c = 24^{\circ}24'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$, $c = 24^{\circ}24'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$, $c = 24^{\circ}24'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$, $c = 24^{\circ}24'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$; TE: no p, no c (b) TM: $p = 22^{\circ}27'$; TE: no $p = 22^{\circ}27'$; TE: no p = 22zone has been included, the last phasor is advanced by p relative to the first and ends at T. The amount of rotation caused by optically active liquids is much less by comparison. The CO2 laser is one of the most versatile and efficiencies ranging from 10% to 40%. Typically the cover glass index is 1.522 and the oil index is 1.516, providing an excellent match. For the present, we assume monochromatic light, which has its own characteristic refractive index in the prism medium. The technique was introduced by Vander Lugt in 1963. Infrared radiation is also used in optical fiber communication systems and in a variety of remote control devices. (33) and (34) may then be calculated using K1 = P1D n1D - 1 and K2 = P2D n2D - 1 (46) Finally, from the values of K1 and K2 , the four radii of curvature of the lens faces may be determined. Throughout this chapter, we will assume that all effective path-length differences between interfering beams that originate from the same source are much less than the coherence length of the source. The doublet is an equiconvex lens of radiu 50 mm, index 1.50, and central thickness 5 mm. n2 b n1 up Production of Polarized Light The active medium of a gas laser is often bounded by two Brewster windows, located at the ends of the gas plasma tube. F enters the prism at face AD, making an angle of 90° with the incident direction. A voltage placed across an individual subpixel causes the gas in the cell to ionize (that is, causes a plasma to be formed) and to subsequently emit ultraviolet light, which in turn strikes the phosphor coating causing the emission of red, green, or blue light. G1 and G2 represent two phase-coupled generators radiating coherent ultrasonic waves. Further, when n 7 - n 7 0, the crystals are said to be uniaxial positive, and when this quantity is negative. New York: Academic Press, 1972. 8 ELECTROMAGNETIC WAVES The harmonic waveforms discussed so far can represent any type of wave disturbance that varies in a sinusoidal manner. All that is required etalon length d: etalon nfsr = d 6 c 7 6 GHz 2d 3 # 108 m>s c = 2.5 cm = 216 # 109 Hz2 1.2 # 1010 Hz Laser Frequency Stabilization. The normalized form must be divided by 2A2 + B2 + C 2 . 18 A certain argon-ion laser can support lasing over a frequency range of 6 GHz. Estimate the number of standing wave modes that might be in the laser cavity is 1 m long. 13 Waves on the ocean have different velocities, depending on their depth. 18 Show that elliptical polarization can be regarded as a combination of circular and linear polarizations. In traversing the lens, the ray undergoes two refractions and one translation, steps for which we have already derived matrices. The exact distribution of the emerging laser beam, and thus the transverse irradiance of the beam, depends on the construction of the resonator cavity and mirror surfaces. In each of these figures, the roles of object and image points may be reversed by the principle of reversibility. Interference fringes are seen on a screen 1 m away. This virtual image is what we customarily view. What is the effect on the fringe separation d of an emulsion with a high refractive index? 8 Use a computer to calculate and plot the reflectance curves of Figure 4.5 Referring to problems 3 and 4 and Eq. (2), construct an energy level diagram for the H2 molecule that shows the first vibrational and rotational states associated with the ground electronic state of the molecule. The normalized correlation function g1t2, sometimes called the degree of coherence, can be simplified by expressing I1P and I2P in terms of the amplitude of the source field. The detection point is located 50 cm on the other side of the aperture plane. Values of M¿ for fused quartz over the same range are only about 1 to 4.5 ps/nm-km.11 For example, the calculation carried out for material dispersion, using a LED source at 0.82 mm, with M = 100 ps>nm-km, gave a temporal pulse broadening of 2000 ps/km. In Figure 10, the
results of such calculations are shown for two metal surfaces, solid sodium and single-crystal gallium. The divergence angle u associated with a field of beamwaist radius w0 is indicated. 1 Entering values, we have for the first convex surface at entry, + 25 1.50 1.50 - 1.00 = , which gives s_i = 150 cm, real. In general, the refractive index depends on the B propagation direction and wave polarization relative to the crystal axes. A R station relative indices and accord emirror, R, is negative. (19) and (20) for constructive and destructive interference are reproduced. The object is an extended object of transverse dimension ho . Jenkins and Harvey E. The composite phasors in Figure 5b begin at the start of the phasor an for any number n of contributing Fresnel zones. In the high-loss state, the population inversion grows, which in turn leads to an increase in spontaneous emission. In other words, what is the focal length of a single refracting surface? Using Eq. 20, the distances from the central spot are ky (a) E E0 sin ky Y1 = (1) 1488 * 10-92 10.42 lf = 112 m = $9.76 \times 10-3$ H = $2.93 \times 10-3$ at P as if from a plane tangent at P, satisfying the law of reflection. Phys., Vol. Calculate reflectance for (a) TE and (b) TM modes at angles of incidence of 0°, 30°, 50°, 70°, and 90°. We know that the time difference between paths, relative to the average coherence time to of the source, is crucial to the degree of coherence achieved. 15 Enlarge the optical system of Figure 15 to include an object space to the left and an image space to the right of the lens. The edge of the shadow is clearly not sharp. At a given point, the amount of light passed by the mask depends both on the amount of light passed by the mask depends both on the amount of light available in the image and the transparency of the mask depends both on the amount of light passed by the mask depends both on the amount of light passed by the mask depends both on the amount of light available in the image and the transparency of the mask depends both on the amount of light passed by the mask depends both on the amount of light passed by the mask depends both on the amount of light available in the image and the transparency of the mask depends both on the amount of light passed by the mask depends both on the amount of light passed by the mask depends both on the amount of light passed by the mask depends both on the amount of light passed by the mask depends both on the amount of light passed by the mask depends both on the amount of light passed by the mask depends both on the amount of light passed by the mask depends both on the amount of light passed by the mask depends both on the amount of light passed by the mask depends both on the amount of light passed by the mask depends both on the amount of light passed by the mask depends both on the amount of light passed by the mask depends both on the amount of light passed by the mask depends both on the amount of light passed by the mask depends both on the amount of light passed by the mask depends by the mask depe O that encounter the lens at symmetrically placed points P converge at axial point N, while rays from O that encounter the lens at points Q converge at axial point M. H., and M. The spatial coherence of the wavefield is also perfect since along each wavefield is also perfect since along the transformation of the relative phase of the field is zero. (Hint: Think of the oil layer as an intermediate thin lens.) 23 A small object is placed 20 cm from the first of a train of three lenses with focal lengths, in order, of 10, 15, and 20 cm. A wide-angle lens is a short focallength lens with a large field of view. Specialize Eqs. Finally, we mention Doppler weather radar, in which a source emits an electromagnetic radio wave towards moving raindrops and other particulates. To provide quality images, the ocular is corrected to some extent for aberrations and, in particular, to reduce transverse chromatic aberration. In Figure 10, let the region labeled "optical system" include any number of reflecting and/or refracting surfaces, of any curvature, that may alter the direction of rays leaving an object point O. Figure 7b shows a comparable condition and prescription for hyperopic astigmatism. If the fast and slow axes of the QWP are interchanged, a similar calculation shows that the result is left-circularly polarized instead. The real image formed by the eyepiece, whose angular magnification contributes to the overall magnification of the instrument. Then yf = Ay0, independent of a0. Techniques involving interferometric and electronic servo-control have been used to enhance the precision of the most modern ruling engines. In a modern version of this experiment, a laser is typically used to illuminate the two holes. 11 The total path difference executed by a Fourier-transform spectrometer operating in the infrared is 2.78 mm. f -1.00 m b. In this case, Eq. (42) reduces to normal incidence quarter-wave thickness R = a n 0 ns - n21 b n 0 ns + n21 2 (43) From Eq. (43), it follows that a perfectly antireflecting film can be fabricated with a coating of l>4 to the infrared is 2.78 mm. f -1.00 m b. In this case, Eq. (42) reduces to normal incidence quarter-wave thickness R = a n0 ns - n21 b n0 ns + n21 2 (43) From Eq. (43) From thickness and refractive index n1 = 1n0ns. Determine the radii of the first and second bright rings surrounding the Airy disc in the diffraction pattern is translated relative to the other, however, the bright points of the image no longer all coincide with the transparent regions of the mask. ng the motion of the vibrating surface. The inverse transform, as in Eq. (6), is EA1x, y2 = 1 A P1kX , kY2e -i1xkX + ykY2 dkX dkY 12p22 O (18) Within the approximations made, we have shown that the Fraunhofer diffraction and correlation are reduced. The resulting hologram effectively contains a large number of ima pattern described by A P1kX , kY2 is just the two-dimensional Fourier transform of the aperture function described by EA1x, y2. (c) Spontaneous emission initiates stimulated emission. Similarly, we consider the observation screen to be effectively at infinity by using a lens on the exit side of the slit, as shown 269 Fraunhofer Diffraction 1 (c) ds u s b u u y P lens on the exit side of the slit, as shown 269 Figure 1 Construction for determining irradiance on a screen due to Fraunhofer diffraction by a single slit. Figure 1 shows the polarization as a function of the electric field for the linear case and the deviation from linearity due to this second-order term. We conclude that the situations depicted in Figure 21b and c must be physically equivalent, so that we can write $Ei = 1r^2 + t_c t^2 Ei$ and $0 = 1r_c t + t_r t^2 Ei$ or $t_c = 1 - r^2 t = -r^2 (42) (43)$ Equations (42) and (43) are the Stokes relation of 10-3 cm and illuminated by light of 600 nm? If the reference beam is white light, the continuously displaced images due to different spectral regions of the light overlap and produce a colored blur. Which component now limits the cone of light rays? The first condition is satisfied by making the angle of reflection relative to N; equal to the angle of reflection relative to N; equal to the angle of reflection relative to N; equal to the angle of reflection relative to N; equal to the angle of reflection relative to N; equal to the angle of reflection relative to N; equal to the angle of reflection relative to N; equal to the angle of reflection relative to N; equal to the angle of reflection relative to N; equal to the angle of reflection relative to N; equal to the angle of reflection relative to N; equal to the angle of reflection relative to N; equal to the equation of the equation that the angle um satisfy the grating equation, ub u N ml = a 1sin ui + sin um2 (14) a h ub Figure 6 Relation of the blaze angle ub to the incident and diffracted beams for a reflection grating. These phase changes reflect the erratic process by which excited atoms in a light source undergo transitions between energy levels, producing brief and random radiation wave trains. In this chapter we define more precisely the area of nonlinear optics, describe and categorize some nonlinear phenomena, and discuss some of their practical applications. Parrent, Mark J., and George B. Thus we should have both P2 = e0x21 + E22 and - P true if P2 = 0. Light is incident on the unsilvered side. further than s¿ from the lens, one sees an unfocused blur that has the general shape of the aperture placed against it. There is no Jones vector representing unpolarized or partially polarized light.2 2 MATHEMATICAL REPRESENTATION OF POLARIZERS: JONES MATRICES Various devices can serve as optical elements that transmit light but modify the state of polarization. For the g-expression, we write 1 g- 2ikx 1 1 0w g¿ b + = - C1 a 2 g w q w 0z g w (53) We can show, with the help of Eqs. Incorporating Eqs. Notice that low-order modes—m small -correspond to w 90°, or ray directions that are nearly axial, and high-order modes—m large—correspond to rays that propagate with w near wc, or at steeper ray angles. (a) I d d (b) 201 Optical Interferometry as suggested in Figure 7b. Recalling that a dipole oscillator radiates only weakly along directions making small angles with the dipole axis 1I r sin2 u2, we conclude that only a fraction of the Ep component of the original light (compared with the Es component) appears in the reflected beam. Now the ratio of effective object-to-image distance is smaller, and pincushion distortion appears in the reflected beam. Now the ratio of effective object-to-image distance is smaller, and pincushion distortion appears in the reflected beam. the angles of incidence are 0°, 10°, 45°, and 90°. London: Butterworths, 1980. z b where u is the angle of incidence and n is the ratio $n^2 > n^1$. Meyer-Arendt, Jurgen R. The plate thickness is 1.50 mm. The fringes are
observed to be separated by 0.03 cm. Solving Eq. (21) for the mode number m gives m = relation in Eq. (22) yields $\psi L = a n \psi L 1 l^2 + b l^2 r$ Solving this expression for ¢L gives n¢L. The object distance s is positive when O is to the left of V, corresponding to a real object. Ideally, when the real object. Ideally, when the real object distance s is positive when O is to the left of V, corresponding to a real object. Ideally, when the real object. Ideally, when the real object distance s is positive when O is to the left of V, corresponding to a real object. At the first refracting surface, of radius R1, n2 n2 - n1 n1 + ∞ = s1 s1 R1 (23) and at the second surface, of radius R2, n1 n1 - n2 n2 + ∞ = s2 s2 R2 (24) We have assumed that the lens faces the same medium of refractive index n1 on both sides. Using Eq. (44) in Eq. (43) yields the indicative relation Iout = T3IS a 1g0 - gth2L b 1 - S (45) Let us obtain the expression for the threshold small-signal gain coefficient gth in another fashion. The fusion by the brain of two distinct images into a single image is referred to as binocular vision. However, the situation in the region u 7 uc , where r is complex, requires further investigation. In an alternating electric field, however, forced oscillations of electrons remove a certain amount of energy from the incident radiation, the energy that the electrons radiate in turn and the energy of interaction with neighboring atoms that shows up as thermal energy. This relativistic expression3 for kinetic energy EK approaches 12 my2 for y V c. The circular fringes of equal inclination no longer appear; in their place are seen fringes of equal thickness. Arrays of diode lasers allow for relatively high average power devices. Secondary maxima result because a uniform phase difference between waves from adjoining slits causes the phase diagram to curl up, with a smaller resultant. 2 Two harmonic light waves with amplitudes of 1.6 and 2.8 interfere at some point P on a screen. The forms of the lineshape functions given in the preceding paragraphs are appropriate for those relatively common cases in which either homogeneous broadening or Doppler broadening is dominant. Photosensitive crystals, such as potassium bromide with color centers or lithium niobate can be used in place of thick-layered photoemulsions. Similarly, one typically replaces the wavelength 11 appearing in Eq. (37) by its nominal value 1. A third DWDM design challenge that has been met is the limiting of dispersion so that separating the wavelength channels by 0.8 nm provides isolation sufficient to prevent cross talk between channels over long hauls. Also plot the corresponding transmittance. Although the length ¢y along the spiral remains fixed, its placement at different positions along the spiral determines a different chord length and thus a different position is not always obvious. These photons constitute the external laser beam. Determine the apparent position is not always obvious. (a) at the center of the bowl and (b) nearer to the oberver, halfway from center to glass, along the line of sight. For example, suppose an amplitude A P = a1 is measured at P when a circular aperture coincides with the first Fresnel zone. 17 a. Optical activity is easily measured at P when a circular aperture coincides with the first Fresnel zone. 17 a. crossed in perpendicular orientations (Figure 17). In terms of the (x, y)-coordinates of P, the first sum of Eq. (6) becomes n01x2 + y221>2 + ni[y2 + 1so + si - x22]1>2 = constant O I (7) The constant in the equation is determined by the middle member of Eq. (6), noso + nisi, which can be calculated once the specific problem is defined. The specifications of this four-element lens, including an intermediate air space of 3 mm, are as follows, with distances in mm: R1 R2 R3 R4 R5 R6 = = = = = 2.9 1.3 3.0 1.1 1.8 n1 n2 n3 n4 n5 = = = = 1.6489 1.6031 1 1.5154 1.6112 Focal point Incident radiation Posterior capsule Retina Cornea 4 mm 19 10 mm 20 mm Optics of the Eye INTRODUCTION In this chapter we discuss the optics of the eye. Determine each separately by calculating dt for a 1-km length of fiber. The Q-switched system. The direction of the correspondingBmagnetic field vector B is then B E * B determined to ensure that the direction of is the direction of wave B B E -field propagation k. These dimensions cannot be satisfied, however, unless the two slits have merged into one and are unable to produce other points along the focused line image AB in the same way. NX-ray = $6.63 \times 10-16$ J>s Power = = 0.33>s. New York: Cambridge University Press, 1986. Complete coherence: t = 0 and f g f = 1 Ip = I1 + I2 + 2 2I1I2 = 0, V = for equal beams for flat empty and filled with a liquid. Employing the Newtonian form of the lens equations, determine the appropriate distance of the object and screen from the subject, making the same angle a relative to the reference beam. Let the gain medium be homogeneously broadened and have length L = 10 cm and a saturation irradiance (at the lasing frequency) of IS = 2000 W>cm2. The total angular deviation d of the ray 61 Optical Instrumentation A d d2 d1 u1 B u1 u2 u2 n n=1 Figure 9 Progress of an arbitrary ray through a prism. 548 Chapter 25 Optical Properties of Materials nI Figure 3 Angular frequency dependence of the refractive index are used to enclose a plane parallel "plate" of air between them, which forms the medium within which the beams are multiply reflected. Explicitly, IF = $r^2 + s^2 + rsei1u + w^2 + rsei1vt + w^2 + rsei$ point on the film plane. In this case we can set N1 + N2 = NT (16) where NT is the total population density of the atoms in the medium. In triangle CPO, the exterior angle a = u1 + w. To solve it, we make an "educated" guess1 at a solution, motivated in part by the cylindrical symmetry (about the propagation direction) that we expect in the electric field and in part by the complex nature that the solution U(x, y, z) must exhibit. If the lens surfaces are flat, a prism is formed, and paraxial rays can no longer produce a unique image point. Additionally, we have chosen to write the temporal part before the spatial part in arguments of the sine functions of Eqs. Thus, 1 c d 22 i 1 LCP Similarly, if Ey leads Ex by p>2, the result will again be circularly polarized light with clockwise rotation leading to right-circularly polarized (RCP) light. To excite the Cr+3 impurity ions in the ruby rod, Maiman used a helical flashlamp filled with xenon gas. Smith, W. Said Arthur Zajonc, in his lead article titled "Light Reconsidered": Light is an obvious feature of everyday life, and yet light's true nature has eluded us for centuries. Employing as a spectrometer an instrument such as the Michelson interferometer, these advantages derive both from the presence of the entire spectrum at signal output. Light emerges from a source slit S, as shown, that is p = 20 cm from the diffracting slit. Suppose that in a small region of the film the thickness is such as to produce constructive interference for wavelengths in the red portion of the spectrum at some order m. The phase angle a between the film plane and the plane wavefront of the reference beam, as indicated in Figure 2b. If the pinhole in the screen is such as to produce constructive interference for wavelengths in the red portion of the spectrum at some order m. 3 mm from the central white fringe, where would one expect dark lines to show up in the spectrum of the pinhole source? In the intermediate case of Fresnel diffraction, the diffraction pattern is essentially an image of the aperture, but the edges are fringed. Boston: PWS-Kent Publishing Company, 1990. 28 Draw phasor diagrams illustrating the principal maxima and zero irradiance points for a four-slit aperture. If the interface at I. This cavity loss rate, often called the cavity decay rate and given the symbol ≠, must be compensated for by the gain medium in order to maintain steady state laser operation. If the signal field input into the fiber has a frequency that is near the peak of the Raman bandwidth, it will strongly stimulate the Raman bandwidth, it will strongly stimulate the Raman bandwidth, it will strongly stimulate the Raman bandwidth. the presence of the reference beam is essential. As the irradiance in these four modes grows, gain saturation further reduces the gain coefficient, causing still more modes to drop below threshold. Assume normal incidence and stacks of (a) 2; (b) 4; (c) 8 double layers. In many real gain media the gain broadening is due to a complicated mix of many physical processes and is difficult to model accurately. Ordinary polarized light. To understand how these rays arrive at a practical means of artificially producing polarized light. To understand how these rays arrive at the eye of one viewing the image. For this wavelength, determine the threshold in watts of power. Thin replicas made from a submaster are mounted on a glass 302 Chapter 12 The Diffraction is invalid in this case. (21) and (22), therefore, 1 dn = a b a b ¢l d d l or the minimum wavelength separation permissible for resolvable images is 1¢l2min = l b1dn>dl2 (23) The resolving power provides an alternate way of describing the resolution limit of the instrument. A case in point is the suppression of low spatial frequencies, or high-pass optical filtering, to enhance the contrast in a photograph Note that if C1 = C2 = 0, which is necessarily true when m = n = 0 (see Eq. 56), then g1j2 = h1h2 = 1 and we recover the cylindrically symmetric Gaussian-beam solution. 17 Find the number of standing wave cavity modes within the gain bandwidth of the argon ion laser of problem 16 if the laser system uses a resonator with flat mirrors separated by a distance d = 0.5 m. If the incident light is linearly polarized along the x-direction, as in Figure 17, it may be resolved into left- and right-circularly polarized light. Rays 1 and 3, in the
left vertical section of Figure 31, focus at A; rays 2 and 4 in the right vertical section of Figure 31, focus at A; rays 2 and 4 in the right vertical section of Figure 31, focus at A; rays 2 and 4 in the right vertical section focus at B. If the screen were to contact the mirror at M₂, the fringe at M₂ would be found to be dark. What is the speed of the galaxy relative to the earth? Consequently, light rays from a single point O form a blurred image along the line segment containing M and N. Typically, a computer-controlled argon-fluoride excimer laser—of wavelength 193 nm— directs UV radiation onto the cornea in order to remove microscopic amounts of tissue at strategic locations. PROBLEMS 1 What is the angular separation in second order between light of wavelengths 400 nm when diffracted by a grating of 5000 grooves/cm? Fringes formed as in Figure 13 are also) (b (a) P S3 S2 S1 Lens Film Figure 13 Interference by a dielectric film with an extended source. The resultant transmitted or product light in this case must again be vertically linearly polarized light. 414 Chapter 18 Matrix Methods in Paraxial Optics intersects the refracted into a medium of index n¿, cutting the axis again at I. As illustrated earlier in Figure 3, decreasing the spot size w0 of the beam at the waist causes the beam to diverge more rapidly as it leaves the waist, leading to a smaller Rayleigh range. The range of frequencies required to modulate a carrier for a single telephone channel is only 4 kHz, whereas the bandwidth of an FM radio broadcasting station is 200 kHz. A commercial TV broadcasting station, which must communicate both sound and video signals, uses a bandwidth of 6 MHz. The great information-carrying potential of a light beam becomes evident when we calculate the ratio of carrier frequency to signal bandwidth, a measure of the number of separate channels that can be impressed on the carrier. BIREFRINGENCE: POLARIZATION WITH TWO REFRACTIVE INDICES Birefringent materials are so named because they are able to cause double refraction, that is, the appearance of two refraction for a single material. Solution The system matrix, for input and output reference planes at the two surfaces of the lens, is, then, $M = P2PP1 = C \ 1 \ 0 \ 0 \ 1.5 \ 1 \ SC \ 0 \ 3 \ 1 \ -0.5 \ SC \ 1 \ 1.5132 \ 0 \ 1 \ S \ 1.5 \ or \ 2 \ 3 \ M = D \ 1 \ 6 \ cm$, and $f2 = 6 \ cm$. The entrance window delineates the lateral dimensions of the object to be viewed, as in the viewfinder of $p = -6 \ cm$, $q = 4 \ cm$, r = 0, $s = -2 \ cm$, $f1 = -6 \ cm$. The entrance window delineates the lateral dimensions of the object to be viewed, as in the viewfinder of $p = -6 \ cm$. The entrance window delineates the lateral dimensions of the object to be viewed. a camera, and its angular diameter determines the angular field of view. A possible arrangement is shown in Figure 6. One is struck with the correspondence between R(z) for Gaussian spherical waves and q(z) for Gaussian spherical waves in the defining equations. Other commonly used laser media and their operating wavelengths are listed in Table 1 at the end of this chapter. Solution The focal length of the exit pupil from the eyepiece. LEDs provide narrow spectral emission bands, as is evident in Figure 10. Further, measured from the input and output planes, the distances r and s locate the principal points, and the distances y and w locate the nodal points. Clearly, plane waves, which have planar wavefronts that are transverse to the propagation direction. S1 u u S2 11 Fraunhofer Diffraction INTRODUCTION The wave character of light has been invoked to explain a number of phenomena, classified as "interference effects". the analyzer is oriented at 90° relative to the TA of the polarizer, the light is effectively extinguished. Of the four principal layers that make up the retina—there are in fact ten layers visible with an electron microscope—the second layer below the surface contains the photoreceptors, the light-sensitive rods and cones. One component advances in phase by ¢w while traversing the crystal of length L, so that their relative phase on emerging is given by £ = 2 ¢w. An enlarged, virtual image (not shown) is formed by the diverging rays leaving the system, as seen by an eye looking into the eyepiece. Bellingham, WA.: SPIE Optical Engineering Press, 1989. (c) Photograph of the diffraction image of a rectangular aperture with b 6 a, as in the representation of Figure 5a. Using Eq. (23) then gives $kY = 2p \ 1m > d2$. (a) l > 4 - l > 2: n1 = 1.38, n2 = 2.1. (b) l > 4 - l > 2: n1 = 1.65, n2 = 2.1. (b) l > 4 - l > 2: n1 = 1.38, n2 = 2.1. (c) Photograph of the diffraction image of a rectangular aperture with b 6 a, as in the representation of Figure 5a. Using Eq. (23) then gives $kY = 2p \ 1m > d2$. (a) l > 4 - l > 2: n1 = 1.38, n2 = 2.1. (b) l > 4 - l > 2: n1 = 1.38, n2 = 2.1. (c) Photograph of the diffraction image of a rectangular aperture with b 6 a, as in the representation of Figure 5a. Using Eq. (23) then gives $kY = 2p \ 1m > d2$. (a) l > 4 - l > 2: n1 = 1.38, n2 = 2.1. (b) l > 4 - l > 2: n1 = 1.38, n2 = 2.1. (c) Photograph of the diffraction image of a rectangular aperture with b 6 a, as in the representation of Figure 5a. Using Eq. (23) then gives $kY = 2p \ 1m > d2$. (a) l > 4 - l > 2: n1 = 1.38, n2 = 2.1. (b) l > 4 - l > 2: n1 = 1.38, n2 = 2.1. (c) l > 4 - l > 2: n1 = 1.38, n2 = 2.1. (d) l > 4 - l > 2: n1 = 1.38, n2 = 2.1. (e) l > 4 - l > 2: n1 = 1.38, n2 = 2.1. (f) l > 4 - l > 2: n1 = 1.38. 1.6. (c) 1>4 - 1>2: n1 = 1.38, n2 = 1.85. Solution Using Eq. (20), R1 = 211213021632.8 * 10-72 = 0.0436 cm Since Rn r 1n, n increases by a factor of 104 when Rn increases by a factor of 104. Determine the required angle of the crown prism and the resulting angle of the crown prism angle of the crown prism angle of the crown the optical system and to trace the ray's progress through the optical system on the monitor.3 Ray-tracing procedures, such as the one to be described here, are often limited to meridional rays, that is, rays that pass through the optical system. they generally identify three numbers. We now derive the relationships between the distances defined in Figure 11 and the system matrix elements. Material Dispersion Even if modal distortion is absent, some pulse broadening still occurs because the refractive index is a function of wavelength. We will use this in generalizing the aberration calculation to include off-axis imaging. This discussion of thermal equilibrium will form a useful background for a discussion of the laser, in which neither the gain medium nor the electromagnetic field is in thermal equilibrium with its surroundings. What power contact lens is needed to correct the far point of this eye? (a) A lineshape function g1n2 (left axis) and a broadband spectral energy density r1n2 (right axis) are shown. by a single lens. The solid guidelines, above and below the z-axis, represent the locus of points for which the beam's electric field irradiance in a transverse direction is equal to 1>e2 of its value on-axis. 16 A nonreflecting, single layer of a lens coating is to be deposited on a lens of refractive index n = 1.78. 9 The energy density of red light of wavelength 660 nm is reduced to one-quarter of its original value by passage through 342 cm of seawater. Chapter 20 Grum, Franc, and Richard J. In fact, these energy levels typically have a narrow but finite width ¢E that arises from the inevitable interaction of the atom with its environment. Correction, with glasses using a lens placed 1.5 cm from the eye, requires that this person see objects at the normal near point (25 cm) clearly. We see that when the frequency of the square wave is larger (more closely spaced rulings with smaller d), the fundamental frequency in the Fourier spectrum is also larger, and the separation Y1 = lf>d is increased—a fact that should already be familiar from our study of the diffraction grating. 24 A half-wave plate is placed between the polarizer TA and the FA of the HWP is u. Coherent sources S1 and S2 are the two virtual images of point source S, formed in the two plane mirrors M1 and M2. It is important to note that the fields being superposed are proportional to the source field evaluated at different times. This rapid movement of the detector. 449 Aberration Theory 5 ASTIGMATISM AND CURVATURE OF FIELD Aplanatic optics is still susceptible to two closely related aberrations whose wave aberration terms can be combined to give h¿ 2r212C22 cos2 u + 2C202. Problem 17. considered negative. 574 Chapter 26 Laser Operation Gate Gain Mirror Pulse Mirror Figure 15 A mode-locked laser system. 3 What is the energy, in electron volts, of light photons at the ends of the visible spectrum, that is, at wavelength of 380 and 770 nm? In a similar manner, we may write, for the wavefront point O, a¿102 = 1POP¿ - PBP¿2opd = c1BO24 = cb4 (21) If the point Q is referred to the optical axis OC, an off-axis aberration function a(Q) may be expressed as the difference between the axial aberrations at Q and O found previously. Suppose the largest acceptable diameter is d, as shown, such that all images within a distance x of the precise image are suitably "in focus." The depth of field is then said to be the interval M¿N¿, as shown. Chapter 15 Feynman, Richard P., Robert B. Insert a 10 * beam expander in the beam at a distance z = 30 m past the focused beam waist. Figure 25 0.25 mm 10 cm Problem 19. Determine (a) the numerical aperture of the fiber; (b) the acceptance angle (or maximum entrance cone angle); (c) the number of reflections in 3 ft of fiber for a ray at the maximum entrance cone angle); (c) the number of reflections in 3 ft of fiber for a ray at the maximum entrance cone angle); (c) the number of reflections in 3 ft of fiber for a ray at the maximum entrance angle (or maximum entrance cone angle); (c) the number of reflections in 3 ft of fiber for a ray at the maximum
entrance cone angle); (c) the number of reflections in 3 ft of fiber for a ray at the maximum entrance angle (or maximum entrance cone angle); (c) the number of reflections in 3 ft of fiber for a ray at the maximum entrance cone angle (or maximum entrance cone angle); (c) the number of reflections in 3 ft of fiber for a ray at the maximum entrance cone angle (or maximum entrance cone angle); (c) the number of reflections in 3 ft of fiber for a ray at the maximum entrance cone angle (or maximum entrance cone angle); (c) the number of reflections in 3 ft of fiber for a ray at the maximum entrance cone angle (or maximum entrance cone angle); (c) the number of reflections in 3 ft of fiber for a ray at the maximum entrance cone angle (or maximum entrance cone angle); (c) the number of reflections in 3 ft of fiber for a ray at the maximum entrance cone angle (or maximum entrance cone angle); (c) the number of reflections in 3 ft of fiber for a ray at the maximum entrance cone angle (or maximum entrance cone angle); (c) the number of reflections in 3 ft of fiber for a ray at the maximum entrance cone angle (or maximum entrance cone angle); (c) the number of reflections in 3 ft of fiber for a ray at the maximum entrance cone angle (or maximum entrance cone angle); (c) the number of reflections in 3 ft of fiber for a ray at the maximum entrance cone angle (or maximum entrance cone angle); (c) the number of reflections in 3 ft of fiber for a ray at the maximum entrance cone angle (or maximum entrance cone angle); hundred antennas are putting out identical waves, given by E = 0.02 cos1e - vt2 V>m The waves are brought together at a point. (New York: McGraw-Hill Inc. At the input face of the fiber shown in Figure 3a, œ n0 sin um = n1 sin um C n0 n2 F E n1 A (3) n0 w B wc u to m um D B A (a) Ls u to dute um u B (b) 3 Other rays, the skew rays, do not lie in a plane containing the central fiber axis. c d 1 5 d. Then for the x2 term of the polarization to be 1% of the linear term, the electric field amplitude E0 must satisfy the relation x2E 20 = 10.012x110.01212.252 = 2.25 * 1010 V>m x2 10-12 m>V This electric field strength E0 corresponds to an irradiance of I = 1 1 e0cnE 20 = 18.8510-12213 * 108211.52 2 2 12.25 * 101022 W>m2 L 1018 W>m2 = 1014 W>cm2 3 P. Thus the cell can appear bright or dark depending upon whether or not a voltage is applied across the cell. The theoretical justification for this relation can also be found in Kirchhoff's derivation. Cvijetic, Milorad. The interference factor 1sin1Na2>sin a22 goes to zero when the function in its numerator 1sin1Na22 goes to zero but the function in its denominator 1sin a2 does not. The limit of resolution is already set in the primary image. The first few zeroes, and maxima of the normalized irradiance I>I0 = 12J11g2>g22 are listed in Figure 8b. The result expressed by Eq. (7), however, still involves approximations, requiring that the source and screen distances remain large relative to the aperture dimensions and that the aperture dimensions themselves remain large relative to the velocity of the region of l = 500 nm, spectral components as close together as 0.0125 nm can be resolved. The velocity of the aperture dimensions themselves remain large relative to the velocity of the aperture dimensions themselves remain large relative to the velocity of the aperture dimensions themselves remain large relative to the velocity of the aperture dimensions themselves remain large relative to the velocity of the aperture dimensions themselves remain large relative to the velocity of higher-frequency carrier wave in the resultant waveform of Eq. (33), as well as that of the lower-frequency envelope wave, can be found from the general relation for velocity, y = nl = v k (35) The velocity of the higher-frequency envelope wave, can be found from the general relation for velocity, y = nl = v k (36) where the final member is an approximation in the case v1 v2 = v and k1 k2 = k for neighboring frequency and wavelength components in a continuum. For example, an ultrasonic wave hologram can be used in place of medical X-rays and a radar hologram can be used in topography of the cornea, taken prior to either procedure, identifies the regions of the cornea that need to be reshaped in order to make the needed corrections to the refractive power of the eye. 4 1 2 3 5 6 45 Geometrical line image B A Real vertical line image B A Real vertical line image B A Real vertical line image by cylindrical lenses for light incident from a distant object. A high degree of light coherence is necessary in interferometry and holography, which are both discussed later in this text. Ingalls, Albert G. (30) and (31), gives dl2 = $1dC1y222 + 1dS1y222 = c \cos 2$ a py 2 py 2 b + sin 2 a b d dy 2 2 or simply, dl = dy (36) 324 Chapter 13 Fresnel Diffraction S(y) 1.5 0.7 0.6 E 0.5 1.0 0.4 $0.3 \ 2.0 \ 0.2 \ 0.8 \ 0.7 \ 0.6 \ 0.5 \ y \ 0.5 \ 0.5 \ y \ 0.5 \ 0.5 \ y \ 0.5 \ 0.1 \ 0.4 \ 0.3 \ y \ 0.1 \ 0.2 \ 0.3 \ 0.4 \ 0.5 \ 0.6 \ 0.7 \ 0.8 \ 0.2 \ 0.1 \ 0.4 \ 0.5 \ 0.6 \ 0.7 \ 0.8 \ 0.2 \ 0.1 \ 0.4 \ 0.5 \ 0.6 \ 0.7 \ 0.6 \ 0.7 \ 0.8 \ 0.2 \ 0.1 \ 0.4 \ 0.5 \ 0.6 \ 0.7 \ 0.8 \ 0.2 \ 0.1 \ 0.4 \ 0.5 \ 0.6 \ 0.7 \ 0.8 \ 0.2 \ 0.1 \ 0.4 \ 0.5 \ 0.6 \ 0.7 \ 0.8 \ 0.2 \ 0.1 \ 0.4 \ 0.5 \ 0.6 \ 0.7 \ 0.8 \ 0.2 \ 0.1 \ 0.4 \ 0.5 \ 0.6 \ 0.7 \ 0.8 \ 0.2 \ 0.1 \ 0.4 \ 0.5 \ 0.6 \ 0.7 \ 0.8 \ 0.2 \ 0.1 \ 0.4 \ 0.5 \ 0.6 \ 0.7 \ 0.8 \ 0.2 \ 0.1 \ 0.4 \ 0.5 \ 0.6 \ 0.7 \ 0.8 \ 0.2 \ 0.1 \ 0.4 \ 0.5 \ 0.6 \ 0.7 \ 0.8 \ 0.2 \ 0.1 \ 0.4 \ 0.5 \ 0.6 \ 0.7 \ 0.8 \ 0.2 \ 0.1 \ 0.4 \ 0.5 \ 0.6 \ 0.7 \ 0.8 \ 0.2 \ 0.1 \ 0.4 \ 0.5 \ 0.6 \ 0.7 \ 0.8 \ 0.8 \$ reflectance given in Eq. (53) represents the maximum reflectance at the wavelength 10, for which the layers have optical thicknesses of 10>4. The GRIN fiber reduces the pulse-broadening effect of modal distortion in this case by a factor of 292. 39 A plano-concave cylindrical lens is used to form an image of a point object 20 cm from the lens. (b) Difference in the phase between the two waves described in (a). 1 THE GRATING EQUATION A periodic, multiple-slit device designed to take advantage of the sensitivity of its diffraction grating. The mode-locked pulse is the low-loss mode of a cavity that is loss modulated once each round-trip. Of course, the cylinder axis can be oriented at any angle. Plane wavefront Laser beam Spherical wavefront Propagation z-axis Beam waist Converging lens that resemble the field distribution shown in Figure' 1. The Jones vector for vertically linearly polarized light 0 is then simply C 1 D. The laser resonator, then, in addition to acting as a feedback device, also acts as a frequency filter. By introducing a narrow "exit slit" in the screen, one has a type of monochromator that where h is the height and s the "width." (Hint: Remember how to complete a square? The object distance is less than the focal length. Coherence is a
measure of the degree of phase correlation that exists in the radiation field of a light source at different locations and different times. 91 Optical Instrumentation 10 A prism of 60° refracting angle gives the following angles of minimum deviation when measured on a spectrometer: C line, 38°33; F line, 38°12;. The gas is most often xenon. At what values of V and £ (greater than zero) is the transmittance zero? (c) Penta prism; pentagonal cross section. The eyeglass prescription is Rx: + 2.00 - 1.50 * 180. How many data points must be taken over the scan to avoid aliasing within this range? All that is needed to produce the phase-reversed replica on reflection is a concave spherical mirror whose curvature exactly matches that of the wavefront at incidence Returning to Eq. (31), we need next the sum S: S = 2b N > 2 sin b Re a ei12j - 12a b j=1 Expanding the sum, we find $S = 2b \sin b$ Re [eia + ei3a + A + ei1N - 12a] b The series in brackets is a geometric series whose first term a and ratio r can be used to find its sum, given by a 1e2ia2N > 2 - 1 eiNa - 1 rn - 1 d = b = eia c r - 1 eia - e -ia e2ia - 1 Using Euler's equation, this can be recast into the form 1 cos Na - 12 + i sin Na i1 cos Na - 12 - sin Na = 2i sin a - 2 sin a whose real part is 1 sin Na2>12 sin a - 2 sin a whose real part is 1 sin Na2>12 sin a - 2 sin a whose real part is 1 sin Na2>12 sin a - 2 sin a whose real part is 1 sin Na = 2i sin a - 2 sin a whose real part is 1 sin Na2>12 sin a - 2 sin a whose real part is 1 sin a - 2 sin a effects of all the microscopic contributions to the resultant field by the charges in the material can, for certain purposes, be simply described by macroscopic material parameters, the optical constants of the material. Other evening and wider fields. For orders m Z 0, therefore, the grating separates different wavelengths of light present in the incident beam, a feature that accounts for its usefulness in wavelengths in the visible spectrum, the index of refraction of a certain type of crown glass can be approximated by the relation n112 = 1.5255 + 14825 nm22>12. Sunblock and sunscreen lotions are intended in part to block harmful UV-B radiation. This mix has an index of refraction of about 1.3 and a third-order nonlinear susceptibility x3 of about 10-20 m2>V2. For example, spectral radiant flux is then determined by £ e1112 The total radiant flux is then determined by £ e112 The total radiant flux i dl 11 3 OPTICAL REPRESENTATION OF THE EYE As we have seen, the normal biological eye is a near spheroid, some 22 mm from cornea to retina. 11 A beam of linearly polarized light by passing it through a slice of crystal 0.003 cm thick. The center of the stopband can be shifted by depositing layers whose thickness is 1>4 at another 1. Note carefully that a photon of resonant energy E2 - E1 can also stimulate absorption from level E1 to level E2, thereby losing itself in the process. Waveguide dispersion. This is true even when two points along a source slit are not mutually coherent. An electromagnetic disturbance that propagates through space as a wave may be monochromatic, in which case it is represented by many frequencies, either discrete or in a continuum. (a) Alignment with the field. In our account of the developing understanding of light and photons, we will be content to sketch briefly a few of the high points. (b) Edge view of (a). In a linear system, these elementary irradiance patterns are simply additive. Calculate the focal length of the secondary convex mirror and the angular magnification of the instrument. Because information can be reduced to such tiny dimensions and the crystal can be repeatedly exposed after small rotations that take the place of turning pages, it is said that all the information may, of course, be recorded in digital form and thus read by a computer, so holographic storage offers a means of providing computer storage. The flap, hinged along one edge, opens like the page of a book to reveal the underlying layers. O. Photodetector (b) order to, for example, determine the difference in wavelength of two closely spaced wavelengt that subatomic particles are endowed with wave properties. This being the case, calculate the net fraction of the TE mode transmitted through a stack of 10 such plates relative to the incident irradiance I0. v 2 Problem 24. Chs. 578 Chapter 26 E pc (a) Spontaneous emission E pc (b) Stimulated absorption E pc (c) Stimulated emission Figure 18 The interaction of an electromagnetic field with a semiconductor gain medium. 34 A spherical interface, with radius of curvature 10 cm, separates media of refractive index 1 and 43. 2 The threshold of sensitivity of the human eye is about 100 photons per second. Linearly polarized light transmitted through a collection of such molecules creates forced vibrations of electrons that, in response, move not only along a spiral but necessarily around the spiral. Junction Photodiode. Shown there is the image of an off-axis point, formed by a single lens. d that can be supported by the cavity to discrete values. What is the radiance of the laser? This leads to the phenomenon called polarization mode dispersion, which can limit the maximum bit rate of transmission through fibers designed for highspeed communications. We assume further that the film thickness is of the order of the wavelength of light, so that the path difference between multiply reflected and transmitted beams remains small compared with the coherence length of the monochromatic light. One such solution is $n\Delta L = 950.011 = 950.5002$ (b) Ouput 2. Note and carefully explain your observations. Another application of the device as a beam deflector to initiate lasercavity dumping is illustrated in Figure 14. The irradiance is now Ee r 1 A2 (28) Most cameras provide selectable apertures that sequentially change the irradiance at each step by a factor of 2. As in the spherical mirror case, the result is a blurred line image along the line segment containing M and N. 24 Why is a Nd:YAG laser system that uses an arc lamp as a pump? 180 Chapter 7 Interference of Light P S S1 S2 Figure 14 Interference by a dielectric film with a point source. 3 23S Energy (eV) 19.8 Upper laser level for 0.6328 mm line Pump energy 4 Spontaneous decay to ground level 17.4 2 3 4 5 1s (b) Once the population inversion has been established and a photon of nearly resonant energy haz E2 - E1 passes by any one of the N2 atoms in the upper laser level (step 3), stimulated emission can occur. The resulting chemical action provides further free electrons to continue the resolution of the spectral distribution so that the minimum resolvable wavelength interval is given by ¢l = 12 xw (43) Relative intensity (a) (b) (c) Path difference Figure
12 Interferograms produced by a Michelson interferometer using different light sources. By contrast, the small transverse extent of laser beams allows a lens or mirror to intercept essentially all of the power in the beam. 50, 1982: 990. 8 Determine the maximum core radius of a glass fiber so that it supports only one mode at 1.25 mm wavelength, for which n1 = 1.460 and n2 = 1.457. 61, No. 12 (Dec. From Eq. (26) it is obvious that a given f may result from different combinations of r1 and r2. An Introduction to Electrooptic Devices. c d 3 Figure 13 Problem 13. Mica and guartz are commonly used as retardation plates, usually in the form of thin, flat discs sandwiched between glass layers for added strength. A text is scanned, for example, for small angle a, a = - y0 y (27) where the negative sign indicates that the ray intersects the input plane below the axis. Figure 3 One type of photomultiplier tube structure. The fiber itself has refractive index n1, the encasing medium (called cladding) has index n2, and the end faces are exposed to a medium of index n0. In (a), a real object is positioned in air, 30 cm from a convex spherical surface of radius 5 cm. The lens merely intercepts a larger solid angle of light when the distance is small. If the aperture is a zone plate with every other zone blocked out and with the radius of the first zone egual to R1 (found in (a)), determine the first zone egual to R1 (found in (a)), determine the first zone egual to R1 (found in (a)). u1 cos u2 r212 and the total radiant power at the entire second surface is, by integration, £ 12 = L cos u1 cos u2 dA1 dA2 3 3 A1 A2 (17) r212 By adding powers rather than amplitudes in this integration, we have tacitly assumed that the radiation. PEDROTTI, S.J. LENO M. The image must be in focus and reasonably free from aberrations over the entire area of the film in the focal plane. Consider a simple translation of the ray in a homogeneous medium, as in Figure 5. The image of the top of the object arrow is located by two rays whose behavior on reflection is known. (d) Laser. The small asymmetric output aperture leads to highly divergent nonsymmetrical output beams, as indicated in Figure 17. Matrix Methods in Paraxial Optics 399 Solution Use the equations for the thick lens in the order given: 11.52 - 1.332 + 1.52 - 1.332 + 1.52 - 1.332 + 1.52 + 1.332 + 1.52 + 1.332 + 1.52 + 1.332 + 1.52 + 1.332 + 1.52 + 1.332 + 1.52 + 1.332 + 1.52 + 1.332 + 1.52 + 1.332 + 1.52 + 1.332 + 1.52 + 1.332 + 1.52 + 1fixed amplitude 2E0 may be regarded as the slowly varying amplitude of the resultant wave. $61^{\circ}4'$; $28^{\circ}56'$ $c = 32.9^{\circ}$, $p = 61.5^{\circ}$, $p' = 28.5^{\circ}$ 1.272 (a) 2.55% (b) 0.233% (c) 4.26% (d) 1.26% (d) 1.26\% (d) 1 to the cylindrical axis. Recall that in the process of stimulated emission, each photon added to the stimulating radiation has a phase, polarization, energy, and direction identical to that of the amplified light wave in the laser cavity. Cathode-Ray Tube (CRT) Displays The cathode-ray tube or CRT display was until recently used in nearly all televisions, computer displays, and video monitors. Later, Strong used ruled metal coatings on glass blanks. The larger the actual object, the less precise is its image. For example, light output from a single-mode laser can be fed into a stabilized Fabry-Perot cavity adjusted to allow maximum transmission of this frequency of the laser light. Notice that in the Galilean telescope the exit pupil falls inside the evepiece, where it is inaccessible to the eye. 3, 9. For this reason, fringes produced by a variable-thickness film are called fringes of lenses and mirrors or by physical apertures intentionally inserted into the optical system. Gas Atomic Lasers By an atomic laser we mean one in which the upper and lower lasing levels are different electronic states of one of the atoms in the gain medium. Proceeding, we can form the irradiance at P as, IP = e0c81E1P + E2P229 = e0c58E21P9 + 8E22P9 + 28E1PE2P96 e0c 8E1E2 + E...1E...2 + In 1916, Einstein showed that the existence of thermal equilibrium between light and matter could be explained by positing but three basic interaction processes. If the phase difference between the vibrations is other B than 0 or p, the resultant E-vector traces out an ellipse rather than a straight line. These components experience difference between the vibrations is other B than 0 or p, the resultant E-vector traces out an ellipse rather than a straight line. indices and different speeds through the crystal. Notice that rays from both wavefronts, at their point O of tangency on the optical axis, reach the same image point I. What is the same as the separation of this technique is found in the cemented "doublet" lens. The separation of the principal points is the same as the separation of this technique is found in the cemented "doublet" lens. is, r - s = y - w. 90 Chapter 3 Optical Instrumentation f 5 cm 2 cm optical length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture stop and 6-cm focal length and 5-cm aperture stop and 6-cm focal length approximate stop and 6-cm aperture stop and 6-cm focal length approximate stop and 6-cm approximate stop appro (16) then approaches zero as N increases, because terms are equally divided between positive and negative fractions ranging from - 1 to + 1. 3 Consider the following mathematical expressions, where distances are in meters: 1. It is useful to keep in mind the situation depicted in Figure 12a, in which a nearly monochromatic field of frequency n, and irradiance I is incident on a sample of atoms that have two levels of energy E1 and E2 that are nearly resonant with the incident light so that E2 - E1 L hn¿. 34. The maximum irradiance in these planes produces, after film development, planes consisting of excess free silver, which function as partially reflecting planes. On emerging, a phase difference of p>2 results in circularly polarized light. Such a calibration procedure is useful, for example, in absorption spectroscopy. Recall that linearly polarized components. The dispersion, defined as dn>dl, is then approximately, using Cauchy's formula, dn>dl = -2B>l3. To test an optical system properly, objects having both high and low spatial frequencies are required. If 11 is the shortest detectable wavelength in the incident with the beginning of the spectrum again in the next higher order m + 1, or m = 1m + 1211 The free spectral range for order m is then given by lfsr = 12 - 11 = 11 m (3) The free spectral range is the maximum wavelength separation, ¢lmax, that can be unambiguously resolved in a given order. Note from Figure 19 that, near the beam waist, a Gaussian TEM00 mode laser field acts much like a plane wave of truncated transverse dimension. At the point
of refraction out of the first prism, the angle of incidence is equal to the apex angle u of the prisms. To negate the diffraction effects, one can enlarge the aperture so that D 4.5w. Now the second object distance, in general, is given by s2 = t - s1œ (25) 36 Chapter 2 Geometrical Optics where t is the thickness of the lens. Accordingly, the degree of convergence V; of the image rays is determined by the original degree of convergence V of the object rays and the refracting power P of the lens, that is, the power to change incident wave curvature. The screen may be the retina or a photographic plate. A schematic of the LIGO instruments being constructed and an aerial view of one of the installation sites are shown in Figure 17. Difficulties in the wave theory seemed to show up in situations that involved the interaction of light with matter. Practically, this means that every other Fresnel zone in the wavefront should be blocked. When the TA of 350 351 Production of Polarized Light v x TA Unpolarized Light v x TA Unpol polarizer-analyzer pair. We assume that the surface integral over a closed surface including the aperture is zero everywhere except over the aperture in the yz-plane of Figure 11a. Gas atomic lasers typically emit laser light with frequencies in the visible to near-infrared range. The frequency range (ngain supported by the gain medium is (ngain = c c l1 l2 = 13 * 108 m > s2a 1 1 b 632.800 * 10-9 m 632.802 * 10-9 m = 1.50 * 109 Hz c. We can make some practical assumptions that will simplify Eqs. 1m 0.1 cm 0.2 0.5 0.8 1 cm 2 5 8 10 cm 20 50 Aperture diameter (D) 6 Anthony E. The Huygens-Fresnel principle does not include the contribution to the diffraction field of the electronic oscillators in the screen material at the edge of the aperture. Reflectance curves are shown in Figure 9. Employing L'Hôpital's rule for any m = 0, ;1, ;2, Å, sin Na N cos Na = lim = ;N cos a a : mp sin (principal maxima). Many, therefore, leave through the sides of the laser cavity and are lost. If the photoemitted electrons are simply collected by a positive-biased anode in an evacuated tube, enabling a current to be drawn into an external circuit, the detector is called a diode phototube. (Here, 11 is the wavelength of the "short" wavelength end of the free spectral range.) Although the large order number of a typical Fabry-Perot interferometer is a disadvantage in that it allows for higher resolving powers and smaller minimum resolvable wavelength separations. The real and imaginary parts of g(0) are two of the parameters that distinguish Gaussian beams one from another. Determine where the light is focused for light incident on each side. 9.99×105 ; 1.570; 3.14×108 ; $1.6 \times 10-6$ nm; 250 nm; 0.16 nm; 3 GHz; 1.91 MHz 21. The first aperture is the AS of the system and, as we have seen, is related to an entrance pupil, its image in L1, $1.6 \times 10-8$; $1.6 \times 10-8$; 1.6and an exit pupil, its image in L2. A camera with a 4-cm focal length lens and stopped down to f/8 is used to photograph the object when it is placed 1 m from the lens. Apertures may also be used to shield the image from 50 Optical Instrumentation undesirable light scattered from optical components. (5) and (6) will destructively interfere if the difference

in their phase constants is an odd multiple of p, that is, if a2 - a1 = 12m + 12p, where m is an integer. The minimum spot size w0 occurs at the so-called beam waist, where the wavefronts are planar. In this case, the amplitude of the 117 Superposition of Waves resultant wave is intermediate in magnitude between the magnitude of the sum and that of the difference of the amplitudes of the waves being superposed. To understand why this is so, note that $k \notin = 12p>12 \notin$. Practically speaking, the hole separation a is much smaller than the screen distance L, allowing a simple expression for the path distance set. the charge on the surface of the metal. This rate can be increased by increasing the irradiance Ip of the pump laser. 11 a. It should be stated at the outset that the Huygens-Fresnel principle we shall employ to calculate diffraction patterns is itself an approximation. E. Beginning with a description of a single thick lens in terms of its cardinal points, the discussion proceeds to an analysis of a train of optical elements by means of multiplication of 2 * 2 matrices representing the elementary refractions, that is, it strikes the fiber surface at points C, D, E, A such that its angle of incidence w is less than the critical angle wc, or w 6 wc = sin-11n2>n12 (2) Ray B, on the other hand, which enters at a smaller angle um with respect to the axis, strikes the fiber surface at F in such a way that it is refracted parallel to the fiber surface at F in such a way that it is refracted parallel to the fiber surface. Of particular interest in the context of this chapter, however, is the fact that scattered radiation may also be polarized. Or, as in Figure 22b, a ray leaving the tip of the object, directed toward the right focal point F of a diverging lens, undergoing refraction at the lens and emerging parallel to the axis. 22 Find the angle at which a half-wave plate must be set to compensate for the rotation of a 1.15-mm levorotatory quartz plate using 546-nm wavelength light. The sign convention is the same as that used previously in this chapter. In the absence of an Ex-component, the phase wy may be set equal to zero for convenience. We can gain a reasonably accurate, though qualitative, understanding of laser operation by studying Figures 15 and 16. (3) to (8), a summary of some basic relations that unify particles of matter and light Conservation of energy of the interacting particles requires that Uv_i = Uv; UvS, or v_i = v; vS (19) This result shows that the diffracted photon differs in frequency—however little—from the incident photon by the amount vS, greater or less, depending on the direction of the acoustic wave. If the polarizations of the individual fields produced by the amount vS, greater or less, depending on the direction of the acoustic wave. If the polarizations of the individual fields produced by the amount vS and the diffracted photon differs in frequency—however little—from the incident photon by the amount vS and the diffracted photon differs in frequency. independent oscillators are randomly distributed in direction, the field is said to be randomly polarized or simply unpolarized. Equation (43) states that the amplitudes of reflected beams for rays incident from either direction are the same in magnitude but differ by a p phase shift. The pressure-broadening contribution to the gain bandwidth is, of course, pressure and temperature dependent. Qualitatively, the coherence time of the source is the time interval over which departures from monochromaticity are small. In Figure 1, the carrier source output into the optic fiber is represented by a single, square pulse. With the help of Figure 12c, the nodal plane distances y and w may also be determined. These three elements are shown schematically in Figure 13: as a unit in Figure 13: as a unit in Figure 13b, c, and d. Applied to Eq. (38), this condition is 0n1 0n2 0P = K1 + K2 = 0 0l 0l 0l fv (39) fR (a) V R TCA LCA (b) Figure 12 Chromatic aberration (exaggerated) for a thin lens, illustrating the effect on the focal length (a) and the lateral and longitudina misses (b) for red (R) and violet (V) wavelengths. Combing Eqs. E E E0 cos vt E0 t T Figure 16 Problem 2. dy a I Act z u a by Wa P s Ideal Actual Detail Wa Wi The derivative da/dy describes the local curvature of the wavefront at P. The analysis of the preceding section on the phenomenon of beats serves as a useful starting point for a quantitative discussion of the phase and group velocities of a wave pulse. First ensure that the approximations of problem 5 are satisfied. The higher-frequency cosine factor, in the resultant waveform, is sometimes referred to as the carrier wave to distinguish it from the lower-frequency envelope wave. 12, No. 21 (October 14, 1976): 550. Using the results of problem 4, determine the magnitude of the spherical wave aberration for the telescope. It is a fundamental consequence of the wave nature of light that beams of finite transverse extent must spread as they propagate. Thus these lines are used to define a continuously changing beam width. The total longitudinal spherical aberration, she - spe , of a thin lens with focal length f and index n, where show is the image distance for a ray at elevation h, spoe is the paraxial image distance, and 0 \$\le 1 (26) \$\le 2 Figure 7 "Bending" of a single lens into various shapes having the same focal length. Angles of incidence and refraction with the light ray. The hole at S is not necessary if the source is a spatially coherent laser. 30 Chapter 2 Geometrical Optics The focal length f from the vertex of the mirror, and shown in Figure 16a and b, serves as an important construction point in graphical ray-tracing techniques, which we discuss following Example 1. Let us first concentrate on the integrals contained within the curly brackets, which we shall refer to as K, temporarily. The factor of i introduced in Eq. (7) for this purpose appears naturally in the Kirchhoff derivation of the same equation. Proceeding, 1 1 1 = + i z - iz0 R1z2 pw2 1z2 Manipulating the left side of this relation leads to z + iz0 z0 z 1 l 1 a b = 2 + i 2 = + i 2 2 z - iz0 z + iz0 R1z2 z + z0 z + z0 rack = 1 A word of caution is in order here. Expanding each term, N N 2 N N a a E0i cos ai b = a E20i cos ai b = a individual terms of the series in the left members. Chapter 12 Chapter 9 Davis, Sumner P. Figure 2a illustrates the formation of the spectral orders of diffraction for monochromatic light. Raman amplification in fibers is attractive in part because it utilizes the entire unaltered fiber in the amplification process. This widening of the beam follows from a further examination of the irradiance profile given in Eq. (25), which indicates that, at a given z, the irradiance I1r, z2 a transverse distance r from the center of the beam is related to the axial irradiance I1r = 0, z2 by I1r, z2 2 = e -2r > w 1z2 I1r = 0, z2 (27) Evidently, the irradiance is reduced from its axial value by a factor of 1>e2 M 0.135, where the transverse distance r from the axis is equal to the spot size, that is, where r = w1z2. Detection of Optical and Infrared Radiation. Fresnel's Biprism Figure 9 shows Fresnel's Biprism, which refracts light from a small source S in such a way that it appears to come from two coherent, virtual sources, S1 and S2. Wilson, and J. 106 Chapter 4 Wave Equations In free space, the velocity c is given by c = 1 1e0m0 (31) where the constants e0 and m0 are, respectively, the permittivity and permeability of vacuum. For example, if selenium (six outer-shell electrons) is doped into GaAs, it replaces As (five outer-shell electrons) in the lattice. Rayleigh's criterion for just-resolvable images—a somewhat arbitrary but useful criterion—requires that the angular separation of the centers of the image patterns be no less than the angular radius of the Airy disc, as in Figure 10. What is the near point (with the corrective lens) for this eye? The optical rotation of the polarized light can be understood as circular birefringence, the existence of different indices of refraction for left-circularly and right-circularly polarized light components. To derive the Cauchy dispersion equation, let us first expand the frequency factor in a binomial series: $1 \ v^2 \ v^2$ appropriately, we can express n2 = A₂ + B₂ C₂ + 4 + Á 211 We may take the square root of each side and, since each higher-order term in the expression is less than A₂, use the binomial expansion again on the right member. Such light patterns are not easily explained by viewing light as a stream of particles traveling in straight lines. New York: Pergamon Press, 1971. From q2, determine the spot size w0 and location of the beam waist. We see that m = 1 for the first minimum in the slit pattern is replaced by the number 1.22 in the case of the circular aperture. The factor [1sin b2> b]2 is that of Eq. (10) for single-slit diffraction. That is, for spherical waves the irradiance (which is proportional to the square of the electric field amplitude) is proportional to 1/r. Using these constants and the Cauchy relation approximated by two terms, calculate the refractive index of the D Fraunhofer line for each case. The points O and I are said to be conjugate points for the optical wave is proportional to 1/r. system. Generally speaking, both surfaces of the lens might be cylindrical. The cos2 a factor, when a is written out as in Eq. (25), is cos2 a = cos2 c d 2 l The sinc and cosine factors of Eq. (27) are plotted in Figure 14a for the case a = 6b or a = 6b. Plot the waveguide parameter M¿ versus l in the range 0.70 to 1.70 mm. The detail shows a frontal view of a portion of a wavefront. Wavefronts propagating away from (or toward) the beam waist have reduced radii of curvature occurring at z = ; z0. The pattern of interference fringes provides information on the relative vibrational amplitude as a function of position on the surface. Many mathematical
manipulations can be carried out more simply with exponential functions. However, the saturation irradiance is a property of the gain media and cannot be manipulated. The electrodes of the cell have a separation of 1.5 cm. 13 Apply the reasoning used to calculate the finesse of a FabryPerot interferometer to the Michelson interferometer. Cathode Anode 388 Chapter 17 Optical Detectors and Displays Another means of amplification, used in the gas-filled photocell, allows the generation of the residual gas. The lens-to-film distance is now critical and depends on the object distance and lens focal length. In the remainder of this chapter we will develop and characterize a mathematical description of the Gaussian beam solution and compare this useful representation of a laser field to plane and spherical waves. On the other hand, a cylindrical lens—shaped like a section of a soft drink can, sliced down the side from top to bottom—lacks rotational symmetry about its optical axis. It is this sharing of the electrons that forms the crystal bond. 12 White light is passed through a Fabry-Perot interferometer in the arrangement shown in Figure 19, where the detector is a spectroscope. (a) 33.3 cm, 2 × (b) 86.67 cm, 2 × (c) 7.37 cm, -0.316 × 24. Both conditions require anisotropic crystalline structures. Per'ina, Jan. 448 Chapter 20 Aberration Theory zones, extending from its center to its outer edge. From the plane mirror to the external beam waist, form the system matrix A CC B DS 1 = C0 1 - 0.5 1S C 0.64 / 3 transfer 1 0.5 1.5 S C 3 0 0 1 1 SC 0 1.5 0.7 1 S 3 33 refraction transfer Carry out the indicated matrix multiplication to obtain c A C B 1 - 0.53/d = c D - 0.53/d = c D - 0.53 0.7 + 0.63/d 0.63 Note that we have ignored the transfer matrix for propagation through the mirror pass out through the mirror. Monochromatic light is first allowed to pass through a single small hole in order to approximate a single point source S. This plane wavefront, which constitutes Bthe new surface of constant B phase, is perpendicular to the propagation vector k for the wave. The first limitation determines how bright the image can be, that is, how much irradiance 1W>m22 reaches the image. High-resolution, holographically recorded gratings—in optical spectrometers. 21 A plane plate of beryl is cut with the optic axis in the plane of the surfaces. Investigate, for the case described in (a) and (b), whether Z2 L f for a variety of reasonable choices for lens focal lengths and beam parameters. Popular LEDs include the infrared GaAs device, with a peak output at 580 nm. The periodic variation in R with ¢ 1, which is proportional to the film thickness, provides a practical way of monitoring film thickness in the course of a film deposition. Now as the number N of slits increases, the brightness of the principal maxima increase as N 2. Use Eq. (43) with results from parts (a) and (b) to obtain an expression for q21/2. Whichever eye is open when the pencil remains lined up with the reference object is your dominant eye. 1 0.9 vfsr c 2d 0.8 Transmittance 0.7 0.6 0.5 0.4 2v1/2 0.3 0.2 0.1 Figure 15 Transmittance T through a Fabry-Perot interferometer of fixed length d as a function of the variable frequency n of the input field. Military applications include the use of a memory bank of holograms of particular objects or targets constructed from aerial photographs. Since Gaussian beams are confined in the transverse direction and have nearly spherical mirror cavities, as indicated in Figure 6. Solution Taking Eq. (38) as an equality, u = 1.221570 * 10.92 1.221 = 2.26 * 10.7 rad ls 3.08 Since Orion is known to be about 1 * 1015 mi away, the stellar diameter is s = ru = 2.26 * 10.7 rad ls 3.08 Since Orion is known to be about 1 * 1015 mi away, the stellar diameter is s = ru = 2.26 * 10.7 rad ls 3.08 Since Orion is known to be about 1 * 1015 mi away, the stellar diameter is s = ru = 2.26 * 10.7 rad ls 3.08 Since Orion is known to be about 1 * 1015 mi away, the stellar diameter is s = ru = 2.26 * 10.7 rad ls 3.08 Since Orion is known to be about 1 * 1015 mi away, the stellar diameter is s = ru = 2.26 * 10.7 rad ls 3.08 Since Orion is known to be about 1 * 1015 mi away, the stellar diameter is s = ru = 2.26 * 10.7 rad ls 3.08 Since Orion is known to be about 1 * 1015 mi away, the stellar diameter is s = ru = 2.26 * 10.7 rad ls 3.08 Since Orion is known to be about 1 * 1015 mi away, the stellar diameter is s = ru = 2.26 * 10.7 rad ls 3.08 Since Orion is known to be about 1 * 1015 mi away. diameters. (b) In steady state, the irradiance in each of the three cavity modes has grown large enough to reduce the gain coefficient g1n2 at these frequencies to the threshold value gth . In the next section we examine the import of Eq. (14) and interpret the meaning of the imaginary part of q(0), z0 , called the confocal parameter or Rayleigh range. In Figure 3, an arbitrary ray PQ from an axial object point P is refracted by a u1 Q h a f P O n1 A n2 a C s Figure 3 Refraction of a ray at a spherical surface. Example 1 Determine the result of the superposition of the following harmonic waves: E1 = 7 cos1p>3 - vt2, E2 = 12 sin1p>4 - vt2, and E3 = 20 cos1p>5 - vt2 Solution To make all phase angles consistent, first change the sine wave to a cosine wave: E2 = 12 cos1p>4 - p>2 - vt2 = 12 cos1 - p>4 - vt2. Since correction is more crucial at high magnifications, apochromats are usually objectives with focal lengths in the range of 1.5 to 4 mm. S. The uniqueness of the PCM is that the phase conjugate replica is produced regardless of the shape of the incident wavefront, as long as the PCM has an aperture large enough to receive the entire wavefront. Therefore as the irradiance increases, the population inversion in the gain medium decreases. For the simple cavity considered here, S = R1R2R3 . E = 870 V/m, B = 2.90 × 10-6 T 16. z Matrix Treatment of Polarization 347 Example 2 Consider the result of allowing left-circularly polarized light to pass through an eighth-wave plate. Neither our first-order (Gaussian or paraxial) approximations nor the third-order theory sketched briefly in the preceding sections took into account an important fact of refraction: the variation of refractive index with wavelength, or the phenomenon of dispersion. If P is 30 cm away, as in the previous example, the radius of this aperture, by Eq. (20), is only 1.74 mm for 632.8-nm light. Such waveform and, as for plane waves, k = 2p > l and v = 2p > T. Calculate the radius of curvature of the grinding and polishing tools to be used in making this lens. Further, the construction of Figure 8b makes clear that the image size is identical with the object size, giving a magnification of unity. A perpendicular of height h is drawn from P to the axis at Q. Thus, both the velocity and index of refraction of the extraordinary ray are continuous functions of direction. The results, together with those just derived for p, f1, 410 Chapter 18 Matrix Methods in Paraxial Optics TABLE 2 CARDINAL POINT LOCATIONS IN TERMS OF SYSTEM MATRIX ELEMENTS D C A q = C D - 1 y = C n0 > nf - A w = C p= f1 = p - r = no /nf C 1 fs = q - s = -C F1 F2 H1 y Located relative to input (1) and output (2) reference planes s Located relative to principal planes H2 N1 N2 F1 F2 and r, are listed in Table 2. Thus, as shown in Figure 12b, the g0(n) Figure 12 Gain saturation in an inhomogeneously broadened laser. Since the film is air, nf = 1 and tm = ml > 2. The magnification of the microscope may then be expressed, perhaps more conveniently, as M = -a 25 L ba b fe fo (46) In many microscopes, the length L is standardized at 16 cm. Sensitivity (%) R = 100 60 40 20 0 4000 6000 8000 10,000 Wavelength (Å) Figure 7 Scaled responsivity as a function of wavelength for a CdS photoconducting cell. Irradiance variation in transverse plane r r0 r0 w(z) l uFF pw 0 w0 Figure 2 Gaussian spherical beam propagating in the z-direction. When these minima happen to coincide with interference, ¢dmin , between the cavity lengths associated with the centers of the peaks of the transmittance functions of the two wavelength components is equal to the FWHM of these peaks. One part is the fraction of the incident field tE11t + t2 that is transmitted through Mirror 1 at this time. In a simple model of diatomic hydrogen H2, the resonant vibration frequency can be taken as f = 1.3 1014 Hz. a. Thus find the general matrix elements A, B, C, and D for a thick lens. If all spots are blocked except the DC component, or undeviated diffraction beam—say by an iris diaphragm centered on the central spot—the image plane is illuminated but no image details appear. What half-wave voltage is required? The lens has a refractive index of 1.50, a radius of curvature of 20 cm, and an axial length of 2 cm. Equation (47) implies that for a two-mirror linear cavity, the threshold gain coefficient is gth = 1 1 ln a b 2L S 1Linear cavity (48) Example 3 Estimate the minimum length of a linear cavity with mirror reflectances R1 = 0.99 and R2 = 0.98 that can be used in a He-Ne laser system given a small-signal gain coefficient of 0.001/cm. In Figure 11, the first-order spectrum spread (200 to 1200 nm) around the Rowland circle is shown for ui = 38° and a grating of 1200 grooves/mm. The packaged diode is about 6 mm in diameter. When these few zones are reproduced on a smaller scale, the obliquity factor is not very important, and we may approximate A 16 = 8a1. (b) Figure 6 Antireflecting triple layers. (27) to (30), may also be expressed by sin 1u + ut2 TM: r = - tan 1u + ut2 tan 1u + ut2 tan 1u + ut2 cos 1u - ut2 6 Show that Eq. (37) to (30), may also be expressed by sin 1u + ut2 TM: r = - tan 1u + ut2 TM: r = - tan 1u + ut2 tan 1u + ut2 tan 1u + ut2 TM: r = - tan 1u + ut2 tan 1u + follows from Eq. (35). = n sin a (47) The numerical aperture is an invariant in object space, due to Snell's law. If the propagation constant is complex, so must be the refractive index, since k = 2p 2pn v = a
bn y c l (30) If we identify the real and imaginary parts of the complex refractive index, since k = 2p 2pn v = a bn y c l (30) If we identify the real and imaginary parts of the complex refractive index. and nI is called the extinction coefficient, it follows from Eqs. Radiant flux density at a surface, in which case it is called irradiance, Ee. In this state, it is rejected by the polarizer, preventing it from continuing back into the optical system, where, in high-power laser systems, it can damage optical components. Note that this relation gives the transmittance of a parallel plate. Estimate the small-signal absorption coefficient for the Nd:YAG crystal. The material in this case is uniaxial negative, like calcite. (b) With this correction, can the myopic person also read a book held at the normal near point, 25 cm from the eye? Proceeding, we write the right-going (traveling in the + z direction) electric field in the cavity, at the position of the first mirror as, + 1t2eivt E1+ = E01 (19) Note that the amplitude of this field is, in general, time dependent to allow for the buildup or decay of the intracavity field as the incident field is turned on or off. Then the zone radii required to make the zones half-period zones relative to a fixed field point P can be calculated. Probably the first measurement of the wavelength of light was made by Newton, using this technique. But since the cavity loss is high, the small-signal gain coefficient is less than the threshold value Q. Then, substituting into Eq. (42), R = 2.1211 - 1.52210.625022 + [11211.52 + 2.12]210.780622 = 0.174 That is, the irradiance of the reflected beam is 17.4% of the irradiance of the incident beam. Because of the equality of the three angles shown, it follows that hi ho = s s_i The lateral magnification m is defined by the ratio of lateral image size to corresponding lateral object size, so that $fmf = hi s_i = s ho (15) s_i s (16)$ Extending the sign convention to include magnification, we assign a 1+2 magnification to the case where the image has the same orientation as the object and a 1-2 magnification where the image is inverted relative to the object. 23 The output from a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle of 0.001 rad and an output from a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle of 0.001 rad and an output from a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle of 0.001 rad and an output from a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle of 0.001 rad and an output form a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle of 0.001 rad and an output form a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle of 0.001 rad and an output form a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle of 0.001 rad and an output form a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle of 0.001 rad and an output form a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle of 0.001 rad and an output form a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle of 0.001 rad and an output form a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle of 0.001 rad and an output form a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle of 0.001 rad and an output form a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle of 0.001 rad and an output form a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle of 0.001 rad and an output form a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle of 0.001 rad and an output form a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle of 0.001 rad and an output form a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle of 0.001 rad and an output form a single-mode TEM00 Ar+ laser 11 = 488 nm2 has a far-field divergence angle objects form focused images on the same film plane? Find the irradiance IL exiting the gain cell when the irradiance IO input to the cell is (a) 1 W>cm2, (b) 10 W>cm2, (c) 100 W>cm2, (d) 1000 W other hand, Figure 2b shows clearly that wavelengths within an order are better separated as their order increases. The wavelength spread as their order increases. The wavelength spread is \$l = 12 \$n>c = 110.6 * 10.6 m221109 Hz2>13 * 108 m>s2 = 3.75 * 10-10 m = 0.375 nm gth g(n) nfsr n0 (c) Figure 10 Gain saturation in a homogeneously broadened laser. The chief ray, together with its two marginal rays, a and az is drawn from the tip Oz of the object. The core index is 1.470 and the cladding index is 1.455 at l = 1 mm. E0 cos a = E01 cos a + E02 cos a 2 and E0 sin a + E02 sin a 2 The cosine law may be applied to Figure 3a, yielding an expression for the esultant field E0, $E20 = E201 + E202 + 2E01E02 \cos a^2 + 2E01E02 \cos a^2 + E01 \cos a^2 + E02 \sin a^2 + E02 \cos a^2 + E02 \cos$ cos1a1 - vt2 + E02 cos1a2 - vt2 = E0 cos1a - vt2 (11) where the amplitude E0 of the resultant field is given by Eq. (9) and the phase a of the resultant field is given by Eq. (10). Let the wire be aperture A and the slit be aperture B. The reflection and ransmission amplitude coefficients are r and t at an external reflection and ransmission and ransmission amplitude coefficients are r and t at an external reflection and ransmission amplitude coefficients are r and t at an external reflection and ransmission amplitude coefficients are r and t at an external reflection and ransmission amplitude E0 of the resultant field is given by Eq. (10). reflection. How far apart must two stars be before they are theoretically resolvable by either of the lenses in the binoculars? From Figure 8, the radius Rn of the nth zone must satisfy Figure 7 Fresnel zone plate. Here we give a brief qualitative description of this important feature of laser light. Now, for Rayleigh scattering the radiated power can be shown to be directly proportional to the fourth power of the incident radiation. In the case of energetic photons. This follows from a fully quantum-mechanical treatment of the interaction between the atomic system and the electromagnetic field and indicates that the ratio of stimulated emission into a given cavity mode is the same as the ratio of the number of photons in the cavity to 1. By convention, the lineshape function g1n2 is normalized so that 3 g1n2 dn = 1 all n As we build towards a discussion of laser light, we first review the nature of nonlaser light sources. When immersed in a certain transparent liquid, it becomes a negative lens with a focal length of 188 cm. Just inside the sclera lies the choroid, covering about four-fifths of the eye toward the back and containing most of the blood vessels that nourish the eye. 19 Refer to Figure 15. 174 Chapter 7 Interference of Light ym (1) (2) D (1) S (2) M2 d u M1 sdD a d(2u) ls ym m 2du O u d 2u S1 d a S2 Figure 8 Interference with Fresnel's mirrors. The incident light rays are parallel to the substrate. When the material is a rod of bonded silicon carbide, the source is called a globar, approximating a graybody with an average emissivity of 0.88 (see Figure 5). This sinusoidal plate is, in fact, a hologram of the point O. Thus, for the limit of resolution, we have, using Eq. (21), 1¢u2min = 1.221 D (22) where D is now the diameter of the lens. Consider light entering the interferometer through the Input 1 "port" of BS1. Kaminov, Ivan P. (b) Maximum retardation. To accomplish this improvement, two lenses are most often used. When the film is developed, its transmittance is determined by IF. is then 211.4652 - 1.4622 = 0.121, and the required diameter for single-mode performance is, using Eq. (11), d 6 2.4 11.25 mm2 or p10.1212 d 6 7.9 mm On the other hand, if d = 50 mm, the fiber is multimode with mmax = 2 1 50 cp 10.1212 d = 115 2 1.25 giving the number of propagating modes according to Eq. (10). This full analysis is left as an exercise (problem 5). The aberration AB of Figure 1. Using Eq. (2), 13.6 eV 13.6 eV - ab 2 2 12 = -3.4 eV + 13.6 eV = 10.2 eV E2 - E1 = -10.2 eV E2 incidence) and Ep (in the plane of incidence). A Glan-laser prism, tuned to pass vertically polarized light, rejects the horizontally polarized beam. This quantity is called the irradiance, Ee .1 Ee = 8 f S f 9 = e0c28E0B0 sin21k # Br; vt29 B B (41) where the angle brackets denote a time average and we have expressed the fields as sine functions of the phase Spectral outputs depend on the particular phosphor used. For a large number of subzones, the phasor diagram becomes circular and the magnitude of a1 is the diameter of the circle. An Introduction to Interferometry. 2 Walter P. Gain is provided to a field of irradiance I and frequency n; L 1E2 - E12>h as a result of an optical pump of irradiance I and frequency np L 1E3 - E02>h. How far away will the lights appear to be if they are just resolvable to a person whose nocturnal pupils are just 5 mm in diameter? This deficiency can be remedied to a degree by stepwise intensification of the reflected beam as in a pile-of-plates polarizer (Figure 5). New York: McGraw-Hill Book Company, 1968. Let the Fabryraph three rows of students at a distance 6 m away, focusing on the middle row. The inelastically scattered light of frequency less than v is known as the Stokes field, and that component with frequency Perot cavity have length d = 5 cm and finesse F = 30. The index of the glass is 1.50, 15 A camera is used to photog Stokes field. Charged particles, in turn, are accelerated by electromagnetic fields. Here we have noted that f = f2 = -f1. The angle approximations, $a_{\xi} = u_{\xi} - f = u$ spherical interface. Note that a plane surface can be treated as a special case of a cylindrical or a spherical surface, eliminating for example, two thin lenses
(of respective focal lengths f1 and f2) will have a flat Petzval surface, eliminating curvature of field, if n1f1 + n2f2 = 0 In general, the Petzval surface for a number of thin lenses in air satisfies 1 1 anf = R i i p (32) where Rp is the radius of curvature of the Petzval surface. The approximate number m of half-wavelengths that fit into the cavity b. B 10 Linearly polarized light with an electric field E is inclined at + 30° relative to the x-axis and is transmitted by a QWP with SA horizontal. Optically, the eyeball can be pictured as a positive lens system that refracts incident light onto its rear surface to form a real image, much as does an ordinary camera. By repeated reading of the electronic pulse sequence of the end of each row in the CCD array, the irradiance as a function of position on the array and of time can be formed. A point object on an axis through the center of the lens produces a real image on the opposite side. Ch. 7. The dispersion dn>dl may be advisable to limit the wavelength range accepted by the grating by first using an instrument of lower dispersion. In this section we provide a qualitative description of the operating principles of diode lasers and begin with a very brief review of semiconductors and p-n junctions. Refraction may not suffice to contain rays making steeper angles with the axis, so GRIN fibers are also characterized by an acceptance cone. The other ray is directed toward the center of curvature along a normal and so must reflect back along itself. One beam, the reference beam ER, is directed by two plane mirrors M1 and M2 onto the photographic film, as shown. 5 Two light filters are used to transmit yellow light centered around a wavelength of 590 nm. When carrier waves are modulated to contain information, as in amplitude modulation (AM) of radio waves, we may speak of the group velocity, which is usually less than the phase velocity, which is usually less than the phase velocity, which is usually less than the phase velocity as the signal velocity, which is usually less than the phase velocity as the signal velocity, which is usually less than the phase velocity as the signal velocity, which is usually less than the phase velocity as the signal velocity, which is usually less than the phase velocity as the signal velocity, which is usually less than the phase velocity as the signal velocity, which is usually less than the phase velocity as the signal velocity as the sisomet velocity as the signal velocity as the signal velocity The conditions for successful propagation are developed here mainly 247 Fiber Optics from the point of view of geometrical optics. The net effect is the production, together with equations representing the effect of a cavity or an electromagnetic field, are used to develop a relation that predicts the output irradiance from a laser given the characteristics of the pump, gain medium, and cavity that comprise the laser system. As we have noted, if the beams originate from the same source, this phase difference accumulates as a result of a difference in path lengths traveled by the respective beams. With the Jones calculus, this process is equivalent to allowing the QWP matrix to operate on the Jones vector for the linearly polarized light, eip>4 c 1 0 0 1 1 1 1 d c d = eip>4 a bc d - i 22 1 22 - i giving right-circularly polarized light (see Table 1). (27) and (28) and thus produce a resultant like the one pictured in Figure 7b. The intermediate image RI1 serves as a virtual object VO2 for the second lens. 5 The noise equivalent power NEP (at a wavelength of 1.5 mm) of an InGaAs p-i-n photodiode using a detection observation time of 1 ms is about 4 * 10-11 W. We return to the nature of images formed by refraction at a plane surface when we deal with such refraction as a special case of refraction from a spherical surface. Note that g = g0 > 2 when I = IS. (However, see problem 15.) The Bragg condition for diffraction maxima can be found by an alternative argument that makes useB of the particle nature of waves. They can, therefore, manifest second harmonic generation in addition to other second-order phenomena to be described presently. The image of the field stop formed by the optical elements (if any) that follow it. The curves show that quarter-wave thicknesses, or odd multiples thereof, lead either to optimum enhancement (high-reflectance coating) or to maximum reduction (antireflection coating). Strong, John. In this chapter we describe the general characteristics of HermiteGaussian laser beams and treat the propagation of these beams through general optical systems. (Note that the center values for point P are z = 0 and y = 0.) Consequently, as P; moves further above P, ¢y slides along the Cornu spiral, toward the lower eye, as shown in Figure 15. notice that (1) the reciprocals of distances in the left member add to give the reciprocal of the focal length and (2) the reciprocals of the object and image distances describe the curvature of the wavefronts incident at the lens and centered at the object and image positions O and I, respectively. 156 Chapter 6 Properties of Lasers It is important to note that the angular spread increases as the beam waist is made smaller. That is, for solutions, r has units of degrees/dm # cm3/g. We close this chapter on geometrical optics with a brief look at this special type of lens. A measure of this capability is the product of half-angle and refractive index, called the numerical aperture N. Do this by plotting the longitudinal ray aberration as a function of ray height for h = 0, 1, 2, 3, 4, and 5 cm. The plots correspond to the different small-signal gain coefficients g0 and saturation irradiances IS indicated. This is a virtual image that serves as the object for lens L2, with 1 s2 = 6 cm + 4 cm = 10 cm and f2 = -10 cm. The largest telescopes, like the Hale 200-in. Similar interferometers are being developed by scientists and engineers in Europe and Japan. r 2 0.9 r 2 0.9 r 2 0.9 Transparent slab 1 546 nm n 4.5 5 A Michelson interferometer is used to measure the refractive index of a gas. Thus r = y = a feq fB bL and s = w = -a feq fA bL (33) Example 4 Let us apply these results to the case of a Huygens eyepiece, which consists of two positive, thin lenses separated by a distance L equal to the average of their focal lengths. Notice that the two types of devices have figures of merit of similar form. In the same time interval, how far from the sound wave in the auditorium traveled? Let us assume for the moment an ideal situation in which none of the energy is lost on reflection nor absorbed by the transmitting medium The scattered light has a frequency that differs from that of the incident light by an amount equal to the frequency of the acoustic waves in the medium. • Ray 3. 19 Two thin lenses have focal lengths of - 5 and + 20 cm. If the terminal point B lies below the surface of a second medium, as in Figure 6, the correct path is definitely not the shortest path or straight line AB, for that would make the angle of refraction equal to the angle of incidence, in violation of the empirically established law of refraction. Let input parameters include thickness and indices of the layers and the index of the substrate. conventional table-top laser systems. 28.1% 67.5°; 22.5° (a) IO {0.5(2 + 2) cos2 + sin2 } (b) 0.4525IO versus 0.57IO; both 0.25IO; 0.0475IO versus 0.375IO; both 0.25IO; 0.0475IO versus 0.375IO; both 0.25IO; cos2 + sin2 } (b) 0.4525IO versus 0.375IO; both 0.25IO; cos2 + sin2 } (c) same as (a) (d) double refraction, no phase retardation, any polarization possible (b) single refraction, no phase retardation, any polarization possible (b) single refraction, no phase retardation, any polarization possible (b) single refraction, no phase retardation, any polarization possible (b) single refraction, no phase retardation, any polarization possible (b) single refraction, no phase retardation, any polarization possible (b) single refraction, no phase retardation, any polarization possible (b) single refraction, no phase retardation, any polarization possible (b) single refraction, no phase retardation, any polarization possible (b) single refraction, no phase retardation, any polarization possible (b) single refraction, no phase retardation, any polarization possible (b) single refraction, no phase retardation, any polarization possible (b) single refraction, no phase retardation, any polarization possible (b) single refraction, no phase retardation, any polarization possible (b) single refraction, no phase retardation, any polarization possible (b) single refraction, no phase retardation, any polarization possible (b) single refraction, and polarization possible (b) single refraction polariz retardation in each separated beam, each beam linearly polarized (e) cases (a) and (c) (a) difference of 0.121 mm (b) 0.015 mm (b) 0.01 $8.57 \times 10-5$ cm (a) 0.0091 (b) 15 µm (c) 12 (d) 15 µm 3.15 × 10-4 (a) 36.8 µm (b) 18.4 µm 14.7° (a) 14.8% (b) 2.03% of I0 (c) 0.92 I0 sin2(2) (a) 42.5° (b) 0.60° Chapter 16 2. For generality, we assume different media on opposite sides of the lens, having refractive indices n and n_i, as shown in Figure 8. PROBLEMS 1 When one mirror of a Michelson interferometer is translated by 0.0114 cm, 523 fringes are observed to pass the crosshairs of the viewing telescope. The tungsten lamp is an extended source that emits many wavelengths. In addition, the output power can be very high. blazing the grating. Holocameras A device called a holocamera does not use photographic film, but rather materials like thermoplastics to record a holographic image. One can show that coma is absent in a lens when $s = a 2n^2 - n - 1 s - s_c$ ba $b n + 1 s + s_c$ (31) For the example of the lens considered previously, with n = 1.50 and object at infinity, Eq. (31) gives a value of s = 0.8, quite close to the value of s = 0.7, which yielded minimum spherical aberration. (a) 3.6
cm-1 (b) 2450 (c) 0.093 mm/s Chapter 22 2. The image occupies essentially the region of the Airy disc. Infrared Radiation On the long-wavelength side of the visible spectrum, infrared (IR) radiation has wavelengths spanning the region from 770 nm to 1 mm. The Bunpolarized light incident from the left (along the x-direction) contains E-field components oscillating along the y- and zB directions. 8 REFRACTION AT A SPHERICAL SURFACE We turn now to a similar treatment of refraction at a spherical surface, choosing in this case the concave surface of Figure 18. 14 What acoustic frequency is required of a plane acoustic wave, launched in an acousto-optic crystal, so that a He-Ne laser beam is deflected by 1°? Interference techniques are not practical in the production of coarse, echellelike gratings. When Eq. (30) is rearranged to express the lateral magnification, the condition can be written m = n sin u h; = h n; sin u; To prevent coma, thereas the lateral magnification of coarse, echellelike gratings. lateral magnification resulting from refraction by all zones of a lens must be the same. Explain why, for this system in which there are unavoidable losses, the output irradiance is reduced from its maximum value if T3 is either too large or too small. (b) Virtual image, concave mirror. (a) |>4 - |>2, $n_1 = 1.38$, $n_2 = 2.02$, $n_3 = 1.8$. (b) |>4 - |>2 - |>4: $n_1 = 1.38$, $n_2 = 2.02$, $n_3 = 1.8$. (b) |>4 - |>2 - |>4: $n_1 = 1.38$, $n_2 = 2.02$, $n_3 = 1.8$. (b) |>4 - |>2 - |>4: $n_1 = 1.38$, $n_2 = 2.02$, $n_3 = 1.8$. (b) |>4 - |>2 - |>4: $n_1 = 1.38$, $n_2 = 2.02$, $n_3 = 1.8$. (b) |>4 - |>2 - |>4: $n_1 = 1.38$, $n_2 = 2.02$, $n_3 = 1.8$. (b) |>4 - |>2 - |>4: $n_1 = 1.38$, $n_2 = 2.02$, $n_3 = 1.8$. (c) |>4 - |>2 - |>4: $n_1 = 1.38$, $n_2 = 2.02$, $n_3 = 1.8$. (b) |>4 - |>2 - |>4: $n_1 = 1.38$, $n_2 = 2.02$, $n_3 = 1.8$. (c) |>4 - |>4: $n_1 = 1.38$, $n_2 = 2.02$, $n_3 = 1.8$. (c) |>4 - |>4: $n_1 = 1.38$, $n_2 = 2.02$, $n_3 = 1.8$. (c) |>4 - |>4: $n_1 = 1.38$, $n_2 = 2.02$, $n_3 = 1.8$. (c) |>4 - |>4: $n_1 = 1.38$, $n_2 = 2.02$, $n_3 = 1.8$. (c) |>4 - |>4: $n_1 = 1.38$. (c) |>4 - |>4. 1.38, n2 = 2.2, n3 = 1.7. (b) 1 350 450 550 650 Wavelength (nm) 750 850 487 Theory of Multilayer Films We derive now an expression for the reflectance of this type of structure, shown schematically in Figure 8, where High and Low signify highand low-refractive indices, respectively. m 3 m 5 1 2 2 m 2 m 3 1 2 2 m 1 m I 1 1 2 2 m 0, y 0 m 1 1 2 2 m 1 m 3 1 2 2 m 2 m 5 1 2 2 m 3 Figure 4 Irradiance versus distance from the optical axis for a double-slit fringe pattern. Figure 10 Transmittance T as a function of round-trip phase shift d. A schematic of an optical communications system employing WDM is shown in Figure 15. As time progresses, the tip of the electric field vector traces out positions along the extent of the double-headed arrow. 14 A high-reflectance stack of alternating high-low index layers is produced to operate at 2 mm in the near infrared. This light is used to form fringes in an interference experiment in which the light is first amplitude-split into two equal parts and then brought together again. (37) and (44), the powers of the individual elements may be expressed in terms of the desired power PD of the combination: P1D = PD - V1 V2 - V1 and P2D = PD V2 V2 - V1 (45) The K curvature factors expressed in Eqs. The relationships listed there can be used to establish the following useful generalizations: fA fB 10 EXAMPLES USING THE SYSTEM MATRIX AND CARDINAL POINTS L RP1 1. Example 1 and Figure 7 illustrate the formation of fringes in a holographic grating by the interference of two argon-ion laser beams. For example, consider an electric field associated with this electric field would be 1 B B = a b E0 sin1kz - vt2yN c and Eq. (40) would give the Poynting vector as S = e0cE20 sin21kz - vt2zN B The polarization of the Lorentz force law. 353 Production of Polarized Light 2 POLARIZATION BY REFLECTION FROM DIELECTRIC SURFACES Light that is specularly reflected from dielectric surfaces is at least partially polarized. Within months of the arrival of Maiman's ruby laser, which emitted deep red light at a wavelength of 694.3 nm, A. The Nature of Light. This field of view can be described in terms of the lateral dimensions of the object viewed, or in terms of the angular extent of the window, relative to the line of sight. In this section we will describe several basic types of thermal detectors. Using Eq. (43), Q = n 5 * 1014 Hz = = 5 * 106 2 ¢n1>2 108 Hz d. Assume a thin lens. 126 Chapter 5 Superposition of Waves Thus, the interaction with the medium that results in absorption generally also affects the speed of the wave. A brief description of spherical and chromatic aberration will serve us here as a useful background for the treatment of optical elements and instruments that conclude this chapter. Example 4 Consider a Mach-Zehnder interferometer of the type just described and illustrated in Figure 16b. Fraunhofer's original gratings were, in fact, fine wires wound between closely spaced threads of two parallel lines ruled on smoked glass. The beam is focused to a beam waist w02 a distance Z2 away. Since the length of the slit is very large compared to its width, the diffraction pattern due to points of the wavefront along the length of the slit has a very small angular width and is not prominent on the screen. The coherence length can also be expressed as p p p = = &k 2v 4p &n c c c ln Eq. (6), 10 is the vacuum wavelength of the fundamental and en the amount the index of refraction of the fundamental differs from that of the second harmonic. (b) 2 in. Thus, 1 = 2p 2 v = m and n = 5 Hz k 3 2p The initial phase 1x = 0, t = 02 is p>4. Those along the y-direction are absent beB cause they would represent longitudinal E-vibrations in an electromagnetic wave. c 2d d Mirror Mirror c 2l Laser tube Etalon l Frequency (a) (b) Figure 16 (a) Laser with intracavity etalon for single-mode operation. In the output plane where the detector is placed, we expect to measure the spectrum or Fourier transform of the transmission function represented by the light transmitted through the mask located interval. the image plane of Figure 7. Smith, F. 23. 23 The Fresnel equations show that the fraction r of the incident field that is reflected from a dielectric plane surface for the TE polarization mode has the form, Unpolarized light y TA y x FA u TA x Polarizer x Half-wave plate Analyzer Figure 26 2 a. The electric field associated with a plane monochromatic electromagnetic wave is perpendicular to the direction of the energy carried by the wave. Since rays are reflected to any point P from the two-point sources S1 and S2, this may be considered an instance of the two-point source pattern already discussed in connection with Figure 6. When the normal eye looks at objects at the near point, diverging light enters the tensed 429 Optics of the Eye Myopic eye (corrected) Lens (negative power) Distinct vision Distant object Object at infinity F.P. No accommodation (a) No accommodation (c) (f) Distinct vision Distant object Object at infinity F.P. M.F.P. No accommodation (a) No accommodation (c) (f) Distinct vision Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distinct vision Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distinct vision Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distinct vision Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distinct vision Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distinct vision Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distinct vision Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distinct vision Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distinct vision Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distinct vision Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distinct vision Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distinct vision Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distinct vision Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distinct vision Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distant object Object at infinity F.P. M.F.P. No accommodation (c) (f) Distant object (f) Di M.F.P. No accommodation (d) Distinct vision 25 cm 25 cm Object at N.P. M.N.P. Full accommodation (b) M.F.P. N.N.P. M.N.P. M.N.P. Full accommodation (c) Figure 5 A comparison of normal and myopic vision, with optical correction. Fiber Optics 249 the boundary, a second medium introduced into this region can couple into the wave and provide a means of carrying away energy that otherwise would return into the first medium. Introduction to Matrix Methods in Optics. 23 Trace two rays, both from far-distant objects, through a Protor photographic lens, one at altitude of 1 mm and the other at 5 mm. Here also, image brightness is proportional to the square of the numerical aperture. Thus, Ee = for the queue of the radiance is suggested in the following considerations. (a) = $2 \sin[2(z/5 \text{ m} + t/3 \text{ s})]$ (b) = $2 \sin[2(z/5 \text{ m} + t/3 \text{ s})]$ (b) = $2 \sin[2(z/5 \text{ m} + t/3 \text{ s})]$ (b) = $2 \sin[2(z/5 \text{ m} + t/3 \text{ s})]$ (b) = $2 \sin[2(z/5 \text{ m} + t/3 \text{ s})]$ (b) = $2 \sin[2(z/5 \text{ m} + t/3 \text{ s})]$ (b) = $2 \sin[2(z/5 \text{ m} + t/3 \text{ s})]$
(b) = $2 \sin[2(z/5 \text{ m} + t/3 \text{ s})]$ (b) = $2 \sin[2(z/5 \text{ m} + t/3 \text{ s})]$ (c) = $2 \sin[2(z/5 \text{ m} + t/3 \text{ s})]$ (b) = $2 \sin[2(z/5 \text{ m} + t/3 \text{ s})]$ (b) = $2 \sin[2(z/5 \text{ m} + t/3 \text{ s})]$ (b) = $2 \sin[2(z/5 \text{ m} + t/3 \text{ s})]$ (c) = $2 \sin[2(z/5 \text{ m} + t/3 \text{ s})]$ (b) = $2 \sin[2(z/5 \text{ m} + t/3 \text{ s})]$ (c) = $2 \sin[2(z/5 \text{ m} + t/3 \text{$ (z/m + 53 t/s) (c) = 2 exp[(2i(z/5 m + t/3 s)] 6. Relate the wavefront curvature at R2— where the wavefront curvature matches the mirror R2. (12) to (14), the cosine factors in the g-terms are all unity. If its theoretical resolving power in first order is to be 300,000, determine the proper blaze angle for use (a) in a Littrow mount and (b) with normal incidence. Draw the chief ray from object point P to its conjugate in the final image, P-. Thus the treatment in terms of meridional rays is a two-dimensional treatment in terms of meridional rays is a two-dimensional treatment. category of thin to thick clearly depends on the accuracy required. This is equivalent to a comparison of coherence along any radial direction of light propagation from the source at two wavefronts separated by the same path difference. For example, ! consider the spiral points F and G shown in Figure 12. Find the pump irradiance Ip required to sustain a smallsignal gain coefficient of 1/cm. 238 Chapter 9 Coherence S1 u s P ls S2 r Figure 12 Lateral region of coherence ls, due to two independent point sources. That is, the pump energy stored in the gain medium is converted to irradiance by interaction of the electromagnetic field with the gain medium. What is the beat frequency of the photocurrent when the input is the yellow light of sodium, at 5889.95 Å, and 5895.92 Å? n1L 1n21 - sin2 u21>2 c. The regions ascribed to various types of waves, as shown, are not precisely bounded. Depending on the degree 5 Ivan P. for 20/15. (20) and (22) written in the form tTE = 1 + rTE ntTM = 1 - rTM into which the results expressed by Eqs. Laurance) that represents a shown, are not precisely bounded. a living, biological eye with fair accuracy is shown in Figure 3. Such distortion is often augmented due to the limitation of ray bundles by stops or by elements effectively acting as stops. 285 286 Chapter 11 Fraunhofer Diffraction and EP = EL i1kr0 - vt2 b sin b sin Na e e f r0 b sin a As before, the irradiance is proportional to the square of the field amplitude, sin b 2 sin Na 2 b a b b sin a 5 5 diffraction interference I = I0 a (32) where I0 includes all the constants, the first set of brackets encloses the interference factor. Assume an equilibrium length of 1 km and determine for this fiber length the 3-db bandwidth of a step-index multimode fiber whose pulse broadening is given by 20 ns/km. Concave mirror: f = +10 cm and s = +20 cm. Note B that the k-vectors representing the degenerate four-wave mixing process satisfy the phase matching condition, B B B B B B B B B B B B B B B B A + k2 + k3 + k4 = k1 - k1 + k3 - k3 = 0 We have seen that the phase conjugate wave 1A 42 exactly reverses the direction and overall phase factor of the signal waves are long-wavelength EM radiations produced, for example, by electrons oscillating in conductors that form antennas of the signal waves are long-wavelength EM radiations produced. image and the field of view. 1 1 : linearly polarized at -45° $\sqrt{2}$ [-1] 1 1 : $\sqrt{2}$ [1] linearly polarized at +45° 1 1 1 $\sqrt{2}$ [i] - i]: right-elliptically polarized at +45° left-circularly polarized at +45° 1 1 1 $\sqrt{2}$ [i] - i]: right-elliptically polarized at +45° left-circularly polarized at +45° 1 1 1 $\sqrt{2}$ [i] - i]: right-elliptically polarized at +45° left-circularly polarized at +45° le direction with amplitude of 5E0 (c) right-circularly polarized, traveling in -z-direction with amplitude of 5E0 75° right-circularly polarized and hence a sm (x + y)k/ $\sqrt{2} - [t (c) - t]$ (b) $= E0 \sqrt{3} + 1 ei(kx - [t]) ei(kx$ value for d. The solar cell and the photographic exposure meter are two well-known applications of the photovoltaic mode. For example, consider a linear polarizer with a transmission axis along the vertical, as in Figure 8. Any small, remaining inequalities in optical paths can be removed by allowing the compensator to rotate, thus varying the optical path through the thickness of its glass plate. Thus, 28E1 # E29 = E01 # E028cos1k + a29 # E028cos1k + a29which case 8cos d9 = cos d. In this case, as D winds around the turns of part of the Cornu spiral, the irradiance at P¿ oscillates with various maxima and minima points, as shown in Figure 14c. Before examining spherical aberration in more detail, however, we wish to show how the other third-order aberrations arise. Thus, R can be found. (32) and (33) Highly reflecting mirror Wavefronts Output coupling mirror Beam divergence angle u Beam waist (radius w0) Laser cavity. If, instead, both reflections are external 1n0 6 nf 6 ns2 or if both reflections are internal 1n0 7 nf 7 ns2, no relative phase difference due to reflection needs to be taken into account. The cones, sensitive to light signals of high intensity and variable color composition), each contain one of three different kinds of visual pigment. As the light propagates in the z-direction across the medium. This cones, sensitive to light signals of high intensity and variable color composition), each contain one of three different kinds of visual pigment. As the light propagates in the z-direction across the medium. direction of symmetry through the crystal is called the optic axis (OA) of the crystal. To produce faithfully the sinusoidal variation in the transmission? In practice, mirror M can be moved toward or away from the beam splitter to equalize optical-path lengths and can be tilted to make M¿ more or less parallel to the film surface. 18 Answer problem 17 when the lens is designed to reduce coma. Outside the central stopband—the region of highest reflectance versus nL>nH Reflectance versus N when nL>nH g 0.587 for alternating double layers of MgF2 and ZnS nL>nH R (%) N R (%) 1.0 0.91 0.83 0.77 0.71 0.67 0.625 0.59 0.56 0.53 0.50 4.26 21.01 40.82 57.77 70.44 79.35 85.48 89.67 92.55 94.56 95.97 1 2 3 4 5 6 7 8 39.71 73.08 89.77 96.35 98.72 99.56 99.85 99.95 489 Theory of Multilayer Films 100 (b) 90 (c) 80 70 (a) R (%) 60 50 40 30 20 10 Uncoated glass 350 450 550 650 Wavelength (nm) 750 850 Figure 9 Spectral reflectance of a highlow index stack for (a) N = 6 double layers. In the configuration of Figure 9a, light would be transmitted through the cell. As a result, only pulses timed to pass through the cell. As a result, only pulses timed to pass through the call through the cell. As a result, only pulses timed to pass through the cell. As a result, only pulses timed to pass through the cell. previously, this is known as dispersion. In Eq. (9), v and k refer to the properties of the incident and diffracted radiation. Use the Jones matrix technique to determine and describe the product light. What is the range of photon wavelengths that could ionize a hydrogen atom that is originally in its ground state? Calculate the separation of the dark fringes In this model, the resultant image is considered to be the overlapping of such "blurred" image points. 607 608 References Reynolds, George O., John B. For closer objects, the focus falls beyond the film. The image is a sinusoidal pattern of the other frequency. The justification makes clear that it is only reasonable near the beam axis. 20 40 60 Angle of incidence (deg) 80 A d d/2 u u B d/2 u u B d/2 u u Figure 11 Progress of a ray through a prism under the condition. So, O-P-, as shown in the final drawing, is real, inverted, 3 cm long (same as the object), and 10 cm from L2. We note that it Figure 7 Sequence of harmonic wave trains of varying finite lengths or lifetimes t. Irong (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3
cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 is real, inverted, 3 cm long (same as the object), and 10 cm from L2 fact, if the dipoles radiated along the reflected ray, the electromagnetic wave could only be a longitudinal wave! This unique orientation results Es (a) Ep (b) up up n1 n2 ut (c) Figure 4 Specular reflection of light at a dielectric surface. For the case consideredBin Figure 1, E is everywhere tangent to the planes at (a) and (b), whereas B consists of both a tangential component (ydirection) and a perpendicular component (x-direction). We know of no simpler physical model that is adequate to handle all cases. The absence of the even harmonics might at first be puzzling, on the basis of Eq. (23), since it would lead us to expect all the higher harmonics in the representation. The gate opens for a brief time during each round-trip to let the pulse pass. One of these phosphors in a cluster emits blue light, and one emits green light when struck by an electron beam. How much information could be stored in the 1-mm-thick CD if the data coul problem 3) is N2 = NT a sI>1hn; A 212 b 1 + 2sI>1hn; A 212 b 1 + 2sI>1hn Assuming n = 1.50 for the glass lens, ideally nf = 21.50 = 1.22. The "miss" along the optical axis, represented by the distance LI, is called the transverse, or lateral, aberration. This integral has other important applications in physics. As P¿ moves up the screen, D moves down along the spiral shown in Figure 14b. (10) and (11) we used the fact that the time average of the square of a rapidly oscillating sinusoidal function is 1/2. Direct light from that is clearly different from that of skylight, which has a predominantly blue hue. In Eq. (34), the reflection coefficient takes the form rTE = 1a ib2>1a + ib2. The change in speed modifies the rate of energy propagation and thus the power of the beam; the change in direction modifies the cross section and thus the power density of the beam. Liquid-Dye Lasers The gain media in liquid-dye lasers are solutions of certain long-chain organic molecules in alcohol or other solvents. The condition for constructive interference at a point P on the screen is, then, to a very good approximation s2 - s1 = ϕ = ml a sin u (19) where m is zero or of integral value. The lenses have focal lengths of fA and fB, which may be either positive or negative. This is an important general feature of the propagation of electromagnetic waves. The curve for the case of external reflection, TM mode, indicates that no wave energy is reflected when the angle of incidence is near 60°. We have looked in detail at the behavior as p ranges from 0 to N. In Figure 8c, where the mirror does not lie directly below the object, the mirror plane may be extended to determine the position of the image as seen by an eye positioned to receive reflected rays originating at the object. 8 Quarter-wave thin films of ZnS 1n = 2.22 and MgF2 1n = 1.352 are deposited in turn on a substrate of silicon 1n = 3.32 to produce minimum reflectance at 2 mm. Here, I1 and I2 are the irradiances due to the reference and signal bear respectively, s is the distance of the object point from the film, and l is the wavelength of the light. We shall neglect lens aberrations and 462 Chapter 21 Fourier Optics Y y X x m2 m1 m0 z m 1 m 2 L1 L2 Aperture plane Figure 2 Fraunhofer diffraction of a Ronchi ruling. Following this we note the errors of refraction in a defective eye and indicate the usual corrective optics. Just as for a prism, greater refraction of shorter wavelengths brings the violet focus nearer the lens for the positive when I is to the right of V, corresponding to a virtual image. If the TAs of the filters are crossed, no light emerges from the pair. Sliney, D. The offset detail construction of Figure 2 then shows that the incremental wave aberration da, expressed as an optical system O ay ay L I S Actual wavefront Ideal wav aberrations. Absorption losses over a length L of fiber can be described by the usual exponential law for light irradiance I, I = 10e -aL (12) where a is an attenuation or absorption coefficient for the fiber, a function of wavelength. 5 For optical fibers, the defining equation for the absorption coefficient in decibels per kilometer (db/km) is given by adb K 110 db>km2log10 a P1 b P2 (13) where P1 and P2 refer to power levels of the light at two fiber cross sections separated by 1 km, as illustrated in Figure 7. This scattered light can include only E-field components polarized along the direction of the forced motion executed by the oscillators, that is, 2 The more general theory of scattering, including larger 1. scattering centers, is often called Mie scattering after its creator. Davis, Lasers and Electro-Optics (Cambridge, UK: Cambridge, UK: Cambrid O₂ are limited by the size of the entrance pupil A 1 ∞ and just make it through the exit pupil A 2 ∞ . (a) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (b) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (b) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (c) $y = (5 \text{ m})
\sin(x/25 \text{ m})$ (c) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (c) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (c) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (c) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (c) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (c) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (c) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (c) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (c) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (c) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (c) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (c) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (c) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (c) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (c) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (c) $y = (5 \text{ m}) \sin(x/25 \text{ m})$ (approaching the screen. It is important to note that there is also a maximum wavelength separation, ¢lmax, that can be resolved in an unambiguous manner. Solution Here, 1 = 513 nm and 12 = 525 nm. Since E has a sinusoidally varying magnitude as it progresses, the electric field vector varies between, say, AyN and - AyN. The high coherence of laser light allows the beam to be focused onto 1 We speak here of the electric polarization, rather than wave polarization, 14 A small goldfish is viewed through a spherical glass fishbowl 30 cm in diameter. Note that the bands are curved and contain states of differing energy E since the carriers in the bands can have different momenta pc. Since p r; the condition for significant curvature (near-field case) is (b) ¢ h2 h2 7 l 2r¿ 2p (9) Figure 2 Edge view of Figure 1. When all waves arrive in phase, the resultant. The laser frequency could be changed, for example by changing the effective length of the laser cavity. The mixing of spontaneous emission into the laser output and environmental noise fluctuations prevent laser light sources from emitting perfectly coherent light. It is useful to note that C1-y2 = - C1y2 S1 - y2 = of y. Estimate the electric field amplitude and irradiance that would cause the second-order nonlinear contribution to be 1% of the linear contribution to be 1% of the linear contribution in KDP 1KH2PO42. When the slit separation a reaches a value of 0.1 mm, f g f = 0 and the fringes disappear. First, the fringes disappear. First, the fringes disappear. largest amplitudes have quite different values and result in incomplete cancellation. Operating in the green at about 550 nm, what is the resolving power in the third order? (55) and (56) and equations n2R - n2I = 1 s 2nRnI = e0v (57) Furthermore, if the complex character of k in the form 'v 'v k = a b n = a b[nR + inI] c (58) is introduced into the harmonic wave, Eq. (52), the result is $E = E0e - 1vnIs > c^2eiv1nRs > c + t^2$ (59) where s is the directed distance along the propagation direction. 3 SPOT SIZE AND RADIUS OF CURVATURE OF A GAUSSIAN BEAM Optical axis Simple translation of a ray. There are, however, several important differences between the underlying systems and their behaviors. For m = 10.2 mm2 For m = 10.2 mm between electrical contacts, as shown in Figure 4. To define this quantity precisely, we utilize Figure 22, which shows an axial object point O at distance s0 from a lens being imaged at O₂, a distance s0 from a lens bei The two integrals in this form can be expressed in terms of the Fresnel integrals, which we name y C1y2 K 3 0 cos a py2 b dy 2 (30) 322 Chapter 13 Fresnel Diffraction y S1y2 K 3 sin a py2 b dy 2 (31) 0 Using these, Eq. (29) may be written as EP = Apei1kD - vt21C1y22 - C1y122 + i1S1y22 - S1y122 Now the irradiance at P, since Ip = IP = (32) 1 e c f EP f2, is given by 2 0 1 e c f Ap f 251C1y22 - C1y1222 - C1y1222 - C1y1222 - C1y1222 - S1y12226 (33) Here we have defined the irradiance scale factor I0 = 11 > 22e0c f Ap f 2. The situation is much the same as when looking through a small, square aperture placed in front of a window. 476 477 Theory of Multilayer Films The relationships we require from electromagnetic theory are summarized here. Chapter 11 Ball, C. The ultimate goal of optical design is to reduce the ray aberrations until they are comparable to the unavoidable blurring due to diffraction itself. An optical cavity that confines and directs the growing number of resonant energy photons back and forth through the laser medium, continually exploiting the population inversion to create more and more stimulated emission, thereby creating more and more photons directed back and forth between the mirrors. 7. They apply also to a medium of refractive index n if e0 is replaced by n2e0 and c is replaced by n2e0 and course, is accompanied by a rapid increase in photon number density. (6) and (7) can be used in this relation to give 8phn30 c 3 1 e hn0>kBT = B12e - 1 A 21 hn0>kBT = B12e temperatures T, the term that multiplies ehn0>kBT and the remaining term in parentheses must each be identically zero. The amount of light from the source intercepted by the lens. At such points, the principal maxima of Figure 15 are produced. I = I0 (2 sin 2 cos 2) 1. As a point of reference for judging the departure of defective vision from the norm, refer to the normal eye depicted in the left column of Figure 5. From then on, light was viewed as a particular region of the electromagnetic spectrum of radiation. Introduction to Classical and Modern Optics, 3d ed. 255 Fiber Optics with only one propagating mode. More precisely, a1Q2 = 1n1/+ n2/2 - 1n1s + n2s/2 (6) Employing the cosine law in triangles PQC and COI, the lengths / and /2 may be exactly expressed, in terms of the quantities defined in Figure 3, by /2 = R2 + 1s + R22 - 2R1s + R2cos f (7) /2 = R2 + 1s + R22 - 2R1s + R2cos f (7) /2 = R2 + 1s + R22 - 2R1s + R2cos f (7) /2 = R2 + 1s + R22 - 2R1s + R2cos f (7) /2 = R2 + 1s + R22 - 2R1s + R2cos f (8) cos f = 11 - sin2 f (2) + R2 + 1s + R22 - 2R1s + R2cos f (7) /2 = R2 + 1s + R22 - 2R1s + R2cos f (7) /2 = R2 + 1s + R22 - 2R1s + R2cos f (8) cos f = 11 - sin2 f (2) + R2 + 1s + R22 - 2R1s + R2cos f (7) /2 = R2 + 1s + R2cos f (7) /2 = R After integration and substitution of limits, we get K = 1.5e-ik sin u[12j - 12a - b]>26 ik sin u [12j - 12a + b]>26 ik sin u[12j - 12a + b]>26 ik sin u [12j - 12a + b]>26 ik sin u[12j - 12a + b]>26 ik sin u parameter of the interferometer, as we shall see. 14.9 cm 27. This nonlinear phenomenon is discussed in the next section. The carbon (C) and oxygen (O) atoms form the base of the pyramid, as shown, with carbon lying in the center of the equilateral triangle of oxygen atoms. In the analysis leading to the irradiance that results from the superposition of two mutually coherent beams, Eq. (14), we assumed that the individual beams were plane waves described by Eqs. The frequency of a photon with this energy is E2 - E1 = hn0 Q n0 = = Hn0 Q Function We have, so far,
treated the energy levels of atoms as if they were truly discrete. 12 For each case of problem 11, find the irradiance energy levels of atoms as if they were truly discrete. 12 For each case of problem 11, find the irradiance energy levels of atoms as if they are truly discrete. 12 For each case of problem 11, find the irradiance energy levels of atoms as if they are truly discrete. 12 For each case of problem 11, find the irradiance energy levels of atoms as if they are truly discrete. 12 For each case of problem 11, find the irradiance energy levels of atoms as if they are truly discrete. 12 For each case of problem 11, find the irradiance energy levels of atoms as if they are truly discrete. 12 For each case of problem 11, find the irradiance energy levels of atoms as if they are truly discrete. 12 For each case of problem 11, find the irradiance energy levels of atoms as if they are truly discrete. 12 For each case of problem 11, find the irradiance energy levels of atoms as if they are truly discrete. 12 For each case of problem 11, find the irradiance energy levels of atoms are truly discrete. 12 For each case of problem 11, find the irradiance energy levels of atoms are truly discrete. 12 For each case of problem 11, find the irradiance energy levels of atoms are truly discrete. 12 For each case of problem 11, find the irradiance energy levels of atoms are truly discrete. 12 For each case of problem 11, find the irradiance energy levels of atoms are truly discrete. 13 For each case of problem 11, find the irradiance energy levels of atoms are truly discrete. 14 For each case of problem 11, find the irradiance energy levels of atoms are truly discrete. 14 For each case of problem 11, find the irradiance energy levels of atoms are truly discrete. 14 For each case of problem 11, find the irradiance energy levels of atoms are truly discrete. 14 For each case of atoms are truly discrete. 14 For each case of atoms are truly discrete. 14 For each case of atoms are truly discrete. 14 Fo an analyzer, the combination contributes a blue tint to the almost canceled transmitted light. (a) 750 MHz (b) 750 MHz (c) 154 MHz that a = 11 > 22 ka sin u = pa sin u > 1, so that the condition for the existence of a principal maximum can be recast as ml = a sin $u \sin 2$ b sin 21 Na2 (34) is sometimes called the diffraction grating equation and m is identified as the order of the diffraction. In that case, constructive interference occurs at P. Sketch the arrangement, showing the OA of the crystal, and explain why this occurs. Thus a detector, placed on axis at the output plane in the optical aberration in a thin-lens system that forms a blurred line image of an axial point object. (a) 0.5 µm (b) 2 × $10-8 \mu m$ (c) $-2.48 \times 10-6 \mu m$ 22. Since dy = fdu, the linear dispersion is given by linear dispersion K dy dum = f = f dl dl (6) The reciprocal of the linear dispersion is known as the plate factor. Thompson. 13 Plot the spectral exitance Ml for a graybody of emissivity 0.4 in thermal equilibrium at 451°F, the temperature at which paper burns. r11 =8.5168 cm; r22 = -434.89 cm; fD = 20.0000 cm, fC = 20.0096 cm; fF = 20.0096 cm; fF = 20.0096 cm; fF = 20.0096 cm; fF = 20.0096 cm; fD = 20.0096 cm; fD = 20.0096 cm; fF = 20.0096 cm; fD = 20.0096those measured within the medium. The edges of the window determine how much of the outdoors we can see. 22 A guarter-wave plate is placed between the polarizer and the QWP fast axis is u. When the refracting medium has characteristic excitations that absorb light of wavelengths within the range of the dispersion curve, the curve is monotonically decreasing, as shown, but has a positive slope in the wavelength) of the wavelength region of the absorption. Note that the propagation constant k is related to the temporal period T. of radiant flux would produce only 0.5 * 685 or 342 lm of luminous flux. With the lens of part (a), what is the far point of the corrected eve? Intentional limitation of the field of view using an aperture is desirable when either far-off axis imaging is of unacceptable guality due to aberrations or when vignetting severely reduces the illumination in the outer portions of the image. Reflection from the bottom surface; 1.60 1.55 1.153 cm 8 cm Light from the bubble is refracted through the plane surface, both directly and after reflection from the spherical mirror; 3.33 cm and 10 cm. It is convenient to choose the z = 0 plane to be the plane in which q(z) is purely imaginary. However, Fresnel and Arago showed experimentally that the spot, now known somewhat ironically as Poisson's spot, did occur as predicted. By doing so the dwell time of the atoms in the upper lasing level 2 increases and so the likelihood of the occurrence of stimulated emission, which leads to gain, is increased. 1.3 × 105 W/cm2 19. This prospect has contributed to interest in developing X-experimentally that the spot, now known somewhat ironically as Poisson's spot, did occur as predicted. By doing so the dwell time of the atoms in the upper lasing level 2 increases and so the likelihood of the occurrence of stimulated emission, which leads to gain, is increased. ray lasers. 300 Chapter 12 The Diffraction Grating ui m ≥ 1 m 0, b 0 m ≤ 1 (a) Unblazed ui m ≥ 1 m0 m ≤ 1 b0 (b) Blazed Figure 5 In an unblazed reflection grating (a), the diffraction envelope maximum at b = 0 coincides with the zeroth-order interference at m = 0. Radiation over the visible spectrum approximates that of a graybody, with emissivities approaching unity for tightly coiled filaments. (19), (21), and (22), respectively. The half-angle beam divergence uFF = l>1pw02 is valid only in the far field. The violet and red components of the white light leaving point P refract differently at the lens and so converge at different image points, labeled V and R, respectively. In fact, under the conditions for which Eqs. cos u - 2n2 - sin2 u 2 cos u + 2n - sin u P = ITM - ITE ITM + ITE where I stands for the irradiance of either polarization mode. In fact, the Stokes field is generated in a range of frequencies known as the Raman bandwidth of the fiber. Contributing zones are like those included in the chord FG of Figure 15b, but with the spiral length FG moved somewhat toward the lower end. When the responsivity is a function of l, the detector is said to be selective. 14 Assume that in a Mach-Zehnder interferometer (Figure 5), the beam splitter and mirror M3 each transmit 80% and reflect 20% of the incident light. (b) /2, /3, 0, -/2, 0.6 (c) Subtract /2 from each. (32) and (33) can be succinctly summarized by stating that convolution in real space corresponds to multiplication in Fourier space. In a developed photograph, for example, the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the optical density of the emulsion at each point is a function of the emulsion at each point is a function of the emulsion at each point is a function of the emulsion at each point is a function of the emulsion at each point is a function of the emulsion at each point is a function of the emulsion at each point is a function of the emulsion at each point is a function of the pattern is formed on a screen placed in the focal plane of the lens. 16 a. (a) Wollaston prism. Laser beam Mirror (d) Laser M2 M1 d (b) Pump (c) Resonator (d)
Laser M2 M1 d (b) Pump (c) Resonator (d) Resonator (d quantization of the energies of electromagnetic fields and atoms. Simple applications of the principle are shown in Figure 2 for a plane and spherical wave. 2 COMMUNICATIONS SYSTEM OVERVIEW No application has given greater impetus to the rapid development of fiber optics than has voice or video communication and data transmission. The influence of the sheets with perpendicular scratches on either end of the liquid crystal and the long-term order of the liquid crystal leads to the twisted orientation of the molecules shown in Figure 9a. Determine the location and size of the intermediate image of OP formed by L1 and the final image formed by the system. The distance r may be referred to the distance r0 as follows. Estimate the electric field amplitude and irradiance that would cause the third-order nonlinear contribution in a certain mix of b-carotene in ethanol. New York: John Wiley and Sons, 1973. (33) and (34) do not differ greatly, and in citing magnifications, Eq. (33) is most often used. If, when it reaches Mirror 2, its wavefront radius of curvature R1z22 matches the radius of curvature RM2 of Mirror 1. Since the media on either side of the refracting surface are characterized by different refractive indices, however, the isochronous rays are not equal in length. Trace the ray through the cube. This arrangement can also be used as an optical means of measuring the radius of curvature of the lens surface. the line O¿CI¿. The E 2 term is considered negligible in the Pockels effects. Notice that the addition of orthogonal components of linearly polarized light is not unpolarized light, even though unpolarized light is often symbolized by such components. What is the overall operational efficiency (wall-plug efficiency) for this laser? 15 The rotation of polarized light in an optically active medium is found to be approximately proportional to the inverse square of the wavelength. For E 7 OA, n7 = 1.4864 and uc = 42.3°, while for E OA, n = 1.6584 and uc = 37.1°. Figure 7b shows a slightly different view of chromatic aberration evident in the behavior of white light incident on a lens from an off-axis point P. We restrict our discussion to cases where nl>r0 V 1, so that the second term in square brackets is negligible compared with the first. (c) Gregorian telescope Variations of a signal voltage superimposed on V are transformed into variations in light intensity in such a device, known as a Pockels electro-optic modulator. Pump energy is provided to the system via the 0 to 3 transition. The irradiance of the subject beam is proportional to the system via the 0 to 3 transition.

earlier, in the absence of pumping, there will be no population inversion between any two energy levels of a laser medium. 4 STANDING WAVES Another important case of superposition arises when a given wave exists in both forward and reverse directions along the same medium. the form of photons of radiation. Thus Eq. (17) describes both the emission and the absorption of a phonon by the crystal lattice. Multiple-beam interference takes place when either set is focused to a point by a converging lens, as shown for the transmitted beam. Solid and liquid gain media are typically pumped either by a flashlamp or another laser. 12 A presbyopic eye has no astigmatism, a near point of 125 cm, and a far point of infinity. (a) He-Cd appears about 1.3 × brighter (b) about 2.4 mW (a) 900 Cd (b) 42.86 mm; +23.33 D (c) 43.65 mm, measured from its second principal plane, or 42.38mm from its second surface; +22.9 D (a) 22.34 mm from cornea (b) 21.60 mm from cornea (c) 21.60 mm from cornea (c) 21.60 mm from cornea (c) A = 0.75846, B = 5.1050, C = -0.05011, D = 0.65180 (c) Focal points are 1.96 mm behind the cornea; principal points same object point, 2 cm above the optical axis and an axial distance of 10 cm from the first surface. One important difference is that the amplitude of the oscillation of the Bessel function decreases as its argument departs from zero. Thus, rays 1, 2 and 3 focus to point A, and rays 4, 5 and 6 focus to point B. As a result the initial gain exceeds the cavity losses and the photon number density begins to grow rapidly. If the screen is moved 75 cm in the process, how far is the object moved? Then at some distance z into the medium, u^c 7 u^P for all t. In this figure, an atom originally in its lowest possible energy state E1, called its ground state, is raised to an excited state of energy E2 by absorption of a photon of energy, E2 - E1 = hn¿. The fiber serves as an optical waveguide to propagate the information with as little distortion and loss of power a distance that can range from meters. See Jurgen R. Find the spherical wave aberration and the longitudinal and transverse spherical ray aberrations. 5 PLANE WAVES We wish now to generalize the harmonic wave equation further so that it can represent a waveform propagating along any direction in space. (b) Aerial view of the guitarists may then adjust the tension in the guitarists may the tension in the guitarists may the tension in the guitarists may then adjust the tension in the guitarists may the tension in tension in tension in the guitarists may the tension in tension guitars are in tune. Viewing the beam head-on, some materials produce a clockwise B rotation (dextrorotatory) of the E-field, whereas others produce a counterclockwise rotation (levorotatory). Since this beam is essentially the subject beam, it appears to come from the subject beam, it appears to come from the subject. On Sundays, they simply prayed." The Strange Story of the Quantum Banesh Hoffmann, 1947 INTRODUCTION The words cited above—taken from a 1947 popular primer on the quantum world—delighted many readers who were just then coming into contact with ideas related to the nature of light and quanta. The difference in wavelength between "adjacent" channels is typically about 0.8 nm. 4 One can define a saturation irradiance IS, abs for an absorptive medium as the irradiance for which the loss coefficient a is reduced by a factor of 2 from its small-signal value. Based on these observations, we conclude that a Jones vector with elements of unequal magnitude, one of which is pure imaginary, represents elliptically polarized light oriented along the x, y-axes. Fincham, W It is precisely the component EDC in the figure that accounts for the zeroth-order diffraction signal. In the first case, the grating is a transmission amplitude grating, functioning like the slotted, opaque aperture. 534 Chapter 24 Nonlinear Optics and the Modulation of Light 12 The speed of sound in glass is 3 km/s. 1, 2. Time-Average Holographic Interferometry This type of interferometry is used to study vibrating surfaces, where the object is moving continuously during exposure of the hologram. (a) Quarter-quarter exposure of the hologram. (b) OA OA (c) Figure 23 TA1 TA2 4 How thick should a half-wave plate of mica be in an application where laser light of 632.8 nm is being used? New York: McGraw-Hill Book Company, 1969. 354 Chapter 15 Production of Polarized Light when the reflected and refracted rays are perpendicular to one another (Figure 4c). This is precisely what occurs in a laser gain medium due to the stimulated emission process caused by the recycling of light within the laser cavity. For the mirror reflectivities of the LIGO device, this enhancement factor is about 50, making the effective length of an interferometer arm about 200 km. Inside the crystal, the extraordinary ray can be described in terms of components polarized in directions both perpendicular and parallel to the optic axis. A detector at the focal point of the second lens records intensity as a function of plate spacing d. The reciprocal of the dispersive power is known as the Abbe number. In looking through the hologram, one now sees the virtual image superimposed over the object itself. When EM wave energy is detected, the detector can record only energies that are multiples of a photon's energy. Results from electromagnetism describing the physics of electromagnetic waves are borrowed to enable a determination of the energy delivered by such waves. Mode Suppression with an Etalon As noted, many laser systems permit so-called multimode operation. What is the penetration depth at which the amplitude of the evanescent wave is reduced to 1/e of its value at the surface? Locate the aperture stop and entrance pupil. 0.10 mW/cm2 nm at 50-cm distance Typical spectral irradiance from bare element per 10-mm2 area Figure 5 Globar infrared source, providing continuous usable emission from 1 to over 25 mm at a temperature variable up to 1000 K. Note that the phenomenon does not occur unless n1 7 n2, so that uc can be determined from Eq. (5). Determine the location of the beam waist. 2 A certain photodiode generates one electron for every 10 photons of wavelength 0.9 mm incident on the detector. Embossed holograms are used also in anticounterfeiting applications. Images are inverted in both vertical and horizontal directions by the pair, so that the Porro prism is commonly used in binoculars to produce erect images. The same information is included in the relation y = nl (5) where we have used Eq. (4) together with the reciprocal relation between period T and frequency n 1 n = (6) T Related descriptions of wave parameters are often used. 16 Show that the visibility of double-slit fringes in the mth order is given by V = 1 am ¢l b l where l is the average wavelength of the light and ¢l is its linewidth. The lens helps to counteract curvature of field without otherwise seriously compromising image quality. Still, if the lens is thin, focusing occurs along the vertical sections, as shown. (New York: Halsted Press, 1987). We now wish to address the question of how the beam changes when it is modified by an arbitrary optical system, one that contains lenses, mirrors, prisms, and so forth. Let this light be transmitted through an element that rotates linearly polarized Light: Production and Use. In general, then, any actual ray of light in an optical system, if reversed in direction, will retrace the same path backward. According to the principle of ray reversibility, the situation shown in Figure 21b must also be valid. When lenses are used in combination, the possibility of canceling spherical aberration arises from the fact that 1 See Francis A. In the 200-in. Write down the rate equations for the population densities of the levels. Calculate the irradiance of the geometrical shadow. Thus if the object plane contains both circular and radial elements, the image distance for a good focus will be different for each type of element, with a compromise image somewhere between. The sign convention is summarized in the inset of Figure 7. (23) and (24) are added, the terms n2>s1œ cancel and there results n1 n1 1 1 + œ = 1n2 - n12a b s1 s2 R1 R2 Now s1 is the original object distance and s2œ is the final image distance, so we may drop their subscripts and write simply n2 - n1 1 1 1 1 a b = + s n1 s₂ R1 R2 (27) The focal length of the thin lens is defined as the image at infinity, giving n2 - n1 1 1 1 = a b n1 f R1 R2 F (a) F (b) Figure 21 Lens action on plane wavefronts of light. The phasor FG that connects these points is ! FG = 1C1yG2 - C1yF22 - C1yF2 i1S1yG2 - S1yF22 The electric field amplitude—see Eq. (32)—at point P of Figure 11 could then be written as IP = I01FG22 (35) ! Here the symbol FG is intended to represent the length of the phasor FG. The amplitude of each segment of the beam can be assigned by multiplying the previous amplitude E0 and working progressively through 186 Chapter 7 Interference of Light (1) (2) (3) (4) (5) (6) 0 tr 7 E 0 rE ttr 9 E ttr 5 E 8 0 tr E 0 tr 3 E 6 0 tr E 0 0 4 0 tr E ttr E 2 0 tr E ui 0 E0 0 tr 9E 0 tr 7 E 0 rE ttr 9 E ttr 5 E 8 0 tr E 0 tr 3 E 6 0 tr E 0 4 0 tr E ttr E 2 0 tr E ui 0 E0 0 tr 9E 0 tr 7 E 0 rE ttr 9 E ttr 5 E 8 0 tr E 0 tr 3 E 6 0 tr E 0 4 0 tr E ttr E 2 0 tr E ui 0 E0 0 tr 9E 0 tr 7 E 0 rE ttr 9 E ttr 5 E 8 0 tr E 0 tr 3 E 6 0 tr E 0 tr 8 E 6 0 tr E 0 tr 8 tr 3E 0 trE ut tE 0 nf 0 n t n 8 E 0 ttr 6 E 0 ttr 4 E 0 ttr 2 E 0 ttr 4 E 0 ttr 2 E 0 ttr ttE 0 Figure 22 Multiply reflected and transmitted beams in a parallel plate. One need only know the incident beam parameter 1q12 and the overall 2 * 2 matrix that characterizes the optical system. For the case of internal reflection we give ∞ Brewster's angle the symbol up. $\geq 2.5 \geq 1.5$ Straight Edge Fresnel diffraction by a straight edge is pictured in Figure 14a. What is the biprism angle a? In this brief comparison we have remarked on
some of the differences and similarities between classical particles and light and have provided several fundamental relations that apply to both. Location and size of entrance and exit pupils. In this case the irradiance I0 input into the gain cell and the irradiance IL output from the gain cell are simply related (see problem 8) by IL>I0 = eg0L In order for the irradiance to grow during each round-trip. In this latter approach, a mixture of two gases is used such that the two different species of atoms, say A and B, have excited states A* and B* that coincide. Near the center or core of the lens (on axis), the index is about 1.38. In each figure, (a) illustrates the situation for an unblazed grating and (b) shows the result of shaping the grooves to shift the diffraction envelope maximum 1b = 02 away from the zeroth-order 1m = 02 interference or principal maximum. For example, the Pockels effect (involving r) by the second. Figure 11 schematically shows the Michelson interferometer, which uses a beam splitter SP to separate equalamplitude portions of a spectral input beam from source S and reunite them again after reflection from mirrors M1 and M2. When this occurs, the term anomalous about it. A: The image of aperture A backward through L1 is virtual and is shown as A 1œ. Such confusion in high orders is sometimes about it. A: The image of aperture A backward through L1 is virtual and is shown as A 1œ. Such confusion in high orders is sometimes about it. A: The image of aperture A backward through L1 is virtual and is shown as A 1œ. Such confusion in high orders is sometimes about it. A: The image of aperture A backward through L1 is virtual and is shown as A 1œ. Such confusion in high orders is sometimes about it. A: The image of aperture A backward through L1 is virtual and is shown as A 1œ. Such confusion in high orders is sometimes about it. A: The image of aperture A backward through L1 is virtual and is shown as A 1œ. Such confusion in high orders is sometimes about it. A: The image of aperture A backward through L1 is virtual and is shown as A 1œ. Such confusion in high orders is sometimes about it. A: The image of aperture A backward through L1 is virtual and is shown as A 1œ. Such confusion in high orders is sometimes about it. A: The image of aperture A backward through L1 is virtual and is shown as A 1œ. Such confusion in high orders is sometimes about it. A: The image of aperture A backward through L1 is virtual and is shown as A 1œ. Such confusion in high orders is sometimes about it. A: The image of aperture A backward through L1 is virtual and is shown as A 1œ. Such confusion in high orders is sometimes about it. A: The image of aperture A backward through L1 is virtual and is shown as A 1œ. Such confusion in high orders is sometimes about it. A: The image of aperture A backward through the approximate about it. A: The image of aperture A backward through the approximate about it. A: The image of aperture A backward through the approximate about the approximate about the aperture A backward through the approximate about alleviated by using a second dispersing instrument that spreads the first spectrum again but in a direction orthogonal to the first. A plane wavefront, for example, has a curvature of zero. a. One can show that the resultant contribution from these subzones has an effective phase intermediate between the phases at the zone beginning and end, such that effective phases from successive half-period zones are p, or 180°, apart. N. An overlay of the scaled transmittance through the Fabry-Perot cavity (solid curve) and the scaled transmittance through the scaled transmittance through the fabry-Perot cavity (solid curve) and the scaled transmittance through the fabry-Perot cavity (solid curve) and the scaled transmittance through the scaled transmittance through the fabry-Perot cavity (solid curve) and the scaled transmittance through the scaled transmittance through the fabry-Perot cavity (solid curve) and the scaled transmittance through the fabry-Perot cavity (solid curve) and the scaled transmittance through the fabry-Perot cavity (solid curve) and the scaled transmittance through the fabry-Perot cavity (solid curve) and the scaled transmittance through the fabry-Perot cavity (solid curve) and the scaled transmittance through the fabry-Perot cavity (solid curve) and the scaled transmittance through the scaled transmittance through the fabry-Perot cavity (solid curve) and the scaled transmittance through the scaled transmit satisfying total internal reflection at the walls of the fiber. (54) and (55), starting from a nonzero "seed" photon number density. From the two right triangles formed by the intermediate image and the optical axis, it is evident that the angular magnification is M = fo a_i = a fe (48) 84 Chapter 3 Optical Instrumentation Objective Ocular fe fo RO a a ExP EnP Figure 31 Astronomical telescope. However, while high bit-rate signals carried on optical fibers need amplification only every 100 km or so. Since E0x = 3 and E0y = 222 + 12 = 25, the inclination angle of the axis is given by a = 122132 A 25 B cos10.148p2 1 tan-1 a b = 35.8° 2 9 - 5 With this data the ellipse can be sketched as indicated in Figure 7. 1015 1016 v0 Frequency (rad/s) 1017 Extinction coefficient nI 1.0 nR 543 Optical Properties of Materials of a number of resonance frequency (rad/s) 1017 Extinction coefficient nI 1.0 nR 543 Optical Properties of Materials of a number of resonance frequencies to mean that electrons experience different degrees of freedom in response to the applied field. Such an amplifying or gain medium plays a central role in laser action. Notice that the composite phasor a1 makes an angle of 90° relative to the first subzone phasor. As a result, the peak power Ppeak in a Q-switched pulse can be a factor of 1000 or more larger than the CW output power from the same laser system. (a) no ni O (b) ni no O (c) Figure 13 Cartesian refracting surfaces. EA i1kr0 - vt2 e eisk sin u dA r0 O We take a rectangular strip of area dA = x ds as the elemental area of integration, shown in Figure 6. Unlike the T and S surfaces, the Petzval surface is unaffected by lens bending or placement and depends only on the refractive indices two beams are in phase and amplitudes add. Unpolarized light traveling in the + z-direction passes through a linear polarizer, whose preferential axis of transmission, or transmission, or transmission axis (TA), is vertical. Is it true that R1z2 z in the far field? Determine for a Littrow configuration (a) the range of orders in which the visible spectrum (400 to 700 nm) appears; (b) the total number of grooves; (c) the resolving power and minimum resolvable wavelength interval at 550 nm; (d) the dispersion at 550 nm; (e) the free spectral range, assuming the shortest wavelength interval at 550 nm; (e) the free spectral range assuming the short of radiation of radiation at 550 nm; (e) the free spectral range assuming the short estimate as the approximate as presented by the surface decreases in such a way that I1u2 = I102 cos u (13) a relation called Lambert's cosine law. However, the physical import of these equations is the same when they are interpreted in terms of their original figures. Spontaneous Emission Spontaneous Emission, illustrated in Figure 11c, can take place if an atom is in an excited state even when there are no photons incident on the atom. Determine the longitudinal and lateral spherical ray aberration. The same result can be found using Eq. (16), which would take the form 119 Superposition of Waves E20 = $72 + 122 + 202 + 2c17 * 122 \cos a + 112 * 202 \cos$ the resulting harmonic wave is found using Eq. (12). Holographic Interferometry. This beam radius would increase about 8 cm every 3130 m. In contrast, a flat-panel plasma display may have a screen size as large as the largest CRT displays and yet only be a few inches thick. In this instance, the spectral exitance of the the blackbody and their curves are the same except for a constant factor. Laser beam 16 Holography is one of the many flourishing fields that owes its success to the laser. The image distance in each case is defined as the focal length f of the mirrors. So, in Eq. (3), we set KS = 0, and the equation of motion becomes m dvB B + mgvB = - eE dt (40) The equation may be conveniently expressed in terms of the conductor, each electron in the solid is bound to a given atom (that is, it is in the valence band). Thus if the retardation plate acts as a HWP for red light, in the arrangement of Figure 20, red light will be fully transmitted, whereas shorter visible wavelengths will be only partially transmitted, giving the transmitted, giving the transmitted, giving the transmitted light a predominantly reddish hue. done mostly with a surgical blade in the hands of a skilled ophthalmologist, had its beginning in the Soviet Union in 1972. What is the maximum slit space insuring interference fringes that are just visible? 13 Repeat problems 11 and 12 for the case in which the field input into the cell has a frequency $n_c = n0 + cn > 2$, where cn is the homogeneous linewidth of the gain medium. A frequent use of such single-layer films is in the production of antireflecting coatings on optical surfaces. Ch. 9. (b) Resultant displacement of a standing wave, shown at various instants. In this chapter we have discussed but a few of the many important effects and applications associated with the nonlinear interaction of light and matter. Goodman, Introduction to Fourier Optics (New York: McGrawHill Book Company, 1968). The subsequent expansion of the universe lowered the temperature of the spectral irradiance of this background radiation. 497 Fresnel Equations 2 EXTERNAL AND INTERNAL REFLECTIONS When interpreting these equations, it is useful to distinguish between two physically different situations: external reflection: n1 7 n2 or n = n2 6 1 n1 Figure 3 is a plot of Eqs. A hole in
the primary mirror permits viewing the image with an eyepiece of 4-in. Hence it diverges on emerging from the hologram, as if coming from a virtual image behind the hologram. Destructive interference is complete, that is, cancellation is complete, when I1 = I2 = I0 . 3 When viewing virtual images with optical instruments, the images may be at great distances, even "at infinity," when rays entering the eye are parallel. For concreteness, consider a plane sound wave propagating along the x-direction through a sample of air. In an active matrix LCD, thin-film transistors (TFTs) control the voltage across each pixel in the display. Referring to Figure 3, we will now develop an expression for the irradiance at observation points such as P on a screen that is a distance L from the plane containing the two holes S1 and S2. Figure 6 Spectral irradiance from a 100-W quartz halogen lamp, providing continuous radiation from 0.3 to 2.5 mm. At what spacing does the Problem 10. The figure shows that the beat frequency is simply the difference frequency for the two waves. What is the frequency and wavelength of the photon with the same energy as the energy difference E2 - E1 of part (a)? For example, in Eq. (7), w = k1x; yt2 (10) When x and t change together in such a way that w is constant, the displacement y = A sin w is also constant. Analogous to the relations just found, we see that in ¢CMV: sin1 - a_i2 = a_i R in ¢PLC: sin u_i = Q_i - a_i R As before, when a_i is eliminated, there results Q_i = R1sin u_i - sin a_i2 (39) Matrix Methods in Paraxial Optics P T 415 M u A Q Q A 1 L a R ≥ a² ≥ a² ≥ Q V 2 ≥ a₁ A l ≥ a⁴ ≥ a components corresponding to each reference channel are kept separated in the output plane by using a cylindrical lens as the final transform lens. Describe the image of a 1-in.-tall object, situated 8 cm from the first vertex. 27. The results are 266 Chapter 10 l1mm2 0.70 0.90 1.10 1.40 1.70 Fiber Optics d1t>L21ps>km2 1.88 5.02 7.08 8.40 8.80 a. 14 Light of continuously variable wavelength illuminates normally a thin oil (index of 1.30) film on a glass surface. Both criteria are used. We conclude that linearly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as being made up of left- and right-circularly polarized light can be regarded as be regarded as being made up Assume that the glass is thin enough so that its effect on the refraction may be neglected. 172 Chapter 7 Interference of Light Example 2 Laser light passes through two identical and parallel slits, 0.2 mm apart. Notice that the resolving power, like the dispersion, is independent of groove spacing for a given diffraction angle. = B12g1n¿21I>c2N1 (9) Here B12 is the Einstein B coefficient for stimulated absorption. That is, with Pav = PCW, PCW = Pp ¢tp T Using Eqs. Ultraviolet light is sometimes subdivided into three categories: UV-A refers to the wavelength range 380-315 nm, UV-B to the range 280-10 nm. For example, if 520/636 crown glass and 617/366 flint glass are used in designing an achromat of focal length 15 cm, 455 Aberration Theory TABLE 1 SAMPLE OF OPTICAL GLASSES Type Catalog code Borosilicate crown Dense flint Flint Dense 520/636 573/574 638/555 617/366 620/380 689/312 805/255 458/678 64.55 63.59 57.43 55.49 36.60 37.97 31.15 25.46 67.83 1.51461 1.51764 1.62045 1.63810 1.61715 1.62045 1.68893 1.80518 1.45846 1.52262 1.52582 1.57953 1.64611 1.62904 1.63198 1.70462 1.82771 1.52015 1.57259 1.63810 1.61715 1.62045 1.68893 1.80518 1.45846 1.52262 1.52582 1.57953 1.64611 1.62904 1.63198 1.70462 1.82771 1.52015 1.57259 1.63810 1.61715 1.62045 1.68893 1.80518 1.45846 1.52262 1.52582 1.57953 1.64611 1.62904 1.63198 1.70462 1.82771 1.52015 1.57259 1.63810 1.61715 1.62045 1.68893 1.80518 1.45846 1.52262 1.52582 1.57953 1.64611 1.62904 1.63198 1.70462 1.82771 1.52015 1.57259 1.63810 1.61715 1.62045 1.68893 1.80518 1.45846 1.52262 1.52582 1.57953 1.64611 1.62904 1.63198 1.70462 1.82771 1.52015 1.57259 1.63810 1.61715 1.62045 1.68893 1.80518 1.45846 1.52262 1.52582 1.57953 1.64611 1.62904 1.63198 1.70462 1.82771 1.52015 1.57259 1.63810 1.61715 1.62045 1.68893 1.80518 1.45846 1.52262 1.52582 1.57953 1.64611 1.62904 1.63198 1.70462 1.82771 1.52015 1.57259 1.63810 1.61715 1.62045 1.68893 1.80518 1.45846 1.52262 1.52582 1.57953 1.64611 1.62904 1.63198 1.70462 1.82771 1.52015 1.57259 1.63810 1.61715 1.62045 1.68893 1.80518 1.45846 1.52262 1.52582 1.57953 1.64611 1.62904 1.63198 1.70462 1.82771 1.52015 1.57259 1.63810 1.61715 1.62045 1.68893 1.80518 1.45846 1.52262 1.57953 1.64611 1.62904 1.63198 1.70462 1.82771 1.52015 1.57259 1.63810 1.61715 1.62045 1.6893 1.6918 1.57558 1.57558 1.57558 1.57558 1.57588 1.5 1.46313 these equations lead to lenses with radii of curvature given by r11 r12 r21 r22 = = = 6.6218 cm - 6.6218 cm - 6.6218 cm - 223.29 cm With these values, Eqs. However, an additional phase difference, due to the phenomenon of phase changes on reflection, must be considered. 2 Deduce the Cartesian oval for perfect imaging by a refracting surface when the object point is on the optical x-axis 20 cm from the surface vertex and its conjugate image point lies 10 cm inside the second medium. If this filter is placed in front of a source range 5000 ; 0.5 A of white light, what is the coherence length of the transmitted light? It adapts itself to an extraordinary range of intensities, from the barely visible flicker of a candle that is miles away on a dark night to sunlight so bright that the optical image on the retina causes serious solar burn. The irradiance at g : 0 or at u = 0. The height of the ray changes during translations between these points. Hoffmann's amusing and informative account—involving in part the wave-particle twins "tweedledue"—captured nicely the level of frustration felt in those days about the true nature of light. The screen is 1 m from the same intersection, measured along the normal to the screen. Research-grade instruments, however, make use of reflection gratings. The possibility of producing high-energy densities, using laser light, has facilitated the study and use of such effects, making nonlinear optics. A Fabry-Perot cavity used in this manner is often characterized by a quality factor, Q, defined as the ratio of a nominal resonant frequency to the FWHM of the transmittance peaks, Q = n n = F nfsr 2¢n1>2 (43) As noted, the transmittance of a Fabry-Perot interferometer, with an input laser field whose frequency is intentionally changed, can be used to calibrate the frequency is intentionally changed. respective sources at time t = 0. Shown are the extreme paths: an axial ray and one propagating at the critical angle. What will be the irradiance at the lunar surface? Nevertheless, the slight differences between the two images from the left and right eyes provide the basis for stereoscopic vision in humans. A process called Figure 14 Cavity dumping of a laser using an acousto-optic beam deflector. 6 SIMPLIFIED DESCRIPTION OF LASER OPERATION We have described briefly the basic elements that comprise the laser device. This approach is left to the problems. The maximum number of data points, however, is limited by computer data-storage requirements and by computer time in handling the calculations. Then, for any other wave originating at height s, taking the difference in phase into account, the differencial field at P is dEp = a EL ds i[k1r0 + c2 - vt] EL ds i[k1r0 + c2 - vt]turn to the topic of radiometry. Mode-Locking The physical arrangement of a mode-locked system, shown in Figure 15, is similar to that for a Q-switched system. (See problem 16.) If the discharge lamp is replaced with a white light source and a filter of bandwidth 10 nm at 546 nm, how does the visibility change? The
lineshape function g1n2 of the 2 to 1 transition in relation to the frequency n¿ incident 2 1 Before E2 Incident (b) v Figure 12 (a) Monochromatic light of irradiance I and frequency n¿ incident on an assembly of a toms with energy levels 2 and 1 nearly resonant with the energy of a photon in the incident light. of the energy of the wave train is clearly carried by the following equation: photometric unit = K112 * radiometric unit (1) where K112 is called the luminous efficacy. Since irradiance is power per unit area, the interference relation can be recast in terms of the detected power Pdet and the powers of the beams exiting the two interferometer arms, P1 and P2. Then, by the sign convention established previously, we make the virtual object distance, relative to the second surface, a negative quantity when using Eqs. 253 Fiber Optics Attenuation (db/km) $4.0 3.0 \text{ Glass } 2.0 1.0 \ 0.6 \ 0 \ 800 \ 900 \ 1000 \ 1200 \ 1300 \ 1400 \ 1500 \ 1600 \ Wavelength \ (nm) \ (a) 5000 \ 1000 \ 500 \ 200 \ 1000$ possible, through reflection or refraction, to produce virtual images that, acting together or with the actual source, behave as two coherent sources that can produce the zone rings, so the same reference beam is now reinforced in diffraction from the rings along directions that diverge from the equivalent point O¿. A. In the analysis leading to Eq. (9), we assumed that the field strength EL associated with each slit interval ds was a constant. Freeman and Company Publishers, 1969. The plasma display essentially consists of hundreds of thousands of tiny neon and xenon gas cells (fluorescent lights) sandwiched between electrodes and glass plates. Figure 4 summarizes the sequence of Lissajous figures as a function of relative phase ¢w = wy - wx for the general case E0x Z E0y. Consider now a cylindrical surface with a negative power of 1 diopter in the vertical meridian. How do the results for parts (a) and (b) compare? Direct light from S is not eometry is shown in Figure 14. 5 HIGH-REFLECTANCE LAYERS If the order of the layers in a l>4 - l>4 double-layer film optime ved to reach the screen. The pertinent nized for antireflection is reversed, so that the order is air-high index-low index-substrate, all three reflected beams are in phase on emergin firom the structure, and the reflectance is enhanced rather than reduced. He sought to remove the spherical aberration of a primary fs fp fp fs (b) (a) fp fs (c) Figure 34 Basic designs for reflecting telescopes. Collimating lenses are not required, therefore, for the observation of Fresnel, or near-field, diffraction patterns, and in this experimental sense, their study is simpler. Cover glass O be as large as possible. In an attempt to represent the optical powers of the eye more faithfully, schematic eyes have been designed. Using Eq. (28), uFF = 1 632.8 * 10-9 = 4.49 * 10-4 rad 0.45 mrad = -4 pw0 13.142 14.49 * 10 2 RM1 2 m RM2 wo z0 d1m Figure 7 Sketch for Example 1. The particular color seen depends on the direction along which the hologram is viewed as the head is moved along a vertical line. Figure 7 indicates the effects that varying the small-signal gain coefficient g0 and the saturation irradiance IS have on the output irradiance IL from a gain cell. It is important to note that the energy of a free electron is not guantized. Spectrometers have been built with relative mirror displacements of a meter or more, yielding resolving powers of 105 or greater. The computer calculates the complex amplitude that is the sum of radiation due to the object and then directs the drawing of the hologram, which can be photographed and reduced to the appropriate fringe spacings required. Assume n = 1.50 for the glass. The wave Eq (24) is often written more compactly by separating the spatial second derivatives from the wave function c by treating them as operators: a 02 02 02 1 0 2c + + b c = $0x^2 0y^2 0z^2 y^2 0t^2$ The entire operator in parentheses is known as the Laplacian operator, \$2 K 02 02 02 + 2 + 2 2 0x 0y 0z and Eq. (24) becomes simply $\$2c = 1 0 2c y^2 0t^2$ (25) O 6 SPHERICAL WAVES Figure 7 Portions of three spherical wavefronts emanating from a point source O. This effect, like all third-order effects, occurs whether or not a material possesses inversion symmetry. As often happens in such cases, conclusive experimental evidence was already on hand, observed nearly a century before the argument. What is the angle between the glass and water surfaces? This situation clearly yields two "vectors," E¿F and GE, which both contribute to the total field amplitude at point P. (a) 70 (b) 1.5 GHz (c) 21 MHz (d) 2.2 × 107 (e) 8 ns 20. This means that the harmonic waves making important contributions to the actual wave train span a greater frequency interval. Figure 16 Interference by an irregular film illuminated by an extended source. Both of these limitations depend directly on the optical behavior of bundles of rays that leave points on an object and thread their way through an optical system—and its aperture— to a conjugate image point. Top: Amplitude modulation; center: frequency modulation; bottom: digital modulation in which a pulse is either present ("on") or missing ("off"). From the point of view of Figure 9c, the elimination of astigmatism requires that the tangential and sagittal surfaces be made to coincide. In the process, the atom releases a photon of the same energy, direction, phase, and polarization as that of the incident photon. Figure 3 Symbols were support of the same energy o used to signify the cardinal points and locations for a thick lens. If this surface is included in the spectacle design, it would cancel exactly the distortion introduced by the cornea and equalize powers in both meridians. The index of refraction n2 of the cladding, where n2 6 n1, influences the critical angle and numerical aperture of the fiber. Generally, the total energy EEM stored in an electromagnetic field of frequency n is n given by, = EEM n 1 hn + nhn 2 n = 0, 1, 2, A (1) where n is the number of photons in the field. Then if the ray were reversed, following the same path backward, it would have the same total deviation as the forward ray, which we 62 Chapter 3 Optical Instrumentation 40 Angle of deviation (deg) 35 30 25 20 dmin 15 23 Figure 10 Graph of total deviation versus angle of incidence for a light ray through a prism with A = 30° and n = 1.50. Calculate its focal length and refracting power again by treating it as a thick lens of thickness 3.6 mm. Show that the FWHM of the transmittance peaks is 2¢11>2 = 1>mF and the separation between transmittance peaks is lfsr = l>m. In the diagram of Figure 25, the focal length of the field lens, FL, is approximately 1.7 times the focal length of the eye lens, or ocular, EL. For simplicity, refraction is shown only at the front surface and spherical aberration for non-paraxial rays is ignored. Determine the three lowest angular spatial frequencies apart from the DC component, required in a Fourier representation of the Ronchi aperture function. The phase shift f, as determined from Eqs. The former approach was used in producing the curves, in Figure 13, showing the population inversion Ninv = N2 and photon number density Np as functions of time after laser turn on. 478 Chapter 22 Theory of Multilayer Films reflection and transmission at the plane interface (b) separating the film from B the substrate of index ns . 5.3 to 7.0 ft 18. u P u s P1 B Screen 239 Coherence the maximum in the fringe system at P due to source B is replaced by a minimum, and the composite fringe pattern disappears. The nematic liquid-crystal cell consists of the liquid crystal positioned between two glass plates. The scan is for a nominal mirror spacing of 5 cm. (34) and (35) indicates that population inversion and so the gain coefficient are made larger under the following conditions: 1. In this figure four important levels are shown, 5 with the level of energy E0 being the ground state. The lens itself, in this case, acts both as the field stop and the entrance window. 112
Chapter 4 Wave Equations 7 For a harmonic wave given by y = (10 cm) sin[(628.3/cm)x - (6283/s) t] determine (a) wavelength; (b) frequency; (c) propagation constant; (d) angular frequency; (e) period; (f) velocity; (g) amplitude. Beams with random phase relationships are, generally speaking, incoherent beams, whereas beams with a constant phase relationship are coherent beams. Since the electromagnetic field can only take on energy in multiples of the photon energy hn. For the light entering from below, then, both B E-components are perpendicular to the OA and "see" no anisotropy. If, for example, the source light consists of two wavelength components, the output of the two systems is either a double set of circular fringes on a photographic plate or a plot of resultant irradiance I versus the plate spacing d, Figure 7 (a) Fabry-Perot interferometer, used with an extended source and a fixed plate spacing. 218, 1996, 157-163. Absorption of such a photon corresponds to a transition between states differing in energy by Uv0 = hn0 in the energy-band structure of the material. (b) Overlay of transmittance curves. First and second focal lengths of an optical system are equal in magnitude when initial and final media have the same refractive. indices. Recording devices like ordinary photographic film and photomultipliers are sensitive only to the real part of these complex vectors. Matrix Treatment of Polarization 19 Derive the equation of the ellipse for polarized light given in Eq. (12). We see that A P1kX, kY2 and EA1x, y2 are related through a Fourier transformation. We now briefly describe each of these aberrations in terms of their visual effects and indicate some means that are employed to reduce them Thus, in a third row, sketch in curves for column 1, Hm1xs2, column 2 for the electric field, column 3 for the electric field, column 3 for the expected burn pattern. When the fringe systems coincide, the pattern appears sharp, whereas when the fringes of one system in the region of observation lie midway between the fringes of the second system, the pattern appears rather uniform in brightness, or "washed out." The mirror movement ¢d required between consecutive coincidences is related to the wavelength difference ¢l as follows. The diffraction envelope has a minimum 410 sin2 b b2 cos2 a a 0 2p 4p 6p 8p 10p12p a 2p b p (a) (c) 0 (b) (d) Figure 14 (a) Interference (solid line) and diffraction (dashed line) functions plotted for double-slit Fraunhofer diffraction is six times the slit width 1a = 6b2. Light behavior when exchanging energy with matter, as in the Compton and photoelectric effects. Of course, the remaining bottom half of the wavefront is similarly blocked off. Is the assumption of far-field diffraction justified in this case? Note that the constant A appearing in Eq. (26) is not the overall amplitude of the wave, which is instead given by A/r. To the extent that these firstorder approximations are valid, Gaussian optics implies exact imaging. This result follows when y V d. Superposition produces a resultant wave of the same frequency, with amplitude E0 and phase a. As mentioned, if harmonic waves with a wide range of frequencies constitute the waveform, the result will be narrow pulses separated by relatively longer intervals of low field amplitude, as shown in Figure 8.8 INTERFERENCE GRATINGS The availability of intense and highly coherent beams of light has made possible the produced by grating apart from the rulings produced by grating engines. wide. Then, following the approach used earlier, -1 c a c b 1 1 dc d = c d d 1 1 and c a c b 1 0 dc d = c d d -1 0 Equivalently, a + b = 1 c + d = 1 a - b = 0 c - d = 0 1 2. The axis is perpendicular to the circular disc. Let Ei represent the amplitude of the incident light. In this section, we write down the equations that govern the time-dependent exchange of rotation b can be measured by rotating the analyzer until extinction reoccurs, as shown. The gain coefficient is increased by increasing the effective pump rate density Rp2 that feeds the upper lasing level and so increases the likelihood of occurrence of stimulated emission events. At any point x along the medium, the oscillations are given by ER = A1x2cos vt where A1x2 = 2E0 sin kx. The scattered power for violet light of wavelength 400 nm is nearly 10 times as great as for red light of wavelength 700 nm. If this distance is allowed to go to zero, aperture and lens coincide, as in the objective of a telescope. 3., No. 1, October 2003. Diagram (c) is an example of a more complex optical system, showing the angular field of view in object and image space, a and a¿, respectively. Since the lens zones are continuous, so are their associated comatic circles. 16 Answer problem 15 when the lens is designed to reduce coma. In this system, 26 channels are so devoted. What is the irradiance at the spot on the wall 15 m from the laser? That is, I0 = I1r = 0, z = 02 For reasons to be elucidated shortly and illustrated in Figure 2, we have referred to the z = 0 plane as the plane containing the beam waist. Chapter 12 1. Show that solving Eqs. Measurement of the light. When the bundles are small, each bundle consists of paraxial rays that focus at the same distance from the mirror, a distance equal to its focal length, or half the radius of curvature of the mirror. (a) crown: A = 1.511, B = 4240 nm2, nD = 1.715 (b) crown: $-4.146 \times 10-5$ nm-1; flint: $-1.290 \times 10-4$ nm-1 (c) crown: 3110, 1.9 Å; flint: 9675, 0.61 Å 9. 15 A small object faces the convex spherical bases of curvature of the mirror. (a) crown: $-4.146 \times 10-5$ nm-1; flint: $-1.290 \times 10-4$ nm-1 (c) crown: 3110, 1.9 Å; flint: 9675, 0.61 Å 9. 15 A small object faces the convex spherical bases of curvature of the mirror. glass window of a small water tank. Example 1 An object 3 cm high is placed 20 cm from (a) a convex and (b) a concave spherical mirror, each of 10-cm focal length. In that case, all rays emanating from S are associated with a single set of spherical mirror, each of 10-cm focal length. zero when the applied voltage is zero. z Retardation plate 343 Matrix Treatment of Polarization waves are simultaneously present at each point along the axis. Moriyama, S. As before, ER = rei1vt + w2 (8) The resulting emergent beam can then be expressed, except for constants, in terms of the field EH by EH r IF ER = 1r2 + s22ER + r2sei1vt + u2 + w2 (8) The resulting emergent beam can then be expressed, except for constants, in terms of the field EH by EH r IF ER = 1r2 + s22ER + r2sei1vt + u2 + w2 (8) The resulting emergent beam can then be expressed, except for constants, in terms of the field EH by EH r IF ER = 1r2 + s22ER + r2sei1vt + u2 + w2 (8) The resulting emergent beam can then be expressed, except for constants, in terms of the field EH by EH r IF ER = 1r2 + s22ER + r2sei1vt + u2 + w2 (8) The resulting emergent beam can then be expressed, except for constants, in terms of the field EH by EH r IF ER = 1r2 + s22ER + r2sei1vt + u2 + w2 (8) The resulting emergent beam can then be expressed, except for constants, in terms of the field EH by EH r IF ER = 1r2 + s22ER + r2sei1vt + u2 + w2 (8) The resulting emergent beam can then be expressed, except for constants, in terms of the field EH by EH r IF ER = 1r2 + s22ER + r2sei1vt + u2 + w2 (8) The resulting emergent beam can then be expressed, except for constants, in terms of the field EH by EH r IF ER = 1r2 + s22ER + r2sei1vt + u2 + w2 (8) The resulting emergent beam can then be expressed, except for constants, in terms of the field EH by EH r IF ER = 1r2 + s22ER + r2sei1vt + u2 + w2 (8) The resulting emergent beam can then be expressed, except for constants, in terms of the field EH by EH r IF ER = 1r2 + s22ER + r2sei1vt + u2 + w2 (8) The resulting emergent beam can then be expressed, except for constants, in terms of the field EH by EH r IF ER = 1r2 + s22ER + r2sei1vt + u2 + w2 (8) The resulting emergent beam can the resulting emergen r2ei12w2sei1vt - u2 (9) where we have multiplied together Eqs. 0.0012% (a) 1/100 (b) 50.31 cm 1.05, 1.48, 1.82 mm 1.97 mm radius; zero 14.8 cm (a) 0.213Iu (b) 0.223Iu 1.19Iu; 0.861Iu 0.55Iu 21% (b) 0.145 mm (c) 0.655Iu 19 µm 4. 4 An optical system, centered on an optical axis, consists of (left to right) 1. Second, it does not take into account a curious requirement, a p>2 phase shift of the diffracted waves relative to the primary incident wave. The Littrow-mounted plane grating. The overall magnification is given by m = m1m2 = 1-1.5210.42 = - 0.6. Thus, the final image is inverted relative to the original object and 6>10 its lateral size. The total power £ tot in the beam is then obtained by evaluating the integral £ tot = XI I dA = A w20 Ie w 1z2 XI 0 2 -2r2>w21z2 dA A Here the integration is over the entire—infinite in extent—transverse crosssectional area of the beam. Since E is a vector field, the coefficients r and R are tensors that reflect the crystal symmetry. Let the linear polarizer (LP) produce light vibrating at an angle of 45°, as in Figure 11, which is then transmitted by a QWP with SA horizontal. (c) Polarization at Brewster's angle. For example, in one such application, rotating HOEs can be used to scan laser beams on spaceborne platforms in lidar (light detection and ranging) systems to monitor atmospheric profiles of wind, aerosols, clouds, temperature, and humidity. f = 53.3 cm, 13.33 cm, frequency v0 and lifetime t0, ¢v = 2p t0 or ¢n = 1 t0 (15) Equation (15) shows that if t0 : q, corresponding to a wave train of infinite length, ¢v : 0, and a single frequency v0 or wavelength l0 suffices to represent the wave train of infinite length, ¢v : 0, and a single frequency v0 or wavelength l0 suffices to represent the wave train of infinite length, ¢v : 0, and a single frequency v0 or wavelength l0 suffices to represent the wave train of infinite length, ¢v : 0, and a single frequency v0 or wavelength l0 suffices to represent the
wave train of infinite length, ¢v : 0, and a single frequency v0 or wavelength l0 suffices to represent the wave train of infinite length, ¢v : 0, and a single frequency v0 or wavelength l0 suffices to represent the wave train of infinite length, ¢v : 0, and a single frequency v0 or wavelength l0 suffices to represent the wave train of infinite length, ¢v : 0, and a single frequency v0 or wavelength l0 suffices to represent the wave train of infinite length, ¢v : 0, and a single frequency v0 or wavelength l0 suffices to represent the wave train of infinite length, ¢v : 0, and a single frequency v0 or wavelength l0 suffices to represent the wave train of infinite length, ¢v : 0, and a single frequency v0 or wavelength l0 suffices to represent the wave train of infinite length, for a wave distance corresponds to a total distance of 25.5 cm from the eye. Higher orders—both plus and minus—produce spectral lines appearing on either side of the zeroth order. Each photodiode, or MOS (metal-oxide-semiconductor) device, responds to the incident radiation to provide one pixel (picture element) of output. A little thought should convince one concerning on either side of the zeroth order. that light transmitted through the film and the optical flat will also show circular interference fringes. The line image is virtual at a distance of 13.33 cm on the object side of the lens and 0.67 cm long. Adding more Mach-Zehnder interference fringes. channels. If points like P fall along a circle in an object plane perpendicular to the optical axis, the corresponding line images in the T surface merge into a well-focused image circle. 31 An astronomical telescope is used to project a real image of the moon onto a screen 25 cm from an ocular of 5-cm focal length. Finally, according to fifth-order aberration theory, the T and S surfaces may actually be made to come together again and intersect at some distance from the optical axis. 11. So, -15 + s12œ = -110 gives s2œ = 10 cm. Typically, laser mirrors have spherical surfaces, and so the stable repetitive field patterns (i.e., the modes of the cavity) are more complicated than the plane standing wave modes. produced by flat mirror cavities discussed earlier. 349 b. Therefore, to protect the optical quality of the fiber, it is essential that it be coated with a layer of plastic or glass called the cladding. Pumping, is required to produce the "unnatural" condition of a particular interaction between charged particles and electromagnetic fields. When this is done, (see problem 13) one obtains for the total beam power £ tot = I0 a pw20 b 2 Thus the total power carried by the beam is, as it must be, independent of z and has the form of the irradiance I0 at the center of the beam 1r = 0, z = 02 multiplied by an effective area of the beam, pw20>2. Assume that n = 1.5000. Let the unknown image be formed at the output reference plane, a distance x from the spherical cap. From Figure 13a and the precise intermediate value of the velocity vB of the extraordinary ray depends on the relative contributions of y7 and y , that is, on the relative orientations of the incident beam and the OA of the crystal. Determine (a) radii of curvature; (b) focal lengths for D, C, and F Fraunhofer 457 lines; (c) powers and dispersive powers of the individual elements. 246 Chapter 10 Fiber Optics fiber, the light signal is coupled into a detector that changes the optical signal back into an electrical signal Kingslake, Rudolf. The light coming from such a source is then a superposition of electromagnetic fields with differing and randomly distributed polarizations. Corneal Sculpting Laser corneal sculpting is a medical procedure, introduced in the early 1980s, that uses beams of laser energy to reshape the surface of the cornea. 464 Chapter 21 Fourier Optics a. Optical rectification results in a timeindependent polarization in the medium that manifests itself as a DC voltage, in a direction transverse to the field propagation, across the nonlinear crystal. Solution In Figure 7, Beam 1 and Beam 2 are shown together with their respective wavefronts or crests C1 and C2 labeled throughout the emulsion. In Figure 7, Beam 1 and Beam 2 are shown together with their respective wavefronts or crests C1 and C2 labeled throughout the emulsion. 19b, the opposite case is also pictured, for which b is a negative angle and the optical activity is dextroroB tatory. For lower levels of illumination, when adapted for night or scotopic vision, the curve shifts toward the green, peaking at 510 nm. Figure 19 shows a specific cavity design and an external laser beam with a (far-field) angular spread signified by the angle u. Nondestructive Testing Suppose that the hologram of the fish itself are returned exactly to their original positions, and suppose that the same reference beam illuminates the scene. Determine the complex radius of curvature q1 at the plane mirror in the cavity. Appropriate refractive indices are n1694 nm2 = 1.505 and n1347 nm2 = 1.534. Thus, the external beam waist has a spot size w21/2 of 0.54 mm located 6 cm from the R3 surface of the mirror-lens combination. The outline of the solution is given in the example that follows. An antireflecting single coat, with n1 6 ns , never reflects more than the uncoated glass at any wavelength. Yariv, Amnon. Several other designs for polarizing prisms constructed from positive uniaxial material (quartz) are illustrated in Figure 16. The lines are images of the slit, so that for precise wavelength measurements the entrance slit should be kept as narrow as possible consistent with the requirement of adequate illumination of the film. As the telescope is rotated around the indexed prism table, a focused image of the slit is seen for each wavelength component at its corresponding angular deviation. The height above the optical axis of the bottommost point O is shown as he . In this section we will borrow relations from thermodynamics that described axis of the bottommost point O is shown as he . In this section we will be a focused image of the slit is seen for each wavelength component at its corresponding angular deviation. atoms and electromagnetic fields in thermal equilibrium at a given temperature T. 10 Write a computer program that will calculate and/or plot reflectance values for a double layer under normal incidence. Typical efficiencies (see Table 1 at the end of this chapter) range from fractions of a percent to 25% or so. In Eq. (1), m takes on integral values and v = 2pn = 2p>T, where T is the period of the arbitrary f(t). The focal length f of a thin-lens doublet with lens separation L satisfies the relation 1 L 1 1 = + f f1 f2 f1f2 R V r12 (2) r22 Figure 13 Achromatic doublet, consisting of (1) crown glass equiconvex lens cemented to (2) a negative flint glass lens. Light source l1 l l2 I figure 12 Symbolic representation of material dispersion. 9 A photodetector has a saturation photocurrent of 10 mA and a responsivity of 100 mA/W. Sommerfeld, Arnold. (d) s' = 0, +8, +14.4 cm a = -0.015 mm; bz = -3.9 mm (a) -0.0296 mm (b) 0.021 mm (a) -0.0296 mm (b) 1.2 mm bz = 1.64 mm; by = -0.49 mm; bz = -3.9 mm (a) -0.0296 mm (b) 1.2 mm bz = -3.9 mm (b) 1.2 mm bz = -3.9 mm (c) -0.0296 mm (c) -0mm at h = 1 cm, 3.84 mm at h = 2 cm, 8.44 at h = 3 cm, 14.53 mm at h = 4 cm, 21.81 at h = 5 cm bz = 1.82 cm; by = 0.970 mm For = 0.7, r1 = 17.65 and r2 = -100 cm; for = 3, r1 = 7.50 and r2 = -100 cm; for = 3.75 cm optimum = +0.867, closer to + 1 than to -1 15. Today, fibers carrying 40 different wavelength channels area (1.5) cm r1 = 17.65 and r2 = -100 cm; for = 3, r1 = 7.50 cm r2 = -100 cm; for = 3, r1 = 7.50 cm r2 = -100 cm; for = 3, r1 = 7.50 cm r2 = -100 cm; for = 3,common, and a combination of TDM and WDM results in optical fibers systems with carrying capacities of more than 1012 bits/s. Then write an equation that represents the pulse moving in the negative direction at 10 cm/s. It can be shown that the frequency of a TEMmn beam that is a resonant mode of a spherical mirror cavity of length d must satisfy the relationship8 nmng = c q + z1 z2 m + n + 1 c - arctan b d aarctan p z0 z0 2d (67) where q is the axial mode number (not the complex radius of curvature); m and n are integers associated with the Hermite polynomials Hm and Hn; z1 and z2 are the coordinates (z = 0 is at the beam waist) of the cavity mirrors; and z0 is the Rayleigh range. Teich. The problem before us is as follows: Given the beam waist w01 and distance Z1 on the incident side of the lens, determine the beam waist w02 and the distance Z2 on the output side of the lens. A
simple experience of a limitation in the field of view is that of looking through an ordinary window. Ch. 4. At the first maximum point, the tail of the phasor proportional to the field amplitude is at the extreme point G. Find and plot the steady-state small-signal population inversion N2 - N1 as a function of pump irradiance. The paraxial image points, such as E, due to rays refracted at lens positions further from the optical axis. Separation and numerical aperture incompatibility are also possible and can lead to large losses when not properly corrected. As a result, any portion of the hologram contains information of the sequence of values a = 0, p>8, 2p>8, 3p>8, 4p>8, 5p>8, 6p>8, 7p>8, and 8p>8. Immediately behind the cornea is the anterior chamber, a small space filled with a watery fluid that provides nutrients for the cornea, the aqueous humor. Aberration at an arbitrary point Q on the wavefront may be related to the symmetry axis PBP; or the optical axis OCS. (24) and (25), the positive distance r can be expressed in terms of p and f1: r = p - f1 = n0 1 n0 D 1 = aD b nf C nf C C (26) Using Figure 12b, one can similarly discover relations for the output distances q, f2, and s. In terms of the spatial angle u, this condition is diffraction minima: ml = b sin u (28) as in Eq. (12). Because data can be reduced by holographic techniques to dimensions of the order of the wavelength of light, volume holograms can be used to record vast quantities of information. For all figures we have adopted the phase lag convention $\psi = wy - wx$. We wish to show that the sum of all phasors $r0 \leq n S \mid 2 r0 r0 \leq Figure 9$ Fresnel half-period strip zones on a cylindrical wavefront in an (a) edge view and (b) front view. W. A He-Ne laser (0.6328 mm) has an internal beam waist of radius of ra near 0.25 mm. M1 Gain M2 L Figure 9 Linear laser cavity. The successful decomposition of a waveform into a series of harmonic waves is insured by the theorem of Dirichlet: If f(t) is a bounded function of period T with at most a finite number of maxima or minima or discontinuities in a period, then the Fourier series, f1t2 = g g a0 + a am cos mvt + a bm sin myt 2 m=1 m=1 (1) converges to f(t) at all points where f(t) is continuous and to the average of the right and left limits at each point where f(t) is discontinuous. Determine the angular radius of the (a) first (smallestdiameter) ring observed and (b) the tenth ring observed and (c) the tenth ring observed and (sensitive film, inclined at an angle. There remains, then, from Eq. (29), ¢ = nf1EB + BF2 = 2nfEB (34) The length EB is related to the film thickness t by EB = t cos ut , so we have, finally, ¢ = 2nft cos ut (35) The optical-path difference ¢ is economically expressed by Eq. (35) in terms of the angle of incidence, which of course can be recovered through Snell's law, Eq. (30). Whereas radiometry involves purely physical measurement, photometry takes into account the response of the human eye to radiant energy at various wavelengths and so involves psycho-physical measurements. In this chapter, we show in particular how the refractive index and the absorption coefficient for isotropic conducting (metals) and nonconducting (insulators or dielectrics) materials can be understood. Such holograms are incorporated into the packaging of a product in order to confirm that it is genuine. This focal length is given by the lensmaker's formula, 1 1 = 1n - 12a - b r1 r2 f \ge 2 \ge 1 for a thin lens of refractive index n and radii of curvature r1 and r2, when used in air. 275 Fraunhofer Diffraction y by b a a x Slit aperture Screen (b) (a) (c) (d) Figure 5 (a) Single-slit diffractionlimited spot of diameter d 1. The gain coefficient, near a cavity mode above threshold, in an inhomogeneously broadened gain medium saturates according to a law that is different from that given in Eq. (37), which is appropriate for homogeneously broadened media. 8 Using Eq. (9), show that the transmittance of a Pockels cell can also be written as I = Imax sin21£>22. A relative p phase shift between the two beams occurs because the reflection coefficients from opposite sides of a beam splitter differ by -1 = eip.1 For dark fringes, then, $p + cr = 2d \cos u + 11 = am + bl 2 2$ or, more simply, 2d cos u = ml m = 0, 1, 2, A dark fringes (4) If d is of such magnitude that the normal rays forming the center of the fringe system satisfy Eq. (4), that is, the center fringe is dark, then its order, given by mmax = 2d l (5) is a large integer. We have concentrated on the important case in which the field suffers a p phase shift upon reflection. Ar l = 488 nm ¢l = 0.004 nm He-Ne l = 633 nm ¢l = 0.002 nm + Rhodamine 6G dye l = 590 nm ¢l = 0.002 nm + Rhodamine 6G dye l = 590 nm ¢l = 0.002 nm + Rhodamine 6G dye l = 590 nm ¢l = 0.002 nm + Rhodamine 6G dye l = 500 nm ¢l = 0.002 nm ¢l W1 Qu b W2 l L1 L2 Figure 4 Spread of the central maximum in the far-field diffraction pattern of a single slit. Rays of light totally internally reflected at the top surface outline a circle of 7.60 cm in diameter on the bottom surface. The light-gathering ability of an optical fiber increases with its numerical aperture. When linearly polarized light is incident on an optically active material, it emerges as linearly polarized light but with its direction of vibration rotated from the original. Consider the situation depicted in Figure 4. The values of nR and nI are given for sodium light of l = 589.3 nm. Finally, in order to use DWDM, 12 See, for example, Milorad Cvijetic, Optical Transmission Systems Engineering (Norwood, MA: Artech House, Inc., 2004, Ch. 2). Now place a thin lens of focal length 10 cm and appropriate diameter at a distance of 20 cm from the output face of the beam expander. The constant a is the absorptivity, or absorption coefficient, characteristic of the material. Lens prescriptions for vision correction are, in fact, expressed in terms of combinations of spherical and cylindrical lenses. Such techniques provide a great deal of flexibility in designing interference coatings with almost any specified frequency-dependent reflectance or transmittance characteristics. Notice that 86% of the beam gets through (14% blocked) when the aperture radius equals the spot size, while just under 99% gets through when the aperture radius is increased to 1.5 times the spot size. 1 1 1 + = s s; for s; = m = -1.1021202 fs = = -6.67 cm s - f 1202 - 1.102 - 6.67 ls; = = -6.67 cm s - 1.102 - 6.67 ls; = = -6.67 cm s - 1.102 - 6.67 ls; = = -6.67 cm s - 1.102 - 6.67 ls; = = -6.67 cm s - 1.102 - 6.67 ls; = = -6.67 cm s - 1.102 - 6.67 ls; = = -6.67 cm s - 1.102 - 6.67 ls; = diameter of the exit pupil Dex is simply related to the diameter of the objective lens Dobj through the angular magnification, as follows. These photoreceptors are linked to about 1 million optic nerve fibers, so there is a significant convergence of receptor signals onto the end of the optic nerve. One surface of the lens is cylindrical while the opposite is plane.6 Thus, the curved surface has a definite, finite radius of curvature, whereas the plane surface has an infinite radius of
curvature. Still, for the 131 132 Chapter 6 Properties of Lasers greater part of the 1960s, the laser was viewed by the world of industry and technology as a scientific curiosity. 2 At what angles will light, externally and internally reflected from a diamond-air interface, be completely linearly polarized? (b) Hg source, violet filter. Useful applications of such coatings include antireflecting multilayers for use on the lenses of optical instruments and display windows; multipurpose broad and narrow band-pass filters, available from near ultraviolet to near infrared wavelengths; thermal reflectors and cold mirrors, which reflect and transmit infrared, respectively, and are used in projectors; dichroic mirrors consisting of band-pass filters to divide light into red, green, and blue channels in color television cameras; and highly reflecting dielectric mirrors for use in gas lasers and in Fabry-Perot interferometers. This object radiates a total power of 25 W into the forward directions that constitute half the total solid angle of 4p. The irradiance of the pattern is given by I = 4I0 sin2 (115y), with y measured in cm from the mirror surface. At face BC, total internal reflection occurs to direct the light beam into the prism section ACD, where it again traverses under the condition of minimum deviation. The same type of variation is to be expected for the irradiance variation in the y-direction. This leaves only the obliquity factor, which is responsible for systematic decreases in the amplitudes as n increases. Consider the operation in order m = 30 of a commercially available echelle grating with 79 grooves/mm, blazed at an angle of 63°26¿ and ruled over an area of 406 * 610 mm. 294 Chapter 12 The Diffraction Grating m2 m1 m0 l m 1 G f m 2 (a) Formation of the orders of principal maxima for monochromatic light incident normally on grating G. (27) and (28), rTE = rTM = $cos130^{\circ}2 - 21.62 - sin2130^{\circ}2 = -0.2740 - 1.62 cos130^{\circ}2 + 21.62 - sin2130^{\circ}2 = -0.2740 - 1.62 cos130^{\circ}2 + 21.62 - sin2130^{\circ}2 = -0.2740 - 1.62 cos130^{\circ}2 + 21.62 - sin2130^{\circ}2 = -0.2740 - 1.62 cos130^{\circ}2 + 21.62 - sin2130^{\circ}2 = -0.2740 = 0.7260 tTM = 1 - rTM 1 + 0.1866 = 0.7416 = n 1.60 1 Some texts use a different convention, in which the$ positive direction of the reflected electric field for the TM case is opposite to that shown in Figure 2, leading to an expression for the reflection coefficient for the reflection gating, as shown in Figure 7c, is given by 1>12 sin u2, where 2u is the angle between the coherent beams. 4 THE CAMERA The simplest type of camera is the pinhole camera, illustrated in Figure 19a. 16 A Fresnel rhomb is constructed of transparent material of index 1.65. (54) and (55) for the steady-state photon number density Np and population inversion N2 gives, E1 = E0 cos12pn1t - k1z2 E2 = E0 cos[2p1n1 + dn2t - k2z] a. What is the energy of a photon in this signal? 8 Consider the unaccommodated crystalline lens of the eye as an isolated unit having radii of curvature and effective refractive index as given for the schematic eye in Table 2. Note that second and third orders in this case partially overlap. 38. Weireich. It is from this volume that any interferometer must accept radiation if it is to produce observable interference fringes. Chapter 27 Heavens, O. The Stokes field can couple the ideally separate channel. Substitution of Eq. (51) into Eq. (9), 7 In many cases, laser beams are first expanded in cross section before being focused to a small spot, as in the case of laser welding. Because of the large selection of laser media, the range of available laser wavelengths that are a sizable fraction of a millimeter. Various regions of the electromagnetic spectrum are referred to by particular names, such as radio waves, cosmic rays, light, and ultraviolet radiation, because of differences in the way they are produced or detected. The phenomenon is therefore due to the diffraction of light, treated later. To achieve efficient operation, the eye takes advantage of special functions. Irradiance grows at each of these frequencies. The stretched material is then impregnated with iodine atoms, which become associated with the linear molecules and provide "conduction" electrons to complete the analogy to the wire grid. "Fourier Transforms and the Use of a Microcomputer in the Advanced Undergraduate Laboratory." American Journal of Physics, Vol. Spherical wavefronts emerge from a point source and encounter an aperture. (14) and (15), N N N E20 = a E20i1sin2 ai + cos2 ai2 + 2 a a E0iE0j1cos ai cos aj + sin ai sin aj2 i=1 j7i i=1 The expressions in parentheses are equivalent to unity in the first term and are equivalent to cos1aj - ai2 i=1 (16) j7i i=1 Summarizing, the sum of N harmonic waves of identical frequency, with amplitude given by Eq. (12). A planoconvex lens with n = 1.50 and R = 60 cm is to be used. 38 Chapter 2 Geometrical Optics (1) (2) RO2 RI1 F1 F2 VI2 F2 RO1 F1 (a) (1) (2) F2 RO1 F1 VO2 RI1 RI2 F1 F2 (b) Figure 23 (a) Formation of a virtual image VI2 by a two-element train of a convex lens (1) and concave lens (2). We begin this chapter with a description of thermal and quantum detectors of optical radiation has penetrated a depth of z = 1>kI, therefore, the amplitude has decreased to 1/e of its surface value. For example, a flexible bundle of fibers might be used to transport light from inside a vacuum system to the outside, where it can be more easily measured. The bundle might be divided into two or more sections at some point to act as a beam splitter. For normal incidence on glass of index n = 1.5, r2 = 0.04. High-quality grating masters ruled over widths as large as 46 cm or more have become feasible. (New York: Holt, Rinehart and Winston, 1985), Ch. 9. Chapter 7 Feynman, Richard P., Robert B. In addition, atoms and molecules have resonant frequencies in this optical spectrum and so EM waves in this frequency range interact most strongly with atoms and molecules. The zeroth order, it will be recalled, contains the most intense interference maximum because it coincides with the max c1 - v dK d 2K dv where c is the speed of light in vacuum. The field is constrained to oscillate in the counterclockwise direction by means not shown. Figure 7 shows a drawing of 16 Fresnel zones in which alternate zones are shaded. We may then write I = I1 + I2 + I12 (5) If light behaved without interference, like classical particles, we would then expect I = I1 + I2. The Graded Index (GRIN) Fiber A GRIN fiber is produced with a refractive index that decreases gradually from the core axis as a function of radius. We apply these methods in the simpler cases to be considered here. Obtain the ratio I>I0 for a point on the screen that is 3/4 of a wavelength farther from one edge of the slit than the other. 4 In viewing the far-field diffraction pattern of a single slit illuminated by a discrete-spectrum source with the help of absorption filters, one finds that the fifth minimum of one wavelength component coincides exactly with the fourth minimum of the pattern due to a wavelength of 620 nm. The bulb is usually a glass envelope, although quartz is used for highertemperature operation. For rays making a small angle with the normal to the surface, however, a reasonably good image can be located. That is, Seg0L 7 1 This condition implies that for the laser field to grow, g0 7 ln11>S2 = gth L (46) 563 Laser Operation If g0 7 gth, the field grows with each round-trip through the cavity, but as it does so the gain coefficient g decreases due to saturation. 15 A positive lens is needed to focus a parallel beam of light with minimum spherical aberration. Reflected beam 2 and M1, respectively, where their directions are reversed. Rays from the object that make increasingly larger angles of incidence with the interface must, by Snell's law, refract at increasingly larger angles, as shown in Figure 9c. Consider first the Es, or TE, component (Figure 4a). Clearly, if S2P - S1P = s2 - s1 = ml, the waves will arrive in phase, and maximum irradiance or brightness results. Under this condition, stimulated emission will exceed stimulated absorption and a net production of photons will occur. Reflection maxima occur, in the other extreme, when cos d = -1, or when and d = p, 3p, Å = A m + 12 B l (51) In this case, Eqs. Gravitational waves exert timevarying forces on matter as they pass by. Calculate the dispersion in the vicinity of the Fraunhofer D line for each glass, using the Cauchy relation. This topography provides the information required for careful control of the positioning, the energy output, the beam diameter, and the pulse length of the computer-driven excimer laser used to reshape the cornea. When the lengths are measured in meters, their reciprocals are said to have units of diopters (D). The arrangement is known as Lloyd's mirror. The important specifications of an eyepiece, assuming its aberrations are within acceptable limits for a particular application, include the following: 1. 368 Chapter 15 Production of Polarized Light follows from use of the Jones calculus: c 1 0 0 1 1 dc d = c d -1 1 -1 HWP FA vertical LP at 45° LP at -45° The light emerging from the HWP is now polarized along a direction that is fully transmitted by the analyzer. 18 Determine the reflectance from tin at angles of incidence of 0°, 30°, and 60°. Taking the average wavelength at 550 nm, Eq. (17) gives lt = 155022 nm 1000 nm 2lav 300 a very small coherence length indeed, of around a millionth of a centimeter or two "wavelengths" of white light. We can show, in fact, that for such values, the expression is a maximum on top of the 306 Chapter 12 The Diffraction Grating Lens m1 1 550 nm m0 S 2.5 in. Of course, the response of the detector should be well matched to the optical frequency of the signal received. Photometry, on the other hand, applies only to the visible portion of the electromagnetic 421 422
Chapter 19 Optics of the Eye 700 y: Luminous flux (lm) 600 500 400 510 nm 610 nm 1.0 616 lm 0.9 548 lm 0.8 480 lm 0.7 411 lm 0.6 342 lm 0.3 137 lm 0.2 68 lm 0.1 300 400 450 500 550 600 Red Orange Yellow Green 100 Blue Violet 200 Figure 2 CIE luminous efficiency curve. 6 Repeat parts (a) and (b) of problem 4 when the source is a point source is due to such an elemental area can be represented by the spherical wave Here, dEP = a dEO i1kr - vt2 be r (2) The wave amplitude dEO >r at the aperture is proportional to the elemental area, so we can write dEO EA = dA r r (3) Here, EA characterizes the field amplitude per unit area of the Huygens wavelet emanating from the infinitesimal region surrounding point O. where N. The matrix elements change and the system matrix now represents this enlarged "system." In any case, the determinant of the system matrix has a very useful property: Det M = AD - BC = n0 nf (19) where n0 and nf are the refractive indices of the initial and final media of the optical system. For simplicity we will treat the ideal, homogeneously broadened, four-level system discussed earlier. With a QWP in front of the polarizer (coming first), one finds a variation in intensity but no angular position of the polarizer that gives zero intensity. Since the entrance pupil is determined by preceding optical elements in the optical system (the diameter of the objective lens, in a simple telescope), this requirement places a limit on the magnifying power of the eyepiece and, thus, a lower limit on its focal length. The curvature, or vergence, V¿, of the wavefronts as they emerge from the lens is 1>s¿. (15) and (16) give Imax = 410 and Imin = 0 168 Chapter 7 Interference of Light I Imax II I2 2 III2 Imin II I2 2 III2 5p 3p p 0 p 3p d 5p (a) I 410 Figure 2 Irradiance of interference fringes as a function of phase difference d. The geometrical transfer to the next surface, at distance t from the first, is shown in Figure 17b, where, in ¢V2MV1, sin1 - a22 = V1M O1œ - O2 = t t TABLE 3 MERIDIONAL RAY-TRACING EOUATIONS (INPUT: n, n œ, R, A, h, D) Ray parallel to axis: a = 0 $a_{i}^{2} = Plane surface: R Q q - Q_{i} sin a_{i} - - n n_{i} sin a cos a_{i} Q_{i} = Q cos a - Q_{i} s_{i} = sin - 1 416$ Chapter 18 Matrix Methods in Paraxial Optics or Q2 = Q1ce + t sin a 2 (41) Table 3 also shows how the equations must be modified for two special cases: (1) when the incident ray is parallel to the axis and (2) when the surface is plane, with an infinite radius of curvature. Other crystalline systems—the triclinic, monoclinic, and orthorhombic—possess two such directions of symmetry or optic axes and are called biaxial crystallizes in monoclinic, and orthorhombic—possess two such directions and so both attenuates and mixes with the forward-traveling signal wave. 1.5448 c. Beam-Shaping Optics for Optimum Beam Propagation Gaussian beams are often passed through apertures such as mirrors, lenses, beam expanders, and telescopes. Since the free spectral range of both devices is 11>m, diffraction gratings typically have a much larger free spectral range than do Fabry-Perot interferometers. 10 A glass lens 3 cm thick along the axis has one convex, of radius 5 cm and the other, also convex, also co Chapter 6 Properties of Lasers from the de-excitation of the atoms or molecules of the material after they have been thermally excited. 18 A sample of SF57 glass with polished, parallel sides and 2.73 cm in length is placed between the tapered poles of an electromagnet. Englewood Cliffs, NJ: Prentice-Hall, 1985. 25 Two thin convex lenses, when placed 25 cm apart, form a compound microscope whose apparent magnification is 20. Repeat (b) for the TM mode. The linear and nonlinear susceptibility coefficients characterizes the response of the optical medium to the field. Show that the actual total distance xt a ray with entrance angle u travels over a total length L of fiber is given by xt = 13 A Ge-doped silica fiber has an attenuation loss of 1.2 db/km due to Rayleigh scattering alone when light of wavelength 0.90 mm is used. We may then write the normalized coherence function, g, for a large number, N, of intervals as 0 0 1 similar terms for 1N - 12 c ei102 dt + eiH1 dt + d Nt0 L0 successive intervals Lt0 - t (""")""* t -t g = e ivt t interval N = 1 Integrating over N terms, g = a eivt b [1t0 - t + teiH12 + 1t0 - t + teiH22 + Á] Nt0 Combining the first terms of each interval and summing the rest, g = a N eivt b c N1t0 - t + teiH12 + 1t0 - teiH12 + teiH12 + 1t0 - teiH12 + teiH12 + 1t0 - teiH12 + tei zero for N sufficiently large. Most importantly for us, functioning as a unique spatial sense organ, it localizes objects in space, accurately mapping out our three-dimensional world. (b) Essential geometry for production of Newton's rings. It was referred to in jest as "a solution in search of a problem." research applications of the laser has increased rapidly. Comparing Figure 28 with the geometry associated with Newton's equation for a thin lens, we see that the magnitude of the lateral magnification is given by $fmf = \hat{h}$ is sociated with Newton's equation for a thin lens, we see that the magnitude of the lateral magnification is given by $fmf = \hat{h}$ is sociated with Newton's equation for a thin lens, we see that the magnitude of the lateral magnification is given by $fmf = \hat{h}$ is sociated with Newton's equation for a thin lens, we see that the magnitude of the lateral magnification is given by $fmf = \hat{h}$ is sociated with Newton's equation for a thin lens, we see that the magnitude of the lateral magnification is given by $fmf = \hat{h}$ is sociated with Newton's equation for a thin lens, we see that the magnitude of the lateral magnification is given by $fmf = \hat{h}$ is the distance between the objective image and its second focal point, as shown. These terms and their units are summarized in Table 1.4 Radiometric guantities appear either without subscripts or with the subscripts or with the subscript e (electromagnetic). Sams and Co., 1982. Directionality. Pulsed Operation We have thus far described only continuous wave (cw) lasers in which the laser system delivers a laser beam of constant irradiance. Note that this scenario indicates that only a single cavity mode can be present in the CW output of a laser containing a homogeneously broadened gain medium. So, taking the curl of Eq. (49), we have B B B B B 0 0B 1 0 2E 1 0J B b = -1§ * B2 = -22 - § E = § * aa b 0t 0t c 0t e0c2 0t 2B B where we have used Eq. (51) in the last step. Example 1 Determine the focal lengths and the principal points for a 4-cm thick, biconvex lens with refractive index of 1.52 and radii of curvature of 25 cm, when the lens caps the end of a long cylinder filled with water 1n = 1.332. The telephoto lens

avoids a correspondingly "long" camera by using a positive lens, separated from a second negative lens of shorter focal length, such that the combination remains positive. (46) and (47), calculate z2 and w02 for the newly focused beam. These spurious effects change the cavity length, lead to multimode oscillations, and adversely affect the coherence length of the laser. reflector on Mount Palomar, use such mirrors. Since y0 is fixed, this means that all rays leaving a point in the input plane will have the same angle at the output plane, independent of their angles at input. Here we simply note that if a laser output consists of the fundamental TEM00 mode, the divergence angle will be u = 1 pw0 (16) where u designates the half-angle beam spread. If light were a longitudinal wave, the production of polarized light in the ways to be described would simply not be possible. Application of an electric field to such a medium causes charge displacement, in which the negative charge distribution bound to the nuclei shifts in a direction opposite to the electric field. If the magnification increases with distance from the axis, the rectangular grid of Figure 10a, serving as object, will have an image as shown in Figure 10b. Optical Transmission Systems Engineering, Boston: Artech House, Inc., 2004. Thus the scattered radiation is essentially wavelength independent, and fog and clouds appear white by scattered light. 586 Chapter 27 Characteristics of Laser Beams We have seen that the real part of q(0) is related to the position of the plane z = 0. This procedure than two isolated point sources, as in the interference calculation. 4 CHARACTERISTICS OF GAUSSIAN BEAMS Let us now try to make sense of the Gaussian beam form given in Eq. (24)— along the way justifying the names "radius of curvature" for R(z) and "spot size" for w(z). The hologram is a record of the entire signal wave. This process is known as self-phase modulation and leads to what is known as frequency chirping. (32) through (34). Coherence 237 5 SPATIAL COHERENCE In speaking of temporal coherence, we have been considering the correlation in phase between temporally distinct points of the radiation field of a source along its line of propagation. Thus the diffracted light also converges to point I, a real image of the original object point O that can be focused onto a screen. The dashed line gives the amplitude of the frequency spectrum and the solid line gives its square, the power spectrum. This technique is called ray tracing because it was formerly done by hand, Matrix Methods in Paraxial Optics 413 graphically, with ruler and compass, in a step-by-step process through an accurate sketch of the optical system. Optics 413 graphically, with ruler and compass, in a step-by-step process through an accurate sketch of the optical system. upon reflection into Output 2, light of freespace wavelength 12 will constructively interfere in the direction of Output 2 if the path length difference ¢L differs by an odd multiple of the half-wavelength 12 will constructively interfere in the direction of Output 2 if the path length difference ¢L differs by an odd multiple of the half-wavelength of this component in the fiber. As always, the effect of the HWP on linearly polarized light is to rotate it through 2a, or, in this case, 90°. Marcatili, and Li Tingye, "Research toward Optical-Fiber Transmission Systems," Proc. Coherent sources are the point source S and its virtual image, S¿. The nature of the eye chart owes its existence to a Dutch ophthalmologist, Herman Snellen. A 4-mW HeNe laser emits at 632.8 nm. If a volume hologram is made by multiple exposures of a scene in each of three primary colors, the reconstruction process with white-light illumination can produce a three-dimensional image in full color. more precisely in what follows. Taking the efficiencies into account sequentially as they "occur," how much of the initial 2500 W is available for power in the output beam? E = hn = 16.63 * 10.34 J # s21100 * 106 Hz = 6.63 * 10.26 J E = 6.63 * 10.26 J E6.63 * 10-26 Ja 1 eV b = 4.14 * 10-7 eV 1.6 * 10-19 J c. For N large, one need not be concerned about the parity of N. The resultant E-field vector consists of many components 333 334 Chapter 14 Matrix Treatment of Polarization whose amplitudes, frequencies, polarizations, and phases differ. 76 Chapter 3 Optical Instrumentation The actual angular magnification depends, then, on the particular viewer, who will move the simple magnifier until the virtual image is seen comfortably. Window 5 R R 5 cm cm 7. diffraction equations. The eye then sees both in focus together, giving the field of view a sharply defined boundary. Efficient, portable Nd:YAG lasers, pumped by an array of diode lasers, are available. If a multiple-order quartz plate 0.735 mm thick functions as a QWP, what is its order m? Lowpower lasers such as the He-Ne laser often need no external cooling system. Emission wavelength (nm) Light-Emitting Diodes A light-emitting diode (LED) is an important light source quite different from those just described. Relative locations of the refracting surfaces are shown, as are the cardinal points of interest for the eye as a whole. As Figure 1 Schematic defining the parameters for a typical Fresnel diffraction. Thus, the ray paths and times for two different wavelengths also vary with l, leading to pulse broadening. y1 a1 y2 a2 (43) Characteristics of Laser Beams Mirror surface R1 R2 2 m Mirror-lens combination R3 0.64 m w0() d 0.7 m Laser cavity t 4 mm External beam waist Determine and w0() The heuristic approach used here to develop this relation to the wave equation for propagation through media that can be represented by an ABCD matrix.5 The relationship between q2 and q1 in Eq. (43) enables one to describe the new shape of the laser beam after it passes through an arbitrary optical system. The result is that the diffraction maximum now favors a principal maximum of a higher order 1 f m f 7 02, and the grating redirects the bulk of the light energy where it is most useful. Let the scaled transmittance through the Fabry-Perot as a function of the change in the cavity length be as shown in Figure 20a and 20b. The energy carried by an EM wave can be specified in many related ways: the power, power per unit solid angle, for example. Consider an aperture function formed by two perpendicularly crossed Ronchi rulings. An electromagnetic wave, of course, represents the transmission of energy. In the Raman process the energy lost or gained by the electromagnetic field is accounted for by a change in energy of the molecule. In practice, such images are formed when the observation screen is quite close to the aperture. Q-switching You should be familiar with the quality factor Q as a measure of the loss rate of the cavity. Such a multifocal lens can be used to restore clear vision, to the presbyopic eye, over the full distance range. The refractive index of the plastic is 1.50 and the object is in air. In Figure 29, the useful light rays originating at the object point O, passing through a thin cover glass and then air to the first element of the objective lens L, make an intitial half-angle of aa on the right of the optical axis. ER has its maximum value at all points when cos vt = ; 1, or when vt = 2pnt = a 2p b t = mp T Thus, the outer envelope of the standing wave occurs at times T 3T T, A = m a b = 0, , T, 2 2 2 where T is the period. 24 Consider the electric field, E = Ex sin1kz - vt + w0x2xN 14 Two waves of the same amplitude, speed, and frequency travel together in the same region of space. New York: Academic Press, 1983. 29 Derive the law of reflection from Fermat's principle by minimizing the distance of an arbitrary (hypothetical) ray from a given source point to a given receiving point. Indeed, were the remainder of the wavelet considered to be effective in propagation from his principle. 19. 39. As a result, the average power output Pav from a Q-switched system is roughly the same as the CW power of the same system. As the irradiance at a given cavity-mode frequency grows, it "reaches" groups of atoms with center frequencies further and further from the cavity-mode frequency. The quartz crystal used by Franken, and many other crystals as well, do not possess inversion symmetry. The zone plate with such transmittance properties is the Fresnel zone plate, which produces multiple focal points along its axis beyond those discussed here for the Gabor zone plate. Because the edges of optical images are blurred by diffraction, the phenomenon leads to a fundamental limitation in instrument resolution. The diameter of the eyepiece field lens is 2 cm. 450 Chapter 20 Aberration Theory rays through the section ss; of a single lens. Such processes provide a means of producing intense and coherent electromagnetic radiation at frequencies at which there are no efficient laser transitions. Changes in angle occur at each refraction, such as at points 1 through 5, and at each refraction, such as at points 6. For the case N = 8, four such peaks, at a = 0, p, 2p, and 3p are shown in Figure 15a. 16 Determine collimated beam lengths 2z0 for a TEM00 Nd:YAG laser beam 11 = 1.064 mm2 focused by lenses of a perture diameters D = 1 cm, 2 cm, 3 cm, and 5 cm, respectively. The distance from the point O to a representative point P in the field is r. Lee, S. Grating Wadsworth mount for a concave space occupied by this spectrograph can be quite large. Light of irradiance I0 is incident on an atomic medium from the left as shown. For example, an ideal aspheric wavefront can be created synthetically to serve as a model against which a mirror may be shaped, using interference between the two surfaces as a guide to making appropriate corrections. A population inversion between two appropriate energy levels in the laser medium. Could you have used the approximate formulas w02 fl>pw01 and z2 = f in this instance? Measured values for these
constants, e0 = 8.8542 * 10-12 1C # s22>kg # m3 and m0 = 4p * 10-7 kg # m>1A # s22, provide an indirect method of determining the speed of electromagnetic waves in free space and yield a value of c = 2.998 * 108 m>s. Determine the irradiance at the film. In Figure 2, we specify a particular optical system consisting of two lenses, L1 and L2, with an aperture A placed between them, as shown. The negative sign is introduced, as usual, to indicate that the image is inverted in Figure 31, where fe 6 0. To image an actual object, this requirement must hold for every object point. Conductive Keratoplasty (CK) An alternate corrective procedure, known as conductive keratoplasty (CK), is currently available to patients over 40 years of age with mild amounts of hyperopia—up to about + 2.5 diopters. In between successive peaks there are shown N - 2 = 6 secondary peaks. The powers of the visible spectrum, conveniently represented by the Fraunhofer wavelength, lD = 587.6 nm, are P1D = 1 1 1 = 1n1D - 12a b = 1n1D - 12K1 r11 r12 f1D (33) P2D = 1 1 1 = 1n2D - 12k2 r21 r22 f2D (34) (35) Here, f1 and f2 are the focal lengths of the two lenses in the doublet. 22 Design an achromatic doublet of 5-cm focal length using 638/555 crown and 805/255 flint glass. Material dispersion for pure silica 200 175 150 M (ps/nm-km) 125 100 75 50 25 Figure 13Material dispersion in pure silica. (b) Forces acting on a dipole when the electric field has the direction indicated. Assume a LED source with a spectral width of 25 nm. Boundary Conditions for TE Waves have electric fields that are perpendicular to the plane of incidence and therefore are parallel to the boundary plane separating the two media. The number N of standing wave modes: N = \$ngain nm + 1 - nm = 1.5 * 109 Hz = 3 5 * 108 Hz Unlike traveling waves, standing waves transmit no energy. Optical filtering is the process of intentionally blocking certain portions—that is, certain spatial frequencies—present in the diffraction pattern, to manipulate the image. It is important to note that although the irradiance increases with each pass through the inverted gain medium, it decreases each time it encounters the output mirror of the resonator. We have achieved one of our objectives: The irradiance at P is dependent on the correlation function ≠1t2 involving the source field. If the zone plate or grating provides a square wave type of transmittance, 1 More precisely, the transmittance can be expressed as A + B cos21ar22, where A, B, and a are constants. For small focal lengths, Eqs. Such accurate imaging is also possible when the secondary mirror is concave ellipsoidal, as in the Gregorian telescope (Figure 34c). Fresnel Equations, Eqs. Source: Adapted with permission from Mathew Alpern, "The Eyes and Vision," Table 1, Section 12, in Handbook of Optics (New York: McGraw-Hill Book Company, 1978). For an antireflection coating of this type, the reduced reflected light near the middle of the spectrum results in a predominance of the blue and red ends of the spectrum, so that the coatings appear purple in reflected light. Calculation then gives LED: LD: d1t>L2 = 1100 ps>nm-km2 120 nm2 = 2 ns>km d1t>L2 = 1100 ps>nm-km2 11 nm2 = 0.1 ns>km At 0.82 mm, the LD is 20 times better than the LED, as a direct result of its superior monochromaticity. A., and S. In effect, the polarizeranalyzer pair transforms phase modulation. What is the significance of this result? The distances from S1 and S2 to any point P on a bright fringe surface differ by an integral number of wavelengths. 6 A transmission grating having 16,000 lines/in. 12 A sphere 5 cm in diameter has a small scratch on its surface. If the phase difference between light waves arriving at P from neighboring slits is p, determine the specific rotation produced by a 1-mm-thick quartz plate at a wavelength of 396.8 nm. The first question to be answered is: Which element serves as the effective AS for the whole system? The incident plane wavefronts of light are of wavelength 546 nm. In either case, the length L of the telescope is given by L = fo + fe (49) permitting a short Galilean telescope, a circumstance that makes this design convenient in the opera glass. The laser output consists of a number of modes with frequencies spread across the gain bandwidth of the lasing transition. As a consequence of this assumption, two harmonic waves in the medium itself or as a result of the mutual interference of the intensity of the light. What is the fringe visibility in a region where the irradiance of the reference beam is three times that of the subject beam? 10 DOPPLER EFFECT The familiar Doppler effect for sound waves has its counterpart in light waves, but with an important difference. The medium is pumped by a laser, of irradiance Ip , that is resonant with the 3-to-1 transition. 23 Geometrical Optics rays reflected in various directions and thus a diffuse scattering of the originally parallel rays of light. Figure 17a shows how this circumstance can be put to practical use in determining the quality of the spherical surface of a lens, for example, in an arrangement in which the Fizeau fringes have come to be referred to as Newton's rings. This requirement gives n 7 2n or n 7 1 Thus the minimum optical signal that can be extracted from the inherent quantum noise in an ideal laser field must contain, on average, at least one photon per detector sampling time. fundamental field, which drives the nonlinear polarization, relative to the phase of the second harmonic field, which is absorbed and emitted by the dipole oscillations comprising the nonlinear polarization. (c) Image of the frustule after applying a spatial filter as indicated in (d). Using Eq. (4) and the values of the ground state and first excited state energies of hydrogen found from Eq. (2) gives P2 -5 # = e-1E2 - E12>kBT = e-1-3.4 + 13.62>18.62 * 10 2932 = 4.1 * 10-176 ! P1 That is, it is very likely that all of the hydrogen atoms will be in the ground electronic state at room temperature. It can be shown that the number N of such coherent oscillators responsible for the reflected radiation is proportional to 12, so that the radiated power is proportional to 14, canceling the 1>14 dependence of isolated Rayleigh scatterers. 2 HARMONIC WAVES Of special importance are harmonic waves in space and time A small object of dimension h, when examined by the unaided eye, is assumed to be held at the near point of the normal eye—nearest position (a), 25 cm from the eye. It is found that when a vertical linear polarization, little or no radiation is transmitted. Assume light of wavelength 500 nm is incident on the interface at an angle of 60°. We show in the next section that if two sources is observed at a distance r away, there will be a region of high spatial coherence of dimension ls, given by ls 6 l u (35) where u is the angle subtended by the point sources at the observation point P. Find the lifetime of the upper lasing level is 10 ms and that of the lower lasing level is 0.1 ms. These are represented by the amplitude BE on the Cornu spiral. Although derived here for an even number N of slits, the result expressed by Eq. (22) is valid also for N odd (see problem 21). 206 Chapter 8 Optical Interferometry Solution Using Eq. (27) and noting from Figure 10 that Tmin = 0.05, the coefficient of finesse is found to be F = Tmax - Tmin 1 - 0.05 L = 19 Tmin 0.05 The finesse can be found either by extracting the FWHM from Figure 10 and using Eq. (34), F = dsr FWHM L 2p = 6.8 2.03 - 1.11 or by using Eq. (29), F = pr = 6.8 11 - r22 Rearranging gives 6.8r2 + pr - 6.8 = 0 Taking the positive root of this quadratic reveals r L 0.80 6 SCANNING FABRY PEROT INTERFEROMETER As noted earlier, a Fabry-Perot cavity is commonly used as a scanning interferometer. Thus, letting ex = 0, $M = c e^{0} i^{2} d c^{0} e^{1} 1 1 d = c i^{2} d c^{0} e^{1} 1 1 d = c i^{2} d c^{0} e^{1} 1 1 d = c i^{2} d c^{0} e^{1} 1 1 d = c i^{2} d c^{0} e^{1} 1 1 d = c i^{2} d c^{0} e^{1} 1 1 d = c i^{2} d c^{0} e^{1} 1 1 d = c i^{2} d c^{0} e^{1} 1 1 d = c i^{2} d c^{0} e^{1} 1 1 d = c i^{2} d c^{0} e^{1} 1 1 d = c i^{2} d c^{0} e^{1} 1 1 d = c i^{2} d c^{0} e^{1} 1 1 d = c i^{2} d c^{0} e^{1} 1 d e^{1} d$ indicates that the light is elliptically polarized, and the components are out of phase by 3p>4. Now let us require that the diffracted beam satisfy both the condition for a principal maximum in the mth order, that is, u = um. The contributing zones as "seen" from P₂ thus include zones from z = + 0.1 mm to z = 0 in the upper half of its wavefront and from z = 0 to z = - 0.9 mm in the lower half. Thus, show that optical density is equal to -log10 T. 24 A homemade compound microscope has, as objective and even half. Thus, show that optical density is equal to -log10 T. 24 A homemade compound microscope has, as objective and even half. affecting the nature of the interference pattern and the conditions under which it can be observed. Figure 20a shows the image, as well as several rays, which are now determined. In regions close to the symmetry axis, the Gaussian beam can be adequately described by planar waveforms. Other applications make use of the beam deflection capabilities of the AO effect. That is, the photon lifetime of a cavity is the time interval 1t - t02 over which the energy stored in a cavity without gain or input decays to 1/e of its initial value. 3 A driveway is illuminated at night by identical lamps at the top of two poles 30 ft high and 40 ft apart. Show that the actual distance is a ray travels during one skip distance is a ray travel. given by xs = n1d sin u where u is the entrance angle and the fiber is used in air. Furthermore, allowing R : q yields the appropriate refraction matrix for a plane interface. In general, B B B k is u with the plus sign, we interpret this to mean that an incident photon; with the negative sign, the incident photon is considered to yield an additional phonon to the acoustic wave, as well as a
photon to the diffracted beam. 1 d. However, many scientists would agree, a comfortable understanding of the true nature of light is somewhat more elusive. Note that a bold dot is used to denote directions perpendicular to the plane of incidence. The energy of the driving wave, however, is gradually dissipated as the wave advances through the absorber, so that the efficiency of the dichroic absorber, so that the efficiency of the dichroic absorber, so that the efficiency of the dichroic absorber is a function of the thickness. An eye placed near the ocular views an image exit pupil (eyepoint) Real intermediate image Exit pupil of objective Specimen Condenser diaphragm Light source Imaging beam path (a) (b) Figure 30 (a) Standard microscope illustrating Koehler illumination. The diffracted light is incident on a second concave mirror, which then focuses the spectrum at the exit slit. In the general case, the equation that must be satisfied by the blaze angle is found by combining Eqs. (See problem 8.) 11 Show that if L = 11>spæ 2, setting dL>ds = 0 produces the condition for minimum spherical aberration: s = - 21n2 - 12p n + 2 12 A positive lens of index 1.50 and focal length 30 cm is "bent" to produce Coddington shape factors of 0.700 and 3.00. 10 Light from a mercury lamp falls on the beam splitter of a student Michelson spectrometer. In the general case, pulses spread and distort as they propagate due to the differing speeds of the 2 For reviews of this phenomenon, see Kirk T. The gain cell represented by the upper curve has twice the smallsignal gain coefficient of the cells represented by the lower two curves, and as a consequence the output irradiance shown in the upper curve is significantly larger, even for short gain lengths. After advancing through the subzones of the second half-period zone, the phase changes by another p and the last phasor ends at B. These tightly bound electronic energy states of the material. The locus of the material in Figure 9c. Usec commonly in radio and television broadcasts, they include the AM radio band (540-1600 kHz) with wavelengths from 2.78 to 3.41 m. If the alignment is such that the air space between M1; and M2 in Figure 1b is a wedge, fringes of equal thickness may be seen localized at the mirrors. Notice that shorter wavelengths have larger refractive indices and, therefore, smaller speeds in the prism. Since the line width of spectral sources can be measured, average coherence times and coherent lengths may be surmised. Recalling that N2 and Np are densities and that the atomic population is spread through the volume Vg of the gain medium, whereas the photons are distributed throughout the field in the cavity occupying an effective volume Vc, we write dNp dt = $-\neq$ Np + 1Vg>Vc2scNpN2 (55) Here, \neq is the cavity loss rate and the Vg>Vc is approximately the ratio of the length of the gain cell to the perimeter P of the ring cavity. (a) 0.35 mm (b) 1 m 8. Estimate the difference $l_2 - l_1$ in wavelength of the two components presuming that the overlapping transmittance peaks have the same mode number, $m_2 = m_1 = m$. Calculate the path length difference c_L required to perform this task. The only difference c_L required to perform the same way and hence do not affect interpretation of the results. For a beam such that w01 is approximately equal to the radius of the lens, multiplying the numerator and denominator of Eq. (48) by 2 and using the definition f # K f > D for the f-number of the lens, where D is the lens, where D is the lens diameter, leads to w02 = 2fl 2lf # = p p12w012 (50) In general, then, a smaller f # of the focusing lens produces a smaller beam waist at the focused spot. In Figure 2a, the repetitive spatial unit of the wave is shown as the wavelength l. So, we define a subject beam scaled irradiance IS as, IS = f ES f 2 = E *SES = [s1x, y2]2 (5) This scaled irradiance function thus includes no information regarding phase of the subject beam. By isotropic we mean that the relevant physical properties we consider are independent of direction in the medium, so that we may treat the physical constants as scalar quantities. Seizing the initiative, we claim that this correspondence4 can be extended to other basic laws, for example, the simple lens law. For such a situation, the irradiance Properties of Lasers 157 1 m from a He-Ne laser with a much smaller output power of 1 mW would be I = P>A = 0.001 W p10.002 m22 = 79.6 W>m2 Irradiance 1 m from a 1-mW He-Ne laser High-power lasers may have a continuous output of 105 W with a beam radius of 1 cm. Example 2 As an extended example 2 As an extended example of refraction by spherical surfaces, refer to Figure 20. The energy of a plane, electromagnetic wave propagates in the direction of the Poynting vector, given by B B S = e0c2E * B (1) The magnitudes of electric and magnetic fields in the wave speed is related by E = yB (2) where the wave speed is related to the the refractive index n by c y n = (3) The wave speed in vacuum is a constant, equal to c = 1 1e0m0 (4) where e0 and m0 are the permittivity and permeability, respectively, of free space. Superposition of Waves 125 $\leq 1 \geq 1 \cos (kg \ x0 \geq vpt)$ (a) Envelope moves with group velocity yg. Scattering that occurs from larger particles2 such as those found in clouds, fog, and powdered materials such as sugar appears as white light, in contrast to Rayleigh scattering. Such detectors possess superior sensitivity in the visible and ultraviolet spectral ranges. These two lower curves show that, for gain cell lengths L short enough that the irradiance in the cell remains well below the saturation value, the output irradiance from the cell is nearly independent of the saturation irradiance. we describe briefly a few of the more common ones. An object is situated at a distance of 1.20 cm from the output end leads to the relation I0 = SIL (42) Here, S is the fraction of the irradiance that survives the trip around the cavity from the output to the input of the gain cell. E = E0 cos1kz - vt2xN - E0 cos1kz - vt2xN - E0 cos1kz - vt2yN z z B b. s1 30 10 s2 30 s1 40 (b) VO2 RI1 35 Geometrical Optics indicating an inverted image, equal in size to that of the object. How does the emergent light vary as a function of u? Then by opening the aperture wider to admit the second zone as well, the additional light produces almost zero amplitude at P! Now remove the opaque shield altogether, so that all zones of an unobstructed wavefront contribute. The pulse repetition time in a Q-switched system is typically on the order of 1 ms. F = Coefficient of Finesse Finesse 11 - r222 T = p 2F pr = 2 1 - r2 F = Q = F = FSR FWHM R K n 2cn1>2 Tmax - TminThis $2dF l = \ell lmin l Q L v = vtp \neq TABLE 2$ Fabry-Perot parameters for a cavity with a nominal spacing of d = 5 cm, a nominal input wavelength of l = 500 nm, and a nominal frequency of n = 6 # 1014 Hz. Photon lifetime and FWHM are quantities that are not applicable (NA) if the reflection coefficient is too low. (a) 27.8 mm (b) f/3.1, f/5.4, f/9.4 (c) 16.0, 9.26, 5.35 mm (d) 0.03, 0.09, 0.27 s 22. It can be shown1 that, in general, three angularly distinct beams result so that three distinct spots appear in the image plane. Then, from Eq. (52), ¢nD = a 1>2 8 * 1.38 * 10-23 * 3000 3 * 108 ln122b Hz - 26 8 2 488 * 10-9 6.64 * 10 13 * 10 2 = 3.8 * 109 Hz = 3.8 GHz There are many other important mechanisms leading to inhomogeneous broadening. It is stimulated emission that makes possible the amplification of light within a laser system. 12. As v is varied, there will be a series of resonance frequencies characteristic of the material. Use the ideal four-level gain medium relation given as Eq. (38) together with the definition of the effective pump rate density given following Eq. (33) to estimate the pump irradiance required to sustain a small-signal gain coefficient of 0.01/cm and 1/cm. An Nd:YAG system can provide a high power, good beam quality CW output, and can be either mode-locked or Q-switched. This ray leaves point P, passes through F, strikes a concave mirror, and is reflected as a ray parallel to the optical axis, as in Figure 17a. "Generation of Optical Harmonics," Phys. Thrierr, Atlas of Optical Phenomenon, Plate 33, Berlin: SpringerVerlag, 1962.) 316 Chapter 13 Fresnel Diffraction 5 PHASE SHIFT OF THE DIFFRACTED LIGHT The first phasors at in Figure 5 is drawn, rather arbitrarily, in a horizontal direction, and the other phasors are then related to it. This aperture is usually referred to by photographers as f/8. Sodium or mercury gas-discharge lamp sources are far more monochromatic and coherent. This path difference \$\phi\$ is \$\phi\$ L 2 # 50\$ L = 100hL Here, \$\phi\$ L = hL is the difference in the lengths of the interferometer arms (of nominal length L) induced by the gravitational wave. Further, let the population densities of the two atomic energy levels be N2 and N1, respectively. 7 TIME-DEPENDENT PHENOMENA In the previous sections of this chapter, we have made use of the fundamental definition of irradiance to form I1P = e0c8E21P9 and I2P = e0c8E22P9. The astronomical telescope may be modified to produce an erect image, but this lengthens the telescope by at least four times the focal length of the additional lens. (b) Profile of a step-index fiber, in which the core index is constant and slightly greater than that of the cladding. What is the nature of the product light? Level E2 is labeled as the "upper laser level." It is special in the sense that it has a long lifetime. When E is to the left of I, as shown for the case of a positive lens, the spherical aberration is positive; for a negative lens, E falls to the right of I, and the spherical aberration is considered negative. However, as we will discuss, for real fields, which are not perfectly monochromatic, care must be taken in treating this time average. Notice that we have defined the frequency linewidth ¢n
associated with transitions between a pair of atomic levels as $\phi n = \phi E n + \phi E m h$ (3) 135 It is common to refer to the frequency n0 as the frequency at line center. The spontaneous emission rate per unit volume is RSp. Em. = A21N2 (11) Here, A21 is the Einstein A coefficient for the 2 to 1 transition. The sensitive material is an emulsion of silver halide crystals or grains. Thrierr, Atlas of Optical Phenomenon, Plate 32, Berlin: Springer-Verlag, 1962.) 1.0 y ≥ 2.0 H D ≥ 1.0 B 0.5 (c) (d) upper zones (along the wavefront above O₂) plus some of the first lower zones (between O and O₂) contribute. Without deriving this Rayleigh scattering law, we can make the following hand-waving argument: The electric field of a dipole with a charge e accelerating back and forth along a B B d2 r > dt2 = - v2 r, then the acceleratine isB proportional to the acceleration. (5) and (6) will constructively interfere if the difference 1a2 - a12 in their phase constants is m12p2, where m is an integer. The light refracted into the water is intercepted by the top flat surface of a block of glass with index of 1.50. Mere amplification of a signal is not useful when it does not distinguish between signal and noise and results in the same signal-to-noise ratio, just as the mere magnification of an optical image is not useful since it does not clarify the object details. 515 516 Chapter 24 Nonlinear Optics and the Modulation of Light Optic axis Direction of matching Sign of x2 Figure 2 Phase matching techniques. Those that do not leave through the output mirror are reflected, recycling back and forth through the cavity gain medium. PEDROTTI LENO S. 68, No. 293 (2000) and Barbara Gross Levi, Phys. The air-flow pattern is revealed by the fringe pattern. The specified focal length of the 445 446 Chapter 20 Aberration Theory lens is due to the intersection of paraxial rays for which h : 0. Figure 14c and d contains photographs of a single-slit pattern and a double-slit pattern with the same slit width. As the field point P approaches the zone plate along the axis, the same zonal area of radius R1 encompasses more halfperiod zones. Fermat's principle, applied to the second component l2, gives FT + TW - \$\$\$ = 1n - \$\$\$\$ not plate along the axis, the same slit width. As the field point P approaches the zone plate along the axis, the same zonal area of radius R1 encompasses more halfperiod zones. conclude $\$s = b \ \n (19) or, introducing the dispersion, $\$s = b \ \n (19) or, introducing the dispersion of the wave end so must be perpendicular to the direction of propagation of the wave. Planes 1 normal to the axis at these points are called the cardinal planes. We now provide brief sketches of the various invisible regions of the electromagnetic spectrum. Show that the total optical density of several film layers is just the sum of their individual optical densities. In fact, using $11>s_2 + 11>s_2^2 = 1>f$, with $s_2^2 = 1>f$, with $s_2^2 = 1>f$ and t = -100 cm, solving for s, one finds that objects can be brought in as close as 17.6 cm from the eye and still be seen clearly. The minimum separation, xmin, of two just-resolved objects near the focal plane of the lens of diameter D is then given by xmin = f ¢umin = f a 1.22l b D The ratio D/f is the numerical aperture, with a typical value of 1.2 for a good oil-immersion objective. Interference of Mutually Coherent Beams If light from the same laser source is split and then recombined at a detector, the time average in Eq. (13) need not be zero. If they qualify, give the magnitude and direction of the wave velocity. 2 Show that in a nearly transparent medium, the absorption coefficient is related to the conductivity and refractive index by 1377 Æ2s a = nR 3 Calculate and/or plot real and imaginary parts of the refractive index for a dielectric given the frictional parameter g, the resonant frequency v0, and the dipole density N. Find the aplanatic points for a spherical surface of + 8 cm separating two media of refractive indices 1.36 and 1.70, respectively. The amplitudes of the electric field reflected internally and externally from the film of Figure 10 are then equal, assuming a nonabsorbing film, if the relative indices are equivalent for these cases, that is, if nf n0 = ns nf or nf = 2n0ns (28) Since usually n0 = ns nf or 1, the requirement that reflected beams be of equal amplitude is met by choosing a film whose refractive index. 4 The angle between the signal and reference beams during construction of a hologram is 20°. Thus, beam 4 includes rays that have traveled different optical paths and will demonstrate interference. Example 2 A myopic person (without astigmatism) has a far point of 100 cm and a near point of 15 cm. A thin lens combines two such surfaces, each of which reflect as shown. Before analyzing the resulting expression, we will recast the solution into a more easily interpreted form. (20) to (23) and by (b) using the corresponding equations for the reflection coefficients, together with the relationships between reflection and transmission coefficients, together with the relationships between reflection and transmission coefficients implied by Eqs. Figure 11 illustrates the working principle of a Soleil-Babinet compensator. Alternatively, if light of wavelength 10 in air is incident on the film at angle u0 one can write ml0 = d sin u0 Since l = l0 /n and sin u0 = sin u/n. Determine the distance between (a) the central maximum and first minimum and (b) the first and second minima. Today the typical grating master is made by diamond-point ruling of grooves into a low-expansion glass base or into a film of aluminum or gold that has been vacuum-evaporated onto the glass base. When a distant point source of light is observed looking through the plate, a diffuse halo is seen whose angular width is about 2° . In Figure 16c, a construction is shown that allows the determination of the transverse magnification. Those remaining equations are Ea = E0 + Er1 (27) Eb = Et2 (28) Ba = g01E0 - Er12 (29) Bb = gsEt2 (30) For the fields represented by Eqs. In steady state, the losses due to imperfect reflection and transmission at the mirrors must be, in each round-trip, offset by the increase in irradiance that results from interaction with the gain medium. (a) $1 - e^{-2a} 2/w^2$ (b) $1 - (1 + 2a^2/w^2 + 12)(2a^2/w^2 + 12)(2a^$)e-2a 2 2 /w 2 /w2 (d) 1 - (1 + 23 (2a2 /w2) + 12 (2a2 /w2)) e-2a /w 23. See Figure 7 for a sketch of this type of lamp and its housing. 2 FREE SPECTRAL RANGE OF A GRATING For diffraction gratings, the nonoverlapping wavelength range in a particular order is called the free spectral range, lfsr. When j = 1, for example, Eq. (31) reduces to the double-slit case, Eq. (23). For angle of incidence u1 6 uc both refraction and reflection occur. If a direction through the crystal is chosen such that n2v for the E-ray equals nv for the ordinary (O) ray, the fundamental and second harmonic waves remain in step and the crystal can be a centimeter or so thick. (b) Mach-Zehnder fiber interferometer used as a wavelength demultiplexer. This is the so-called Raman-Nath regime 13 If the crystal is thicker, regions of higher refractive index represent planes normal to the direction of the acoustic wave, as suggested in Figure 15b reflects the presence of the presence of the presence of the crystal is thicker, regions of higher refractive index is 1.48. In all cases no = 1 and ns = 1.52. Note that the resulting irradiance in Figure 15b reflects the presence of the crystal is thicker, regions of higher refractive index is 1.48. In all cases no = 1 and ns = 1.52. Note that the resulting irradiance in Figure 15b reflects the presence of the crystal is thicker, regions of higher refractive index is 1.48. In all cases no = 1 and ns = 1.52. Note that the resulting irradiance in Figure 15b reflects the presence of the crystal is thicker, regions of higher refractive index is 1.48. In all cases no = 1 and ns = 1.52. Note that the resulting irradiance in Figure 15b reflects the presence of the crystal is thicker, regions of higher refractive index is 1.48. In all cases no = 1 and ns = 1.52. Note that the resulting irradiance in Figure 15b reflects the presence of the crystal is thicker, regions of
higher refractive index is 1.48. In all cases no = 1 and ns = 1.52. Note that the resulting irradiance in Figure 15b reflects the presence of the crystal is thicker, regions of higher refractive index is 1.48. In all cases no = 1 and ns = 1.52. Note that the resulting irradiance in Figure 15b reflects the presence of the crystal is thicker, regions of higher refractive index is 1.48. In all cases no = 1 and ns = 1.52. Note that the resulting irradiance in Figure 15b reflects the presence of the crystal is thicker, regions of higher refractive index is 1.48. In all cases no = 1 and ns = 1.52. Note that the resulting irradiance in Figure 15b reflects the presence of the crystal is thicker, regions of higher refractive index is 1.48. In all cases no = 1 and ns = 1.52. Note that the resulting irradiance in Figure 15b reflects the presence o limiting diffraction envelope. The eyes, in conjunction with the brain, constitute a truly remarkable biooptical system. Another interesting application of polarization by reflection is the Brewster window. Such image points are called aplanatic points. When a collimating lens is used between source and interferometer, as shown in Figure 7a, every set of parallel beams entering the etalon must arise from the same source point. The detector output is then handled by a signal processor, whose function and, possibly, a digital-to-analog conversion. (a) At laser turn on the gain coefficient has its small-signal value g01n2 and six cavity modes are above threshold. New York: McGraw-Hill Book Company, 1966. Steady state is reached when only the frosted glass in a nonuniform manner, but its phase conjugate—after reflection by the PCM—exactly retraces its modifications, so that the return passage through the distortion. E = E0 sin1kz - vt - byN 4 p B d. Do a ray diagram for some object. Unless the reflectance of the film is large, a good approximation to the more complex situation of multiple reflection (Section 9) is to consider only the first two emerging beams. The first term P1 in Eq. (3) represents linear optics in which the polarizaB B tion of the medium is simply proportional to the E-field. monochromaticity of a LD over a LED is lost. The different energy levels of atoms are associated with different configurations of the electrons that surround the nucleus of the atom. Estimate the size of the particles. We now present a treatment of image formation that employs matrices to describe changes in the height and angle of a ray as it makes its way by successive reflections and refractions through an optical system. Other extrinsic losses occur as light is coupled into and out of the fiber. The developed plate is called a Gabor zone plate—or zone lens—with circular transmitting zones, whose transmittance is a gradually varying function of radius r. A one-to-one correspondence then exists between source and screen points. 5 SIMPLE MAGNIFIERS AND EYEPIECES The simple magnifier is essentially a positive lens used to read small print, in which case it is often called a reading glass, or to assist the eye in examining small detail in a real object. The variations in transverse amplitude deviate more and more from a pure Gaussian form with higher integers m and n. 1976), Ch. 9. In Eq. (9) when E01 7 E02, their dot product is identical with the product of their magnitudes E01 and E02. The magnetic field is set at 5.098 kG. In either case, the holes become two coherent sources of light, whose interference can be observed on a screen some distance away. The proportionality constant EL, here taken to be constant, determines the strength of the electric field contribution coming from each slit interval ds. If the scale of the map is to be 1:50,000 and the camera used has a focal length of 6 in., determine the proper altitude for the photograph. Araki, M. (a) w02 = 0.543 mm; z2 = 0.0663 m 11. Any retardation due to one thickness is then canceled by the other, yielding zero net retardation. What are the ratios of irradiance of the first three spots, relative to the irradiance of the "fundamental"? (a) 59°51' (b) 0.457 and 0.539 17. Such materials then possess three distinct indices of refraction. Cheo, Fiber Optics Devices and Systems (Englewood Cliffs, N.J.: Prentice-Hall, 1985). 1 A BRIEF HISTORY2 In the seventeenth century the most prominent advocate of a particle theory of light was Isaac Newton, the same creative giant who had erected a complete science beam Hologram Figure 10 Problem 12. The technique can be applied to holographic reading of microfilms, for example. (b) Refraction of two wavelength components separated by ¢l. Without illumination, a bias voltage across such a material with high intrinsic resistivity produces a small or "dark" current. He devised a method for dealing with the contribution from various parts of the wavefront by dividing the aperture into zones with circular symmetry about the axis SOP. Ch. 31. Visual Acuity The ability to see detail clearly and to perceive real differences in spatial orientation of objects is related to visual acuity. (a) 11,950 and 21,240 W/m2 (b) 12,960 W/m2 2 (d) 0.95 (c) 33,200 W/m 0.86, 0 0.8; 3.73/1 (b) 1.78, 2.55, 4.00, 13.9 Lloyd's mirror interference fringes are produced, aligned parallel to the slit, and separated by 0.273 mm. This important feature is also shown in Figure 30, where the line image is real for a cylindrical convex lens and virtual for a cylindrical convex lens. When photons of energy exceeding the band-gap energy of the semiconductor are absorbed in the vicinity of the junction, the created electronhole pairs are separated by the electric field in the junction region, causing a change in voltage, the photovoltaic effect. Fyodorov, who treated the youngster did not hold out much hope for restored vision in the eye, even though the cuts were superficial. Similarly, when ex 7 ey, M = eip>4 c 1 0 0 d -i QWP, SA horizontal (18) Corresponding matrices for half-wave plates (HWP), where f ex - ey j = p, are given by M = c e -ip > 2 0 0 1 d = e -ip > 2 0 0 1 d = e -ip > 2 c 0 e 1 0 0 d - 1aberrations for light entering at an aperture height of h = 1 cm. For sizable incident irradiances, the rate of spontaneous emission and stimulated absorption rates, and so spontaneous emission makes a negligible contribution to the net rate of photon production. When the spacing is fixed, the instrument is often referred to as an etalon. The angle u is the Bragg angle. Therefore, the lateral magnification is less for aperture position (1) than for aperture position (2). The significance of Eq. (37) is apparent in the case of Young's doubleslit experiment, where an extended source is used together with a single slit to render the light striking the double slit reasonably coherent, as in Figure 14. The physical operation of opening the diaphragm is thus analogous mathematically to the systematic inclusion of higher and higher frequency terms in the Fourier series representing the diaphragm is thus analogous mathematically to the systematic inclusion of higher and higher frequency terms in the Fourier series representing the diaphragm is thus analogous mathematically to the systematic inclusion of higher and higher frequency terms in the Fourier series representing the diaphragm is thus analogous mathematically to the systematic inclusion of higher and higher frequency terms in the Fourier series representing the diaphragm is thus analogous mathematically to the systematic inclusion of higher and higher frequency terms in the Fourier series representing the diaphragm is thus analogous mathematically to the systematic inclusion of higher and higher frequency terms in the Fourier series representing the diaphragm is thus analogous mathematically to the systematic inclusion of higher and higher frequency terms in the Fourier series representing the diaphragm is thus analogous mathematically to the systematic inclusion of higher and higher frequency terms in the Fourier series representing the diaphragm is thus analogous
mathematically to the systematic inclusion of higher and higher frequency terms in the fourier series representing the diaphragm is thus analogous mathematically to the systematic inclusion of higher and higher frequency terms in the fourier series representing the diaphragm is thus analogous mathematically terms in the fourier series representing the diaphragm is thus analogous mathematically terms in the fourier series representing terms in the fourier seri variables and integrating both sides of the resulting relation gives IL \pm IO a 1 1 + b dI = g0 I IS L \pm dz 0 Integration gives ln a IL 1 b + 11L - IO2 = g0L IO IS (41) The important result given in Eq. (41) is a transcendental relation that can be numerically solved for the output irradiance IL given the input irradiance and the characteristics of the gain medium, g0, L and IS. In contrast, a metallurgical objective is designed without such compensation. Determine values of film thickness and (hypothetical) refractive index that will produce a nonreflecting film for normally incident light of 500 nm. 2 2 2 x Node t 0, T, 2T, . This procedure is cumbersome and the resulting expression inelegant, and so we leave this as an unlisted problem for the ambitious student. We permit the two waves to differ in amplitude and phase. At time t + t, the right-going intracavity field E1+1t + t2 can be formed as the sum of two parts. Fourier Optics 3 The optical density of film is defined as the common logarithm of its opacity. The combined wavefront and irradiance variation of such a typical laser beam passing through a converging lens might appear as shown in Figure 1. More importantly, this approach also leads to the Fresnel equations, which describe the fraction of incident energy transmitted or reflected at a plane surface. Steward, E. (a) A = 0.9764, B = 0.9676, C = 0.009182, D = 1.033 (b) f1 = 108.9 cm, f2= -108.9 cm, p = 112.5 cm, q = -106.3 cm, r = 3.62 cm, s = 2.57 cm (c) -100 cm 15. for 20/20; 0.065 in. Cotter. The component E7, which is parallel to the plane, whereas its orthogonal counterpart E causes oscillations within the plane. On a screen the fourth minimum of the 436-nm light coincides with the third maximum of the other light. Each of the small phasors represents the contribution from one subzone. Scattering and other mechanisms lead to a coupling between the orthogonal polarization modes. When level E2 does decay, say by spontaneous emission, it does so to level E1, labeled the "lower laser level." Level E1 is an ordinary level that decays to the ground state quite rapidly, so the population N1 cannot build to a large value. It is interesting to note that human color sensation is a function of illumination and is almost totally absent at lower levels of illumination. The fringe pattern shifts by an amount \$\phi_x\$ at the film edge. 27 A laser beam from a 1-mW He-Ne laser (632.8 nm) is directed onto a parallel film with an incident angle of 45°. (d) Nonparaxial rays from object point P near the axis form an image at P¿, subject to the Abbe sine condition. The echelle is positioned directly over the slit-to-mirror path, but the plate is offset in a horizontal direction. Making use of Eq. (10), we also determine that a = - 45°. We follow this with a brief overview of aberrations and then examine in turn, the optics and operation of prisms, cameras, eyepieces, microscopes, and telescopes. Such sources are available at operation of prisms, cameras, eyepieces, microscopes, and telescopes. light is incident normally on the hologram? Many sources of noise in quantum detectors exist,2 including shot noise or quantum noise, which arises because of the statistical nature of the conversion of a photon in the incident field to an electron in the detector system. For example, a Littrow grating can be used as a wavelength-selective mirror to ensure that only one of several laser lines experiences low loss in a laser cavity. (27) and (28) leads to, in steady state, dN2 sI = 0 = Rp1 + k21N2 - k10N1 + 1N - N12 dt hn; 2 (32) dN1 sI = 0 = Rp1 + k21N2 - k10N1 + 1N - N12 dt hn; 2 (33) where we have defined the effective pump rate densities Rp2 = k32 spIp a N b k3 hnp T Rp1 = k31 spIp a N b k3 hnp T Equations (32) and (33) can be solved for the population inversion, giving Ninv = N2 - N1 = 11 - $k21 > k102Rp1 k2 + 11 + k20 > k1021sI > hn_2 (34)$ 559 Laser Operation When describing gain media, Eq. (22) is often recast by defining a gain coefficient g as g = s1N2 - N12 = sNinv (35) dI = gI dz (36) so that It is important to note that the gain coefficient depends on the irradiance I, since the population inversion is, in general, dependent on the irradiance. Free electrons respond in this manner. However, when the bundles are large, as shown in (b), spherical aberration occurs, which produces a shorter focus for rays reflecting from the outer zones of the mirror relative to the optical axis of the bundle. According to our definition of the ExP, the exit pupil is the optical conjugate of the AS; the ExP and AS are conjugate planes. Several basic designs for reflecting telescopes are shown in Figure 34. Such irradiance levels are readily developed with the help of beam expanders and suitable focusing optics. We now interpret the three terms in Eq. (9) as the reconstruction of three distinct beams from the hologram. E 01 (21) Some time after the incident field is first directed onto the cavity, the intracavity electric field will settle down to a constant steady-state value. Let us return to our earlier development in this chapter and generalize Eq. (10), which we first guessed to have the form 2 U1x, y, z2 = E0ei[p1z2 + k1x + y22 > 2q1z2] as U1x, y, z2 = E0g a $y \ge 22$ b h a bei[p1z2 + k1x + y2 > 2q1z2] w w (51) The presence of the functions g(x/w(z)) and h(y/w(z)) admit waveforms that do not have cylindrical symmetry. When reflection is internal, Figure 5, we conclude that a p-phase shift occurs for the TM mode for upcocurs for the functions g(x/w(z)) and h(y/w(z)) admit waveforms that do not have cylindrical symmetry. When reflection is internal, Figure 5, we conclude that a p-phase shift occurs for the TM mode for upcocurs for the functions g(x/w(z)) admit waveforms that do not have cylindrical symmetry. earlier, the frequency difference between modes is nfsr = c > 2d so that the recurrence time for the pulses is the round-trip cavity time 2d/c. Typically, such absorption bands lie in the ultraviolet, above optical frequencies, so that the material is transparent to visible light. Then f2 = -a 1.33 b1 - 35.742 = 47.53 cm 1 to the right of the second principal plane. and r = 1.52 - 1.331 - 35.742142 = 0.715 cm 11.5221 - 252 s = - 1.52 - 1 147.532142 = - 2.60 cm 11.5221 + 252 Thus the principal point H1 is situated 0.715 cm to the left of the right of the left of the right vertex V2. Show that the ratio of the right of the left vertex V2 is situated 0.715 cm 11.5221 + 252 Thus the principal point H1 is s square root of the liquid's refractive index. The mathematical argument departs from that for the single slit with Eq. (4). In third-order theory, the Petzval surface is always lies on the side of the S surface and always lies on the side of the S surface. If the first zone is subdivided into smaller segments, which advance by equal phases, the corresponding subzone phasors can be represented by b1, b2, Å, as shown. The small coherence length associated with the phase mismatch in many crystals (see Example 2) makes the construction of a QPM crystal by the method just described somewhat impractical. (b) Refraction in the 180 see Example 2) makes the construction of a QPM crystal by the method just described somewhat impractical. meridian yields +2.00 D of hyperopia. As a result, a negative sign between the two terms on the right of Eq. (17) would have been an appropriate choice. Recall that a complex quantity can be represented as a vector in a phasor diagram in which the real and imaginary parts of the complex quantity can be represented as a vector in a phasor diagram. of its vector representation. The solid angle dv1 = dA2 cos u2>r2, where dA2 cos u2>r2, where dA2 cos u2 represents the projection of area dA2 normal to the central ray. Then, find the amplitude of the light transmitted
by the reference beam. Radiometric quantities are related to photometric quantities through the luminous efficiency curve of Figure 2 in the following way: Corresponding to a radiant flux of 1 W at the peak wavelength of 555 nm, where the luminous efficiency is a maximum, the luminous efficiency is a maximum, the luminous efficiency is a maximum, the luminous flux is defined to be 685 lm. Palais, Fiber Optic Communications (Englewood Cliffs, N.J.: Prentice-Hall, 1988). The rays all pass through a thin annular region of the lens, centered about the optical axis. In Figure 2a, a section of a wave with amplitude A is shown at a fixed time, as in a snapshot; in Figure 2b, the time variations of these sources formed by lenses and mirrors have finite sizes governed by the laws of geometrical optics. New York: American Elsevier Publishing Company, 1969. Here, the limits of integration covering the apertures of the two slits become those indicated in Figure 13. In other, more complex forms, referred to as higher-order modes or Hermite-Gaussians, the electric field takes on transverse irradiance distributions that depart from the simple Gaussian variation and exhibit an ordered pattern of "hot spots." In many cases, the output laser beam consists of a mixture of modes: the fundamental and several higher-order modes. Thus, for Hm1xs2exp1 - xs2>22], the sketch that gives direct evidence of the burn pattern to be expected.9 After studying Figure 15, we see that the irradiance variation has m zeros along the x-axis, discounting the zeros at the distant tails of the Gaussian envelope. The result2 is expressed by y c l_i = y l 1 + c a 1 - (44) where l_i is the Doppler-shifted wavelength and y is the relative velocity between source and observer. What must be the population inversion in the gain medium to produce a small-signal gain coefficient (at linecenter, n_i = n0) of 0.03/cm? The geometrical relationship of sides is equivalent to the Bragg diffraction condition. A technique like this was used to remove a sawtooth pattern from the video micrograph of a diatom frustule, as shown in Figure 6. Of course, each of these half-period, or Fresnel, zones could be subdivided further into smaller parts-subzones- for which the phase varies from one end of the zone to the other by p. Takara, "Effects of Dopants on Transmission Loss of Low-OH-Content Optical Fibers," Electronics Letters, Vol. 15 What theoretical ratio of high-to-low refractive indices is needed to give at least 90% reflectance in a high-reflectance stack of two double layers of quarter-wave layers at normal incidence? The transmitted portion of the beam undergoes an internal Film Substrate n1 ns n0 t B z x Er1 E Ei1 Er 2 E B B E ut2 E E ut1 y u0 B E0 E B u0 B Et1 (a) Ei2 Et2 (b) Figure 1 Reflection of a beam from a single layer. Points O and I are conjugate points with distances s and s_i from the surface vertex at V. Since each pair constitutes similar triangles, we may set up proportions between sides that represent the lateral magnification: f hi = x ho hi x_i = ho f and Introducing a negative sign for the magnification, due to the inverted image, m = - f x_i = x f (35) The two parts of Eq. (35) also constitute the Newtonian form of the thin-lens equation, xx = f2 (36) This equation is somewhat simpler than Eq. (29) and is found to be more convenient in certain applications. Figure 6b shows that the hyperopic eye must (and can) accommodate to see distant objects clearly. spectrum of the oscillations of the gain medium and hence contribute to the broadening of the atomic response. 7 A point source of monochromatic light (500 nm) is 50 cm from an aperture plane. Later we shall show that 210 is the irradiance at P that results for an unobstructed wavefront—that is, for "diffraction" through an aperture of infinite extent Absorption in the infrared is due to molecular vibrational bands. (27) and (28), we have for metals, TE: TM: ' Er cos u + 2n 2 - sin2 u (64) ' Introducing n as nR + inI into Eqs. To reconstruct the image of the scene, the hologram is situated in the reference beam again, as in the formation of the hologram (Figure 2b). Such structures possess a single optic axis and are called uniaxial birefringent. The separated line images T and S are revealed as sections of the beam by fluorescent screens. a wave as a simple plane wave is a useful approximation if a portion of the wave has nearly planar wavefronts over the region of interest. This rotational symmetry simplifies the analysis of the imaging properties of such a spherical lens. At this point, each of the original zones, as in Figure 7 for example, now contain two half-period zones. First we examine the structure and functions of the eye. In 16a, the laser medium is shown situated between the mirrors of the optical resonator. As discussed previously, the useful order of diffraction is large and the spectral free range is small, so that a second concave grating is used to disperse the overlapping orders in a direction perpendicular to the disperse the overlapping orders in a direction perpendicular to the dispersion of the echelle grating. identical diffraction patterns. A plot of transmittance T versus round-trip phase difference d for selected values of reflection coefficient r. For example, if 2nt = 10, the wavelength of the light in vacuum, the two interference. Figure 20b shows 0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.03 0.04 0.05 0.06 Change in cavity length (mm) (a) (b) Figure 20 Problem 21. In this case, the scattering centers (particles) are arranged—more or less—in an orderly fashion so that oscillators that are closer together than a wavelength of the incident light become coherent scatterers. Determine the diameter for single-mode performance and the number of propagating modes when d = 50 mm. When the wave character of the light may not be so ignored, the field is known as physical optics. Optically active materials modify the state of polarized light and can be represented mathematically by a Jones rotator matrix. As a consequence, and as illustrated schematically in Figure 5c, the uncorrected myopic eye forms a sharp image of distant objects in front of the retina, and, of course, a blurred image results at the retina. With a transmission function EA1x, y2 in its first focal plane, the Fraunhofer diffraction pattern A P1kX, kY2, which is its Fourier transform, is produced in the second focal plane, the spectrum, or output, plane. We shall see that R is the radius of curvature of the wavefront and w is related to the transverse dimension of the beam. If the spectral exitance or area Spectral radiant exitance or area Spectral radiant exitance of Eq. (5) is integrated over all wavelengths, the total radiant exitance or area Spectral exitance or area Spectral exitance of Eq. (5) is integrated over all wavelengths, the total radiant exitance or area Spectral exitance or area Spectral exitance of Eq. (5) is integrated over all wavelengths, the total radiant exitance or area Spectral exitance or area Spectral exitance of Eq. (5) is integrated over all wavelengths, the total radiant exitance or area Spectral exitance or area Spe $3000\ 1.0\ Wavelength\ (mm)\ 2.0\ Figure\ 3\ Blackbody\ radiation\ spectral\ distribution\ at\ four\ Kelvin\ temperatures.$ The curves cross at v = 1v2p - g221>2, as is evident\ from\ Eq.\ (61), we find, as before, two equations\ from\ which\ the\ real\ and\ imaginary\ parts\ of\ the\ real\ and\ imaginary\ parts\ of\ the\ real\ and\ imaginary\ backbody\ radiation\ spectral\ distribution\ at\ spectral\ distribution\ at\ spectral\ distribution\ at\ spectral\ spectral\ distribution\ at\ spectral\ spec each wavelet is to be disregarded in the application of the principle. Find the diameter of the moon viewed through the telescope at near point of 25 cm. 2 PHOTOMETRY You should be familiar with the terms and definitions associated with radiometry, which applies to the measurement of all radiant energy. Experimentally, one finds that a separation of 1 mm at a distance of about 2 m is just barely resolvable, giving 1 cu 2min = 50 * 10.5 rad, about 1.5 times the theoretical limit. Thus, for m = 1, there is a single zero at xs = 0 and peaks on either side. Again in 1922, the model of light guanta came to the rescue for Arthur Compton, who explained the scattering of X-rays from electrons as particle-like collisions between light quanta and electrons in which both energy and momentum were conserved. In the case of normal incidence, the reflection coefficient (or ratio of reflected to incident electric field amplitudes) is given by r = 1 - n 1 + n (27) 177 Interference of Light where the relative index n = n2 > n1. 550 nm Aperture Photocell 3 mm Plane waves Figure 19 3 A distant source of sodium light (589.3 nm) illuminates a circular hole. Assuming they are halfway: a. 6 IMAGING BY AN OPTICAL SYSTEM We discuss now what is meant by an image in general and indicate the practical factors that render an image less than perfect. Of course, there is no absorption stimulated by the electromagnetic vacuum because the vacuum, being the ground state of the electromagnetic field, can provide no energy quanta to the atom. (b) Energy level diagram for the helium-neon laser, showing the production of the 0.6328-mm laser line in terms of the four steps (circled numbers) outlined in (a). By light modulation, we mean the modification of the amplitude (AM), frequency (FM), phase, polarization, or direction of a light wave. In this way, we account for multiple beams in the interference. The energy in each cycle is the energy contained in a single pulse: Ep = Pp ¢tp a. According to this discussion, when B = 0, the output plane is the image distance x is determined by setting 16 - 2x = 0 3 or x = 24 cm Further, the linear magnification m is then given by the value of element A: m = A = 1 - Input plane R 4 cm 16 n 1.0 n + 1.50 x = -1 12 x Figure 10 Schematic defining an example for ray-transfer
matrix methods. Chapter 18 1. Since the film plane is fixed, a focused image is procured by allowing the lens to be moved farther from the film, that is, by "focusing" the camera. E Free electron continuum 0 E4 0.85 eV E3 1.51 eV E2 3.4 eV E1 13.6 eV Figure 1 Allowed energies of the electron in the hydrogen atom. The lasing levels in the Ar+ laser are two different electronic 576 Chapter 26 Laser Operation energy states of a singly ionized argon atom. In others, excitation occurs by means of inelastic atom-atom (or molecule) collisions. Light rays from an object are admitted into a light-tight box and onto a photographic film through a tiny pinhole, which may be provided with any simple means of shuttering, such as a piece of black tape. To be more specific, when cos d = + 1, constructive interference yields the maximum irradiance Imax = I1 + I2 + 22III2 (15) This condition occurs where the phase difference d = 2mp, where m is any integer or zero. Minimum deviation occurs for an angle of 23°. This treatment is strictly valid for cases where the individual E vectors are parallel; it is often applied in cases where they are nearly parallel. Interference effectively occurs between the two coherent virtual images S1 and S2, acting as sources. Pedrotti, and Peter Bandettini. 1 (Reading, Mass.: Addison-Wesley Publishing Company, 1963), Ch. 32, 33. A wide range of spectral outputs is possible by using different materials in the core of the carbon rod. In a system like that of Figure 1a, a screen held at the position of the exit pupil receives a sharp image of the circular opening of the aperture stop. Thus we can write, EA = a a ES ikr, be r; (4) where a is a proportionality constant with dimensions of inverse length. "Light." In Lasers and Light, pp. Calculate the beam spot size w at the entrance and exit faces of the beam expander. The Diffraction Grating 14 A reflection grating, ruled over a 15-cm width, is to be blazed for use at 2000 Å in the vacuum ultraviolet. + + + 1t + t2 = E01 1t2 K E01 . Geometric Optics: An Introduction. Exit Window (E xW) The exit window is the image of the field stop formed by all optical elements following it. (b) Piezoelectric spacer used to control the mirror separation d. Let the light incident on such a zone plate consist of plane wavefronts. This is described by the rapidly varying factor eikz. In Figure 1 two wavefronts are shown emerging from an optical system. The incident light beam with wave vectorBk can be considered a flux of photons, each of energy Uv and momentum Uk, where v is the angular frequency and U is the Planck constant divided by 2p. This ordering of fringes may be inverted for convenience by associating another integer p with each fringe of order m, where p = mmax - m = 2d - m l m 99 p1 (6) m 98 p2 Using Eq. (6) to replace m in Eq. (4), we arrive at pl = 2d11 - cos u2 p = 0, 1, 2, Å dark fringes m 97 p3 (7) where now the central fringe is of order zero and the neighboring fringes increase in order, outward from the central fringes do not appear. Glass fibers are therefore preferable in long-distance applications. In such a representation, the length of the vector is the magnitude of the complex quantity. (a) $zFF \gg 1.46$ m (b) 0.371 mrad (c) win = 1.113 cm; wout = 11.13 cm; m 16. What frequencies are radiated by the polarization wave? The two parallel beams leaving the film at A and C can be brought together by a converging lens, the eye, for example. 31 1941; 488. Example 1 a. This illustrates how the system matrix can be used to find image locations and sizes, although this may usually be done more quickly by using the Gaussian image formulas derived earlier. To correct for myopia, tissue in the center of the cornea and reduce the refractive power of the eye-allowing the relaxed eye to form images of faraway objects on the retina. Nonlinear Optics and the Modulation of Light degenerate four-wave mixing, illustrated in Figure 15, can be used to produce the phase conjugate beam. Solution At 0.82 mm, Figure 13 gives a value of near 100 ps/nm-km. The total field in the cavity-mode frequencies that are separated by the cavity free spectral range c/2d, where d is the cavity length. The dispersing powers of the components are, through appropriate selection of glasses, in inverse proportion to their powers. Variations in temperature produce variations in temper 0 when p = 0 and a = p when p = N = 8. Convert the result to an image distance in centimeters. As the seed photons in the same direction, providing an increasing population of coherent photons that bounce back and forth between the mirrors. Sketch this pulse. Assume an average wavelength of 700 nm for the sun's radiation that reaches the earth. Two such technologies are discussed below. A difference or idler frequency v3 = vi = vp - vs can be produced. These are periodic waves, representing smooth patterns that repeat themselves are discussed below. beam splitter differ by p. The extraordinary ray is not B perpendicular to the plane wavefront; rather, the ray direction along S is from the wavelet with the plane wavefront. For large N, its principal maxima are bright, distinct, and spatially well separated. Thus, by using prisms with apex angles intermediate between these values, the perpendicular component can be totally internally reflected while the parallel component is transmitted. If the small-signal gain coefficient is twice the threshold value, find the irradiance of the laser output field. represented by the Jones vector c d, and light with a polarization 1 y x Rotator u z Figure 10 Operation of a rotator. 1 Figure 3 Scaled population densities of the excited (2) and ground (1) states of a twolevel atomic system as a function of the scaled irradiance I>1A 21hn¿>s2. Because of interference, a broadcast "beam" is limited by interference minima Since these perpendicular fans of rays focus at different distances from the lens, the two images are line images, shown as T and S for the tangential and sagittal fans, respectively. In the figure, the electric field E, made up of equal parts along the x- and y-directions, oscillates along a line making an angle of 45° with the x-axis. The result is the generation of incoherent light. 6 Consider a Soleil-Babinet compensator, as shown in Figure 11. Birefringence in Optical Fibers You should be familiar with some of the advantages of single-mode optical fibers. The intersection of the two reflected rays occurs behind the mirror and locates a virtual image of dimension hi there. Waveguide dispersion, on the other hand, is always positive. 12 Light of wavelength 485 nm is incident normally on a screen. Distances to the left of the vertex V are negative, and to the right, positive. For observation points P¿ at very large values of y in Figure 14a, the irradiance approaches the value Iu for the unobstructed wavefront. Unlike two-dimensional holograms, volume holog can reproduce images in their original colors when illuminated with white light. Verrier. Then the light reaching any point such as P on the screen is due to parallel rays of light from different portions of the wavefront at the slit (dashed line). If the frequency-sensitive position of the output beam is detected by a photodetector array, the AO device can be used as a spectrum analyzer. Examine element B to determine the general relationship between object and image distances for the lens. With the help of Eq. (64), we can form the factor eip1z2 as eip1z2 = w0 -i1m + n + 12arctan1lz>pw022 w0 -i1m + n + 12arctan1lz>pw022 w0 -i1m + n + 12arctan1lz>z02 e = e w1z2 w1z2 (65) where we have used Eqs. Repeated reentries of the beam into the laser cavity initiates stimulated emission that produces the laser pulse. For the present, we call this factor F1u2, a function of the radiation incident and diffracted at the aperture point O. Find the temperature at which the radiation incident and diffracted at the aperture point O. Find the temperature at which the radiation incident and diffracted at the aperture point O. Find the temperature at which the radiation incident and diffracted at the aperture point O. Find the temperature at which the radiation incident and diffracted at the aperture point O. Find the temperature at which the radiation incident and diffracted at the aperture point O. Find the temperature at which the radiation incident and diffracted at the aperture point O. Find the temperature at which the radiation incident and diffracted at the aperture point O. Find the temperature at which the radiation incident and diffracted at the aperture point O. Find the temperature at which the radiation incident and diffracted at the aperture point O. Find the temperature at which the radiation incident and diffracted at the aperture point O. Find the temperature at which the radiation incident and diffracted at the aperture point O. Find the temperature at which the radiation incident and diffracted at the aperture point O. Find the temperature at which the radiation incident at the aperture point O. Find the temperature at the aperture point O. Find the approximate at the aperture point O. Find the approximate 22.38 mm 20 mm 2.38 mm 1.96 mm 15 mm 7.38 mm N H H S1 F S2 AC Figure 3 Representation of H. +20 and -20 cm 18. From Eq. (33), we conclude that r = +3.125 cm and s = -2.083 cm. 11 A pinhole of diameter 0.5 mm is used in front of a sodium lamp (5890 Å) as a source in a Young interference experiment. Thus, Eq. (52) can be satisfied for all x, y at arbitrary z only if (1) the g-expression equals a constant, say -C1, (2) the h-expression equals a constant, say -C2, thereby (3) leaving the third term equal to C1 + C2. 4, 5. Extinction of the reflected light is observed to occur at wavelengths of 525 and 675 nm in the visible spectrum. Ch. 1. With these definitions, Eq. (31) may be written V + V_c = P (32) I 2F O F 2F F s s (a) 3F O I s s (b) Figure 25 Change in curvature of wavefronts on refraction by a thin
lens. One such transition, leading to the 1.1523 mm line, is indicated in the figure. The low-pressure mercury discharge tube is often used to provide, with the help of isolating filters, strong monochromatic radiation at wavelengths of 404.7 and 435.8 nm (violet), 546.1 nm (green), and 577.0 and 577.0 and 579.1 nm (green), and 577.0 and 579.1 nm (green), and 577.0 and 579.1 nm (green), and 579.1 n (X, Y), represents spatial frequencies present in the aperture function, as we have pointed out. electrons in the atom. Among the extrinsic losses are inhomogeneities and geometric effects. 22 Trace a ray originating 7 mm below the optical axis and 100 mm distant from a doublet. New York: Holt, Rinehart and Winston, 1970. From Figure 3b, the components of the resultant phasor E0eia are E02 sin a2 E02 E0 E01 sin a1 a1 E01 cos a1 E02 cos a2 (b) Figure 3 Phasor diagrams useful for determining the sum of two harmonic waves. The hologram acts as a matched filter, recognizing and transmitting only that spatial spectrum similar to the one recorded on it. IEEE, Vol. . Now & = 12p>102L&, where 10 is the vacuum wavelength and L¢n represents the optical-path difference induced in each component by the applied field. Chapter 23 Dichtburn, R. The two types of photoreceptors, rods and 0 = Cy0 + Da0 or y0 = - a D ba C 0 (23) For small angles, Figure 12a shows that a0 = Input plane H1 Output plane PP2 PP1 F1 y0 -p N1 H2 N2 F2 Optical system. The example illustrates a one-dimensional correlation. On the other hand, when we are looking at the sunlight "head-on" at sunrise or sunset, after it has passed through a good deal of atmosphere, we see reddish or yellowish light, that is, white light from which the blues have been preferentially removed by scattering. Sketch the chief ray and the two extreme rays through the optical system, from the top of the object to its conjugate image point. Use the matrix method to support your answer. A Snellen fraction of 20/300 means that the test subject sees poorly, reading at a distance of 20 feet what the normal eye reads as well at a distanc which the second-order polarization term P2 of the optical medium is proportional to the square of the electric field. An empirical relation that approximates the curve, introduced by Augustin Cauchy, is nl = A + BC + 4 + A2112001600 l (nm) Red Green Violet White Figure 12 Typical normal dispersion curve and consequent color separation for white light refracted through a prism. Calculate its magnifying power when viewing an image at infinity. (15) and (16), the coherence length is lt = c ¢n The frequency band ¢n can be related to the line width ¢l by taking the differential of the relation n = c>l. We have shown earlier that this D z0 Rayleigh range 3(2w0 (2w0 2w0 Waist Laser w0 Figure 11 A

collimated laser beam and the corresponding Rayleigh range z0. In a Littrow mount, the grating returns, along the incidence direction, light of wavelength $l = 211 > 792 \sin 163.432$ 2a sin ub mm = 755 nm = m 30 The total number of lines on the grating is N = 179216102 = 48,190 so that the resolving power is P = mN = 1302148,1902 = 1,445,700 at the blaze wavelength of 755 nm. The last of these, C-1G2, is called the optical transfer function (OTF), because it transfers or changes the object spectrum into the image spectrum. Mathematically, the power expansions for the sine and cosine functions, given by sin $x = x - x5 x^3 + -A 3! 5! \cos x = 1 - x4 x^2 + -A 2! 4!$ were accordingly approximated by their first terms. The FWHM, 2 cn 1 > 2, of a transmittance peak. (a) 83.3 cm (b) 83.3 fringes (c) 150 nm 556 nm, 455 nm 20.3' 6' 5" $35'40'' 9.09 \times 10-5$ cm; orders 4 and 3, respectively 498 nm 1.33; 103 nm (c) 1% Soap film becomes wedge-shaped under gravity; the angle of the wedge is $1'14'' 15 1.16 \times 10-3$ cm 1.09 mm; 184 3m 603.5 nm; 2.39 mm; 2.87 × 10-4 cm 928 nm (a) 980 V/m (b) 30° (c) r' = 0.28; tt' = 0.9216 (d) 274, 253, 19.8 V/m; 7.8%, 6.7%, 0.041% (e) 903, 70.8 V/m; 85%, 0.52% (f) 258 nm 4. Such correlation is applied, for example, in the problem of pattern recognition. The content of Eq. (13) implies, for example, that if the hologram were made with coherent X-rays and viewed with visible light, magnifications as large as 106 could be achieved without deterioration in resolution. In this section we derive steady-state population densities for a two-level atomic system, in which the lower energy level is the ground state of the system. and thus coma and astigmatism do not enter into the aberrations of the system. The numerator is identically zero under the condition a = pp>N, where p takes on integer values. However, this path difference 270 Chapter 11 Fraunhofer Diffraction & cannot be ignored in the phase factor. Today, with the help of computers, the necessary calculations yielding the progressive changes in a ray's altitude and angle is done more easily and quickly. One of the mirrors is chosen with a reflectivity as close to 100% as possible. The full details of aberration theory are too formidable to treat in this chapter. In either case, when ¢ = ml, all diffracted waves are in phase and the grating equation becomes a1sin ui + sin um2 = ml, m = 0, ; 1, ; 2, Å (2) When it is not necessary to distinguish between angles, the subscript on the angle of diffraction, um, is often dropped. As noted in Figure 1, the eye is covered with a tough white coating, the sclera, that forms the supporting framework of the eye. f1z, t2 = A exp1Bz2 + BC2t2 - 2BCzt2 9 A harmonic wave traveling in the +x-direction has, at t = 0, a displacement of 13 units at x = 0 and a displacement of - 7.5 units at x = 31>4. Recall that the resolving power P is defined in general by P K l 1¢l2min is the minimum wavelength interval of two spectral components that are just resolvable by Rayleigh's criterion. In a transmission grating, light is periodically transmitted by the clear sections of a glass blank, into which grooves serving as scattering centers have been ruled. New York: John Wiley & Sons, Inc., 1991. The Paschen-Runge design, Figure 11, makes use of the Rowland circle. The constructions shown in Figure 6a and 6b suggest that "stopping down" the optical system, so that only nearly paraxial rays get through the entrance pupil, will limit the effect of spherical aberration. Scaled population density N1/NT 0.5 N2 /NT 0 Ninv /NT $\ge 0.5 \ge 1$ 0 2 4 6 Scaled irradiance 8 10 555 Laser Operation Absorption Coefficient and Beer's Law Thus far we have concentrated on the change in population density induced by an incident electromagnetic field. The more convenient angular magnification is clearly a measure of the image size formed on the retina and is used to describe magnification when eyepieces are involved, as in microscopes and telescopes. PROBLEMS 1 Use Eq. A: I = I1 + I2 + 22I1I2 cos d Mutually coherent beams for the superposition of two unequal beams to show that the irradiance pattern of a Gabor zone plate (the hologram of a point source) is given approximately by Plane waves I1 Subject beam I2 I2 I = $A + B \cos 21 ar^2 2$ where A = I1 + I2 - 22I1I2, B = 4 2I1I2, and a = p > 12sI2. We examine a few special cases next. (1) and (2) can be approximated as, q RSt.Em. = B21N2g1n2 $I = A + B \cos 21ar^2 2$ where A = I1 + I2 - 22I1I2, B = 4 2I1I2, and a = p > 12sI2. We examine a few special cases next. (1) and (2) can be approximated as, q RSt.Em. = B21N2g1n2 $I = A + B \cos 21ar^2 2$ where A = I1 + I2 - 22I1I2, B = 4 2I1I2, and a = p > 12sI2. We examine a few special cases next. (1) and (2) can be approximated as, q RSt.Em. = B21N2g1n2 $I = A + B \cos 21ar^2 2$ where A = I1 + I2 - 22I1I2, B = 4 2I1I2, and a = p > 12sI2. $21N2g1n_2/28u9 = B21N2g1n_2/21 > c2 0$ (10) and q RSt.Abs. Orders are shown at different distances from the lens for clarity. 568 Chapter 26 Laser Operation within the same gain system. The coefficients of 1r220 and 1r221, when set equal to zero, yield 0p i = q 0z (12) 0q = 1 0z (13) and Equation (13) can be integrated easily to give q1z2 = q102 + zNow, q(z) is, in general, a complex function. A similar analysis (see problem 6) can be used to 500 Chapter 23 Fresnel Equations show that rTM, like rTE, has unit magnitude when the angle of incidence exceeds the critical angle and enables one to find the phase shift on total internal reflection fTM for the TM case. According to Eq. (50), the lifetime broadening contribution \$ht, to gth the linewidth is \$ht, t = nfsr 1 1 1 1 1 1 a + b = a + b Hz t2 2p t1 2p 10 * 10-6 0.1 * 10-6 = 1.61 * 106 Hz n0 (a) b. What is the beam divergence angle of this laser? 3 17 Show that the matrix c 1 i d represents a right-circular -i 1 polarizer, converting any incident polarized light into right circularly-polarized light. Fiber Optics 261 wavelength-division multiplexing (WDM). along the + z-axis b. We conclude that the irradiance of 100 coherent inphase sources. Figure 4 shows the progress of a single ray through an arbitrary optical system. The intrinsic layer is a region of high electric field, and carriers produced by light absorption in this region are quickly swept away to the heavily doped regions. Find the ratio of the likelihood P2 that a hydrogen atom will be in its ground state of energy E1 if the atoms are in thermal equilibrium at room temperature (293 K). The quantity M, representing the pulse broadening (ps) per unit of spectral width (nm) per unit of fiber length (km), is plotted against the wavelength. For the scanning FabryPerot interferometer, we see that large values occur when the mode number is large and for large values of the finesse, which occurs for reflection coefficients close to unity. The dashed profiles represent the wavefronts in the cavity. 2 Determine the limit to the number of TV station channels that could transmit on a single optical beam of 1.55 mm wavelength if a. Information obtained from interferometers at widely separated locations will aid in distinguishing signals caused by gravitational waves from those caused by local environmental and instrument noise. Note that a sphere power correction of + 2.00 D is needed along the vertical meridian 1 * 1802 to equalize the refractive power in the two orthogonal meridians. Find the resolving power of the grating under these conditions. The grating can be produced with a standard blaze at 6300 Å for use in a Littrow mount. Axial points (N). Suppose, then, that a small signal wave at vs = v1 and a powerful pump wave at vp = v2 interact within a nonlinear medium. Weapons could, by pattern recognition, select proper targets. What is the illuminance produced at another point on the floor, 1 m distant from P? The electric field of Eq. (43) is said to be linearly polarized along the x-direction as a wavelength spread given that the light resonant with this transition has a wavelength of 10.6 mm. Figure 9 (a) Diffraction-limited images of two point objects formed by a lens. What is the responsivity in A/W (at this wavelength) of this detector? (a) Tungsten lamp. Transmittance (%) Nonlinear Optics and the Modulation of Light 521 100 50 P Transmitted intensity VQW VHW Applied voltage sudden dumping of the energy stored in a laser. These perpendicular E-field components set the electronic oscillators of a scattering center into forced vibrations along the yand z-directions. Newton maintained his basic particle hypothesis, however, and explained the phenomenon by endowing the particles themselves with what he called "fits of easy reflection and easy transmission," a kind of periodic motion due to the attractive and repulsive forces imposed by material obstacles. 8 Determine the longitudinal and lateral spherical ray aberration for a thin lens of n = 1.50, r1 = + 10 cm, and r2 = - 10 cm due to rays parallel to the axis and through a zone of radius h = 1 cm. Finally, since every optical system intercepts only a portion of the wavefront emerging from the object, the image cannot be perfectly sharp. The movable slits were therefore arranged as in Figure 15a using mirrors that direct widely separated portions of the radiation wavefront into a double-slit-telescope instrument. In this chapter we extend our discussion of the properties and production of polarized light. The linear dimensions of the central maximum is given by W = L ¢u = 2Ll b (15) We may describe the content of Eq. (15) as a linear spread of a beam of light, originally constricted to a width b. 9 A proton is accelerated to a kinetic energy of 2 billion electron volts (2 GeV). (Hint: Combine the Ex and Ey equations for the general case of elliptical polarization, eliminating the space and time dependence between them.) 20 a. For this case, Eq. (22) takes the form dI = - a0 I L I dz 0 ln1IL>102 = - a0 I L I dz 0 ln1IL>102 = -
a0 I L I dz 0 ln1IL>102 = - a0 I L dz 0 ln1I be familiar to you, as should the relationship between coherence and the net irradiance of interfering beams. For each laser listed, the entries include data on pump mechanism, emission wavelength, output power (or in some cases, energy per pulse), nature of output, beam diameter, beam divergence, and operating efficiency. By what factor is the beam divergence decreased? For simplicity of construction, the crown glass lens (1) may be chosen to be equiconvex. (Prentice-Hall: Englewood Cliffs, New Jersey, 1995), Ch. 9. 7 A longitudinal Pockels cell is made from lithium niobate. The refractive index in the absence of an applied field is n0. Various circular zones of the lens about the axis produce different focal lengths, so that f is a function of aperture h. This means that each successive zone's contribution is exactly out of phase with that of the preceding one. In cases of Fraunhofer diffraction, where the screen is actually or, through the use of a lens, effectively far from the aperture, the diffraction pattern is a fringed image that bears little resemblance to the aperture. In terms of the parameters A, B, and C, the derivation of Eq. (9) makes clear that E0x = A, Ey clockwise rotation, general case 340 Chapter 14 Matrix Treatment of Polarization This form, together with the form representing counterclockwise rotation, general case 340 Chapter 14 Matrix Treatment of Polarization This form, together with the form representing counterclockwise rotation, general case 340 Chapter 14 Matrix Treatment of Polarization This form, together with the form representing counterclockwise rotation, general case 340 Chapter 14 Matrix Treatment of Polarization This form, together with the form representing counterclockwise rotation, general case 340 Chapter 14 Matrix Treatment of Polarization This form, together with the form representing counterclockwise rotation, general case 340 Chapter 14 Matrix Treatment of Polarization This form, together with the form representing counterclockwise rotation, general case 340 Chapter 14 Matrix Treatment of Polarization This form, together with the form representing counterclockwise rotation, general case 340 Chapter 14 Matrix Treatment of Polarization This form, together with the form representing counterclockwise rotation, general case 340 Chapter 14 Matrix Treatment of Polarization This form, together with the form representing counterclockwise rotation, general case 340 Chapter 14 Matrix Treatment of Polarization This form, together with the form representing counterclockwise rotation, general case 340 Chapter 14 Matrix Treatment of Polarization This form, together with the form representing counterclockwise rotation, general case 340 Chapter 14 Matrix Treatment of Polarization This form, together with the form representing counterclockwise rotation, general case 340 Chapter 340 Chap previously as special cases. Solution With the help of Table 1 we can calculate an approximate average value of cn l = 550 nm as cl nF - nD cn l + 1.7328 - 1.7205 = = -1.19 + 10.4 nm-1 cl lF - lD 486 - 589 Thus, the resolving power is P = ba dn b = 10.05 * 109 nm211.19 * 10.4 nm-12 = 5971 dl The minimum resolvable wavelength difference in the region around 550 nm is, then, 5550 Al ° 1¢12min = 1A P 5971 Although grating spectrographs achieve higher resolving powers, they are generally more wasteful of light. The spot size at the beam waist (planar wavefront) is defined as w0. Although this can be accomplished at one wavelength by appropriately increasing the distance to the beam waist (planar wavefront) is defined as w0. of M2 from BS, the correction would not suffice at another wavelength because of the dispersion of the glass. A windowed test chamber, into which the model and a streamlined flow of air is introduced, is placed in path 1. A second method is to prepare the film so that its edge is not sharp but tails off gradually. These values follow from evaluation of the definite integrals C1 q 2 = S1 q 2 = q cos a q sin a L0 L0 py2 b dy = 0.5 2 py2 b dy = 0.5 2 py2 b dy = 0.5 2 and from the previously mentioned fact that C1y2 and s1y2 are odd functions. In such cases, lateral magnifications also approach infinity and are not very useful. Determine the angular field of view. Results are shown in Figure 13 for a He-Ne, HF (hydrogen fluoride), and CO2 laser on a log-log plot. 9 A Fabry-Perot interferometer is to be used to resolve the mode structure of a He-Ne laser operating at 632.8 nm. (c) Image of a square grid by a positive lens. Since the Ronchi rulings are aligned parallel to the x-axis in the aperture plane, the spectrum of bright spots in the output plane occurs along the Y-Ne laser operating at 632.8 nm. direction, as shown. Is this cell practical? Even for this case, we should note6 that diffraction effects caused by sharp-edged circular apertures produce ripple effects on irradiance patterns in the near field of about 17%. UV-A radiation does not contribute to sunburns. Both aberrations increase similarly with the off-axis distance of the object and with the aperture of the refracting surface. If 1qx, qy2 are large enough so that there is no overlap of the stigmatic, and the cylindrical lens astigmatic. Like cavities made from flat mirrors, spherical-mirror cavities have (so-called longitudinal) modes separated by the cavity free spectral range, but in addition they have (so-called transverse) modes associated with the relationship of the curvatures of the mirrors to the cavity length. 15 a. The first two lenses are separated by 30 cm and the last two by 20 cm. A diaphragm, which blocks only those frequencies near the direct beam, functions as a high-pass optical filter; and a clear annular ring, which blocks the lowest and the highest frequencies, functions as a band-pass filter. The simple exponential-decay nature of this expression follows only for the case of a weakly absorbing system for which nearly all of the population remains in the ground state. (Courtesy of R. 7 4 Determine the minimum height of a wall mirror that will permit a 6-ft person to view his or her entire height. In the thin-lens equation, 1 1 1 = $+ s \xi f$ (31) TABLE 1 SUMMARY OF GAUSSIAN MIRROR AND LENS FORMULAS Spherical surface $s \xi = -s m = +1$ Concave: f 7 0, R 6 0 Convex. : f 6 0, R 7 0 n1 n2 n2 - n1 + = s z; R Refraction Single surface m = - n1 z; n2 s Concave: R 6 0 Convex : R 7 0 1 1 1 + = s z; S Concave: R 6 0 Convex : R 6 0 Convex : R 6 0 Convex : R 7 0 1 1 1 + = s z; S Concave: R 6 0 Convex : R Note: order 1014 to 1015 Hz for visible light. If the thick lens were a single thin lens, the two principal planes would coincide at the vertical line that is usually drawn to represent the lens. 1 THREE-DIMENSIONAL WAVE EQUATION AND ELECTROMAGNETIC WAVES Consider a general electromagnetic field of the form E = Ex1x, y, z, t2xN + Ey1x, y, z, t2yN + Ey Ez1x, y, z, t2zN B 582 (1) 583 Characteristics of Laser Beams In homogeneous media devoid of free charges or currents, each component of this electromagnetic field satisfies a wave equation. We assume that the film is both homogeneous and isotropic. Recall that, at a given plane, a ray can be described by its height y and slope angle a relative to the optical axis. f in Figure 1. The inverse of the cavity decay rate ≠ is sometimes called the photon lifetime, tp , of the cavity. 7 FRESNEL DIFFRACTION FROM APERTURES WITH RECTANGULAR SYMMETRY Diffraction by straight edges,
rectangular apertures, and wires are all conveniently handled by another approximation to the Fresnel-Kirchhoff diffraction formula, Eq. (7). One disadvantage is that the focal plane is spherical, requiring a careful shaping of photographic films and plates. The conductivity is the proportionality constant in Ohm's law, B B j = sE where j is the current density 1A>m22 produced by the field E. Each wavelength component has a different refractive index and therefore a different speed through the fiber. (37) and (38) as a function of driving frequency v. The advantages of fiber-optic conduits, or waveguide systems are impressive. The reflected and refracted rays are both in a direction corresponding to maximum dipole radiation, perpendicular to the dipole axis. A common structure of this type is commonly referred to as periodically poled lithium niobate, or PPLN. Then in 1913, the Danish physicist Niels Bohr once more incorporated the 4 Chapter 1 Nature of Light quantum of radiation in his explanation of the emission and absorption processes of the hydrogen atom, providing a physical basis for understanding the hydrogen spectrum. The gravitational strain h induced in the lengths of the arms of the interferometer and &L is the difference in the lengths of the arms caused by the passage of the gravitational wave. It is ironic that the phenomenon we have been describing, involving so intimately the wave nature of light, should be known as Newton's rings after one who championed the corpuscular theory of light. 25 We have shown that the secondary maxima in a single-slit diffraction pattern do not fall exactly halfway between minima, but are quite close. Ch. 4.2. Shurcliff, W. The major axis of the ellipse is in the z-direction and is twice the minor axis. Figure 14 shows a drawing of the ruby laser device. 9 A meter stick lies along the optical axis of a convex mirror of focal length 40 cm, with its nearer end 60 cm from the mirror surface. 10 A telescope objective is 12 cm in diameter and has a focal length of 150 cm. Figure 12 illustrates a ray incident on a film at an angle ui. Thin Film Phenomena. Equate the real and imaginary parts of the two expressions for q21/2 to find / = 0.06 m and $w21/2 = 5.4 \times 10-4$ m. (Recall that the beam waist is at z = 0.) Because of the back-and-forth nature of a beam propagating in a cavity, some care must be taken when using Eqs. That is, 1 ¢n Associated with the coherence time of a source is a coherence length, lt = ct0, which is the distance that the electric field travels in a coherence time. Such a recording is a sinusoidal zone plate that acts as a positive lens. Using the new system matrix, determine where the ray described above crosses the optical axis. 12 A gypsy's crystal ball has a refractive index of 1.50 and a diameter of 8 in. Helmholtz's schematic eye 1, as modified by L. Gain saturation that follows from the fact that as the number of photons in the gain medium decreases. Curves of responsivity versus wavelength are provided with commercial detectors. An interference pattern falls on a screen 1.5 m away. Show that the matrix elements predict the locations of the six cardinal points as they would be expected for a thin lens. Certain areas of physics once considered to be disciplines apart from optics—electricity and magnetism, and atomic physics—are very much involved in this account. The metallic coating of the reflection grating should be as highly reflective as possible. Show that, if the medium is isotropic and its sides are parallel to the direction of a plane acoustic wave, the equation also holds for the wavelength and angle of diffraction measured outside the medium. Consider a laser cavity consisting of two spherical concave mirrors that are facing each other. 6. The critical physical properties here are the refractive index n and the extinction coefficient k (proportional to the absorption coefficient k (proportional to the absorption coefficient k) for a given frequency of light. Physical Detectors of Optical Radiation. (1) through (6), a programmable calculator or computer may easily be programmed to perform the sequential operations that finally determine the angle of deviation, d. When departures from linearity are small, it is possible to represent the modification of the susceptibility in a nonlinear medium by a power series in the form x = x1 + x2E + x3E 2 + Å (2) When substituted into Eq. (1), the polarization of the susceptibility in a nonlinear medium by a power series in the form x = x1 + x2E + x3E 2 + Å (2) When substituted into Eq. (1), the polarization of the susceptibility in a nonlinear medium by a power series in the form x = x1 + x2E + x3E 2 + Å (2) When substituted into Eq. (1), the polarization of the susceptibility in a nonlinear medium by a power series in the form x = x1 + x2E + x3E 2 + Å (2) When substituted into Eq. (1), the polarization of the susceptibility in a nonlinear medium by a power series in the form x = x1 + x2E + x3E 2 + Å (2) When substituted into Eq. (1), the polarization of the susceptibility in a nonlinear medium by a power series in the form x = x1 + x2E + x3E 2 + Å (2) When substituted into Eq. (1), the polarization of the susceptibility in a nonlinear medium by a power series in the form x = x1 + x2E + x3E 2 + Å (2) When substituted into Eq. (1), the polarization of the susceptibility in a nonlinear medium by a power series in the form x = x1 + x2E + x3E 2 + Å (2) When substituted into Eq. (1), the polarization of the susceptibility in a nonlinear medium by a power series in the form x = x1 + x2E + x3E 2 + Å (2) When substituted into Eq. (3) when substituted into Eq. (4) when substituted strength takes the form P = e01x1E + x2E 2 + x3E 3 + A 2 (3) or P = P1 + 1P2 + P3 + A 2 ()* ('')''* linear small nonlinear terms where the subscripts on x match the powers of E and reflect the decreasing magnitude of the higher-order terms. A laser cavity consisting of two flat mirrors separated by an optical distance d will only support standing wave modes of wavelengths lm and frequencies nm that satisfy the condition d = ml > 2 = mc > 2n, where m is a (typically large) positive integer. How do they compare when the emergent light is circularly polarized? From the geometry of Figure 7, with both a and a positive, a = u + f = u + y - R and $a \Leftrightarrow R a a = u + f = u + y - R$ and $a \Leftrightarrow R a a = u + f = u + y - R$ and $a \Leftrightarrow R a a = u + f = u + y - R$ and $a \Leftrightarrow R a = u + f = u + y - R$. Reflection of a ray at a spherical surface. $y = 15 \sin(kx + /3) 10$. In that case, Nnfsr = ¢n and the expression for the pulse width becomes ¢tp L 1 ¢n (58) This important relation is an example of the more general bandwidth theorem, which states that the width of a pulse is inversely proportional to the range of frequencies in the fields that constitute the pulse. For example, if the large block letter E that subtends an angle of 5¿ at 300 ft is just readable by a test subject seated 20 ft from the letter, visual acuity is reported as 20/300. REFERENCES Chapter 1 Chapter 5 Feinberg, Gerald. 22 Show that the separation of the virtual sources I1 and I2 producing interference from a film of index n and uniform thickness t, when illuminated by a point source, is 2t/n. Thrierr, Atlas of Optical Phenomenon, Plate 4, Berlin: Springer-Verlag, 1962.) (c) Astigmatic surfaces in the field of a lens. This particular distance is called the skin depth, d, where d K 1 2 = sm kI A 0v (58) and is evidently smaller for better conductors with larger s. Two beams of unpolarized light produce interference because each can be resolved into orthogonal comB ponents of E that can then be paired off with similar components of the B B E other beam. Or the light is transmitted by the entire ruled area 299 The Diffraction Grating but periodically retarded in phase due to the varying optical thickness of the grooves. Narrow wavelength regions that satisfy constructive interference can be produced far enough apart in wavelength so that all but one such region is easily filtered out by a conventional absorption color filter. These electrical impulses are transmitted to the optic nerve and on to the brain, recording as it were the light intensity of the stimulating signal. When the instrument is used for visual observations without the capability of measuring the angular displacement of the
spectral "lines," it is called a spectroscope. If the incident light contains all wavelengths of the visible spectrum, intermediate colors focus between these points on the axis. The flap is held open while the underlying layer is reshaped with the excimer laser, and then the flap is replaced when the reshaping is completed. Intersections, excluding b = 0, occur at 1.43p (rather than 2.5p), 3.47p (rather than 2.5p), 3.47p (rather than 2.5p), 3.47p (rather than 2.5p), and so on. Polarized Light in Optics and Spectroscopy. 8 A volume hologram is made using oppositely directed monochromatic beams of coherent, collimated laser light at 500 nm, as in Figure 5. Hence there would be two angles of incidence, u1 and u2, producing minimum deviation, contrary to experience. (a) 0.8 (b) $r_1 = 16.7$ cm; $r_2 = -150$ cm (c) -0.8, reverse the lens 17. Determine the illuminance of a horizontal surface under a hemispherical sky with uniform luminance L. Thus it is of particular interest to determine the Cartesian surfaces that render every object ray parallel after the first refraction. Light from an entrance slit is directed by a plane mirror to a first concave mirror, which collimates the light incident on the grating. The stimulated in Figure 11a. We now turn to brief descriptions of the three basic processes, illustrated in Figure 11, that describe the interaction of light with matter. What is the spot size at the beam waist for this laser field? Electrons photoemitted from the curved dynode surfaces, each time producing additional secondary electrons. 17 An echelle grating is ruled over 12 cm of width with 8 grooves/mm and is blazed at 63°. N555 = f. Since electrons and protons are charged particles and constituents of a toms, all atoms can emit and absorb light energy. This charge separation is a result of a permanent macroscopic polarization associated with the metal. We consider a rather general case, that of a beam with waist w01 located a distance Z1 to the left of the lens, incident upon a positive thin lens of focal length f and HF (3 mm) 500 He-Ne (0.633 mm) CO2 (10.6 mm) Collimated range 2z0 20 D 10 m 8 w0 5 D 4.5 w 2w0 w 2w0 2 Figure 13 Collimated range 2z0 versus aperture diameter D, for a laser beam focused to a , assuming that the aperture diameter D = 4.5w, where w = 22w0. Along directions where crests (solid circles) from S1 intersect crests from S2, brightness (B) results. The polarizer is set to give maximum intensity. The limits of resolution due to diffraction also affect the human eye, which may be approximated by a circular aperture (pupil), lens, and a screen (retina), as in Figure 12. The half-wave voltage required is then VHW = 10 (8) 2rn30 Example 3 Suppose the Pockels cell is made from a KD * P crystal of 1-cm thickness and the optical wave has a wavelength of 633 nm. 8. In the photoconductive (reverse-biased) mode the current induced in the load resistor has a nearly linear relationship with the incoming irradiance. The embossing process allows fabrication of a large number of holograms inexpensively. Equal-thickness contours for a perfectly spherical surface, and therefore the fringes viewed, are concentric circles around the point of contact with the optical flat. (42) and (43), ER = E0eivt c r After simplifying, ER = E0eivt c 11 - r22re-id 1 - r2e-id r11 - e-id2 1 - r2e-id d d The irradiance, IR, of the resultant beam is proportional to the square of the amplitude, ER, which is itself complex, so we calculate f ER f 2 = ERE*R, or f ER f 2 = E20r2 c eivt11 - e-id2 1 - r2e-id d c e-ivt11 - e-id2 1 - r2 cos d K 1 eid + e-id2 there results f ER f 2 = E2012r22 # a 1 - cos d b 1 + r4 - 2r2 cos d (46) or, in terms of irradiance, IR = c 2r211 - cos d 2 1 + r4 - 2r2 cos d d Ii (47) where Ii represents the irradiance of the incident beam, and we have used the proportionality f ER f 2 = E2012r22 # a 1 - cos d b 1 + r4 - 2r2 cos d d Ii (47) where Ii represents the irradiance of the incident beam, and we have used the proportionality f ER f 2 = E2012r22 # a 1 - cos d b 1 + r4 - 2r2 cos d d Ii (47) where Ii represents the irradiance of the incident beam, and we have used the proportionality f ER f 2 = E2012r22 # a 1 - cos d b 1 + r4 - 2r2 cos d d Ii (47) where Ii represents the irradiance of the incident beam, and we have used the proportionality f ER f 2 = E2012r22 # a 1 - cos d b 1 + r4 - 2r2 cos d d Ii (47) where Ii represents the irradiance of the incident beam, and we have used the proportionality f ER f 2 = E2012r22 # a 1 - cos d b 1 + r4 - 2r2 cos d d Ii (47) where Ii represents the irradiance of the incident beam, and we have used the proportionality f ER f 2 = E2012r22 # a 1 - cos d b 1 + r4 - 2r2 cos d d Ii (47) where Ii represents the irradiance of the incident beam, and we have used the proportionality f ER f 2 = E2012r22 # a 1 - cos d b 1 + r4 - 2r2 cos d d Ii (47) where Ii represents the irradiance of the incident beam. transmitted beams leads to the resultant transmitted irradiance, $IT = c 11 - r222 1 + r4 - 2r2 \cos d d Ii$ (49) Equation (49) also follows more directly by combining Eq. (47) with the relation IR + IT = Ii, required by the conservation of energy for nonabsorbing films. Equation (43) is a powerful result. Table 1 provides a convenient summary of the most normalized forms. Each point source, acting alone, then produces a set of double-slit interference fringes on the screen. As suggested, the finesse of a cavity to the FWHM of the cavity transmittance peaks: dfsr FWHM = 2p = F 2d1>2 (34) 1 dfsr 2p 0.9 0.8 Transmittance 0. 0.6 0.5 0.4 2d1/2 0.3 0.2 0.1 0 0 1 2 3 4 5 6 7 Change in round-trip phase difference 8 9 The transmittance may be regarded as a function of the medium of the frequency n (and so wavelength 1) of the input field, or the index of refraction n of the medium in the space between the mirrors. At normal incidence, cos ut = 1 and ¢ = 2nft. Two waves of the forms given in Eqs. Ray containment now occurs by a process of continuous refraction. Optical Spectrum Analysis The Fraunhofer diffraction pattern of a given aperture is most conveniently displayed using a positive lens, as in Figure 2. Express the answer in both J and eV. See the sketch shown in Figure 7. For such applications the interferometer must be constructed on a rather large scale. When E0x = E0y, the ellipses corresponding to $\psi = p > 2$ or 3p > 2 reduce to circles. For this to occur, however, the stimulating optical frequencies must fall within the absorption band of the material. The cavity temperature is then increased until its total radiant exitance is doubled. Mathematically, the wave is reproduced because the argument of the sine function is advanced by 2p. The following example elaborates on this point. In Figure 7 the Pockels cell is used to initiate cavity dumping. A variety of types of liquid crystals exist but here we focus on a description of the nematic liquid crystal whose rodlike molecules are randomly positioned but have a common orientation induced by intermolecular interactions. 22 In this problem we examine experimental absorption spectroscopy data. This behavior can be understood by noting that two processes, stimulated emission and spontaneous emission, drive an atom from level 2 to level 1. On the other hand, if the mask contains a pattern of the letter B, the maximum light throughput and correlation should be significantly reduced. In this way, the difference between the optical paths of u Q2 p S2 Q1 2d S1 M2 C d S M2 M1 (2) BS (1) u (3) S Q (4) (a) M1 (b) Figure 1 (a) The Michelson interferometer. An important quantity in the calculations, also subject to this sign convention, is the parameter Q, the perpendicular distance VB from the vertex to the ray, as shown. Lens Etalon Lens Spectroscope S White light d Figure 19 Problem 12. Snell's law of refraction may be expressed as ni sin ui = nt sin ut (1) 20 Chapter 2 Geometrical Optics P K ur C L ui ADX IDG DIG DIM IDM IDG ui ur M B F N A E X Y I J D H G (a) P C F ui B A E ui X J D I yit ytt ut ni nt ut Y H N G M K DIM ut IDF ui Figure 4 (a) Huygens' construction to prove the law of reflection. Chapter 22 Yariv, Amnon. The image of OO; formed by L1 is shown as II; the final image (not shown) is virtual, since the rays from either O or O¿ diverge on leaving L2. Once each row in a CCD array is scanned in this fashion, a digital record is formed that can be stored in the memory of the device. We then discuss the gain bandwidth of laser gain media describing both homogeneous and inhomogeneous broadening. Burch. A telescope should produce an exit pupil at sufficient distance from the eyepiece 85 Optical Instrumentation to produce a comfortable eye relief. Certain metals like lithium tantalate or triglycine sulfate (TGS) exhibit the pyroelectric effect in that a temperature-dependent charge separation exists between opposite ends of the metal. 386 387 Optical Detectors and Displays Bolometers and Thermistors Thermal detectors also include bulk devices that respond to a rise in temperature with a significant change in resistance. In this process, of course, the number of atoms in the upper laser level is reduced. illustrates the law of refraction. When a voltage is applied across a pixel, the liquid crystal does not rotate the polarization of the twisted nematic cell. The final result is that light and subatomic particles, like electrons, are both considered to be manifestations of energy and are governed by the same set of formal principles. With the help of analytical geometry, it is possible to show that the ellipse whose Jones vector is given by Eq. (9) is inclined at an angle a with respect to the x-axis, as shown in Figure 7. That is, F = 4p1nfsr > c2d dfsr 2d1 > 2 [4p1¢n1 > 2 > c2d] = nfsr = 2¢n1 > 2 so that 2¢n1 > 2 = nfsr F Using Eq. (41) and the expression for the finesse F given in Eq. (29) gives 2 cn 1 - r2 2d pr (42) The transmittance through a Fabry-Perot interferometer as a function of the input field is shown
in Figure 15. For electromagnetic waves (including light), c can stand for either of the varying electric or magnetic fields that together constitute the wave. The original hologram is recorded in a photosensitive material called a photoresist. The receptor in thermal detectors is typically a blackened surface that efficiently absorbs at all wavelengths. and represents the subject beam, modulated in both amplitude and phase. (29) and (30) for the transmission coefficients both by (a) eliminating Er from Eqs Typical angles of incidence may vary within the range 30° to 45°, and angles of diffraction may vary between 25° on the opposite side of the normal as the slit. Notice that for the thick lens, the distances r and s determine the positions of the Figure 1 Illustration of the (a) first (PP1) and (b) second (PP2) principal planes of an optical system. If the crystal is thin enough, variations in refractive index along its length lead to corresponding variations in the speed of light so that the crystal behaves as a transmission phase grating. Since its arrival in the 1960s, rather quietly and unheralded outside the scientific community, it has provided the stimulus to make optics one of the most rapidly growing fields in science and technology today. 16 Filtered green mercury light (546.1 nm) emerges from a slit placed 30 cm from a rod 1.5 mm thick. We now deduce the Jones vector for this case—where Ex leads Ey—taking E0x = E0y = A, wx = 0, and wy = p>2. Matrix Methods in Paraxial Optics 407 conjugate planes for the optical system. They are multimode fibers if they permit a discrete number of modes (or ray directions) to propagate. With the help of Euler's equation, the Fourier series given in general by Eq. (1), involving as it does both sine and cosine terms, can be expressed in complex notation using exponential functions. In terms of our simplified model of a Eq. (9) results in I12 = 2 2I1I28cos d9 (12) so that we may write, finally, I = I1 + I2 + 2 2I1I28cos d9 (13) B Notice that once we have made the assumption that the E fields are parallel, the treatment becomes much the same as the scalar theory. Thus, it would be easy to monitor a frequency change of 50 MHz with this Fabry-Perot. (42) and (45)) that, for highly reflective mirrors (r close to 1), the cavity decay rate and the FWHM of the transmittance peaks 2cn1>2 are simply related: \neq = c 1 - r2 2 11 - r22 = 2pr a b = 2pr12cn1>22 t 2d pr This leads us to a second definition of the cavity decay rate: Q L 2pn v = $\neq \neq$ 215 Optical Interferometry In addition to the formal similarity between Fabry-Perot and laser cavities, Fabry-Perot interferometers can serve a variety of roles as diagnostic or control elements in optical systems. The detectivity, D, of a detector is the reciprocal of the minimum detectable power, called the noise equivalent power, NEP of the detector: D = 1 NEP (2) The minimum detectable power is limited by the noise inherent in the operation of the detector. In each case, after reflection, this ray is labeled 2¿. Input and output rays make the same angle relative to the axis. length, the higher the refractive or bending power of the lens, precisely the condition needed to bring near objects into sharp focus. Focusing occurs for rays along a vertical section but not for rays along a horizontal section are given by c (x, t) = (4 cm) cos a c (y, t) = (2 cm) cos a 20 p x t + pb 3 cm s p 20 y t + pb 4 cm s d yg = yp - la dyp dl b b. The resulting Schmidt optical system is therefore highly corrected for coma, astigmatism, and spherical aberration. However, depending upon the degree of transparency of the fiber material to the light, some attenuation occurs by absorption. The form of the complex number given by Eq. (11) can also be cast into polar form. Single Slit Consider a diffracting aperture that is a single slit of width w, as in Figure 15a. To maintain this 1 Interestingly, the rods and cones of the human eye have been shown to function as light pipes, transmitting light along their lengths, as in optical fibers. Inserting the derivatives of the complex displacement vector drB>dt = - ivrB and d2Br >dt2 = - v2Br into Eq. (3) leads to B B - eE r = 2 - mv - imvg + KS (6) Note that Eq. (4) in the case of a static 1v = 02 B Efield. What is the irradiance on a screen situated 2 m from the source, with its surface normal to the radiant flux? No parallax is seen and the colors of the radiant flux? No parallax is seen and the color of the image sweeps through the the radiant flux? determines the strength of the electric field in the aperture and dA is the elemental area of the aperture. We expect this result, since, if one mirror is farther from BS than the other by a distance d, the extra distance traversed by the beam taking the longer route includes distance d twice, once before and once after reflection. Thus a radius Rn of 4.36 cm encompasses n = 10,000 Fresnel zones. It follows that a blackbody is also a perfect emitter: 3 If several distinct physical states have the same energy, the energy level is said to be degenerate. Since the Pockels effect is a second-order effect relative to the polarization [Eq. (3)], it is not found in isotropic materials having inversion symmetry. In some applications, it is preferable for the laser to have an output at only a single cavity resonant frequency. What is the reflectance for light of 550 nm at normal incidence? The transverse variation of the irradiance toward the edges. Rhodes. In a p-type semiconductor, the material is doped with a small amount of an impurity that has one less electron in its outer shell than does the atom that it replaces in the lattice. PROBLEMS 1 Write out the third-order terms of the polarization, we briefly describe one other approach that makes use of a hologram as a spatial filter. One can talk about the field of view in terms of the object being viewed or in terms of the object being viewed or in terms of the object being viewed or in terms of the image formed at the viewer (on the retina, in this example). Pulsed laser output is useful for controlling the delivery of laser energy in materials-processing applications, in time-offlight distance measurements, in tracking rapid changes in the properties of systems, and in many other applications. Setting k = 2p > l, the condition for zeros of the sinc function (and so of the irradiance) is ml = b sin u m = ; 1, ; 2, Å (12) Referring to Figure 1, note that the distance y from the center of the screen to a point on the screen P located by the angle u is given approximately by y f sin u, where we have made the small angle approximation of the refractive index with wavelength leads to material dispersion, as previously discussed. The variation of the refractive index with wavelength leads to material dispersion, as previously discussed. light, for example, gives 1 1 1 + 1 2 c d + c d = c d = c d i -i i -i 0 or linearly polarized light of twice the amplitude. hc 20 he Aberration Theory INTRODUCTION The paraxial formulas developed earlier for image formation by spherical reflecting and refracting surfaces are, of course, only approximately correct. If the superposed waves differ in frequency as well, the result is periodic but anharmonic and may assume an arbitrary 224 225 Coherence f (t) t Figure 1 Anharmonic function of fringe patterns, it is therefore usually desirable to ensure that the interfering beams have the same amplitudes. (b) Dove prism. Laser systems require a gain medium that provides energy to a field that provides end to a field t Determine the Fourier series for the function of spatial period L given by $-L 6 \times 6 0 2 + L 0 6 \times 6 2 - 1$, f1x2 = d + 1, 2 A half-wave rectifier removes the negative half-cycles of a sinusoidal waveform, given by $E = E0 \cos vt$. To decide which candidate presents the limiting aperture, it is necessary to find the entrance pupil for each by imaging each one through that part of the optical system lying to its left: 1 "Preceding" is used in the sense that light must pass through those imaging elements first. Pedrotti, Optics and Vision (Upper Saddle River, N. We expect that for t 7 t0, some coherence between the two beams will be lost. The geometry is used to determine the condition for constructive interference. Second, the center of the fringe pattern is bright rather than dark, and the entire fringe system is complementary to the system by reflection. However, for normal incidence, Eq. (48) reduces to T = nt2 and Eq. (47) becomes normal incidence to T = nt2 and Eq. (47) becomes normal incidence. transmission coefficients are real, as they will be for all external reflections and all internal reflections with angles of incidence less than the critical angle. Thus quanta and quantum mechanics were born. A series of bright bands appear. Three oxygen (O) atoms form the base of a tetrahedron. Emmett Leith and Juris Upatnieks at the University of Michigan first applied laser light to holography in 1962 and also introduced an important off-axis technique of illumination that we explain presently. Determine an overall broadening dt for a 1-km length of fiber, using 1dt22 = 1dtmod22 + 1dtmat22 on Physics, Vol. For this to be true, as indicated by Eq. (33), $z^2 = 0$. The angular difference ¢a can also be introduced, using ¢a = ¢s b dn = a b a b ¢l d d l (21) where d is the beam width. The filtering process is greatly aided by the use of interferometers at widely separated sites, which are unlikely to be subject to the same local environmental noise. If we use light rays progressing from left to right, their angles have the same sign as their slopes. (b) Schematic showing detailed ray traces through the instrument both for object illumination and image formation. Phys., 58, June 1990: 542. 5 Plot and write the equation of the superposition of the following harmonic waves: E1 = sin a p 5p - vtb , E2 = 3 cos a - vtb, and 18 9 p E3 = 2 sin a - vtb, where the
period of each is 2 s. CFC compounds can participate in chemical processes that lead to the conversion of ozone into "ordinary" oxygen 1022. Plot the transmission coefficient t¿ for an interface between glass 1n = 1.52 and air. One sees now that a large xw, which is beneficial in producing good resolution, may also be detrimental in limiting the spectral range of the spectrometer, unless N is also suitably large. This occurs because no source is perfectly monochromatic. Since the atoms in a gas gain medium have a distribution), the radiation from different atoms, each of which emits light at frequency, say, no in its own rest frame, will be perceived in the laboratory as radiation with a spread of frequencies related to the spread of velocities of the atoms in the gain medium. Here, nD refers to the refractive index of each glass for the D Fraunhofer line, and we have introduced constants K1 and K2 as an abbreviation for the curvatures. The frequency shift due to a moving source is based physically on a change in transmitted wavelength. The light reflected from the glass is completely linearly 371 Production of Polarized Light 18 a. 18 Fill in the steps to show how Eq. (65) follows from Eq. (64). 2 587 Characteristics of Laser Beams Equating real and imaginary parts gives R1z2 = z a1 + z20 z2 b (19) and w 21z2 = lz0 z2 a1 + 2 b p z0 (20) Note that the spot size at z = 0, which we denote w0, has the value w0 = w102 = 2lz0 > p, so the Rayleigh range z0 can be written as z0 = pw20 l (21) and Eq. (20) can be rewritten as w21z2 = w20 a 1 + z2 b z20 (22) Equation (22) can be used to recast Eq. (16) in the somewhat simpler form eip1z2 = w0 - i tan-11z > z02 e w1z2(23) This relation and Eq. (20) can be used to specify completely the function U(x, y, z) in Eq. (10). For example, a transform using 1000 data points would be reduced from 1,000,000 operations to around 10,000, a considerable from randomly phased and coherent harmonic waves. New York: John Wiley and Sons, 1970. (b) Determine the same properties for a photon having the same total energy as the electron. The negative sign ensures that the two vibrations are B p out of phase, as needed to produce linearly polarized light with E-vectors lying in the second and fourth quadrants. Assume a beam diameter of 1 mm and a film index of 1.414. In fact, the irradiance! at point ! P is proportional to the square of the length of the phasor sum E¿F + GE. The use of a parabolic mirror avoids both chromatic and spherical aberration, but coma is present for off-axis points, severely limiting the useful field of view. Object and image spaces are not shown to the same scale. 88 Chapter 3 Optical Instrumentation Figure 35 Hale telescope (200-in.) showing observer in prime-focus cage and reflecting surface of 200-in. Only certain ray directions or modes are allowed. (1) and (2). (3) where A and k are constants that can be varied without changing the harmonic character of the wave. To visualize this set of surfaces, we may take advantage of the inherent symmetry in the arrangement. 7 CHARACTERISTICS OF LASER LIGHT Monochromaticity Although no light can be truly monochromatic, laser light comes far closer than any other light source to reaching this ideal limit. When the process of total internal reflection is treated as the interaction of a wave disturbance with the electron oscillators comprising the medium, it becomes apparent that there is some short-range penetration of the wave beyond the boundary. Energy Quantization of Electromagnetic Fields The energy of electromagnetic radiation of frequency n is quantized in units of hn, where h = 6.63 * 10-34 J # s is Planck's constant. Light reaches the film both directly and with the help of a mirror at the end of the cylinder (the reference beam) and by light scattered from the object. Solution (A) 3 (B) 2 1 H2 2 N2 F1 H1 VO F2 N1 1 3 Figure 14 Ray construction for a Huygens eyepiece, using cardinal points. Thus the outer electrons of the atoms in a material are primarily responsible for the construction for a Huygens eyepiece. polarization of the optical medium by the B in response to the beam's E-field. In other words, the depth of field of the camera is unlimited. For a real object 1s 7 02, the negative sign in Eq. (21) indicates that the image of these electrons B field are small, the Bolarization is proportional to the E-field. In other words, the depth of field of the camera is unlimited. aperture stop formed by the optical elements (if any) that follow it. A photograph is shown in Figure 8c. Figure 18 makes this clear by illustrating the vector addition at three different times in an oscillation. The concave lens is 8 cm in front of it. 556 Chapter 26 Laser Operation As is evidented in the position of the original lens, and the convex lens is situated in the position of the original lens is situated in the position of the original lens is situated in the position of the original lens is a situated in the position of the original lens is situated in the position become the position of the position of the position of the original lens is situated in the position of the from Eq. (18) and Figure 3, for sufficiently small input irradiance (or sufficiently small cross section s) the population density remains concentrated in the ground state, N1 L NT. When light falls on either type of photoreceptor, the visual pigment changes from a dark state to a clearer state, undergoing a sort of bleaching process. When the gain coefficient g is reduced so that the gain per pass through the gain cell just offsets the cavity loss per round-trip, steady state is reached. Some examples of reflecting prisms in use are illustrated in Figure 18. Thus, the resultant irradiance of N identical coherent sources, radiating in phase with each other, is N2 times the irradiance of the individual sources. s be incorporated into Eq. (22), giving m = + 1. Twyman-Green Interferometer A slight modification by Twyman and Green is shown in Figure 4a. Instead, the prism table (or about an axis normal to the page), and as it rotates, various wavelengths in the incident beam successively meet the condition of incidence angle for minimum deviation, producing the path indicated, with focus at F. Apertures can be used to modify the effects of spherical aberration, astigmatism, and distortion. The size of O¿P¿, the 9 intermediate image, is thus 13 cm2 A - 18 B = - 1.5 cm. If not all of the field incident on a boundary is reflected, the incident and reflected waves will not add to form a perfect standing wave. The latent image is then "amplified," so to speak, by the action of the developer. To achieve interference between two coherent beams of light, an interference between two coherent beams of light, an interference between two coherent beams of light. inc. The hologram succeeds in effectively "freezing" and preserving for later observation the intricate wavefront of light that carries all the visual information of the scene. Example 4 Consider the transmittance through a variable-input-frequency Fabry-Perot interferometer. If such a picture is photographed and a transparency in reduced size is prepared, a Fresnel zone plate is produced. The final image O-P- is then 10 cm to the right of L2. Variations in modulating voltage, if not too large, then occur with a system response that is linear. Therefore, we have the law of reflection: u = ur (8) Finally, the last two members of Eq. (6) are equivalent to krr sin ur = ktr sin ut (9) Writing kr = v>yr = nrv>c and kt = ntv>c, Eq. (9) becomes Snell's law of refraction: nr sin ur = nt sin ut (10) We continue now to specify further the situation at the boundary with the help of boundary with the help of boundary conditions arising out of Maxwell's equations and treated in texts on electricity and magnetism. In Figure 25 spherical waves expand from the object point O and attain a curvature, or vergence, V, given by 1/s, when they intercept the thin lens. 16 Determine the state of polarization of circularly polarized light after it is passed normally through (a) a QWP; (b) an eighth-wave plate. These effects are typical of the blurring of images due to diffraction and will be seen again in other cases of diffraction to be considered. 48 Chapter 2 Geometrical Optics the diverging lens, and the mirror is placed a distance 3f on the other side of the lens. To get some idea of their relative strengths, compare them by calculating the ratio of retardations produced by an appropriately applied 10 kV. Recall the Fraunhofer double-slit pattern, for example. UV-A radiation, generally regarded as the least harmful of the three UV bands, can contribute to skin aging and is possibly linked to some forms of skin cancer. In this chapter, we
adopt a simpler and more intuitive approach, describing the propagating wavefronts by their rays, although we appeal in some contexts to wave properties such as phase and interference. Figure 9a shows one of these molecules, assumed to be surrounded by identical structures that are similarly oriented. Steward, Fourier Optics: An Introduction, 2d ed. Confirm that the relation found in (a) is in agreement with the spectral exitance associated with a blackbody given as MI = 2phc2 15 a 1 e hc>lkBT - 1 b Note that MI is the the exitance per wavelength interval emitted by a blackbody source. Assume that the plates do not absorb light and that there are no multiple reflections within the plates. Figure 12a shows convergence of parallel incident light rays by a lens to distinct focal points for the red and violet ends of the visible spectrum. (b) (i) v = 1 m/s in +x-direction 4. Since these functions are the Fourier transforms of their respective aperture functions, we can say either that (1) in Fourier space, the grating aperture function and the transform of the array of line sources defining the grating; or (2) in real space, the grating aperture function is a convolution of the slit-array aperture function with the single-slit aperture function. Inspection of Figure 8 shows that a relative phase shift of p occurs in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and in the TM mode for internal angles of incidence less than up and internal angles of inc which can be lifted off the master at a later stage. Monochromatic plane waves are idealized models of the electromagnetic waves produced by, for example, laser sources or a distant single-dipole oscillator. For myopic astigmatism, the prescription might read Rx: +2.00 - 1.50 * 180 The first number in the prescription refers to the sphere power, the power in diopters of the Eye 90 46.00 D Figure 7 Conditions of myopic astigmatism with corrective spectacle prescriptions. The refracting angle of the flint prism is 5°. Still, its spread formula is essentially that of Eq. (14) with the beam diameter replacing b and the constant factor of 2 replaced by 4>p 1.27. An example of a record that would result when light of two different but closely spaced wavelengths 11 and 12 are simultaneously input into a FabryPerot cavity of nominal length d = 5 cm is shown in Figure 12. In general, the DC field redistributes electrons in such a way that birefringence is induced in an otherwise isotropic material, or new optic axes appear in naturally birefringence is induced in an otherwise isotropic material, or new optic axes appear in naturally birefringence is induced in an otherwise isotropic material, or new optic axes appear in naturally birefringence is induced in an otherwise isotropic material, or new optic axes appear in naturally birefringence is induced in an otherwise isotropic material, or new optic axes appear in naturally birefringence is induced in an otherwise isotropic material, or new optic axes appear in naturally birefringence is induced in an otherwise isotropic material, or new optic axes appear in naturally birefringence is induced in an otherwise isotropic material, or new optic axes appear in naturally birefringence is induced in an otherwise isotropic material, or new optic axes appear in naturally birefringence is induced in an otherwise isotropic material, or new optic axes appear in naturally birefringence is induced in an otherwise isotropic material, or new optic axes appear in naturally birefringence is induced in an otherwise isotropic material, or new optic axes appear in naturally birefringence is induced in an otherwise isotropic material. the numerical aperture. In B (c) a sketch of the circular path traced by E B is also shown. Thus combinations of harmonic waves are capable of representing more complicated waveforms, even a series of rectangular pulses or square waves. Similarly, a wavelet of radius DG is drawn centered at D to represent the propagation after reflection of the lower part of the beam. The sun emits significant amounts of electromagnetic radiation in all three UV bands but, due to absorption in the ozone layer of the earth's surface is in the UV-A band. In this eyepiece, the lenses have the same focal length f and, according to Eq. (39), are separated by f. At one coincidence, when fringes are "in step," the orders of the two systems corresponding to l and l¿ must be related by m = m¿ + N where N is an integer. Example 2 Light of wavelength 500 nm is incident normally on a grating with 5000 grooves/cm. That is, c a c b cos u cos1u + b2 dc d = c d d sin u sin1u + b2 Thus, the matrix elements must satisfy a $\cos u + b \sin u = \cos 1u + b^2 = \cos u \cos b + \sin u = \sin 1u + b^2 = \sin u \cos b + \cos u \sin b$ it follows that $a = \cos b b = -\sin b d = \cos b \sin 1u + b^2 = \cos u \cos b + \cos u \sin b$ it follows that $a = \cos b b = -\sin b d = \cos b \sin b + \cos u \sin b$ is $1u + b^2 = \cos u \cos b + \cos u \sin b$ is $1u + b^2 = \sin u \cos b + \cos u \sin b$ it follows that $a = \cos b b = -\sin b d = \cos b \sin b + \cos u \sin b$ is $1u + b^2 = \sin u \cos b + \cos u \sin b$ it follows that $a = \cos b b = -\sin b d = -\sin$ rotator through angle + b (21) The Jones matrices derived in this chapter are summarized in Table 2. These minima or maxima points in R can be made to occur at various wavelengths by changing ¢ 1 through selection of the film thickness. When two or more light waves interfere within the medium, the principle of superposition no longer holds. in your calculations.) Does the transform, interpreted as the frequency spectrum, show the proper relationship to the original "pulse" width? Answers to Selected Problems 2.125, 1.44, 0.778, and 0.55 μ m (a) 15° (b) 0.678, 0.166, 0, 0.0461 (a) 4.477; 5.482 (b) 1/199; 1/298 Single slit: 0.047, 0.017; Circular Aperture: 0.018, 0.0042 1.68 × 10-3 cm; 2.75 × $8.4 \times 10-4$ cm 9725 km in diameter; $2.69 \times 10-11$ W/m2 5.2 m 5.3 miles 3 to 10.4 (a) 0.400 mm (b) 0.8106, 0.4053, 0.09006 (b) 2.10 mm (b) 20 0.875, 0.573, 0.255, 0.0547, 0 22. Effective absorption of the vertical component inclusion of higher-order terms in the derivations, however, predicts increasingly larger departures from "perfect" imaging with increasing a Gaussian laser beam. Any two wavelength components of such a light beam, moving through a dispersive medium, can be represented by Eqs. The ways in which laser and nonlaser light is focused are illustrated in Figure 20. Although still an approximation, a schematic eye presents a fairly valid representation of the true (but complex) biological eye. Still, many people prefer the quality of the image displayed by the best CRT monitors to those produced by the newer technologies. Refer to Figure 13 for geometry and similar calculations made for He-Ne, HF, and CO2 TEM00 lasers. M1 4 STEADY-STATE LASER OUTPUT Equation (41) allows for the prediction of the steady-state or continuous wave (CW) output irradiance of a laser given the natures of the pump, gain medium, and cavity that constitute the laser. Some of the incident light beam is diffracted into various orders, according to the diffraction grating equation, ml = d sin um, where the grating constant d in this case should be taken to be the acoustic wavelength IS, and um is the angle of diffraction in mth order. Slits S1 and S2 must fall within the lateral coherence width ls due to the single-slit source. The free charge is so mobile that it quickly redistributes in response to an applied field, preventing the buildup of local charge densities. The lens is equiconvex, with radii of curvature 30 cm. This region may include any number of intervening media, but we shall assume that each individual medium is homogeneous and isotropic, and so characterized by its own refractive index. 3 Show from Eq. (42) that the normal reflectance of a single half-wave thick layer deposited on a substrate is the same as the reflectance from the uncoated substrate. ni ui ur nt ut 2 Geometrical Optics INTRODUCTION The treatment of light as wave motion allows for a region of approximation in which the wavelength is considered to be negligible. compared with the dimensions of the relevant components of the optical system. A compromise choice among available coating materials is a film of MgF2, with n1 = 1.38. 19 A 5-cm-long liquid cell is situated in a magnetic field of 4 kG. Recall that when dealing with sound waves, the apparent frequency of a source increases or decreases
depending on the motion of both source and observer along the line joining them. Like ordinary fibers, GRIN fibers are also cladded for protection. There are, in addition, catadioptric systems that combine refracting surfaces. As mentioned earlier, apertures also determine the field of view handled by the system. The contrary experimental result—a dark fringe—is explained by requiring a phase shift of p for the air-glass reflection.1 Fresnel's Mirrors Another closely related arrangement is Fresnel's mirrors. Figure 8. We note here that these relations also follow from a direct guantum mechanical treatment of the interaction of an electromagnetic field with an atom. More commonly, O-switching is accomplished through electro-optic or acousto-optic means. So, ¢Le = £e 5 * 10-3 W = ¢A S ¢v 12.5 * 10-3 cm2211.33 * 10-6 sr2 = 1.5 * 106 W cm2 # sr a robust value indeed! PROBLEMS 1 Calculate the de Broglie wavelength of (a) a golf ball of mass 50 g moving at 20 m/s and (b) an electron with kinetic energy of 10 eV. Symbolically, if M = M1M2M3 Á MN, then Det1M2 = 1Det M121Det M221Det applied voltage is zero. The line image is virtual at a distance of 21.4 cm on the object side of the lens and 17.97 cm long. 13. At the same time, Newton's rings. Optics of the Eye from the two eyes come together at the optic chiasma, near the brain. Find, for each case, (a) the separation on the screen between the zeroth- and first-order maxima; (b) the number of bright fringes (principal maxima) that fall under the central diffraction envelope; (c) the width on the screen of the central interference fringe. If a certain electromagnetic field consists of the superposition of fields with many different polarizations, of which one or more predominates, we say the field is partially polarized. For other orientations, for example, $a = 60^\circ$, $1\ 1\ 2\ T = D\ T = D\$ suppose a were a negative angle, as in Figure 3b. The most common solution is achieved with the achromatic doublet (Figure 13), consisting of a convex and concave lens, of different glasses, cemented together. In a more complete mathematical argument, the extended source is represented by a continuous array of elemental emitting areas rather than by two point sources. The location, nature, magnification, and orientation of the image are indicated or suggested. Figure 2 illustrates the relationship between orders m and p for the arbitrary case where mmax = 100. A system for which C = 0 is sometimes called a "telescopic system," because a telescope admits parallel rays into its objective and outputs parallel rays for viewing from its eyepiece. The required modification involves the replacement of the incremental electric field amplitude EL ds>r0 by EA dA>r0 and the conversion of the integral over the slit width to an integral over the slit width to slit width to an integral over the slit wi solved by using curved, reflecting surfaces in place of lenses. Each interval contributes a spherical wavelet at P whose magnitude is directly proportional to the infinitesimal length ds. In the case of reflection, such surfaces are the conic sections, as shown in Figure 11. Lateral ray aberrations corresponding to the wave aberration AB may be calculated once the variation in AB with perpendicular distance from the optical axis is known. This matrix and those previously derived are summarized for quick reference in Table 1. For example, if z = A + iB, then, in polar form, z = 1A2 + B221>2ei[tan 1B>A2] -1 and the square root becomes $z_1 > 2 = 1A2 + B221 > 4ei[11 > 22$ tan 1B > A2] -1 (67) The complex expression in Eq. (67) can then be returned to the general complex form C + iD using Euler's equation. The development of ruling machines capable of ruling machines capable of ruling machines capable of ruling to 3600 sculptured grooves per millimeter over a width of 10 in. $2\Delta = 0.12$ Å Chapter 5 1. T1 T2 V1 T2 T1 V2 V1 (b) Figure 1 (a) Thermocouple made of dissimilar materials (dark and light lines) joined at points T1 and T2, where a difference in temperature produces an emf between terminals V1 and V2. What is the irradiance at the point 1x = 2, y = 32 mm? Thus the amplitude at r0 = f1>3, zone by zone, is reduced by a factor of 1/3, so that the irradiance at this point is 1/9 that at r0 = f1 . Anticounterfeiting holograms have been used on many high-value products, including perfumes, automotive parts, and curvatures of the surfaces involved and in refractive indices of the elements, the design of the lens system is gradually optimized. Symbolically, A sin k[1x + l2 + yt] = A sin[k1x + kt + 2p] 97 Wave Equations or A sin1kx + kt + kyt2 = A sin1kx + kt + 2p2 It follows that kl = 2p, so that the propagation constant k contains information designed to use continuous radiation in the visible and into the infrared region. For n2 7 n1, on the other hand, the refracted ray bends toward the normal. Approximating for paraxial rays and substituting for u1 and u2 in Eq. (17), we have n11a - w2 = n21a; - w2 (18) Next, writing the tangents for the angles by inspection of Figure 18, where again we may neglect the distance QV in the small angle approximation, n1 a h h h - b = n2 a - b s R s₂ R 33 Geometrical Optics al u2 rm No P u1 u2 a w C h a O I Q n1 V n2 s s R Figure 18 Refraction at a spherical surface for which n2 7 n1. How does this change when the distance moved is 5 cm? An interesting aspect of the Faraday rotation is that the sense of rotation relative to the magnetic field direction is, for a given material, independent of the propagation direction of the light. + 1 = 2n21 - n22 + 111(9) We have added 1 to the total number of modes to account for the "straightthrough" mode 1m = 02 at $w = 90^{\circ}$. Stimulated Brillouin scattering is a nonlinear interaction in which light from an incident field is scattered by an acoustic wave, which in turn was generated in the medium by the incident electromagnetic field. Before turning to that discussion we complete our general solution by using Eq. (14) in Eq. (12). In this case, $ER = E1 + E2 = E01 \cos 1a1 - vt2 + E02 \cos 1a1 - vt2 + E02 \cos 1a1 - vt2$ Note that when waves of equal amplitude destructively interfere, the resultant disturbance, at the point of interference, is zero, as shown in Figure 2b. Solution $L = d - f_0 - f_0 = 16.4 - 3.8 - 5 = 7.6$ cm and M = -a 25 L 25 7.6 b = -10, ba b = -a ba fe fo 5 3.8 a magnification of 10* Numerical Aperture To collect more light and produce brighter images, cones of rays from the object, intercepted by the objective lens (usually the aperture stop), should 81 Optical Instrumentation L Oil no ng Air ao aa ao aa Figure 29 Microscope objective, illustrating the increased light-gathering power of an oilimmersion lens. The equations should be compared with those of Eq. (17) to appreciate the analogous role played by the Bessel function. (Photograph courtesy of NASA.) Optical Detectors and Displays supply and signal readout. Newton's model of light propagation, therefore, seemed not to allow for the energy of the diffraction pattern falls under the central maximum, which is much larger than the adjoining maximum on either side. Working with SI units we obtain, from Eq. (3): 214.82 * 10-13 J22 - 18.19 * 10-14 J22 2E2 - 1mc22 = c 3 * 108 m > s = 1.58 * 10-21 kg # m > s p = from Eq. (4): 3 This discussion is not meant to be a condensed tutorial on relativistic mechanics, but, with the help of Eqs. 38 A plano-cylindrical lens in air has a radius of curvature of 10 cm, a refractive index of 1.50, and an axial length of 5 cm. The diode symbol indicates the orientation of the high reflectance region in these curves is nearly independent of the number of double layers used but increases when the ratio nL>nH decreases. $|g()|^2 = (A2\ 02\ /4\ 2)(\sin\ u/u)^2$, where $u = 0\ /2$ The narrow-band filter has a coherence length better by one order of magnitude: $3.48 \times 10-5$ m 1.3 fm: 106 Hz: 300 m 0.0243 mm (a) 0.00138 nm (b) 1 ns 2.5 mm 0.0625 cm; (b) 0.36, 0.36 (c) $531.01 \times 10-4$ cm, $2.90 \times 10-6$ cm2: 1.8, 35 (b) 2.55, 0.998, 0.63, 0.937, 0.686, 15.95 cm (a) 0.0, 0.596 cm (b) 0.36, 0.36 (c) $531.01 \times 10-4$ cm, $2.90 \times 10-6$ cm2: 1.8, 35 (b) 2.55, 0.998, 0.63, 0.937, 0.686, 15.95 cm (a) 0.0, 0.596 cm (b) 0.36, 0.36 (c) $531.01 \times 10-4$ cm, $2.90 \times 10-6$ cm2: 1.8, 35 (b) 2.55, 0.998, 0.63, 0.937, 0.686, 15.95 cm (a) 0.0, 0.596 cm (b) 0.36 (c) $531.01 \times 10-4$ cm, $2.90 \times 10-6$ cm2: 1.8, 35 (b) 2.55, 0.998, 0.63, 0.937, 0.686, 15.95 cm (a) 0.0, 0.596 cm (b) 0.36 (c) $531.01 \times 10-4$ cm $2.90 \times 10-6$ cm2: 1.8, 35 (b) 2.55, 0.998, 0.63, 0.937, 0.686, 15.95 cm (a) 0.0, 0.596 cm (b) 0.36 (c) $531.01 \times 10-4$ cm $2.90 \times 10-6$ cm2: 1.8, 35 (b) 2.55, 0.998, 0.63, 0.937, 0.686, 15.95 cm (a) 0.0, 0.596 cm (b) 0.36 (c) $531.01 \times 10-4$ cm $2.90 \times 10-6$ cm2: 1.8, 35 (b) 2.55, 0.998, 0.63, 0.937, 0.686, 15.95 cm (a) 0.0, 0.596 cm (b) 0.36 (c) 0.36 (0.895 mm Chapter 8 Chapter 10 1. Energy>photon 1.99 * 10-15 J One X-ray would be detected every 3 seconds or so. By geometry, each has a magnitude of IS sin u. (c) 0.94 - 2E0 cos 4t 15 +… 1. In other words, the scattering due to these larger particles can be understood in terms of the usual laws of reflection and refraction. Thus, the two waves are periodically in and out of step as they traverse the crystal. (a) 7 × (b) 2 cm (c) 5 mm (d) 2.3 cm (e) 337 ft 28. If u is the angle between the line segments S1S2 and S1Q, then ¢ = a sin u. Photodiodes using p-i-n junctions have response times on the order of 10 GHz. 3 IMAGE DETECTION Images can be detected and recorded on a surface sensitive to incoming radiation. (12) through (16) are valid, the paths of any two rays leaving P are sufficient to locate the conjugate image point P. Parrent, Jr., and Brian J. 509 15 Unpolarized light is reflected from a plane surface of fused silica glass of index 1.458. Contributing zones
then span a continuous range from $z_1 = -0.9$ mm to $z_2 = 0.1$ mm relative to the axis SO; P. Now the light is "coherent," but the available power is far below that initially radiated by the lamp. Calculate the normal reflectance of 560 nm light. = B12r1n02N1 Here, n0 is the center frequency of the 2 : 1 atomic transition. The angle up at which RTM = 0 is known as Brewster's angle or the polarizing angle and takes the value, up = tan-11n2 = tan-11 The chief ray in the cone of rays leaving the axial point O always coincides with the optical axis. Laser systems with solid gain media are typically cooled by surrounding the gain media are typically cooled by surrounding the gain media are typically cooled by surrounding the gain media are typical pump) in a cooling jacket. For this film, the two reflections are from glass to air (internal reflection) and from air to glass (external reflection). so that ¢ r in Eq. (38) is 1>2. Huygens also ignored the wavefront formed by the back half of the wavefronts implied a light disturbance traveling in the opposite direction. Figure 16b shows a Mach-Zehnder fiber interferometer acting as a demultiplexer. The coherence length Lc is related to the coherence time by the equation Lc = ctc , where c is the speed of light. The large irradiance in the cavity induces a high stimulated-emission rate, which depletes the population inversion, driving the laser system below threshold. (c) Sernamont prism. 3 NONLASER SOURCES OF ELECTROMAGNETIC RADIATION Before we examine the production and properties of laser light, we make a brief survey of some important nonlaser light sources. The stability in the angular relationship of prism faces may also be an important advantage in some applications. Progressing to the second derivative, we write da t d dk d dk b = a b ¢v = a b ¢l L dv dv dl dv and substitute Eq. (17), giving da d 1 1 dn dn d2n dn t b = c an - l b d ¢l = a - l b ¢l c dl L dl c dl dl dl2 258 Chapter 10 Fiber Optics or simply, material dispersion: d a t l d 2n b = ¢l K - M¢l c dl2 L (18) where M is a property of the core material defined by the prefactor, 11>c2 1d2n>dl22, involving the second derivative of the dispersion. 11 Sodium light (589.3 nm) from a narrow slit illuminates a Fresnel biprism made of glass of index 1.50. Both systems require the insertion into the laser cavity of an element that performs loss modulation. The beam waist spreads more rapidly than the beam waist spreads more ra cavity is 1.5 m long, and the CW output power of the Nd:YAG laser system is 10 W. The locus of such image points is then the spherical surface indicated by the dashed line. What is the percent error involved? 456 Chapter 20 Aberration Theory PROBLEMS 1 Carry out the "rearranging" called for in arriving at Eq. (18). The participating energy levels in the gain medium, which may be a gas, liquid, or solid, determine the wavelength of the laser radiation. Returning now to the single-layer film, we want first to generalize the conditions for constructive interference by drawing appropriate rays on your sketch. A nematic liquid crystal cell is placed between crossed polarizers as shown in Figure 9a. For the ideal four-level gain medium, these parameters take the form g0 = sRp2 + 2 g0 (38) and g g0 / 2 IS = $hn_2 > st2$ (39) 0 Note that the small-signal gain coefficient is the approximate gain coefficient when the irradiance I in the medium is much less than the saturation irradiance IS. The first set of terms describes the amplitude variation of the electric field at any transverse plane z. This arrangement eliminates astigmatism and spherical aberration and dispenses with the need for the Rowland circle. v1x, t2 = A1x/m - t/s22 3. Optical Fibre Devices, Bristol and Philadelphia: Institute of Physics Publishing, 2002. The frequencies for which a fixed-length Fabry-Perot cavity, would experience low loss. With 1qx, qy2 fixed, the integral is the area under a curve representing the product of the two functions. The sodium arc lamp, for example, provides radiation almost completely confined to a narrow "yellow" band due to their respective wavefronts, do not intersect the paraxial image plane at the same point. These integrals simplify in two general

cases that are of particular interest. 1. After cancellation of the constant 1e0m0 and some simplification, we find r = n1100 - ns2cos d + i1n0ns - n212sin d (40) 482 Chapter 22 Theory of Multilayer Films The reflectance R, which determines the reflected irradiance, is defined by $R = frf^2$ (41) To calculate R, first notice that the reflection coefficient r is complex and that it has the general form r = A + iB C + iD so that f r f 2 = $rr^* = a A2 + B2 A + iB A - iB$ ba b = 2 C + iD C - iD C + D2 By inspection then, we may write R = n211n0 n211n0 n211n0 n211n0 n211n0 n211n0of ZrO2 1n = 2.102 is deposited on glass 1n = 1.502. 12 CYLINDRICAL LENSES Spherical lenses and mirrors with circular cross sections are far more common in optical systems than are cylindrical lenses. This is the monomode (or single-mode) fiber. (When an aperture through which the beam is passed is made small enough, however, even a laser beam begins to spread out in a characteristic diffraction pattern.) When a light ray traverses an optical system consisting of several homogeneous media in sequence, the optical path is a sequence of straight-line segments. If the actual length of the cell is accurately known to be L, the change in optical path is given by ¢d = nL - L = L1n - 12 (9) and using Eq. (8), it follows that the index can be determined from n - 1 = a l b ¢m 2L (10) Consider another direct application of the Michelson interferometer, the determination of wavelength difference between two closely spaced components of a spectral "line," l and l¿. New York: Academic Press, 1978. As it moves, the pulse maintains its shape. Naturally occurring calcite crystals are cleavable into rhombohedrons as a result of their crystallization into the trigonal lattice structures. Once the AS is identified, it is imaged through the optical elements to its right to find the exit pupil. Notice that the dipole oscillations include a component along the direction of the reflected beam. As indicated in the figure, carrier signals of different wavelengths originating from different transmitters are combined by a multiplexer into a single optical fiber. When interest lies primarily in the effects of enhancement or diminution of light. Concepts of Classical Optics. If the wavelength separation is too large, the transmittance peak associated with the mode number m + 1 of 11 will overlap the transmittance peak with mode number m associated with l2. Chief Ray The chief, or principal, ray is a ray from an object point that passes through the axial point, in the plane of the entrance pupil. What is the far-field beamdivergence angle uFF for this laser? (d) Diffraction pattern due to a double-slit aperture, with each slit of width b like the one that produced (c), but with a/b unspecified. In practice, one often follows the evolution of a cavity photon number (c), but with a/b unspecified. In practice, one often follows the evolution of a cavity photon number (c), but with a/b unspecified. (3), and (4), the magnitudes of the magnetic and electric fields can also be related by E n = a bE = n 1e0m0E y c B = (5) 1 TRANSFER MATRIX Our analysis is carried out in terms of the quantities defined in Figure 1. Example 3 For a straight edge, calculate the irradiance at the first maximum above the edge of the shadow. The glass rod has a refractive index of 1.60. Intermediate to the good insulator and good conductor we have treated separately are materials, like semiconductors, for which neither of these extreme cases suffices to explain the properties. Assume that the beam irradiance is constant across the diverging beam. To obtain a qualitative understanding of temporal and spatial coherence, consider an ideal monochromatic point source of light. The second cosine factor represents a wave with frequency vg and propagation constant kg that are much smaller by comparison, since differences of the original values are taken in Eq. (32). 6 A Michelson interferometer is used with red light of wavelength 632.8 nm and is adjusted for a path difference of 20 mm. The speed of response is described by a time constant, a measure of the time required to regain equilibrium in output after a change in input. Typically, cos d will take on alternating maximum and minimum values, and interference fringes, spatially separated, will occur in the observation plane. 370 Chapter 15 Production of Polarized Light b. (d) Image of a square grid by a positive lens. Stimulated Absorption, or simply absorption, is the process by which electromagnetic waves transfer energy to matter. (a) Compact arc lamp. The beam diverges strongly as it propagates on past the beam waist. Image formation by an optical 26 Chapter 2 O Geometrical Optics I (a) Ellipsoid I O (b) Hyperboloid O (c) Paraboloid Figure 11 Cartesian reflecting surfaces showing conjugate object and image points. Chapter 14 Gerrard, A., and J. Determine the visibility of the fringes on a screen 1 m away, in the vicinity of the fringes on a screen 1 m away, in the vicinity of the fringe of order m = 20. On reconstruction, each scene appears in its own light when viewed along the direction of the original scene, without mutual interference. Interference fringes produced by light reflected and transmitted at a plane interface separating two optical media. From our knowledge of Fourier series, we conclude that the finer features of the image disappear when spots corresponding to the higher spatial frequencies are blocked. 4 INTERFERENCE IN DIELECTRIC FILMS The familiar appearance of colors on the surface of oily water and soap films and the beautiful iridescence often seen in mother-of-pearl, peacock feathers, and butterfly wings are associated with the interference of light in single or multiple thin surface layers of transparent material. Shield Output mirror Flashlamp Power supply The Gain Medium Laser systems are typically named by the makeup of the gain medium used in the device. Consider a ray with parameters 1y1, a12 incident on the entrance plane of an arbitrary optical system matrix c A C B d D Upon emerging from the system, the same ray has parameters 1y2, a22. With this definition, the rate equations can be written as dN2 sI = - A 21N2 1N - N12 dt hn¿ 2 (14) dN1 sI = + A 21N2 + 1N - N12 dt hn; 2 (15) and Now s has a dimension of area which accounts for its designation as a cross section. In the ordinary case of a lens in air, with n = n; = 1, notice that r = y and s = w: First and second principal points are superimposed over corresponding nodal points. The fractional power £ frac = £1r = a2> £ tot passing through a circular versus the ratio a/w, where w is the 100% Aperture geometry 99% 86% w a (r a) tot 50% aw a 1.5 w a Transverse Gaussian irradiance of beam entering aperture volume a circular aperture of radius a. 26, 27. In this case, we find ID IC IF f1 f2 f 6.3653 cm 6.3961 cm 6.2966 cm - 11.0575 cm - 11.147 cm - 10.8485 cm 15.0000 cm 15.007 cm 15.007lateral aberration at the same time. When we speak of linear optics, we assume that an optical disturbance propagating through an optical from the left. Presbyopia As mentioned in the preceding section, human eyes lose ability to accommodate with age When illuminated with sodium light (589.3 nm), fringes appear on the screen with a spacing of 0.5 mm. The aberration function $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$ or the point Q on the wavefront may be expressed as $a_i 102 = 1PQP_i$. vertical plane approximating the wavefront at O. In these inelastic interactions, the collisions induce a change in internal state of one or both of the atoms participating in the collisions. 17 Calculate the focal length of a thin meniscus lens whose spherical surfaces have radii of curvature of magnitude 5 and 10 cm. Overall, the eye can be represented approximately as a thin, positive lens of focal length equal to 17 mm in the relaxed state (distant vision) or 14 mm in the tensed state (near vision). Two consecutive internal reflections thus produce a relative phase shift of 21- 3p>42 = - 3p>2 (equivalently, +p>2) beB tween the perpendicular components of the E-field. In the far field 1z W z02, the phase fronts again become planar. 100 mm Metal electrode ps GaAs 10 mm 1 mm p GaAlAs active region n GaAlAs active region n GaAlAs n GaAs substrate Figure 19 Stripe-heterojunction semiconductor laser. When their image patterns begin to overlap substantially, it becomes more difficult to discern the patterns as distinct, that is, to resolve them as belonging to distinct object points. A laser system converts pump energy (which may be electrical or optical in nature) into intense, highly directional, nearly monochromatic, electromagnetic wave energy. Determine the critical and polarizing angles. Again, we find
that the propagation constant must be a complex number to properly describe the propagation of the wave in a metal. (c) If the lens is to be used instead to produce a collimated beam, how do these answers change? For most photographic work, d is of the order of thousandths of an inch. Each elemental irradiated area dA1 contributes to each elemental irradiated area dA2. to form a resultant wave that has an amplitude that is (in magnitude) the difference of the amplitudes of the waves being superposed and which is in step with the individual wave of largest amplitude. Similarly, viewed from a point on the z-axis, the z-vibrations are missing, and light is linearly polarized along the y-direction. This balance is not maintained at the edge of an aperture in the screen, where the distribution of oscillators is interrupted. Consequently, infrared radiation is sometimes termed "heat radiation" and finds application in nightvision scopes that detect the IR emitted from objects in absolute "darkness" and in infrared photography wherein objects at different temperatures (and so with different peak wavelengths of emitted radiation) are imaged as areas of contrasting brightness. For a grating of 1200 grooves/mm and ui = 38°, the firstorder spectrum for wavelengths between the angles - 22° and 56°, respectively. Thus if z = a + ib, $\dots z = a - ib$ or $\dots z = f z f e -iu$ (16) u eiu 0 1 p/2 i p ≥ 1 3p/2 $\ge i$ where the asterisk is used to denote the complex conjugate. The method lends itself to computer techniques for tracing a ray through an optical system of arbitrary complexity. Proceeding from Eq. (29), kr = k1x2 + y2 + z221 > 2 = kz11 + r2 > z221 > 2 = kz1expansion in the small quantity r2>z2. First, any Jones vector may be multiplied by a real constant, changing amplitude but not polarization mode. Ghatak, Ajoy K. = B12N1 I 0 and q RSp.Em. = A21N2 I 0 g(n) r(n) r(n) In the last relation we have used the fact that the lineshape function g1n2 is normalized so that its integral over all frequencies is unity (3) and (4). "The Optical Properties of Materials." Scientific American, Sept. When the electric fields are parallel, on the other hand, the interference term makes its maximum contribution. What ratio of amplitudes produces a visibility of 0.5? 4 a. Thus linearly polarized incident light with equal TM and TE components, after two internal reflections at 53°, will be transformed into circularly polarized light. Since the sum of the light transmitted under both conditions must be all the incident light, it follows that the colors observed under these two transmission conditions are complementary colors. Such a series of terms is called a Fourier series. A typical CCD panel in a wire-bonded package is shown in Figure 6. We appeal now to Rayleigh's criterion, which determines the limit of resolution of the diffraction-limited line images. The result is a compound lens that has a net focal length but reduced dispersion over a significant portion of the visible spectrum. Example 2 For the He-Ne laser geometry given in Figure 10, use the ABCD propagation law to determine the spot size w0 of the external beam waist and its distance from the outer surface R3 of the mirror-lens combination. The coherence length LC is defined by the relation ¢kLC = p. Notice also that with the correcting plate attached at twice the focal length of the mirror, the telescope is twice as long as the telescopes described previously in Figure 34. The output of a Michelson spectrometer is fed to a photodetector. Thus, vertically polarized along the horizontal direction and so pass through the second horizontal direction and the second horizontal direction and the second horizontal direction direction direction and the second horizontal d radiance L1 at dA1 is given by L1 = d2 £ 1 d2 £ 1 = dv11dA1 cos u12 1dA2 cos u2>r221dA1 cos u12 (15) By a similar argument, in which we reverse the roles of dA1 and dA2 in the figure, L2 = d2 £ 2 d2 £ 2 = dv21dA2 cos u2>r221dA1 cos u1>r221dA2 co continuous bundle of rays remains constant, that is, d£ 1 = d£ 2, so that we can conclude from Eqs. The effect of variations in signal strength is then to produce variations in spacing of the fringes. In general, both homogeneous and inhomogeneous broadening occur g (n) OnD OnH n0 n Figure 11 A Doppler-broadened lineshape function g1n2 (solid curve) is shown as a function of n. The fiber couplers FC1 and FC2 function as beam splitters. The solid angle ¢v is equal to ¢AT>R2, where ¢A T = pr2T = p1R tan1a>2222 M pR21a>222, since tan1a>22 M a>2 for small angles. Accordingly, the corrective contact lens should have a focal length of - 100 cm. To be detected as a single pulses. Heated cathode Deflecting coil Vacuum tube Electron beam Anodes 17 Screen Deflecting coil Vacuum tube Electron beam Anodes 17 Screen Deflecting coil Vacuum tube Electron beam Anodes 17 Screen Deflecting coil Vacuum tube Electron beam Anodes 17 Screen Deflecting coil Vacuum tube Electron beam Anodes 17 Screen Deflecting coil Vacuum tube Electron beam Anodes 17 Screen Deflecting coil Vacuum tube Electron beam Anodes 17 Screen Deflecting coil Vacuum tube Electron beam Anodes 17 Screen Deflecting coil Vacuum tube Electron beam Anodes 17 Screen Deflecting coil Vacuum tube Electron beam Anodes 17 chapter we give a qualitative description of the more common types of optical detectors and displays. Note that the arrow in the diode symbol points from the p-side to the n-side of the diode. See problem 1. If the two patterns are identical, for example, and so situated that Aperture Spectrum Image Output S L1 Figure 7 Optical correlator formed by the combination of an optical filter and a spectrum analyzer. Find the wavelengths of the three shortest-wavelength photons in the Lyman series. Vest, C. Calculate the final image position relative to the last lens and its linear magnification relative to the last lens and its linear magnification relative. (c) the first and last lenses are negative. Both of the Stokes relations will be needed in the discussion that follows. The designation "6 * 30" for binoculars means that the angular magnification M produced is 6* and the diameter of the objective lens is 30 mm. Shkunov, and Boris Ya. Zel'dovich, "Optical Phase Conjugation," Scientific American, Dec. Thus, using Eq. (33) gives Iu = I01E; E22 = I051C1 q 2 - C1 - q 222 + 1S1 q 2 - S1 - q 2226 = I0112 + 122 = 2I0 (37) Other irradiances may be compared conveniently to this value of Iu = 2I0 for the unobstructed wavefront. If the illumination is green light of 546.1 nm, what is the dimension of the "step" in the film that caused the shift? (b) Cassegrain telescope. What magnification would result if coherent X-rays of 1 Å wavelength were available to construct the hologram? Telescopes may also be distinguished by the erectness or inversion of the final image and by either a visual or photographic means of observation. The Michelson, Twyman-Green, and Mach-Zehnder interferometers are all two-beam interference instruments that operate by division of amplitude. This careful recontouring of the surfaces, or three optical components in series, 93% of the incident light survives in the case of MgF2 coatings, compared with 77% in the case of uncoated glass. The component of P2 oscillating at 2v corresponds to dipole oscillations in the medium at this same frequency. T E B AR A1 A2 b2 b1 O Reference direction Figure 10 Phasor diagram for the first two half-period Fresnel zone strips, each subdivided into smaller zones of equal phase increment. Many important applications of lasers require that the laser output be pulsed, in the sense that the laser output turns on and off in very short time periods. This decrease in lateral magnification due to the aperture position is more noticeable as the object point recedes farther from the axis, so that the image suffers from barrel distortion. 21 Plot each of the transmittance functions found in problem 20 as a functior of a/w(z). Solution The visibility is given by V = 1 - t ¢ = 1 t0 /t where the ratio of time delay to coherence time is replaced by the corresponding ratio of path difference to coherence time is replaced by the following component efficiencies: 80%—power supply operation 30%—arc lamps for pump light to Nd:YAG pump levels 50%—due to internal cavity/rod losses a. As the irradiance grows the population inversion N2 - N1 necessarily decreases since an excess of stimulated emission creates photons at the expense of the population of the upper lasing level. A typical spectral irradiance curve for a 100-W quartz-halogen filament source is given in Figure 6. A., we can write mtot 2d 2d N. 6 A continuous He-Ne laser beam (632.8 nm) is "chopped," using a spinning aperture, into 1-ms pulses. A minimum in reflected irradiance occurs, according to Eq. (47), when cos d = 1, or when d = 2pm and ¢ = 2nft cos ut = ml (50) Necessarily, this must also be the condition for a transmission maximum. This slower saturation results because, although irradiance at a frequency equal to that of a given cavity mode interacts primarily with the group of atoms whose center frequency is at the cavitymode frequencies. In each case estimate the pulse width from the plot and compare the pulse width from the plot and compare the pulse width to the range of frequencies. In each case estimate the pulse width from the plot and compare the pulse width to the range of frequencies. In each case estimate the pulse width to the range of frequencies. In each case estimate the pulse width from the plot and compare the pulse width from the plot and compare the pulse width to the range of frequencies. slightly curved surfaces that can be considered plane in the paraxial approximation. (a) 5 × 10-7 T (b) 19.88 W/m2 3 17. R., and F. Some familiar examples of such disturbances are waves, and sound waves. An axial pencil (shaded) from the on-axis object point O forms an image at and around the paraxial image
point I. (6) and (7), taken together. However, an excited rare-gas atom (like Kr*) has a single electron in its outer shell and so can form an ionic bond with a halogen atom (like F), which is one electron short of a filled outer shell. Quantum mechanics describes both light and matter and, together with special relativity, predicts that the momentum, p, wavelength, l, and speed y, for both material particles and photons are given by the same general equations: p = 2E2 - m2c4 c (3) l = h hc = 2 p 2E - m2c4 c (3) l = h hc = 2 p 2E - m2c4 c (3) l = h hc = 2 p 2E - m2c4 c (3) l = h hc = 2 p 2E - m2c4 c (3) l = h hc = 2 p 2E - m2c4 c (4) y = pc2 m2c4 = c 1 E B E 2 (5) 5 Nature of Light In these equations, m is the rest mass and E is the total energy mc2 and kinetic energy EK, that is, the work done to accelerate the particle from rest to its measured speed. 1 SUPERPOSITION PRINCIPLE To explain the combined effects of waves successfully one must ask specifically: What is the net displacement c at a point in space where waves with independent displacement c at a point in space where waves with independent displacements c1 and c2 exist together? The virtual image now appears colored. Thus, the refracting power of a lens of focal length 20 cm is said to be 1 = 5 diopters. If light travels more slowly in the second medium, as assumed in Figure 6, light bends at the interface so as to take a path that favors a shorter time in the second medium, thereby minimizing the overall transit time from A to B. or more, with suitably uniform depth, shape, and spacing, has been an impressive and far-reaching technological achievement. 20 Write a computer program that incorporates Eqs. Assume that l>x is much smaller than 1. 23 The objective of a microscope has a focal length of 0.5 cm and forms the intermediate image 16 cm from its second focal point. We now make the previous qualitative explanation somewhat quantitative. When this is the case, equal focal lengths for two wavelengths, measured as they are from their respective principal planes, do not lead to a single focal point on the axis, and longitudinal chromatic aberration remains (Figure 14a). The numerous, thin rods are multiply connected to nerve fibers, making it possible for any one of a hundred rods or so to activate a single nerve fiber. Several important cases of the combined effects of two or more harmonic waves are treated in this chapter. The average total irradiance reaching the earth's surface on a clear day is about 1000 W>m2. Thus a CCD array can be (and is) used in digital video cameras, which update the image some 30 times a second. To the right of the interface, the refractive index is that of water. The wavefront from G2 is deformed by an underwater object and interferes with the undeformed reference beam from G1. The angular magnification is M = 25 25 = = 7 f 3.57 In designing eyepieces, one usually desires an exit pupil that is not much greater than the size of the pupil of the eye, so that radiance is not lost. Figure 5f shows the corrected vision for distant objects. A telephoto lens is a long focal-length lens, providing magnification at the expense of subject area. These variations may be described by the harmonic waveforms B B B B B E = E0 sin1k # Br - vt2 (28) B = B0 sin1k respectively, and E0 B and B0 are their amplitudes. For example, in solid-state lasers in which the active atom is doped into a transparent host, inhomogeneities in the host lead to broadening. Plot the laser output irradiance as a function of the variable reflectance R = R1 = R2 of the other two cavity mirrors. However, if one considers object points below T, the upper rays from such points, passing through the aperture, miss the lens. 5.99°, 2.16' 12. In the astronomical telescope, the evit pupil is situated just outside the eyepiece and is designed to match the size of the pupil is situated just outside the eyepiece and is designed to match the size of the pupil is situated just outside the eyepiece and is designed to match the size of the pupil of the eye. 10 A transmission grating is expected to provide an ultimate first-order resolution of at least 1 Å anywhere in the visible spectrum (400 to 700 nm). The absorption or loss coefficient a characterizes the spatial rate of change of the irradiance, that is, dI = - aI dz (20). Let us now form the left-hand side of Eq. (20). Let us now form the left-hand side of Eq. (20). Let us now form the left-hand side of Eq. (20). Let us now form the left-hand side of Eq. (20). The geometry of this particular rays emanating in air from a point object. provides a means of approximately determining the virtual source separation a in terms of prism index n and angle a: a = 2ddm = 2da1n - 12 (25) Interference fringes are then described by Eq. (22), as usual. In optics, the definite integral is the integral of the time required for the transit of a light ray from starting to finishing points.1 3 PRINCIPLE OF REVERSIBILITY Refer again to the cases of reflection and refraction pictured in Figures 5 and 6. An image of the object is projected on the back wall of the box, which is lined with a piece of film. Maiman's laser used a ruby crystal as the laser amplifying medium and a two-mirror cavity as the optical resonator. The vibrational amplitudes of diffusely reflecting surfaces may be measured with high precision, and such measurements can be very useful for determining the modes of vibration of complex structures. When the erbium-doped fiber section is optically pumped, it serves as an amplifer for light near 1550 nm and so can be used to restore attenuated signal strength. (a) Convex lens. The accompanying increase in the magnitude of u, or of the denominator of Eq. (12), gradually decreases the amplitude of an otherwise harmonic variation. c 3i d i 4i c. The cornea is roughly 12 mm in diameter and 0.6 mm thick at its center, thickening somewhat further at its edges, with a refractive index of 1.376. In step 4, one of the inverted N2 atoms, which dropped to level E1 during the stimulated emission process, now decays rapidly to the ground state E0. The cell can be made nontransmitting by applying a 3 B. Accommodation Depending on the distance of the object or scene from the eye, the lens accommodates—tenses or relaxes—appropriately to "fine-focus" the image on the retina. a a0 a0 (1 ≤ cos u) 2 Illustration of the obliquity factor on the secondary wavelets originating at points on the wavefront was introduced by Fresnel. (a) 102 nm, 1.22 (b) 0.084% (a) 2.81% (b) 3.17% (c) 4.26% 32.3% 2; $0.25 \mu m$; ZrO2 (a) 859 Å of aluminum oxide, 1058 Å of cryolite; 0.0003% (b) 15.6% (a) 227 nm and 370 nm (b) 10% (c) 1.2% For example, from surface to substrate: MgF2 (n = 1.35), SiO (n = 2.2) (a) 81.1% (b) 98.4% (c) 99.99% 99.96% 2.24 Chapter 23 2. Recall that r1n2 is the energy per unit volume per unit frequency interval in the field. Note also that the segment of the chief ray from L2 to P-, if traced backward, will appear to be coming from point N, the center of the exit pupil ExP. The gain cell has length L and is characterized by small signal gain coefficient g0 and saturation irradiance IS. Let the irradiance of such a (hypothetical) perfect image be given by I01X, Y2 K I01x, y2. As an example of the convolution theorem, recall the results for the Fraunhofer diffraction of a grating. Ch. 18. You will want to comment on the following considerations: Single or double refracted rays? 191 Interference of Light 26 A fringe pattern, such as that in Figure 20, found using an interference microscope objective, is observed to have a regular spacing of 1 mm. Strong discrimination between the TE and TM modes in the incident radiation is exhibited by the curves for single-crystal gallium surfaces. twice the distance of source S above the mirror plane. A.2 4 Amnon Yariv, Optical Electronics, 3d ed. Entrance Pupil (EnP) The entrance pupil is the limiting aperture (opening) that the light rays "see," looking into the optical system from any object point. All of the stimulated emission photons have the same direction with a range of frequencies described by the lineshape function. Field components not phase-locked to form
constructive interference, at the position of the gate when the gate is opened, are blocked by the closed gate. The adjustable hole or opening in the iris through which the light passes is called the pupil. Plane mirrors may substitute for the reflecting prisms, but the faces are easier to keep free of contamination, and the process of total internal reflection is capable of higher reflectivity. "Ruling Engines." Scientific American, June 1952: 45. Lasers with lower heat losses can sometimes be sufficiently cooled by forced air. Assume a fused silica core index of 1.446. Equation (11) also indicates that there is a frequency-dependent phase shift between the applied field and the polarization. 375 376 Chapter 16 Holography M2 M1 ER Subject ER y a Laser a BS Film (a) (b) Figure 2 (a) Off-axis holographic system. In this mode of operation, the frequencies associated with the transmittance peaks provide frequency markers that can be used to monitor and calibrate the changing frequency of the input laser field. Equation (22) can be used to obtain spot size at z = z0 w1z W z02 = Spot size in the far field 1z W z02 w0z l = z z0 pw0 Here we have used Eq. (21) to obtain the final expression for the far field (that is, for z W z0) spot size. 364 Chapter 15 Production of Polarized Light y x Unpolarized Light TA Polarizer TA b b Active cell Figure 17 Measurement of optical activity. Notice that in these cases, the ordinary rays are separated without the agency of total internal reflection. fs = s - f s; m = = s s; = 11021202 = + 20 cm 20 - 10 20 = -1 20 31 Geometrical Optics The image is real (because m is negative), 20 cm to the left of the mirror vertex, and is inverted (because m is negative) and the same size as the object, or 3 cm high. To move the near point in from 150 cm for the unaided eye to 40 cm for the eye/corrective lens system, the corrective lens must form a virtual image of an object placed 40 cm from the eye at a location of 150 cm from the eye. Sinusoidal waves without a beginning or an end are, however, mathematical idealizations. Lasers and Electro-Optics. Fabry-Perot Interferometers. As this distance is reduced, the angular aperture seen by the film is larger, so that more of the scene is recorded, with corresponding decrease in size of any feature of the scene. PPB PPR Red Blue fB fR FB FR fB fR (b) Figure 14 Doublet with second principal planes separated for red and blue light. In particular, the line expected at 513 nm shows up at 525 nm. To see why, we consider the simpler case of a symmetric planar or slab waveguide, shown in Figure 4. Polarized Light. A plot of reflectance versus the optical path difference $c_1 = n1t$ associated with one traversal of the film is shown in Figure 2, where the abscissa is calibrated in ratios of $c_1 > 1$, with l = l0 > n1 being the wavelength in the film. The group velocity of the signal is the velocity at which the positions of maximal constructive interference propagate. The magnitude of the film index n1 evidently determines whether the reflectance is enhanced (for n1 6 ns) from that for uncoated glass. Each length has a 5-db loss and each splice contributes a 1-db loss. Physical Optics Notebook: Tutorials in Fourier Optics. These Aberration Theory quantities also dependent of the film index n1 evidently determines whether the reflectance is enhanced (for n1 7 ns) or reduced (for n1 7 ns) or reduced (for n1 6 ns) from that for uncoated glass. Each length has a 5-db loss and each splice contributes a 1-db loss. on the object distance. Notice the large changes in the composite phasor A n, for small n, as the contribution from each new Fresnel zone is added. The small-signal absorption in the the Nd:YAG crystal by a two-level system with no degeneracies is a rather drastic oversimplification of the real situation. Ring Laser We choose to illustrate the development of an expression for the steady-state irradiance output from a laser cavity by considering a ring laser consisting of three mirrors as shown in Figure 8. The result is the Wien displacement law, given by lmaxT = hc = 2.898 * 103 1mm # K2 5kB (6) and is indicated in Figure 3 by the dashed curve. (b) Linearly polarized electric field vectors whose x- and p-components are p out of phase lie in the second and fourth quadrants. Suppose this were not the case, as in Figure 9. The output of a stereo system is more faithful to the original signal than is the output of a telephone receiver because a greater frequency range is devoted to the process of reproduction. At any specified time and place, E = cB (30) E E 0 k B 0 E (a) x E B E B 0 E 0 B y B B E E z 1/2 (b) Figure 10 Plane electromagnetic wave described by Eqs. Thus, larger-diameter fibers. g0 1/cm IS 10 W/cm2 10 5 g0 1/cm IS 10 W/cm2 10 0/cm IS 10 W/cm2 10 W/cm 0 0 1 2 Gain length L (cm) 3 561 Laser Operation but different saturation irradiances. Fringes, often called Fizeau fringes, are seen localized at the film, from which the interfering rays diverge. Figures 7 to 9 illustrate three such examples. Find the matrix for the simple "system" of a thin lens of focal length 10 cm, with input plane at 30 cm in front of the lens and output plane at 15 cm beyond the lens. 513 Nonlinear Optics and the Modulation of Light This irradiance would result, for example, from a pulsed laser field of power 100 MW focused to a spot of radius about 5 mm. This alternative point of view emphasizes the degree of 0.2 m wave curvature or ray convergence rather than object and image distances. For each value of m, monochromatic radiation of wavelength l is enhanced by the diffractive properties of the grating. Referring to Figure 2, the angle between actual and ideal rays from a point P of the wavefront, at elevation y, is the same as the angle between wavefront tangents at P. Figure 14 suggests waveguide dispersion, in the ray representation. Find the irradiance of the light exiting each of the output ports of the interferometer and show that the sum of these output irradiance. Which filter would be better to use for an interferometer and show that the sum of these output irradiance. distribution of frequency components. By the matrix approach, determine the location of its principal points. Clearly, Eq. (26) is not valid as r approaches zero but rather describes the disturbance at a finite distance from a small physical source. t1 a. 12 Using the materials given in Table 1, design a three-layer multifilm of quarter-wave thicknesses on a substrate of germanium that will give nearly zero reflectance for normal incidence of 2 mm radiation. Sketch rays from the person, and determine the proper placement of the mirror. 17 Given the generating function, Eq. (58), for Hermite polynomials of the person, and determine the proper placement of the mirror. Hm1j2, where j = 22x>w, verify the particular cases for m = 0, 1, 2, A given in Eq. (45). The arrangement is shown in Figure 3 and is plotted as curve (a) in Figure 4. Determine the minimum base length of the prism if it is to resolve the hydrogen doublet at 656.2716- and 656.2852nm wavelengths. (a) Velocity ellipsoids for orthogonally polarized light beams in a birefringent medium. Notice that the dimension indicated by ¢ is zero when the wavefront is plane. Spectra are observed over a range making small angles to the grating normal, perhaps 10° to either side. Figure 8b shows that each zone produces a different magnification, so that hc due to the central ray is not equal to he due to the extreme rays. For definition of symbols, refer to Table 2. In practice, the time average is carried out by a detector. The relation between group and phase velocities can be found as follows. The radius DM can also be expressed as DM = ytt = yt a ni DG b = a b DG yi nt Similarly, a wavelet of radius 1ni>nt2 JH is drawn centered at J. There are many different methods used to change the length of the cavity in a controlled fashion. Symbolically, C1Ii2 = C1I02 * C1G2 (33) The content of Eqs. The near-point distances, s1 and s2, of the depth of field (MN) can be determined once the allowable blurring parameter d is chosen and the lens is specified by focal length and relative aperture. The principal points H1 and H2 are also shown. As the hole increases in diameter, the irradiance I0 is incident on a series of N successive linear polarizers, each with its transmission axis offset from the previous one by a small angle u. Further, if the incident beam is near normal, the beams are brought together with their E vibrations nearly parallel. (See problem 26.) The Mach-Zehnder fiber interferometer shown in Figure 16b operates by the same set of principles as the standard interferometer shown in Figure 16a. Notice B the sense of rotation of the tip of the E-vector around the ellipses shown in Figure 4, which makes the case $\psi = 7p>4$. A.2 Example 1 Suppose an optical fiber (core index of 1.465, cladding index of 1.460) is being used at l = 1.25 mm. Using the thin-lens sign conventions and noting that the spectacle lens is placed 2 cm from the eye, this condition implies that the image distance is s = 38 cm. Suppose then we consider the contribution of all the zones in Figure 7, alternately transparent and opaque. Astonishingly, though, as the corneal surface healed with all its scars, the cornea flattened out and most of the myopia disappeared. Reflecting Prisms Total internally-reflecting prisms are frequently used in optical systems, both to alter the direction of the thickness d, any device that allows a continuous change in thickness makes possible a continuously adjustable retardation plate. The deviation AB of the actual from the optical axis at which the ray intersects the wavefront and is referred to as spherical aberration. Find the principal points using the matrix method. Example 4 A certain presbyopic eye can form the eye to very far from the eye. What displacement of the interferometer? This result can be shown by applying the rules
of graphical vector addition in order to subtract the vec! tor associated with the zones blocked by the ! wire FG from the vector associated with the unobstructed wavefront E¿E. If emulsion shrinkage is 15% during processing, what wavelength is reinforced by the blue-light fringes on reconstruction? Take n = 1.50 for the glass. Silver films are most useful in the visible region of the spectrum, but their reflectivity drops off sharply around 400 nm, so that follows that follows that the retardation is very nearly inversely proportional to the wavelength. In such a case, the electric fields are said to be mutually coherent and the irradiance of the combined fields will have the form t0 = I = I1 + I2 + 2 2112 cos d Mutually coherent beams (14) where d is the total phase difference at the point of recombination of the beam. 4. 325 Fresnel Diffraction S(y) 1.5 2.5 E 0.5 1.0 2.0 y $0.5 \ge 0.5 0.5 C(y) \ge 0.5 \ge 2.0 y \ge 1.0 \ge 0.5 E 0.5$ phasor E¿E representing the unobstructed wavefront has a length on the Cornu spiral of 22. If w01 w02—that is, a strong positive lens is used in the focused beam waist w02 is given approximately by w02 fl = f1uFF21 pw01 (48) Next, in Eq. (47), if we have a physical system for which pw201>1 1Z1 - f22 — not an uncommon situation7—then it follows that Eq. (47) reduces to Z2 f (49) The important special case in which the lens is placed at the beam waist of the input beam 1Z1 = 02 is explored in problem 12. These shapes, as well as their mirror images with negative shape factors, are shown in Figure 7. 1 "The Nature of Light: What is a Photon?" OPN Trends, Vol 3., No. 1, October 2003. Let us assume that only such an excited state 2 accumulates a significant population density as a result of the interaction with the electromagnetic field. Assume that the operating temperature is 400 K and recall that neon is the lasing species. (c) Empty optical cavity, or resonator, bounded by two mirrors. (a) $R = 4r2 \sin 2/2 \ 2 + 4r2 \sin 2/2 \ 1 - r$ () 16. Thus, the focusing properties of a spherical lens are invariant to rotation about its central (optical) axis. Looking again at Figure 31, imagine a screen placed on the exit side of the lens so as to capture the light from the lens. Thus, R1z22 = q . Fundamentals of Photonics. 9 The Lick Observatory has one of the largest refracting telescopes, with an aperture diameter of 36 in. The pulse repetition time (time between pulses) can be no less than the time needed for an inversion to build, which is reflected normally from a plane mirror, receding at a speed y. Equation (49) gives IT = Ii, as expected. The difference in path lengths can be controlled by a delay line (or a variety of phase shift mechanisms) in one of the "arms" of the fiber interferometer. The distances from slit to prism and from prism to eye are in the ratio of 1:4. If one mirror translates at a speed of 5 mm/s, what is the frequency of modulation of the photocurrent? 4 OPTICS OF PROPAGATION We consider now the manner in which light propagates through an optical fiber. How is the visibility modified if the path difference is doubled? A pinhole in aluminum foil, supported by a larger aperture, works well. The real refractive index experiences a sharp rise and then a fall as v increases toward and then passes through resonance, after which it increases again, approaching the value nR = 1 at high frequencies. 5 Suppose a hologram is to be made of a moving object using a 1-ns laser pulse at a wavelength of 633 nm. Equivalently, this means that as d is varied, fringes of the pattern appear to move inward toward the center, where they disappear, or else move outward from the center, where they seem to originate, depending on whether the optical-path difference is decreasing or increasing. Suppose a plane radiator or reflector is perfectly diffuse, by which we mean that it radiates uniformly in all directions. More often, though, the sharpness of optical images is more seriously degraded by optical aberrations due to the imaging components themselves. When the test pattern g matches the desired pattern f, the correlation image appears with a bright, as in Figure 4, the transmittance of the system is zero when V = 0 and maximum when V = VHW . 11 Nonlinear Optics and the Modulation of Light 525 TABLE 4 VERDET CONSTANT FOR SELECTED MATERIALS V (min/G-cm) l = 589 nm Material H2O Crown glass Flint glass CS2 CCl4 NaCl KCl Quartz ZnS 0.0131 0.0161 0.0317 0.0423 0.0160 0.0359 0.02858 0.0166 0.225 When the constants are evaluated and V is expressed in the standard units of min/G-cm, Eq. (15) becomes V = 1.00831 dn dl We note that the Verdet constant is proportional to both the wavelength of the light and the induced rotatory dispersion in the medium. 86 Chapter 3 Optical Instrumentation Figure 33 Cutaway view of binoculars revealing compound objective and ocular lenses and image-inverting prism. Obtain a second expression for q21/2 by using Eq. (17), 1 il 1 = +, with R21/2; q. The Schmidt Telescope is due to a design of Bernhardt Schmidt. As the grating is rotated, the dispersed spectrum moves across the slit. If the refractive index of the prism is 1.50, determine the prism angle. Thus using a grating with fewer grooves and a larger grating constant requires that we work at a higher order m, where there is increased complication between irradiance and electric field amplitude, I = a ey b E 20 2 and the facts that yi = yr, and ei = er, since they correspond to the same medium, we arrive at the equation E20 = E20r + a ytet cos ut 2 ba bE0t yiei cos u (44) 503 Fresnel Equations Ar Ai u ur A ut At Figure 9 Comparison of cross sections of incident, reflected, and transmitted beams. Water, or a cooling oil, flows through the jacket, removing heat from the laser system. Using the expression for the finesse, F = 2 cn1 > 2 = nfs r > F = 13 GHz2>30 = 100 MHz. a. Light that is linearly polarized along one of the symmetry axes of such a fiber can maintain its state of linear polarization over long distances. Take the nominal frequency of the laser to be n = 5 * 1014 Hz. a. Thus coma is absent when, for all values of u, sin u = constant sin u₂. The bending of a lens, found useful in reducing spherical aberration, is also useful in reducing coma. Determine the maximum width of the primary or single slit. During the progress of ray CF from F to I in time t, however, the ray AD has entered the lower medium, where its speed is, let us say, slower. In general, all one can say is that for constructive interference the two amplitudes subtract (being exactly out of phase). In common parlance, the two amplitudes add (being in phase), and for destructive interference the amplitudes subtract (being exactly out of phase). The virtual image can be observed clearly, without confusion from the other beams. For the case shown, the amplitudes of E1 and E2 are equal, so, at the point of interference, the resultant disturbance is zero. Thus the condition for bright and dark fringes, Eqs. In this case, Eq. (26) can be solved in steady state to give N3 L 1 spIp N k3 hnp T (31) It is important to note that, in the undepleted pump approximation, N3 is approximately constant and although N3 V N0, the rate k3N3 is not negligible. Optical Detectors and Displays Heated cathode Deflecting coil In modern video monitors the entire phosphorescent front of the tube is repetitively scanned in a fixed raster pattern. d (17) where A, B, C, A are empirical constants to be fitted to the dispersion data of a particular material appears transparent and yet behaves as a linear polarizer for all optical wavelengths. Label points on the x-axis with corresponding values of a and b. (a) +0.714 (b) r1 = 17.5 cm; r2 = -105 cm (c) -0.714, reverse the lens 16. This situation occurs when ' the phase difference ψ between E0x and E0y is some angle other than $\psi = 0$, ; p, ;2p, ;mp (linear polarization) or $\psi w =$; p>2, ; A m + 12 B p (circular or elliptical polarization oriented symmetrically about the x,y-axes). Find the phase velocity, in this glass, for a pulse with frequency components centered around 500 nm. In the latter case, suppose that 8 bits (on or off pulses) are required to represent the amplitude of an analog signal. (6)-(9). 20. Most of the common descriptions of the various frequency ranges are given in Figure 1, in which the electromagnetic spectrum is (m) (Hz) 1016 3 1024 GAMMA RAYS 1014 1012 1Å 1010 3 1022 3 1020 X-RAYS 3 1018 1 nm 108 V (Vacuum) 3 1016 UV (Near) 1 mm 106 (Near) 0PTICAL 104 IR 102 1m 1 m-WAVES (radar) (UHF-TV) (VHF-TV) Y Visible spectrum O 3 1012 (Far) 1 cm B G 3 1014 380 nm R 770 nm 3 1010 3 108 (FM-radio) 102 3 106 UV (Near) 1 mm 108 V (Vacuum) 3 1016 UV (Near) 1 mm 108 V (Vacuum) 3 1016 UV (Near) 1 mm 108 V (Vacuum) 3 1016 UV (Near) 1 mm 108 V (Vacuum) 3 1016 UV (Near) 1 mm 108 V (Vacuum) 3 1010 3 1022 3 1020 X-RAYS 3 1018 1 nm 108 V (Vacuum) 3 1016 UV (Near) 1 mm 108 V (Vacuum) 3 1016 UV (Near) 1 mm 108 V (Vacuum) 3 1016 UV (Near) 1 mm 108 V (Vacuum) 3 1016 UV (Near) 1 mm 108 V (Vacuum) 3 1016 UV (Near) 1 mm 108 V (Vacuum) 3 1016 UV (Near) 1 mm 108 V (Vacuum) 3 1018 1 nm 108 V (Vacuum) 3 101 (AM-radio) 1 km RADIO WAVES 104 1000 km 106 108 (AC power) 3 104 3 102 3 Figure 1 Electromagnetic spectrum, arranged by wavelength in meters and frequency in hertz. 6 ATTENUATION The irradiance of light propagating through a fiber invariably attenuates due to a variety of loss mechanisms that can be classified as extrinsic and intrinsic Introduction to Lasers and Their Applications. If light of wavelength 630 nm is used, compute, using the Cornu spiral, the irradiance of the diffraction pattern on the accuracy of the first two chosen rays. When the instrument is used specifically to select individual wavelengths from a discrete spectral source or to allow a narrow wavelength range of spectrum through the exit slit, it is called a monochromator. (a) r11 = 3.4535 cm r22 = -12.6576 cm (b) fD = 5.0026 cm r22
= -12.6576 cm (c) P1D = 0.3695 cm -1, $\Delta 1D = 0.01802$, $\Delta 2D = 0.03928$ (d) yes 23. A brief discussion of interference gratings and several conventional types of grating spectrographs ends the chapter. -2.5 ft, -180 × 23. The law also requires that ray 3, incident normal to the surface 1u1 = 02, be transmitted without change of direction 1u2 = 02, regardless of the ratio of refractive indices. For the example used previously, where n1 = 1.46 and n2 = 1.45, we have \$<2 = 1>292\$ (26) though (29) must sum to zero. If the retardation plate introduces phase differences other than p, the light is rendered elliptically polarized, and some portion of the light will still be transmitted by the analyzer. The source has a spectral distribution close to that of a graybody at 6000 K. Therefore, the propagation constant k is the spatial frequency of the wave. Observation plane 589.3 nm < 1 mm S Double slit 0.04 mm 15 cm 30 cm Problem 18 Straight edge 60 cm > 2 mm 120 cm Figure 23 Problem 15. For a TV station using a 300-MHz carrier, this ratio is 300 MHz/6 MHz, or 50; for an optical fiber using a carrier of 1-mm wavelength 13 * 108 MHz2 to carry the same information, the ratio is 13 * 108 MHz2>6 MHz, or 50,000,000! Currently, optical fibers use only a small fraction of the entire bandwidth theoretically available to an optical signal. At least one of M1 to be made perpendicular to that of M2. In general, the averaging time of physical detectors greatly exceeds an optical period 110-14 - 10-15 s2. Clark Jones.1 First we develop two-element column matrices or vectors to represent light in various modes of polarization. (c) Tungsten lamp with pinhole and filter. Stars are so distant that imaging techniques are unable to resolve their diameters. 13 Two headlights on an automobile are 45 in. Note that the rate coefficients for stimulated emission and stimulated absorption are equal. Combination of the two thus shifts the wavelength of zero net dispersion toward a longer wavelength of zero net dispe switched pulse and (b) estimate the energy in each pulse. Diffraction effects in the near field on the exit side of the aperture are then of the Fresnel type. The amplitude r = r1x, y2 of the reference beam can be assumed constant over the essentially plane wavefront. The first term, EH1 = 1r2 + s22R = 1r2 + s22beam modulated in amplitude but not in phase. In the former case, all rays of a parallel beam incident on the surface obey the law of reflection is obeyed locally for each ray, the microscopically granular surface results in 1 It is of interest to note here that a similar principle, called Hamilton's principle of least action in mechanics, that calls for a minimum of the definite integral of the Lagrangian function (the kinetic energy minus the potential energy), represents an alternative formulation of the laws of mechanics and indeed implies Newton's laws of mechanics themselves. reflectance oscillates between a series of maxima and minima. When $\phi = ml$, an interference principal maximum results, so that the reflection-grating grooves illuminated by light incident at angle ui with the grating normal. The ray incident at the vertex must reflect to make equal angles with the axis. Since the total exposure 1J>m22 of the film depends on the product of irradiance A m2J # s B and time (s), a desirable total exposure may be met in a variety of ways. When the movable mirror is translated by 0.073 mm, a shift of 300 fringes is observed. The radius of each wavelet is, accordingly, yt, where y is the speed of light in the medium. (7) to (9) can be generalized further to yield any initial displacement, therefore, by the addition of an initial phase angle w0 to the phase. Even so-called monochromatic light, unless it has infinite spatial extent and has been in existence for all time, possesses a spread of wavelengths, however narrow, about its average wavelength. Calculate its focal length and refracting power as a thin lens in air. Thus, in 1 m of fiber, there are approximately 1>Ls, or 6580, reflections! Table 1 lists various core and cladding possibilities, for which the critical angle, numerical aperture, and skip distances have been calculated. Consequently, the growing irradiance only reduces the population inversion, and so the gain coefficient, in atoms within, roughly, one homogeneous gain bandwidth of the corresponding cavity-mode frequency. Further, for Eqs. Minimizing dt for all modes requires a value of ap = 2. Thus, xmin 1 The resolution of a microscope is roughly equal to the wavelength of light used, a fact that explains the advantage of ultraviolet, X-ray, and electron microscopes in high-resolution applications. The annual average of total irradiance just outside the earth's atmosphere is the solar constant, 1350 W>m2. Solution As given, s = 25 cm, R = 10 cm, n1lens2 = 1.50 and CL = 5 cm. and a focal length of 56 ft. As shown, the aperture stop (AS) in front of the lens determines the extreme (or marginal) rays that can be accepted by the lens. This is sensible since stimulated absorption attenuates the irradiance, and a large decay rate from level 1 indicates that the atoms do no not dwell a long time in level 1 and so the chances of stimulated absorption events occurring are reduced. The required pump power would be Ppump = Pout 57 W = = 1900 W efficiency 0.03 Two-Mirror Linear Cavity The analysis leading to the output irradiance for the more common two-mirror linear laser, but nevertheless can be carried out in a similar fashion.6 The result for a twomirror cavity like the one shown in Figure 9 (see problem 19) is Iout g012L2 - ln A R11R2 B T2IS = 2 A 1 - 2R1R2 B A 1 + 2R2>R1 B (47) 6 See, for example, Joseph T. What is the maximum depth of polishing defects on the surface? Suppose that the image defocusing or blur circles due to object points in the first and third rows is to be kept smaller than a typical silver grain of the emulsion, say 1 mm. For light diffracted in the direction um, the net path difference from the two slits is ¢ 1 + ¢ 2. As ls is increased, the fringes disappear when equality in Eq. (38) is satisfied. The eyeglass prescription is Rx : -2.00 -1.00 * 180. 3 A conventional 1-mm-thick compact disc (CD) can store 1 Gb of information in the form of digital data, with all of the data stored in the top 1-mm-thick layer of the CD. In problem 3 you will be asked to show that a significant number of hydrogen molecules will be in the first excited rotational energy state at room temperature. If myopic astigmatism is present, for example, vision is faulty on two counts. Liquid-Crystal Displays (LCDs) The atoms or molecules will be in the first excited rotational energy state at room temperature. completely disordered fashion, whereas those in a (solid) crystal are regularly arranged in a periodic fashion. How do they arise and where do they arise are regularly arranged in a periodic fashion. of this value, the fringe contrast is correspondingly improved. And for the second s¿ 10 A Line image B Cylinder axis Figure 29 Focusing property of a convex cylindrical lens. Consistent with his corpuscular theory, however, Newton interpreted this quantity as a measurement of the distance between the "easy fits of reflection" of light corpuscles. 16 A grating is needed that is able, working in first order, to resolve the red doublet produced by an electrical discharge in a mixture of hydrogen and deuterium: 1.8 Å at 6563 Å. E3 k32 E2 spIp k31 hnp sI hn k21 E1 k30 26 k10 k20 E0 Laser Operation INTRODUCTION In this chapter we give a quantitative treatment of laser operation. Since N2 is greater than N1 , however, and B21 = B12 , the rate for stimulated emission, B21g1n2211>c2N2 , exceeds that for stimulated Properties of Lasers absorption, B12g1n2211>c2N1 . The discreteness of the energy of light quanta would be very evident in this case. T. Thus if a volume hologram is illuminated at a given angle u0, only the single wavelength that satisfies the Bragg equation locally, where planar spacing is d, is reinforced and appears as a brightly reflected beam. In this idealized case we have a perfectly monochromatic beam, as considered previously. Shurcliff, W. Their magnitudes, however, are easily shown to be unity in this range, giving total reflection for u 7 uc. Ray diagrams using the principal planes and nodal points are constructed for an arbitrary real object. Simplifying, we find EP = ELb sin b i1kr0 - vt2 e r0 b (9) Thus, the amplitude of the resultant field at P, given by Eq. (9), includes the sinc function 1sin b2> b, where b varies with u and thus with the observation point P on the screen. Another remedy for spherical aberration is achieved by combining positive and negative lenses in an arrangement such that the spherical aberration from one tends to cancel that from the observational arrangement just described, fringes are observed on a screen placed perpendicular to the optical axis at some distance from the aperture, as indicated in Figure 4. The deviation between the two surfaces along any principal ray from a given object point, approximately proportional to the square of the distance from the optical axis. On the other hand, at t = 0 within the 493 Fresnel Equations boundary plane, Eq. (4) yields: B B B k # Br = kr # Br = kr # Br = kr # Br = kr # Br (6) Several conclusions can be drawn from the relations of Eq. (6). 1 RAY AND WAVE ABERRATIONS The departure from ideal, paraxial imaging may be described quantitatively in several ways. The slit is 0.75 mm wide. Second, a narrow-band filter can be used to decrease significantly the linewidth of the light. 8 STOKES RELATIONS In order to account for the multiple internal reflections in a thin film, we must develop some relations for the reflection and transmission coefficients for electric fields incident on an interface between two difference for light rays from the m ≤ 1 m 0, b 0 m ≥ 1 ui (a) Unblazed m ≤ 1 m0 m $\geq
1$ b0 ui (b) Blazed Figure 4 In an unblazed transmission grating (a), the diffraction pattern of a single slit of width 2.125 mm when illuminated normally by a collimated beam of 550-nm light. (a) With no applied voltage the liquid-crystal molecules change orientation through the twisted nematic cell. Maiman built the first laser device. The size of the phase shift resulting from an astronomical event that produces a certain gravitational strain h can thus be increased by using interferometers with longer arms. All crystalline materials exhibiting a Pockels effect8 are also piezoelectric; that is, they show induced birefringence due to mechanical strain. The transmitted light, amplitude modulated and image dat the position of the mask in the image plane of Figure 7, is then represented by E11-x, - y2. For even higher magnifications, the objective is usually designed as an immersion objective. The irradiance at P is, therefore, 11622, or 256, times as great, even for an aperture encompassing only these 16 zones. In this section, we discuss some of the components used in high-bit-rate fiber-optic communication systems. What is the irradiance at the center of the beam waist 1r = 0, z = 02 for this field? (This situation is discussed in the following paragraph.) The perpendicular component propagates with speed y = c > n, as for the ordinary ray. Determine (a) the angle of refraction into the diamond. The intrusion of the reflecting surface, however, means that during the same time interval required for ray CF to progress from F to I, ray BE has progressed from E to J and then a distance equivalent to JH after reflection. (32) or (33), uE and uB are shown to be equal. Assume that the interferometer is designed to demultiplex two light signals of free-space wavelengths l2 = 1550 nm and l1 = 1551 nm. In this way, the other Seidel aberrations will also appear. Izawa, and H. Since a corrective measure for one type of aberration often causes greater degradation in the image due to another type of aberration, the optical solution represents one of many possible compromise lens designs. The pulse is then amplified by the gain medium and returns as a larger pulse just as the gate opens again. One way to do this is to allow the phases f1 and f2 to be functions of time. X-rays X-rays are EM waves with wavelengths in the 10 nm to 10-4 nm range. E01 E02 E1 E2 Figure 23 P Problem 1. To sense the spatial orientation of three-dimensional scenes, the eyes make use of stereoscopic vision. From the point of view of the stationary coordinate system, then, the moving pulse has the mathematical form $y = y_{\xi} = f1x_{\xi}^2 = f$ = a E20i + 2 a a E0iE0j i=1 j7i i=1 since all of the cosine factors are unity in this case. Anyone who has used a camera is aware that the actual color response of film depends on the type of light used to illuminate the subject. The top portion of the figure shows a section of an eye chart (reduced) containing the letter H and several other letters. The parameter w(z), shown in Figure 9, is often called the spot size and marks the transverse distance from the axis of the beam to the point at which the irradiance falls to e-2 L 0.135 of the maximum irradiance f 0.95 b. Modal distortion occurs because propagating rays Figure 8 (a) Spectral attenuation for allglass multimode fibers. New York: Academic Press. In the latter case, the net path difference \$\02222 1 + \$\02222 2 \$, as would be evident in a modified sketch of Figure 1. Another type of noise, called Johnson noise, due to the thermal agitation of current carriers, is found in all photodetectors. As we show in the next section, the spreading due to diffraction from a circular aperture follows a form similar to Eq. (14) but with the replacement of the wavelength l by the factor 1.221. In most cases, however, the image is desired in the same optical medium as the object. When the space between prisms is filled with some other transparent material, such as glycerine, the apex angle must be modified. If the system represents the even prisms is filled with some other transparent material, such as glycerine, the apex angle must be modified. 16 Location of focal points (a) and (b) and construction to determine magnification (c) of a spherical mirror. Solving either Eq. (4) or (5) in steady state (that is, setting the left-hand side of either of these equations to 0) results in the relation r1n02 = A 21 B121N1 > N22 - B21 In thermal equilibrium, Eqs. Is it true that tan uFF w122>z, where uFF is the beam divergence angle, can be used as a good approximation to determine w(z) at z = 50 m? Some of the shards of glass, in one of those freak accidents of nature, Optics of the Eye 435 Myopic eye Blurred vision Myopic eye Before Distinct vision Cornea After Eyeball (a) Flattening (b) embedded themselves in the lad's cornea in a somewhat regular, radial pattern, deep enough to form cuts but not deep enough to penetrate the cornea. In the following we derive the relationships that describe exactly the progress of a single ray of light through a prism. A square wave input arrives at the fiber end at different times, depending on wavelength. Chapter 14 2. 16. Noting that q has the dimension of a length, let us take the real and imaginary parts of q(0) to be, respectively, zOR and zOI so that q102 = zOR + izOI. How far from the pattern center are the first minima along the x and y directions? This language allows a fruitful comparison with the techniques of radio wave communication. This transition gives rise to photons of wavelength 0.6328 mm, photons that are amplified via stimulated emission and form the common red beam characteristic of helium-neon lasers. Note that as far as the optics of the eye itself is concerned, light from distant objects appears to originate at its own myopic far point (M.F.P.), ensuring sharp vision. Substitution of Eq. (17) into Eq. (63) for 1/q(z) and then Eqs. For example, curves (b) and (c) of Figure 4 show two such solutions to the problem, where the inner coating has a thickness of 1>2, as illustrated in Figure 5. As in many other fields, the availability of the laser as a coherent light source has ensured rapid growth. The effect is easily seen by viewing the clear sky through a rotating polarizing filter. Rather, the different wavelength components refract to form image points between the focal lengths fV and fR, as indicated in Figure 7a. The other part is the fraction r2PF1¢z = 2d, ¢t = t2E1+1t2 of the entire right-going intracavity field that existed at Mirror 1 one cavity round-trip time t earlier. Chapter 13 Born, Max, and Emil Wolf. Fiber Optic Communications. 228 Chapter 9 Coherence period T, then in Eqs. As a result, a significant amount of light from these sources cannot be "focused" to a small spot. The overall efficiency of a laser system is the ratio of the total power of the laser. For example, Eq. (7) with the sine function becomes y = A sin[k1x; yt2 + w0] Now suppose our initial boundary conditions are such that y = y0 when x = 0 and t = 0. Electromagnetic waves of different frequencies travel with slightly different speeds through a given medium. Even plane surface will produce some such scattering, since a perfectly smooth surface can only be approximated in practice. These terms comprise the five monochromatic, or Seidel, aberrations, as follows: r4 h¿ r2 cos 2 u h¿ 2r2 h¿ 3r cos u O M I E spherical aberration coma astigmatism curvature of field distortion Each aberration is characterized by its dependence on h¿ (departure from axial imaging), r (aperture of refracting surface), and u (symmetry around the axis). There will thus exist multiple parallel beams emerging from the top surface, although with rapidly diminishing amplitudes. Rowland circle ≥22 with a concave grating. 8 Compare the relative irradiances of the first two secondary maxima of a circular diffraction pattern. flap is created with a precisely controlled laser so that computer-driven lasers perform the entire optical-sculpting procedure. (35) and (36), n2R - n2I = 1 + v20 - v2 Ne2 c 2 d me0 1v0 - v222 + g2v2 (37) and 2nInR = gv Ne2 c 2 d me0 1v0 -
v222 + g2v2 (38) The equations can be solved simultaneously for nI and nR. The slowly increasing index with frequency (decreasing with wavelength) is characteristic of normal dispersion. The ring radii are given by Eq. (39). This system is described by Eqs. Compare N0 to N1, N2, and N3 for the pump irradiances of parts (d) and (e). To function as a half-wave plate, f = p, and we find that the required voltage VHW is given by VHW = d (12) 22KL Example 4 Consider a nitrobenzene Kerr cell for which K = 2.4 * 10-12 m>V2 (see Table 3) at room temperature and l = 589 nm. The real part of f(t) is plotted. Ray B thus represents an extreme ray, defining the slant face of a cone of rays, all of which satisfy the condition for total internal reflection within the fiber. A double hyperbolic lens then functions as shown in Figure 14. At that point, t = 0 and the path difference between reflected rays is l>2, as a result of reflection. 70 Chapter 3 Optical Instrumentation Lens Figure 20 Simple camera. Further, let us take the index of refraction of the fiber to be n so that the wavelength of L = 2 cm, a small-signal gain coefficient at the transition linecenter of g01n02 = 1 > cm, and a saturation irradiance at the transition linecenter of IS1n02 = 100 W > cm2. The controlling element in this connection is called the field stop, and it is related to an entrance window and an exit pupils. Determine the size of the block letter and letter detail (in inches) for each row of letters. 7, 8. Are clear distinguishable fringes then formed on a screen near point P1? The approximation to a square pulse obtained using a Fourier series representation with a finite number of terms is illustrated in Figure 3. Thus the circles do not close but spiral inward. At a wavelength of 492 nm and a refractive index of 1.30, determine the storage capacity of 1 mm3 of hologram volume. Thus they cancel and so no light is focused by the zone plate at the focal point r0 = f1 > 2. This example illustrates the general rule: The entrance pupil EnP is the image of the controlling aperture stop is the first such element (a front stop), it serves itself as the entrance pupil. The radius of curvature of the window is 5 cm. (46) For a glass substrate 1ns = 1.522 and incidence from air 1n0 = 12, the ideal ratio for the two films is n2>n1 = 1.23. 4 THE REFRACTION MATRIX Consider next the refractive indices n and n_i, as shown in Figure 6. We have argued that when the screen is at the distance si from the lens, one sees a focused line image AB on the screen, in this case with a horizontal orientation. 2 A lamp located 3 m directly above a point P on the floor of a room produces at P an illuminance of 100 lm>m2. Lloyd's Mirror In Figure 7, interference fringes are produced due to the superposition of light at the screen that originates at the actual source S and, by reflection, also originates effectively from its virtual source S_{i} below the surface of the plane mirror MM_{i} . From Eq. (22), with a0 = af = a, a = Cy0 + Da or y01 - D = a C (28) Combining Eqs. The regions of low field amplitude between the pulses result from the juxtaposition of constituent waves more or less out of phase. If the path OPQ is resolved into its x-, y-, and z-components, it is clear that the direction of ray OP is altered by the reflection, and then in such a way that its z-component is simply reversed. Further, it should be evident from Figure 31 that, as a screen, initially positioned just behind the lens, moves toward the line image AB, the horizontal dimension (width) of the blur increases and its vertical dimension (height) decreases. Thus the sinusoidal grating produces a transmission function like that of Figure 3, show that, for a guided ray traveling at the steepest angle relative to the fiber axis, the skip distance Ls can be expressed by Ls = 14 a. 17 Remember that the energy of a light beam is proportional to the square of its amplitude. The family of circular and straight, parallel fringes we have been discussing can be seen as special cases of two point-source interference, observed in planes perpendicular and parallel, respectively, to the axis joining the points, Nevertheless, cylindrical lenses are important, for example, in the field of optometry for correcting the visual defect known as astigmatism, as well as in novel visual displays where it is useful to image points as lines. The four radii of curvature are indicated. The potential offered for submarine detection is an obvious military application. After traversing the vitreous humor, light rays reach their terminus at the inner rear layer of the eye, the retina, literally translated as "net." The retina is that part of the eye, the retina is that part of the eye, the "screen," that receives light energy and converts it into electrochemical energy. Solution 1 M = C 1 50 0 1 1.6 S C 0 5 1 S C- 1 1 120 0 1 S 1.6 or 23 24 M = D 7 1200 25 8 T 17 16 The elements of this composite ray-transfer matrix, usually referred to in the symbolic form M = c A C B d D describe the relevant properties of the optical system, as we shall see. Using Eq. (16), the trigonometric identity cos d = 1 - 2 sin21d>22, and simplifying a bit allows the transmittance to be put into the form of the Airy function, T = 1.1 + [4r > 11 - r222]sin 21d > 22 (24) Coefficient of Finesse Fabry called the square-bracketed factor in Eq. (24), which is a function only of the reflection coefficient r of the mirrors, the coefficient r of the mirrors, the coefficient of Finesse Fabry called the square-bracketed factor in Eq. (24), which is a function only of the reflection coefficient r of the mirrors, the coefficient r of the mirrors, the coefficient r of the mirrors, the coefficient r of the mirrors of the mirr T = 1 1 + F sin21d>22 (26) The coefficient of finesse is a sensitive function of the reflection coefficient r since, as r varies from 0 to 1, F varies fro act independently (incoherently), so that their net irradiance is the sum of their individual irradiances. Because dispersion is present in materials, ¢k is not typically zero and the irradiance factor describes the consequent reduction in the ir they propagate through the nonlinear crystal. Determine (a) the frictional constant g, (b) the plasma frequency vp, (c) the real and imaginary parts of the foil. The rear stop in Figure 1b is automatically the ExP for the system because it is the last optical component. In two dimensions, the transform pair takes the form +q 1 g1kx, ky2 = i12p22 O - q (6) + q g1kx, ky2 = 0 f1x, y2ei1xkx + yky2 dx dy (7) - q Any nonperiodic function of plane waves, each with amplitude g1kx , <math>ky2 = 0 f1x, y2ei1xkx + yky2 dx dy (7) - q Any nonperiodic function of plane waves, each with amplitude g1kx , <math>ky2 = 0 f1x, y2ei1xkx + yky2 dx dy (7) - q Any nonperiodic function of plane waves, each with amplitude g1kx , <math>ky2 = 0 f1x, y2ei1xkx + yky2 dx dy (7) - q Any nonperiodic function of plane waves, each with amplitude g1kx , <math>ky2 = 0 f1x, y2ei1xkx + yky2 dx dy (7) - q Any nonperiodic function of plane waves, each with amplitude g1kx , <math>ky2 = 0 f1x, y2ei1xkx + yky2 dx dy (7) - q Any nonperiodic function of plane waves, each with amplitude g1kx , <math>ky2 = 0 f1x, y2ei1xkx + yky2 dx dy (7) - q Any nonperiodic function of plane waves, each with amplitude g1kx , <math>ky2 = 0 f1x, y2ei1xkx + yky2 dx dy (7) - q Any nonperiodic function of plane waves, each with amplitude g1kx , <math>ky2 = 0 f1x, y2ei1xkx + yky2 dx dy (7) - q Any nonperiodic function of plane waves, each with amplitude g1kx , <math>ky2 = 0 f1x, y2ei1xkx + yky2 dx dy (7) - q Any nonperiodic function of plane waves, each with amplitude g1kx , <math>ky2 = 0 f1x, y2ei1xkx + yky2 dx dy (7) - q Any nonperiodic function of plane waves, each with amplitude g1kx , <math>ky2 = 0 f1x, ky2 = 0

kx and ky are the spatial frequency components needed in the expansion to represent the desired function f(x, y). We now show that Eq. (17) is equivalent to the Bragg diffraction condition. By far the largest amount of light energy is diffracted into the central maximum. The total energy density is the sum u = uE + uB = 2uE = 2uB or u = e0E2 = a (35) Consider next the rate at which energy is transported by the electromagnetic wave, or its power. (Courtesy Carl Zeiss, Inc., Thornwood, N.Y.) angles a¿>a, as shown. We may argue rather neatly that when minimum deviation occurs, the ray of light passes symmetrically through the prism, making it unnecessary to subscript angles, as shown in Figure 11 This speed emerges naturally from Maxwell's equations and is given, approximately, as c = 3 * 108 m>s. Quantum Optics. The dashed curve is the observed sum of independent diffraction peaks. A thicker composite of two plates may also be formed, in which one plate compensates for the retardance of all but the desired ¢w of the other. Because of the rapid decrease in the subzone phasor magnitudes 1b1, b2, Å 2 the phase angle of A 1 relative to the reference direction is less than p>2. Thus a reduction in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by an increase in the population density of state 2 must be accompanied by a must be accompanied Fermat's principle of least time must predict the same path as determined for the original direction of light propagation. Determine the luminance of the sun. Let light from this source be incident on a scanning Fabry-Perot interferometer of nominal length d = 5 cm. The transmission function of a given object in the aperture plane can be simultaneously correlated with many different reference functions by separating the reference functions as horizontal strips, or channels, on the mask. To assist in the calculation, point G is shown midway between A and C at the foot of the altitude BG in the isosceles triangle ABC. Although such scattering is much less effective, per oscillator, than Rayleigh scattering, the density of oscillators in this case leads to considerable scattering. Also, the distances r and r¿ are no longer so much greater than the size of the aperture that Fraunhofer different points of the source but in the same plane and making the same angle ut with the axis satisfy the same path difference and also arrive at P. For example, if the aperture diameter 4.5w = 1 cm, the collimated beam length 2z0 is equal to 24.5 m for He-Ne light at 1 = 632.8 nm and 1.46 m for CO2 light at 10.6 mm. Let us now examine these figures in turn. 2 a. Such a review naturally begins with a discussion of the interaction of light and matter in thermal equilibrium. Reading, MA: Addison-Wesley Publishing Company, 1963. Thus, for the single slit z = w, and by S(y) 1.5 2.5 \ge 0.5 1.0 2.0 P \Leftrightarrow O \Leftrightarrow S y O w \ge 0.5 \ge 0.5 \ge 0.5 \ge 0.5 \ge 0.5 1.0 2.0 P \Leftrightarrow O \Leftrightarrow S y O w \ge 0.5 \ge 0.5 \ge 0.5 \ge 0.5 \ge 0.5 \ge 0.5 1.0 2.0 P \Leftrightarrow O \Leftrightarrow S y O w \ge 0.5 \ge 0.5 \ge 0.5 \ge 0.5 \ge 0.5 \ge 0.5 \ge 0.5 1.0 2.0 P \Leftrightarrow O \Rightarrow 0.5 \ge 0.5 \ge Cornu spiral (b). And today, some 60 years later, the puzzle of tweedledum and tweedledue lingers. The radiant power density, or irradiance, Ee 1W>m22, measures the time average of the square of the wave amplitude. Two other closely related applications of the Pockels cell are illustrated in Figures 6 and 7. (b) 241 Coherence Example 3 When Michelson used this technique on the star Betelgeuse in the constellation Orion, he found a first minimum in the fringes at ls = 308 cm. Each procedure modifies the top layer of the 530-mm-thick cornea, while preserving the structural integrity of the layers underneath. (1)-(3) can be written as B E0 = EvN B E0r = EtvN (11) Here, E, Er and Et are the complex field amplitudes associated, respectively, with the incident, reflected, and transmitted waves. Express the answer as some number times the unobstructed irradiance there. For normally incident light, however, the grating equation limits the maximum wavelength (at u = 90°!) under these conditions to 200 nm. Also, since 'E0 = x RCP Notice that one of the elements in the Jones vector for circularly polarized light is now purely imaginary, and the magnitudes of the elements are the same. However, this large photon number density (cm aginary, and the magnitudes of the elements are the same. However, this large photon number density (cm aginary, and the magnitudes of the elements are the same. 0.2 0.4 0.6 0.8 1 1.2 1.4 Time (ms) to drive the population inversion below its threshold value, at which time cavity loss exceeds gain and the photon number density begins to decrease. Electromagnetic (EM) waves are produced by 7 Nature of Light accelerating charge distributions, carry energy, and exert forces on charged particles upon which they impinge. Iodine reacts with the deposited tungsten to form the gas tungsten iodide, which then dissociates at the hot filament to redeposit the tungsten and free the iodine for repeated operation. Notice that the off-axis system illustrated in Figure 2a produces a hologram in which the tungsten iodide, which then dissociates at the hot filament to redeposit the tungsten indice that the off-axis system illustrated in Figure 2a produces a hologram in which the tungsten indice, which then dissociates at the hot filament to redeposit the tungsten indice that the off-axis system illustrated in Figure 2a produces a hologram in which the tungsten indice, which then dissociates at the hot filament to redeposit the tungsten indice the tungsten indice that the off-axis system illustrated in Figure 2a produces a hologram in which the tungsten indice the tungsten indindindice the tungs zeroth-order beam. Between positions of common phase, since the fields have different frequencies, the fields tend to destructively interfere. The amount and location of pigment in the iris determine whether the eye looks blue, green, gray, or brown. Thus, f = - R 7 0, e 2 6 0, concave mirror (13) s f (b) ho a ui hi ur and the mirror equation can be written, more compactly, as 1 1 1 = + s & f F C a (14) s s (c) 5 Although this set of sign conventions is widely used, the student is cautioned that other schemes exist. Goodman, Joseph W. Absorption and emission of electromagnetic waves is therefore an important mode of energy exchange between systems. A critical angle of incidence uc is reached when the angle of refraction reaches 90°. Example 1 A traveling wave in a string has a displacement from equilibrium given as a function of distance along the string x and time t as $y(x, t) = (0.35 \text{ m}) \sin[(3p/m) * - (10p/s)t + p/4)]$ Determine the wavelength, frequency, velocity, and initial phase angle. This source is a cylindrical tube or rod of refractory material (zirconia, yttria, thoria) heated by an electric current and useful from the visible to around 30 mm. Of course, the Jones calculus can handle a case where polarized light is transmitted by a series of polarizing elements, since the product of element matrices can represent an overall system matrix. (b) Refraction by a thick lens. (c) 0 (d) 1100 W/m2 (e) 1.11×105 W/m2 (f) For = 1/cm: N0 /NT = 0.993; for = 0.01/cm: N0 /NT = 0.9993 reasonable for both (g) 1100 W/m2; 1.10×105 W/m2 7. $0 \ge 25 \ge 50$ 0.7 0.8 0.9 1 1.1 1.2 1.3 Wavelength (m) 1.4 1.5 1.6 1.7 Example 3 Using Figure 13, calculate the pulse spread due to material dispersion in pure silica for both a LED and a LD light source. Even when the signal is zero, the reference beam is of sufficient strength to stimulate the emulsion within its region of linear response to radiant energy. Thrierr, Atlas of Optical Phenomenon, Plate 16, Berlin: Springer-Verlag, 1962.) Example 3 Find the diameter of the Airy disc at the center of the = 10 m from a uniformly illuminated circular aperture of diameter D = 0.5 mm. the train of reflections. We wish to find next the particular function f. Note that the beam spreads while maintaining nearly spherical wavefronts that change radius of curvature as the beam propagates. Take the electric fields of the individual beams to be $E1 = 2 \cos 1 ks^2 - vt^2 1 kv > m^2 1 kv >$ Evaluate modal distortion in a fiber by
calculating the difference in transit time through a 1-km fiber required by an axial ray and a ray entering at the maximum entrance angle of 35°. Many of the quantum detectors discussed in the next section are better suited to high-frequency operation. To produce a 1 + 2 magnification in the construction of Figure 16c, where stimult itself be negative, we modify Eq. (15) to give the general form m = - The following example illustrates the correct use of the sign convention. How long is the image of the meter stick? So as ¢ varies by one wavelength, the phase k¢ varies over an entire cycle of range 2p. Thus, as atoms funnel rapidly from pump levels E3 to E2, they begin to pile up at the metastable level, which functions as a bottleneck. For real mirrors with absorption losses, the maximum transmittance is somewhat less than unity., when a monochromatic field of frequency n? and irradiance I is incident on an assembly of atoms like the one depicted in Figure 11a is RSt. Abs. For this ray the deviation angle dm is given by dm = a1n - 12. The unpolarized light is represented by two perpendicular (x and y) vibrations, since any direction of vibration present can be resolved into components along these directions. The image is turned inside out. Objective lens Star light 12 Assume that a 2-mm-diameter laser beam (632.8 nm) is diffraction limited and has a constant irradiance over its cross section. If there were several nearby point sources emitting light of the same frequency but with random relative phases, the spatial coherence of the resulting wavefield would be reduced. Assume the crown glass lens to be equiconvex. In symbolic form, we have, from Eq. (13), c yf A d = c C af B y0 dc d D a0 (21) which is equivalent to the algebraic relations yf = Ay0 + Ba0 af = Cy0 + Da0 (22) 1. To do so, we should first relate the round-trip phase shift d to the frequency of the input field n. Symbolically, g1k2 = C-15g1k26 (4) Here C and C-1 represent, respectively, the Fourier-transform operation and its inverse. From this approach, one can reason that the diffraction pattern of the slit is symmetrical about its center and that the irradiance, while oscillatory, is never zero. Note that the Rayleigh range z0 is also a convenient measure of the distance over which a beam spreads appreciably in the near field. A lens of focal length 60 cm is placed behind the slit. For example, 1 dm of turpentine rotates sodium light by - 37°. For propagation between two points in the same uniform medium, the path is clearly the straight line joining the two points. On the other hand, the refractive index of the ordinary ray is a constant, independent of direction. For an assembly of gain atoms each of mass M at temperature T, ¢nD = a 8kBT Mc2 1>2 ln122b (52) n0 Figure 11 shows the lineshape function g1n2 for a Doppler-broadened gain medium consisting of atoms each of which has a homogeneous linewidth ¢nH. Dye lasers emit radiation tunable across the entire visible spectrum. 1 + s11œ = 16 gives OP imaged through L1: s1 = 18 cm, f1 = 6 cm; 18 s1œ = 9 cm right of L1 or 5 cm to the right of L2. (46) and (47) together with Figure 14 to obtain values for w02 and z2. 348 Chapter 14 Matrix Treatment of Polarizet with transmission axis at 45°; (c) a quarter-wave plate with slow axis horizontal. The concept is defined 232 S Path Pa th 2 1 Chapter 9 Coherence S1 P S2 Figure 8 Interference at P due to waves from S traveling different paths. To see that this is not always the case, look at Figure 8 Interference S1 P S2 Figure 8 Interference at P due to waves from S traveling different paths. Both its location and size (magnification) are shown. Beam-shaping optics with D U 4.5w transmit essentially 100% of the beam power without superimposing additional diffraction effects on the beam. Cambridge: Harvard University Press, 1962. Broader regions of low reflectance result for 1>4 – 1>4 coatings when the substrate index is larger than that of the adjacent film layer, that is, ns 7 n2. The labor involved in the design of a suitable lens that meets particular specifications within acceptable limits has been reduced considerably with the help of computer programming. The directly propagated light could therefore be represented by a phasor in the vertical direction, making an angle of p>2 with a 1. Find the FWHM 2¢n1>2 of the transmittance peaks. One also inputs the desired overall focal length of the achromat. A geometrical relation exists between the radius of curvature R of the air film or the lens surface. Gas atomic lasers are typically Doppler broadened and have low efficiencies (less than 1%). Evidently, the electric field vector may reverse direction on reflection. Optical data processing represents a fruitful convergence of the fields of optics, information science, and holography. However, spherical-mirror cavities also have a more complex transmittance spectrum than do the flat-mirror cavities just considered. To extend the usefulness of the spectrograph farther into the ultraviolet, for example, prisms made from quartz 1SiO22 and fluorite 1CaF22 have been used. (Courtesy Corning Glass Works.) (b) Spectral attenuation for all-plastic fiber cable. By such optical means, two-dimensional pictures or text are processed at once, without the necessity of the spectrograph farther into the ultraviolet, for example, prisms made from quartz 1SiO22 and fluorite 1CaF22 have been used. sequential scanning of the object. Light, Vol. An unpolarized incident beam is B conveniently represented by two perpendicular E-vibrations. The shortest distance L from A to B is taken by the environment of the convolution of two functions is equal to the product of their individual transforms. The shortest distance L from A to B is taken by the environment of the convolution of two functions is equal to the product of their individual transforms. axial ray; the longest distance L; from A to B is taken by the steepest propagating ray that reflects repeatedly at the critical angle wc. The chapter next treats standing waves that result from the superposition of a harmonic wave with its reflected counterpart. In this example we have assumed that the medium to the right of the spherical surface extends far enough so that the image is formed inside it, without further refraction. Although simple in structure, it is a high-resolution instrument that has proven to be a powerful tool in a wide variety of applications. This must be the edges of EnP are the images of the edges of t of AS. Figure 15a shows, in four steps, what happens to a typical atom in the laser medium during the creation of a laser photon. When AB = ml, the grating Eq. (34) follows immediately. In doing so we have implicitly assumed that the irradiance of the field is constant temporally and spatially. Now the quantity r2 is just the reflectance R: R = EOr 2 Pr Ir = = a b = r2 Pi Ii E0i Comparing Eq. (47) with Eq. (42), it follows that the transmittance T is expressed by the relation cos ut 2 bt T = na (48) cos u 504 Chapter 23 Fresnel Equations Notice that T is not simply t2 since it must take into account a different speed and direction in a new medium. The stored charge contributed by each pixel, a measure of the local irradiance, is electronically scanned to produce an electronic record of the image. In the process, N2 grows to a large value. This procedure is outlined next and illustrated in Figures 22 and 23. In this case, af = Cy0, independent of a0. The carrier wave can be modulated to contain the signal information in various ways, usually by amplitude modulation (AM), frequency modulation. Using Eq. (52), we conclude that the exit pupil for this pair of binoculars is 5 mm, a good match for the normal pupil diameter. Boundary Conditions for TM Waves Before pursuing the significance of Eqs. The lower curves have the same small-signal gain coefficient 20 g0 2/cm IS 10 W/cm2 IL (W/cm2) 15 Figure 7 Irradiance output IL from a gain cell as a function of the length L of the gain cell. In addition, as we show later, the rate at which light energy stored in an optical cavity decreases over time due to transmission through and absorption by the cavity mirrors is directly related to the FWHM, 2¢n1>2, of the transmittance peaks of the same cavity used as a Fabry-Perot interferometer. A variation in transmittance of the type T = T0 + Tm cos21ar22 is produced, and higher-order images are eliminated. Typically, two blackened sensitive elements are used in adjacent arms of a bridge circuit, one of which is exposed to the incident radiation. In this way, the spectral range of the incident light is limited by filtering until overlap is removed and each line can be correctly identified. How many visible 11 = 555 nm2 photons/s would correspond to a detected power of 6.63 * 10-16 J>s? The third number refers to the orientation of the cylinder axis, specifying whether the axis of the cylinder is to be vertical, horizontal, or somewhere in between. The second formulation is suggested by Figure 9. These demultiplexing relations are explored in Example 4 and problem 28. 405 406 Chapter 18 Matrix ELEMENTS We examine now the implications that follow when each of the matrix elements in turn is zero. The reflected light is admitted into a prism spectroscope. (a) At laser turn on, the gain coefficient has its smallsignal value and three cavity modes are above threshold, and so the irradiance grows at these frequencies. The wave vector E of the incident wave is chosen in the +y-direction, so that the wave is chosen in the +y-direction, so that the wave is chosen in the +y-direction. r Br Bt ut Plane of incidence Er P ur kr n1 E u z k B x Normal Figure 1 Defining diagram for incident, reflected, and transmitted rays at an xyplane interface when the electric field is perpendicular to the plane of incidence, the TE mode. The mode-locking "gate" can be any of the devices, described earlier, that could be used as Q-switches, provided that the gate
can be opened and closed over a time period shorter than a cavity round-trip time. Then P2 = 12 e0x2E 20 + 12 e0x2E 20 cos 2vt (5) Evidently, the second-order polarization P2 consists of a term of twice the frequency of the applied optical field as well as a constant or DC component that represents optical rectification. Compare with the distances given in Figure 3. The situation is shown graphically at an arbitrary instant in B B Figure 19a. f. 296 Chapter 12 The Diffraction Grating The angular dispersion in the wavelength region around 500 nm can now be calculated: $\mathcal{P} = 1 \text{ m} = 5165 \text{ rad} \times \text{m} + 2000 \text{ m} + 20000 \text{ m} + 200000 \text{ m} + 200000 \text{ m} + 200000 \text{ m} + 2000000000000000$ linear dispersion is then found from f = 1500 mm215.165 * 10-4 rad>nm2 = 0.258 mm>nm and the plate factor is 1>0.258 = 3.88 nm>mm. A variation of the photovoltaic cell, the avalanche diode, provides an internal mechanism of amplification that results in enhanced sensitivity out to around 1.5 mm. An investigation of the general case of arbitrary elliptical polarization is left as an exercise (see problem 24). When two systems at different temperatures are brought together, there is a net energy flow from the system at higher temperature to the system at lower temperatures are brought together, there is a net energy flow from the system at lower temperature to the system at higher temperature to the system at lower temperature temperat hologram is that a contact print of the hologram, which interchanges the optically dense and transparent regions, has the same properties in use. The source is a 6.2-mm diameter silicon carbide resistor. Now group velocity yg = dv>dk and phase ve expected. y Aperture sin x - cos x 1px Problem 22. Sketch a level diagram like Figure 5 appropriate for this case and indicate the various stimulated and decay processes with arrows on the level diagram. To this end, we first review briefly some important relations involving complex numbers. Then, in terms of the line width \$\epsilon\$1, the coherence length takes the form lt 12 ¢l (17) 12 lt (18) Thus, the line width ¢l is ¢l To digress briefly, it is interesting to note that Eq. (18) has a formal similarity to the uncertainty principle of quantum mechanics, where a wave pulse can be used to represent, say, the location of an electron. beyond ball (a) Elements of a system matrix: A = 16, B = 23, $15 \ 1 \ C = -150$, D = 14 (b) p = -140, q = 160, r = s = 10, 15 f1 = -150, f2 = 150, all in cm 14. Thus, the first principal maximum from the center, at a = p, occurs when the phase difference between successive waves is precisely 2p. New York: Academic Press, 1979. The electron is set into forced oscillation by the alternating electric field of incident light and at the same frequency By comparison, this amplitude at P is 16 times the amplitude 1a1>22 of a wholly unobstructed wavefront. (Photo by J. At the screen, point P with coordinates (x, y) is on the required surface ©. To show how his model of light propagation implied the laws of geometrical optics, he enunciated a fruitful principle that can be stated as follows: Each point on the leading surface of a wave disturbance— the wavefront. By taking the square of the magnitude of both sides of Eq. (29), the 541 Optical Properties of Materials result describes instead the energy flux density, giving I = I0e -az where a = 2kI is the absorption coefficient of the medium. (a) 29.3%, 34.5%, 45.4%, 65.7%, 100% (b) 29.3%, 24.2%, 14.9%, 5.4%, 100% 18. New York: Holt, Rinehart and Winston, 1985. The three subpixels are coated with red, green, or blue phosphor. We call the real image formed by surface (2). A population inversion is shown near the center of the bands where there is an excess of electrons in the conduction band. Since multiplying a Jones vector by an overall constant does not change the character of the polarization described by surface (2). by the Jones vector, we shall adopt the convention that A is positive. c d 6 + 8i i b. Determine its angular and linear dispersion in first order when used with a lens of focal length 0.5 m. Show in a phasor diagram the following two harmonic waves: E1 = 2 cos vt and E2 = 7 cosa p - vt b 4 b. Thus, the chief ray involves the centers of AS, EnP, and ExP, as defined. However, the usual departures from perfectly ordered atomic arrangement lead to some scattering in other directions as well. What thickness of quartz is required to give an optical rotation of 10° for light of 396.8 nm? The radii of curvature thus satisfy r12 = - r11 , r21 = r12 , and r22 = r12 1 - K2r12 (47) In the design of an achromatic doublet the three indices of refraction for each of the glasses to be used are taken from manufacturer's specifications, like those presented in Table 1., 3 31, 32, 21 + 2, 1 ± 3 , 2 ± 3 (a) 5983 nm (b) 0.046 9.84 kV; VHW is independent of the length 7.9 × 10-6; /2 (a) $\Phi = 2, 4, ...; V = 2VHW$, 4VHW, ... (b) At V = 2VHW, 4VHW, 0, I = I max; at V = VHW, I = 0 $\Phi \text{pock} / \Phi \text{kerr} = (r/K)(n30 / 0 VL)$; 73 3.47 m; not practical The sound wave advances 150 nm, which is /3.3 for = 500 nm (d) 67 221 MHz 2.97 For a 5-cm length, the current is 31.8 A (a) 0.0647 min/G-cm 14.1°; 0.0712 µm-1 Chapter 25 (b) $nI = 0.455\sqrt{KI}$; $nR = 1.099\sqrt{KI}$ (a) $4.80 \times 1013 \text{ s}-1$ (b) $1.38 \times 1013 \text{ s}-1$ (b) $1.38 \times 1013 \text{ s}-1$ (b) $1.38 \times 1013 \text{ s}-1$ (c) $1.38 \times 1013 \text{ s}-1$ (c) $1.38 \times 1013 \text{ s}-1$ (d) $1.38 \times 1013 \text{ s}-1$ (e) $1.38 \times 1013 \text{ s}-1$ (f) $1.38 \times 1013 \text{ s}-1$ (f) $1.38 \times 1013 \text{ s}-1$ (h) $1.38 \times 1013 \text{ s}-1$ (h) 1.1016 s-1 (c) nR = 0.0292; nI = 3.926. Notice that in this B case of the extraordinary ray in an anisotropic medium, E is not perpenB dicular to k. The matrix elements from Eq. (24), appropriately modified to become m11 = cos d m12 = m21 = in1 1e0m0 m22 = cos d (39) are substituted into Eq. (36). (Hint: The molecule can be vibrating and rotating at the same time.) a. The OA of calcite is directed through these diagonally opposite corners in such a way that it makes equal angles with the three faces there. Circular Polarization f p 2 Left: ~ E 1 Right: ~ E 1 ~ E Right: ~ E 1 ~ E Right: ~ E 1 ~ E A certain He-Ne laser cavity of the type shown in Figure 6 has a mirror separation of 30 cm. This situation means that the corneal surface is more sharply curved in the vertical meridian and that vertically oriented details. Miller, Enrique A. Solution From Table 2, we find r = 24.1 * 10-12 m>V and a refractive index of 1.51 A Q-switched laser system is an optical analogue to a capacitor. The strength and duration of the relaxation oscillations are sensitive functions of the parameters governing the laser system. Reducing the hole spacing expands the fringe pattern formed by each color. According to a general theorem, known as the Van Cittert-Zernike theorem1, a plot of the degree of coherence versus spatial separation / of points P1 and P2 is the same as a plot of the diffraction pattern due to an aperture of the same size and shape as the extended source. Thus, the sharper or narrower the pulse, the greater is the number of frequencies required to represent it, and so the greater the frequency bandwidth of the harmonic wave package. If the substrate is glass, with ns = 1.52, the ideal index for a nonreflecting coating is n1 = 1.23, assuming an ambient with n0 = 1. Recall that the irradiance of the resulting fringe pattern was calculated by treated as points. D = 0. 17 A 20-cm focal length positive lens is to be used as an inverting lens; that is, it simply inverts an image without altering its size. Spatial coherence between wavefront points A and B at the slits is insured as long as the source S is a true point source. The redirected rays can be used to locate the image. In this chapter, we begin with a brief history of light, addressing it alternately as particle and wave. Before adding to our collection of new concepts that arise from a consideration of apertures in optical systems, we consider a system slightly more complex that arise from a consideration of apertures in optical systems. axis with the same result. Determine the solid angle ¢v in terms of R and a. The following example helps clarify the differences in the momentum, wavelengths, however, the l>2 layer helps to keep R below values attained by a single l>4 layer alone. As long as the Airy discs are well separated, the images are well resolved. Previously, as Eq. (34), we formed this ratio using the round-trip phase shift d as the independent variable. rays from object points striking spherical surfaces at angles that exceed those set by the paraxial approximation. The interaction of an electromagnetic field with a pair of atomic or molecular energy states can be described by three processes: stimulated absorption, and spontaneous emission. If each of these planes is moved some distances. Shioda, T. Notice that the chief ray passes (actually or when extended) through the centers of AS and its conjugate planes, EnP and ExP. Equation (4), which describes the total electric field at point P of Figure 17a are simply reversed, shows clearly that an array of Mach-Zehnder interferometers can also serve a multiplexing function. In this case, the phase difference f21t2 - f11t2 will be strictly zero if the beam waist in the cavity. Both the shape and size of the diffraction pattern depend on the distance between the aperture and the screen. 28 Chapter 2 Geometrical Optics u u P R a O V s Figure 15 surface. If, in turn, one of the apertures, say A, and then the other, B, are put into ude there. Notice that in each case, rays intersecting the edg es of the entrance pupil also (actually edges of the exit pupil. 116 Chapter 5 E1 Superposition of Waves 1.5 1 0.5 0 $\geq 0.5 \geq 1 \geq 1.5$
t 1.5 1 E2 0.5 0 $\geq 0.5 \geq 1 \geq 1.5$ t 1.5 1 E2 0.5 0 $\geq 0.5 \geq 1 \geq 1.5$ ER t 1.5 1 0.5 0 $\geq 0.5 \geq 1 \geq 1.5$ t 1.5 1 E2 0.5 0 $\geq 0.5 \geq 1 \geq 1.5$ t 1.5 1 0.5 0 $\geq 0.5 \geq 1 \geq 1.5$ t 1.5 1 0.5 0 $\geq 0.5 \geq 1 \geq 1.5$ t 1.5 1 0.5 0 $\geq 0.5 \geq 1 \geq 1.5$ t 1.5 1 0.5 0 $\geq 0.5 \geq 1 \geq 1.5$ ER t 1.5 1 0.5 0 $\geq 0.5 \geq 1 \geq 1.5$ t 1.5 1 0.5 0 \geq 0.5 \geq 1 \geq 1.5 t 1.5 1 0.5 0 \geq 0.5 \geq 1 \geq 1.5 t 1.5 1 0.5 0 $\geq 0.5 \geq 1 \geq 1.5$ t 1.5 1 0.5 0 \geq 0.5 \geq 1 \geq 1.5 t 1.5 1 0.5 0 \geq 0.5 \geq 1 \geq 1.5 t 1.5 1 0.5 0 \geq 0.5 \geq 1 \geq 1.5 t 1.5 1 0.5 0 \geq 0.5 \geq 1 \geq 1.5 t 1.5 1 0.5 0 \geq 0.5 \geq 1 \geq 1.5 t 1.5 1 0.5 0 \geq 0.5 \geq 1 \geq 1.5 t 1.5 1 0.5 0 \geq 0.5 \geq 1 \geq 1.5 t 1.5 0 = 0.5 \geq 1 \geq 1.5 t 1.5 1 0.5 0 \geq 0.5 \geq 1 \geq 1.5 t 1.5 0 = 0.5 \geq 1 \geq 1.5 t 1.5 0 = 0.5 \geq 1 \geq 1.5 t 1.5 0 = 0.5 \geq 1.5 t 1.5 0 = 0.5 \geq 1 \geq 1.5 t 1.5 0 = 0.5 \geq 1.5 t 1.5 0 = 0.5 Three cases of the superposition of waves of the same frequency at a fixed point in space. 327 Fresnel Diffraction Solution Consider Figure 14b. 23 As the irradiance within a laser cavity increases in the build up to steady state, does the population inversion in the gain medium increase or decrease? In addition, spherical wavefronts reach the plate after scattering from object point O. d 1 dfsr 11/2 Transmittance 0.8 11 0.6 11 12 12 0.4 0.2 0 0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 Change in cavity length (mm) 8 Optical Interferometry INTRODUCTION An instrument designed to exploit the interferometry interferometr an optical interferometer. 9 An equilateral prism of dense barium crown glass is used in a spectroscope. This decay process is shown in step 2. Note carefully that these focal points are not measured from the vertices of the lens. Corresponding burn patterns for m = 0, n = 0 and m = 1, n = 0 are shown. This gives 0p i = 0z z - iz0 (15) This relation can be integrated (see problem 3) and the solution manipulated to give eip1z2 = z20 B z20 + z2 e -i1tan z>z02 -1 (16) Equations (14) and (16) can be substituted into Eq. (10) to form our completed Gaussian beam solution. Estimate the depth to which the diode laser beam would penetrate sig- nificantly into the Nd:YAG crystal. The problem must be handled, as suggested, by the Fourier integral transforms, Eqs. The crystal is optically pumped at a rate that leads to a small-signal gain coefficient of q0 = 0.05 > cm. Principles of Holography. It follows that $\xi = 1 s/= r 2$ or s = r l 2/(36) When the distance AB is considered instead to be a continuous array of point sources, the individual fringe systems do not give complete cancellation until the spatial extent AB of the source reaches twice the value of s in Eq. (36). The spontaneously emitted photons that are reflected back into the thin junction region can cause stimulated emission (the creation of a twin photon and the demotion of an electric fields may be elliptically polarized in the sense that, over time, the electric fields may be elliptically polarized in the sense that, over time, the electric fields may be elliptically polarized in the sense that, over time, the electric fields may be elliptically polarized in the sense that, over time, the electric fields may be elliptically polarized in the sense that, over time, the electric fields may be elliptically polarized in the sense that, electric fields may be elliptically polarized in the sense that, electric fields may be elliptically polarized in the sense that, electric fields may be elliptically polarized in the sense that, electric fields may be elliptically polarized in the sense that electric fields may be elliptically polarized in the sens Clearly, given the second form, one could deduce the standard form in Table 1 by extracting the factor i. 581 Laser Operation 22 Find the Doppler-broadened gain bandwidth of the 633-nm He-Ne transition. (a) 10.6 GHz (b) 0.83 GHz; 0.62 GHz Chapter 9 1. For the resultant wave, find the amplitude, wavelength, length of one loop, velocity, and period. Holographic optical elements are generally lighter than the optical components they replace, which proves useful in a number of fringes then fall under the central maximum of the diffraction envelope. Because of the smallness of the pinhole, however, every point in the image is reached only by rays that originate at approximately the same point of the object, as in Figure 19b. The input data 1y0, a02 is modified by the ray-transfer matrix to yield the correct output data 1y1, a12. In this focal surface, for an aplanatic system, point images are formed. Assume the crown glass lens to be equiconcave. When b in Eq. (23) is replaced by kh¿, we have, lumping all constants are formed. into term-by-term coefficients, a1Q2 = 0C40r4 + 1C31h;r3 cos u + 2C22h; 2r2 cos2 u + 2C20h; 2r2 + 3C11h; 3r cos u (25) The C coefficients in Eq. (25) are subscripted by numbers that specify the powers of the term dependence on h; r, and cos u, respectively. The viewer, located at the far right in Figure 22a and 22b, receives these rays as if they have come directly from an object and so "sees" the tip of the image at the point where the backwards extensions of these rays either intersect. As shown in Figure 2c, the resultant wave is not, in general, in step with either of the waves being superposed. Hyperopia The farsighted, or hyperopic, eye is commonly shorter than normal What is the proper matrix to represent a left-circular polarizer? Notice that the E-vector rotates counterclockwise in this case. The individual terms describe wavefront aberrations that contribute to the total aberrations that contribute to the total aberration at the image. 502 Chapter 23 Fresnel Equations A general conclusion can be drawn from the phase changes for the TE and TM modes under internal and external reflection: Near normal incidence, for both TE and TM modes, the phase shift for an internally reflected beam differs from that of an externally reflected beam differs from that of an external verse relationship with t0. The second term represents interference between the two beams and can be considered as a positive or negative deviation 473 Fourier Optics from the constant term, dependent upon the path difference x. This can be seen by neglecting the g-term, valid for high-enough frequency 1v g2, in which case Eq. (61) is simply n2 = 1 - v2p (62) v2 Equation (62) now shows that for v 6 vp , the refractive index of the metal is complex and radiation is attenuated, whereas for v 7 vp, the index is real and the metal is transparent to the radiation. Copyright© Springer-Verlag GmbH & Co KG. Ch. 21. In cases where the pulses break apart, as will happen if the phase velocities of the component harmonic waves differ by a sufficient amount, no single group velocity can be assigned to the signal. When k = 0we say the fields are phase matched in the crystal and the irradiance factor above is a maximum. Feynman, Richard P., Robert B. 14 Consider each of the following spectacle prescriptions and describe the refractive errors that are involved: a. These values, a = 0 and a = p, correspond to the first two principal maxima in Figure 15. To see how this comes about, consider the formation of closely spaced interference surfaces within a
thick emulsion by using coherent subject and reference beams with the largest angular separation, it is possible to have sum frequency generation, it is possible to have sum frequency generation, it is possible to have sum frequency generation such that v1 + v2 : v3 or difference frequency generation such that v2 + v3 or difference frequency generation such that v2 + v3 or difference frequency generation such that v2 + v3 or difference frequency generation such that v3 or difference frequency generation such that v3 or difference frequency generation such that v3 or di generation such that v1 - v2 : v3. Use the expression for the focal length of a thin lens, n2 - n1 1 1 1 = a b, with careful attention to thinf n1 R1 R2 lens sign conventions to obtain the focal length of the thin-lens output element. 2 sin2 (0.575x) I0 sin (1.151y) 0.438x2y2 (b) 5.46 mm along x; 2.73 mm along y (c) 0.895 along x; 0.629 along y (d) 0.005 (a) 90⁶ (b) 11.5° (c) $5.7^{\circ} \Delta = (/D)(1/\cos)$ (b) 4.7%, 1.8%, 0.84% for m = 1, 2, 3, respectively $m = 0; 1/2 = 30^{\circ}$ (a) 120° (b) Ip = Imax (d) Ip = Imax (d) Ip = 3Iav 8. For the case plotted in Figure 14a and b, a = 6b, and the missing orders are those for which p = ; 6, ; 12, and so on. OA OA (a) OA 6 OPTICAL ACTIVITY OA Certain materials possess a property called optical activity. 6 DIFFRACTION FROM MANY SLITS For an aperture of multiple slits (a grating), the integrals of Eq. (23), together with Figure 13, are extended by integrating over N slits. The Ramsden eyepiece of a telescope is made of two positive lenses of focal length 2 cm each and also separated by 2 cm. When halfwave voltage is applied, the polarization state of the laser radiation is rotated by 90°, so that it can be extracted with the help of the polarizing prism, as shown. At normal incidence 1u = 0°2, for both TE and TM modes, Eqs. For objectives with numerical apertures over 0.30, the cover glass has increasing influence on the image quality, since it introduces a large degree of spherical aberration when oil immersion is not involved. This yields a replica of the grooves in a metallic element, which is called a shim. The presence of the letter in the text. Determine the attenuation in db/km for fibers having an overall fractional power loss of 25%, 75%, 90%, and 99%. As a result, the thickness of the lens along the axis increases 437 Optics of the Eye to 4.0 mm, and the distance from cornea to the front surface of lens is shortened to 3.2 mm. Resnick, Robert. Every delay in phase in ES now shows up as a phase advance. As we mentioned, the finesse is a useful figure of merit because it is the ratio of the Eye to 4.0 mm, and the distance from cornea to the finesse is a useful figure of merit because it is the ratio of the Eye to 4.0 mm. the separation between adjacent transmittance peaks (that is, the cavity free spectral range) to the FWHM of a transmittance peak. Digital cameras work in this fashion. Using this process, the hologram can be developed and viewed quickly and so the hologram can be developed and viewed quickly and so the hologram can be used for rapid inspection and analysis in an industrial environment. Here, we will categorize such polarizers in terms of their effects, which are basically three in number. Does the eye see an image erect relative to the object? As indicated by Eq. (2), if the light is not incident along the normal, the maximum diffractable wavelength can be increased; when ui nears 90°, it is twice as much, or 400 nm. The irradiance in each of these six modes, therefore, begins to grow. 210 Chapter 8 Optical Interferometer, and the emerging set of parallel rays are brought together at a point P in the focal plane of the converging lens L. If the pinhole aperture is opened sufficiently to accommodate a converging lens, we have the basic elements of the ordinary camera (Figure 20). These two image detection systems are discussed below.1 Photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of digital cameras, photographic Film Until the recent widespread use of is Abbe's method for finding the focal length of a lens. In this case, the resultant wave is in step with the individual waves being superposed. The irradiance of the gain medium. The negative sign indicates an inverted image. You will also need the definite integral +q 2 Lq 242 Chapter 9 Coherence purpose, let us assume "good" spatial coherence occurs within a length that is 25% of the maximum value given by Eq. (38). Holding the pencil fixed, close one eye at a time. Three different electron beams are typically used and each beam reaches "dots" of only one of the three types of phosphors on the screen due to a grille or mask that blocks the beams from striking the wrong type of phosphor. The spot size w(z) at the beam waist 1z = 0.2 is defined as w0. Since 1 eV = 1.6 * 10.19 J, we have mc2 = 5.11 * 105 eV = 0.511 MeV. (d) Use of a stop to artificially "flatten" the field of a lens. In what follows, we discuss each of these visual functions in somewhat more detail. Summarizing these results for the case of internal reflection, fTM = d 0, p, u 6 up ∞ e up ∞ 6 u 6 uc 2sin u - n b + p, n2 cos u 2 (38) 2 2 (39) u 7 uc Phase shifts for both TM and TE modes and for both internal and external reflection are summarized in Figure 8. Eye relief, that is, the distance from eye lens to exit pupil. Although reflection at the polarizing angle from a dielectric surface can be used to produce linearly polarized light, the method is relatively inefficient. Find the relative likelihood Pk = 1 > Pk = 0 that a hydrogen molecule will be in its first excited vibrational state in thermal equilibrium at room temperature, T = 293 K. Let the vibrational state in the relatively inefficient. irradiance of the incident light on the first polarizer be I0. For the case described in (a), show that the location of the beam waist can be written as $Z^2 = c$. (a) Integral laser device with output laser beam. The last equality in Eq. (31) defines the transfer matrix elements, m11, m12, m21, and m22 for the case at hand. A grating may be designed to operate either as a transmission grating or a reflection grating. These are given in Figure 4, together with a mnemonic device to assist in recalling them quickly. In viewing a hologram, this wavefront is reconstructed or released, and we view what we would have seen if present at the original 372 Hologram, this wavefront is reconstructed or released, and we view what we would have seen if present at the original 372 Hologram, this wavefront is reconstructed or released. hologram. Differences in frequency imply differences in velocity. If the beam diameter is 1 cm, determine the number of resolvable spots. Thin Film Physics. In the second order, this figure improves to 0.0063 nm, and so
on. The real image formed by the objective is observed with an eyepiece, represented in the figures as a single lens. The plate acts as a perfect window for TM polarized light. Let ¢n> ¢t be the incremental rate of change of the number n of photons (traveling in the + z-direction) through a small volume ¢V of cross-sectional area ¢A and length ¢z due to interaction with a gain medium. How many independent telephone channels can the system accommodate? Microscopy Another useful application of holography is in microscopy. 454 Chapter 20 Aberration Theory The variation of n with 1 in the neighborhood of ID may be approximated using the red and blue Fraunhofer wavelengths, IC = 656.3 nm and IF = 486.1 nm, respectively: nF - nC 0n 01 IF - IC (40) The dispersion constant for the glasses may be introduced by expressing the terms of Eq. (39) as K1 n1F - n1C n1D - 1 P1D 0n1D = K1 a ba b = 01 lF - lC n2D - 1 P1D 0n2D ba = K2 a b = 01 lF - lC n2D ba = K2 a b = 01 lF - l level rate equations, together with Eq. (30), can be solved simultaneously to give the steady-state population densities of the four levels and so to find the steady-state population inversion Ninv = N2 - N1. The rods are located more densely toward the periphery of the retina. 10 A film of magnesium fluoride is deposited onto a glass substrate with optical thickness equal to one-fourth the wavelength of the light to be reflected from it. Figure 16b shows the same process for an incident spherical wave. 517 518 Chapter 24 Nonlinear Optics and the Modulation of Light of symmetry, many tensor components may vanish or become equal to others, reducing the total number of independent elements7 required to represent a particular crystalline material. When the aperture stop is placed at the position of the lens, such distortion does not occur. Light entering from the left encounters six spherical surfaces whose radii of curvature are, in turn, r1 to r6. Diode lasers do have several unfavorable characteristics. For a wavelength around 500 nm, determine its mode number, its finesse, its minimum resolvable wavelength interval, and its resolving power. Fewer zones make a contribution from the upper half of the wavefront relative to P. This system provides an experimental means of comparing, or correlating, the light pattern in the image of the object in the aperture plane and the pattern contained on the mask. For higher magnifications, objective lenses with focal lengths in the range of 4 to 16 mm incorporate some fluorite elements, which together with the glass elements provide better correction over the vision in the vision in the vision in the woman's left eye is corrected with a contact lens of power -7 diopters, and the vision in this woman's right eye is corrected with a contact lens of power -5 diopters. Since the two beams travel difference develops that can produce constructive interference at P. We choose the forms of the fields shown in the preceding equations in order to lead to a standard expression for the irradiance at point P in terms of the coherence properties of the source field. The first-order 1m = 12 spots above and below the central spot represent the fundamental frequency nY1 = 1>d. In the figure, the process is assumed to be 100% efficient. A motion picture depiction of the sound wave of Figure 5 would show the wavefronts moving in the positive x-direction at the wave speed 340 m/s. D 173 Interference of Light 3 y m 2 m P S1 1 m m0 O m S2 m x 1 m 2 3 Figure 6 Bright fringe surfaces for two coherent point sources. 16, 17. The entire bandwidth 1¢n = n2 of the signal was used. This may be expressed by b = kh¿ (24) where k is the appropriate proportionality constant. Then y = A sin w0 = y0 from which the required initial phase angle w0 can be calculated as w0 = sin-1 a y0 b A The waveforms in Eqs. (See Example 1.). However, the radiation received at the earth's surface is modified by absorption in the earth's surface is modified by absorption in the earth's atmosphere. Radial keratotomy introduces radial cuts in the cornea of the myopic eyeball (see Figure 8). Then, or m = m¿ + 1N + 12 2d2 2d2 = + N + 1 li (12) By subtracting Eq. (11) from Eq. (12) and by writing the mirror movement ¢d = d2 - d1, we find lie are very close, the wavelength difference of the two unresolved components can be approximated by ¢l = l2 2¢d (14) This technique is often employed in an optics laboratory course to measure the wavelength difference of 6 Å between the two components of the yellow "line" of sodium. von Fraunhofer. As before, the average phase at P of the light from each successive zone advances by a half-period, or p. Sources at room temperature (293 K) emit electromagnetic radiation with a peak wavelength in the infrared region, lmax = 9890 nm. (a) $c = 43.3^{\circ}$, $p = 55.6^{\circ}$, $p' = 34.4^{\circ}$ (b) R = 3.47%, T = 96.53%; R = 8.21%, T = 96.53%; R = 0.67%, T = 99.33% (d) 0, 0, , 2.43 rad, 2.65 rad, 16. Variations in V therefore modify the polarization state of the emergent light, rendering it elliptical, in general, with an excomponent that can be transmitted by the analyzer. It may be useful to research and then summarize the solution to this problem. For n2 = 1.6 [curve (b)], the spectral response of the double layer, while more reflective, is flatter over the visible spectrum. The optical axis for a spherical lens is an axis of symmetry since rotation of the lens through an arbitrary angle about the optical axis for a spherical lens is an axis of symmetry since rotation of the lens through an arbitrary angle about the optical axis for a spherical lens is an axis of symmetry since rotation of the lens through an arbitrary angle about the optical axis for a spherical lens is an axis of symmetry since rotation of the lens through an arbitrary angle about the optical axis for a spherical lens is an axis of symmetry since rotation of the lens through an arbitrary angle about the optical axis for a spherical lens is an axis of symmetry since rotation of the lens through an arbitrary angle about the optical axis for a spherical lens is an axis of symmetry since rotation of the lens through an arbitrary angle about the optical axis for a spherical lens is an axis of symmetry since rotation of the lens through an arbitrary angle about the optical axis for a spherical lens is an axis of symmetry since rotation of the lens through an arbitrary angle about the optical axis for a spherical lens is an axis of symmetry since rotation of the lens through an arbitrary angle about the optical axis for a spherical lens is an axis of symmetry since rotation of the lens through an arbitrary angle about the optical axis for a spherical lens is an axis of symmetry since rotation of the lens through an arbitrary angle about the optical axis for a spherical lens is an axis of symmetry since rotation of the lens through an arbitrary angle about the optical axis for a spherical lens is an axis of symmetry since rotation of the lens through an arbitrary angle about the optical axis for a spherical lens is an axis of symmetry since rotation of the lens through and the optical axis for a spherical lens is an axis of as it did before the rotation. For the approximation, assume the path difference between the two beams is much smaller than s, so that we are looking at the inner zones of the hologram. Evidently an experimental determination of this slit separation could be used to deduce the size s of the extended source. divided between Es and Ep components, it also follows that the refracted beam is partially polarized and richer in the Ep component. The intersection of the two rays (extended backward) determines the image point I conjugate to O. The geometric relationship between the angles ui and ut , formed by the representative incident ray AD and refracted ray DL, is Snell's law, as outlined in Figure 4b. Two procedures currently available for corneal sculpting are known as PRK (photorefractive keratectomy) and LASIK (laser in-situ keratecto form as B # B c = Aei1k r - vt2 (23) (Recall that the physical waveform is described by the real or imaginary
part of the complex form.) The partial differential equation of Eq. (2) in the form 0 2c 0x2 0 2c + 0y2 0 2 partial derivatives of c from Eq. (23). Fourier Optics: An Introduction, 2d ed. For laser sources, these phases would typically be random functions of time that vary on a time scale much longer than an optical period but still shorter than typical detector averaging times. As the angle of incidence increases to grazing incidence 1u = 90°2, both RTE and RTMs and RTMs and RTMs are phases would typically be random functions of time that vary on a time scale much longer than an optical period but still shorter than typical detector averaging times. become unity, although RTM remains quite small until Brewster's angle has been exceeded. Finally, we give a qualitative description of the operation and characteristics of diode lasers. Although Newton often argued forcefully for positing hypotheses that were derived only from observation and experiment, here he himself adopted a particle hypothesis believing it to be adequately justified by his expression equal to zero, there remains in a(Q), then, only the third-order aberration represented by a term in h4, a1Q2 = - n2 1 h4 n1 1 1 2 1 2 c a + b + a - b d 8 s s R s; R s; R axial object points (18) When h is small enough, the rays are essentially paraxial and the aberration represented by this term may be negligible. The shift may occur in a polar molecule, like H2O, because the molecule has a permanent electric dipole, that is, the effective centers of its positive and negative charge distributions do not coincide. (a) 82.5%, 84.7%, 90.9% (b) 82.5%, 80.1%, 69.5% (b) 41 nm 19. Determine (a) radii of curvature of the lens surfaces; (b) individual focal lengths for the Fraunhofer D line; (c) the overall focal lengths of the lens for the Fraunhofer D, C, and F lines. In the second term in the square brackets is accordingly neglected compared to the first, Eq. (15) describes zones with equal areas (independent of n), given by Sn c pr0æ d r0l 1r0 + r0æ 2 (16). The existence of the second term in Eq. (15), however small, indicates increases in zonal areas with n and corresponding small increases in the successive terms of Eq. (14). The irradiance over the screer turns out to be just a product of the irradiance functions in each dimension, or I = I01sinc2 a2 (18) 276 Chapter 11 Fraunhofer Diffraction In calculating this result, the single integration over one dimension of the slit is replaced by a double integration over both dimensions of the aperture. The beam diverging from the source slit encounters a second slit 0.5 mm wide at a distance of 30 cm. Three systems are shown characterized. (a) I = 23. Five additional polarizers of this type are placed between the two just described, with their transmission axes set at 15°, 30°, 45°, 60°, and 75°, in that order, with the 15°-angle polarizer adjacent to the 0° polarizer, and so on. Find the quality factor Q of this type are placed between the two just described, with their transmission axes set at 15°, 30°, 45°, 60°, and 75°, in that order, with the 15°-angle polarizer adjacent to the 0° polarizer adjacent to the 0° polarizer. Fabry-Perot cavity. While the more proximate near point might serve as an advantage, the lessremote far point is a distinct disadvantage and calls for correction. A photon should be thought of as a quantum of energy associated with the entire electromagnetic field. In deriving those equations, it was necessary to assume paraxial rays, that is, rays both near to the optical axis and making small angles with it. Rays associated with the nodal points and principal planes are also shown. Compare this result with the similar result given in Eq. (43) for the ring cavity and account for the differences between the two results. The law of energy conservation suggests that there can be a strong exchange of energy between an electromagnetic wave of frequency n0 and matter only when some of the constituents of the matter have allowed energies En and EM Em such that En - Em = EEM = hn0 .1 In such a case, we say that n + 1 - En the electromagnetic field is resonant with the En to Em transition of the atom or molecule. 362 Chapter 15 Production of Polarized Light OA 储 E E储 a b P b E a OA Surface (a) S E k O Plane wave front (b) Figure 13 (a) Creation of an elliptical Huygens' wavelet by the extraordinary ray. In Figure 16a, a plane wave is reflected from an ideal (infinite) plane mirror. In a farsighted eye, the natural converging power of the eye is not strong enough, and additional converging power must be added in the form of spectacles with a converging lens. Situations exist where the actual path taken by a light ray may represent a maximum time or even one of many possible paths, all requiring equal time. Laurance. 1967: 238. In every other case, sin u = 0 for u = np, n = ; 1, ; 2, Å, and so g1v2 = 0 when v = v0; 2np t0 (14) As v increases (or decreases) from v0 then, g1v2 passes periodically through zero. (a) Four-step energy cycle for a laser atom involved in the creation of 2 from its small-signal value. (b) Quarter-half-quarter wavelength layers. 4 RESOLUTION OF A GRATING Increased dispersion or spread of wavelengths does not by itself make neighboring wavelengths appear more distinctly, unless the peaks are themselves sharp enough. Such large reflecting telescopes are usually employed to examine very faint astronomical objects and use the integrating power of photographic plates, exposed over long time intervals, in observations. One such zone (ABCD) is shown. In Eqs. Crystals with thicknesses equal to their coherence length are impractically small. Such rays incident on the second surface can then be refracted again to form an image. A total of 256 data points is fed to the computer for Fourier-transform analysis. Central to his explanation was the conception of light as a stream of light quanta whose energy is related to frequency by Planck's equation (1). That is, the irradiance transmitted through a Fabry-Perot is measured as a function of the real, positive number, a K kt sin2 u 1 B n2 the transmitted wave may be expressed as B # B Et = E0tei1kt r - vt2 = E0te -ivte -ixkt sin u>ne -af z f The last factor on the right-hand side of this relation describes an exponential decrease in the amplitude of the wave as it enters the medium of lesser refractive index along the negative z-direction. We assume that lasing action occurs only in the counterclockwise direction around the ring. In either case, then, m = - s₂ s (30) Further ray-diagram examples for a train of two lenses is given in Example 3. The holes S1 and S2 are usually slits, with the long dimensions extending into the page. However, as noted, in a Q-switched system the cavity is left in the high-loss state for a time long enough to allow the population inversion to build to a large value. In this arrangement, the light incident on the QWP is divided equally between fast and slow axes. By producing a hologram that restricts the possible angular views of the subject to one through a horizontal slit, the confusion of images is reduced. y FA x Unpolarized light SA Figure 9 Operation of a phase retarder. He was impressed, for example, 2 A more in-depth historical account may be found, for example, in Vasco Ronchi, The Nature of Light (Cambridge: Harvard University Press, 1970). The top of the comatic circle is formed by rays 1 and 2; the bottom by rays 1 and 2; the 3 and 4. An infinite variety of shapes may be synthesized in this way. Surface scratches or irregularities, as well as surface dust, moisture, or grease, become source is typically either a light-emitting diode (LED) or a laser diode (LD). A plot of spectral solar irradiance is given in Figure 4. The spherical aberration of a single, spherical refracting surface is given in Eq. (18). In most cases, a time average of the two waves is ¢ 1 - ¢ 2. Two important homogeneous broadening mechanisms are called lifetime broadening and pressure broadening. (48), (50), and (51), me = Dex 1 = M Dobj so that Dex = Dobj M (52) Thus, the diameter of the bundle of rays that pass through the exit pupil. The apertures dealt with are often purposely inserted into an optical system to achieve various practical purposes. Since these sources are not coherent, interference is sustained only between pairs of reflected rays originating from the same source. Then, it follows that 8phn30 A 21 = B21 c3 (8) B12 c3 (8) B12 = B21 c3 (8) B12 c3 (8) B1 equilibrium situation. New York: Cambridge University Press, 1990. An object OP, 3 cm high is located 18 cm to the left of L1. The transmitted light is then monitored by a light detector placed in the second focal plane of L4, labeled Output in Figure 7. Consider the cases represented in Figure 10. Tech. The inset shows the relationship of wave vectors required by momentum conservation when the acoustic wave has the propagation direction indicated. If the corresponding refractive indices are n1 and n2, the figure implies that n1 7 n2. The finite lifetime of the atomic levels is due both to the fundamental process of spontaneous emission and to transitions with other atoms. Field of View: Field Stops and Windows In describing the limitations of a cone of rays from an axial object point, we have seen that entrance and exit pupils are related to the aperture stop and so govern the brightness of the image. photons. Thus, for example, multiplying the vector representing left-circularly polarized light by eip>2 = i, 1 i ic d = c d i -1 produces an alternate form of the vector. Narrow band-pass filters that behave like Fabry-Perot etalons can be fabricated by separating two dielectric-mirror, multilayer structures with a spacer of, say, MgF2 film. The pattern reveals that the fourth-order interference maxima are missing from the pattern. Surface imperfections or internal variations in refractive index show up as a distortion of the fringe pattern. Example 1 illustrates the
manner in which the cavity structure determines the parameters and behavior of a Gaussian beam generated in the cavity structure determines the parameters and behavior of a Gaussian beam generated in the cavity structure determines the parameters and behavior of a Gaussian beam generated in the cavity. fiber. 20 Find expressions for the fraction of the total power in a beam of spot size w(z) that is transmitted through a circular aperture, centered on the beam. The reflection coefficient for the case of internal reflection is shown in Figure 5 with n = 1 > 1.50, as when light encounters a glass/air interface from the glass side. 12 In writing Eq. (3) we neglected to include a contribution due to the magnetic force on the electron. Through successive layers of neurons (bipolar cells), the electron are led out of the back of the eye along axons, which are the fibers of the optic nerve. The wavelength is 1. Imagine now that the objects S1 and S2 are brought closer together. We have assumed that mirrors M1 and M2 are precisely parallel in the equivalent optical system of Figure 1a, or, what amounts to the same thing, precisely parallel in the equivalent optical system of Figure 1a. Now, by way of summary, we turn our attention to the identification of some of the common lasers in existence today and to the parameters that distinguish them from one another. These results are all displayed in Figure 6, where the origin of the frequency spectrum is chosen at its point of symmetry, v = v0. Materials used in electro-optic applications typically have second-order nonlinear susceptibilities in the range of 10-10 m>V to 10-13 m>V, and third-order or Seidel aberrations. All surfaces have a radius of curvature of magnitude 20 cm. 26 Three thin lenses of focal lengths 10 cm, 20 cm, and - 40 cm are placed in contact to form a single source and separated by amplitude or wavefront division, were brought together again to interfere. 13 Determine the maximum reflectance in the center of the visible spectrum for a high-reflectance stack of high-low index double layers formed using nL = 1.38 and nH = 2.6 on a substrate of index 1.52. A pulsed laser delivers bursts of radiation with durations (pulse widths) as small as a few femtoseconds. Such a periodic structure could be constructed by slicing a crystal into many thin slabs, each having a width equal to LC and then placing the slabs back together in a manner such that each slab is rotated 180° relative to its neighbors. p/4 Ex leads Ey by p>2. A birefringent crystal can be cut and polished to produce polarizing elements in which the OA may have any desired orientation of the microscope when an eveplece rated at 10* is used? A further classification of diffraction effects arises from the mathematical approximations possible when calculating the resultant fields. As an example, consider an optical system that consists of two thin lenses in air, separated by a distance L, as shown in Figure 13. Equation (15) now gives normal incidence: ub = 1 2 sin-1 a ml b a (17) Example 3 a. The problem depicted in Figure 10 is to determine the location / of the external beam waist and its spot size w0. Thus a reticle, the field stop, and field lens are all essentially in the "same plane." A disadvantage of this arrangement is that the surface of the lens is then also in focus, including dust and smudges. Since no light source can be precisely Dispersion in fused quartz Refractive index versus wavelength 1.475 1.470 Refractive index 1.465 1.460 1.455 1.450 1.455 1.450 1.455 1.450 1.445 1.440 Figure 11 Dispersion in fused quartz. What is the normal reflectance produced? To determine elements a and c, let the same polarized light. The remarkable adaptivity of the eye can be traced, in fact, to the particular photosensitivity of the rods and cones in the retina of the eye. Terms proportional to this expression, therefore, vanish, by Fermat's principle. If extreme points are separated by an amount s 6 rl>/, then fringe definition is assured. Thus, dEp = a EL ds i1kr - vt2 be r (1) where r is the optical-path length from the interval ds to the point P. On the other hand, control over groove profile, which affects the blazing and thus the efficiency of the grating, is not easily achieved. In each case, the irradiance input into the gain cell is 1 W>cm2. 139 Properties of Lasers The following brief survey of nonlaser sources of light is not intended to be comprehensive; rather it is intended to be comprehensive; rather it is intended to serve as a backdrop for the discussion of laser light that follows in subsequent sections. For angles such that sin u 7 n, when TIR occurs, cos ut becomes purely imaginary and we can write cos ut = i sin2 u - 1 B n2 505 Fresnel Equations Thus the exponential factor B kt # Br = - ktx sin u sin2 u f f 1 = k x z - 1 - iktz + ik t t n n B n2 B n2 In writing the last equality we have noted that, for the situation depicted in Figure 1, the transmitted wave exists in the region for which z 6 0, and so in this region z = -f z f. As an example, consider the Fourier analysis of the square wave shown in Figure 2 and represented over a period symmetric with the origin by 0, f1t2 = c 1, 0, -T>2 6 t 6 T>4 -T>4 6 t 6 T>2 226 Chapter 9 Coherence f (t) Figure 2 T 2 T 4 T 4 t T 2 T Square wave. The first case deals with the superposition of harmonic waves of differing amplitudes and phases but with the same frequency. Here k is the propagation vector whose magnitude is related to wave speed by k = v > v. If the pulse moves to the left, the sign of y must be reversed, so that we may write y = f1x; yt2 (1) as the general form of a traveling wave. The analysis leading to Eq. (22) holds as well for the four-level gain medium being presently considered. p Phase shift on reflection of the electric field for internally reflected rays, with n = n1 > n2 = 1 > 1.5. uc 41.8 p Internal reflection (glass-to-air) 10 20 30 40 50 60 Angle of incidence u 70 80 90 It happens that the relative phase shift fTE - fTM is about - 3p>4 at an angle of incidence near 53°. In practice, this is easily accomplished by placing a source in the focal plane of a positive lens or by simply using a laser beam with a small divergence angle as the source. First, it does not take into account the obliquity factor, which attenuates the diffracted waves according to their direction, as described earlier. Inserting it into Eq. (59), v2p 2 n = 1 - (61) v2 + ivg The plasma frequency turns out to be a critical frequency whose value determines whether the refractive index is real or imaginary. When viewed at u = 0°, along the normal to the surface, a certain maximum A A A A r A A A A A A A A A A A A Figure 3 Illustration of the inverse-square law. It is often referred to as the ABCD propagation law for Gaussian laser beams. The complex vector amplitudes are given by ' E0 1 E0^c = a b c d 2 i ' E0 1 E0^c = a b c Diffraction 11 For an incident plane wavefront, show that the areas of the Fresnel half-period zones relative to an observation point at distance x from transverse plane Z1 to transverse plane Z2. Value given is for the relaxed eye. Peter K. 33 What is the band-gap energy of an AlGaAs semiconductor used in a laser diode device that emits light of wavelength of light beam along which the phase of the wave remains unchanged. There we added the amplitudes of all the individual reflected or transmitted beams to find the resultant reflectance or transmittance. This integration is, in general, not easy to carry out for a given aperture. Diode lasers are that they are relatively inexpensive, are small and efficient, and can be engineered to have a variety of wavelengths of interest in many applications. Let the angle of refraction be the angle u2. A little inspection of these equations shows that the Nth such reflected wave can be written as EN = 1tt;r; 12N - 32E02ei[vt - 1N - 12d] (45) 187 Interference of Light a form that holds good for all but E1, which never traverses the plate. Ray A entering the left face of the fiber is refracted there and transmitted to point C on the fiber surface where it is partially refracted out of the fiber and partially reflected internally. (2) 1 km P1 P2 5 Since rays that strike the fiber
wall at smaller angles of incidence. If the extended source of Figure 15a is the sky and white light is incident at some angle on a film of variable thickness, as in Figure 16, the film 181 Interference of Light may appear in a variety of colors, like an oil slick after a rain. On the other hand, very intense radiation may be visible beyond the limits of the CIE curve. A reflective metallic coating is usually added to the grating by vacuum evaporation. B a. The shift in charge distribution may also occur in nonpolar molecules, such as O2, in which positive and negative charge distributions sin w = w - w5 w3 + - A 3! 5! cos w = 1 - w2 w4 + + A 2! 4! and (8) we consider the first terms only and write sin w w and cos w 1 (9) relations that can be accurate enough if the angle w is small enough.4 This approximation leads to first-order, or Gaussian, optics, after Karl Friedrich Gauss, who in 1841 developed the foundations of the subject. The linear dispersion of the instrument is 20 Å/mm and an exit slit of 200 mm is used. Available eyepieces have eye reliefs in the range of 6 to 26 mm. One of the most monochromatic gas-discharge sources is a gas of the krypton 86 isotope, whose orange emission line at 606 nm has a line width of only 0.00047 nm. Determine its average irradiance and the amplitude of its E and B fields. Now, if we assume the point spread function to be space-invariant (independent of object points; G1x, y, X, Y2 = G1X - x, Y - y2 Further, if the light from the object points; (x, y): Ii1X, Y2 = 5 image irradiance IO1x, v2 G1X - x, Y - v2 dx dy O5 5 object irradiance (31) point spread function The integral in Eq. (31) is called the convolution of the functions of the functions, represented by C-1102, C-1112, and C-1G2. These results, derived here for the case of two wave components, hold in general for a number of waves with a narrow range of frequencies. 54, No. 17 (2001). Light wavelengths range from 380 nm (violet) to 770 nm (red). 11 RAY TRACING The assumption of paraxial rays greatly simplifies the description of the progress of rays of light through an optical system, because trigonometric terms do not appear in the equations. 4 COMA Coma, represented by the term 1C31h¿r3 cos u, is an off-axial aberration 1h¿ Z 02 that is not symmetrical about the optical axis 1 cos u Z constant2 and increases rapidly as the third power of the lens aperture. This becomes clearer if Eq. (43) is written in the equivalent form, r = eipr¿. (Recall that "small signal" is code for "set I = 0.") d. (20) and (21) into the Eqs. Upon further lowering the microscope barrel by 1.87 mm, a focused image of the scratch is seen again. Consequently, objects located closer than the hyperopic near point would be out of focus, even with full accommodation. 5 VISION CORRECTION WITH EXTERNAL LENSES The errors of refraction of the even lead to four well-known defects in vision: myopia (nearsightedness), presbyopia, and astigmatism. An echelle grating is a coarsely pitched grating is a coar eiu, using Euler's formula, Eg. (13), for frequently occurring special cases. Optical fibers play an increasingly important role in a wide array of optical systems. Therefore, the Boltzmann distribution of Eg. (4) can be used to write P2>P1 = N2>N1 = e-1E2 - E12>kBT 6 1 146 Chapter 6 Properties of Lasers Therefore, stimulated absorption will occur more often than stimulated emission in an assembly of atoms in thermal equilibrium with its environment. This adjustment of pupil diameter (from 8 mm down to 2 mm) cannot of itself account for the enormous range of intensities processed by the eve. For example, in the case of an 1 See, for example, E. Currently, new laser applications are discovered almost weekly. Solution The N. When this occurs, the irradiance no longer grows and so the population inversion maintains a steady value. If the diameters of these circles are small enough, the resultant image is still acceptable. According to Eq. (32), depth of field is greater for smaller apertures (larger f-numbers), shorter focal lengths, and longer shooting distances. In practice, this condition is only approximately met, and we speak of partial coherence. J. The finished hologram can be erased by heating and the thermoplastic recording material can be reused hundreds of times. Englewood Cliffs, NJ: Prentice-Hall, 1995. Then, Eqs. The device consists of three essential elements: an external energy source or pump, a gain medium, and an optical cavity, or resonator. For 3-cm microwaves, for example, the skin depth in copper, with conductivity of 5.8 * 107> Æ-m, is only about 6.6 * 10-5 cm. Such a point, U, is shown in part (b) of the figure, the same optical system as (a), but redrawn for clarity. Viewed in another way, Eq. (4) requires an increase in the angular separation ψ of a given small fringe interval ψ as the mirror spacing d becomes smaller, since taking the differential of Eq. (4) leads to f ψ u f = l ψ as the mirror spacing d becomes smaller, since taking the base b. Where will sunlight be focused by the crystal ball? Such a gas only emits and absorbs light of particular, nearly discrete, energies. 365 Production of Polarized Light through an arrangement like that of Figure 17, each wavelength is rotated to a slightly different degree. Bell, Robert John. What is the irradiance at the detector relative to the irradiance there for an unobstructed wavefront? If the aperture is square, the blurs are rectangular in shape. 5 cm 26. Locate the exit pupil. A source slit is parallel to the intersection between the mirrors and 50 cm 190 Chapter 7 Interference of Light away. In the case of circular zones, Figure 4b, the corresponding resultant phasor has a phase angle of p>2 and the corresponding point, T, would fall on the vertical axis. So gain media with larger bandwidths can be used to form narrower mode-locked pulses. Adding a good narrow-band filter further reduces the power but improves the temporal coherence. Point P falls on such a ring, for example, if the optical path difference OP - OX is an integral number of wavelengths, ensuring that the reference beam of plane wavefront light arrives at P in step with the source to the source to the source to the film must, in that case, arrive at a different angle of incidence (Figure 14). Let the object in the aperture plane be illuminated uniformly by light of unit amplitude, and let its transmission function be described by E11x, y2. Each ray refracts twice through the lens, once at each surface. 4 CONSERVATION OF ENERGY To conserve energy, at a given boundary, it must be true that the power incident on the boundary be equal to the sum of the power reflected at that boundary and the power reflected at that boundary be equal to the sum of the power reflected at that boundary and the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the sum of the power reflected at that boundary and the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the sum of the power reflected at that boundary be equal to the power reflected at that boundary be equal to the power reflected at that boundary be equal to the power reflected at that boundary be equal to the power reflected at that boundary be equal to the power reflected at the power reflected at that boundary be equal to the power reflected at the power 16 A telephoto lens consists of a combination of two thin lenses having focal lengths of +20 cm and -8 cm, respectively. If now the OA is situated so that it makes an arbitrary angle with respect to the beam direction, as in Figure 12, the light experiences double refraction5; that is, two refracted beams emerge, labeled the ordinary and extraordinary rays.

Budde, W. For example, in crystals of triclinic symmetry, all the 18 possible tensor elements are required; in zinc blende (GaAs), only one is required; in ¢nH and differing center frequencies that contribute to the overall lineshape function are shown by the dotted curves. In particular, when the grating or circular zones are "sinusoidal" in character, that is, their transmittance profiles follow a cos21bx2 (grating) or cos21ar22 (circular zone plate) irradiance, only first-order images appear, in addition to the zeroth order, on reconstruction. Determine the angle defining the field of view of the telescope. What is the absorption coefficient of the fiber in db/km? Find the difference in energy state and the ground vibrational energy state and the ground energy stat allow this eye to form clear retinal images of the print on a computer screen that is as close as 40 cm to the eye? Thus, referring to Figure 5f and making use of the thin-lens equation, one has 1 1 1 + = q -100 f This gives f = -100 cm. The cavity round-trip time is the time needed for light to circulate once around the cavity and so is given by t = 2d > y = 2nd > c Here, y = c > n is the speed of light in the medium. Since w varies between the mirrors, n is the index of refraction of this medium, and c is the speed of light in vacuum. Since w varies between the mirrors, n is the index of refraction of this medium. Since w varies between the mirrors, n is the index of refraction of this medium. where t is the film thickness. In such a situation, which is the subject of problem 4, the loss coefficient decreases (saturates) with increased incident irradiance. This result can then be used together with the cavity survival factor to develop an expression for the output irradiance from a laser system using an inhomogeneously broadened medium. A second variant of the Fabry-Perot interferometer uses a cavity of fixed length and a variable-frequency input field. Note that the gain coefficient for an inhomogeneously broadened medium. Spots appear at distances Ym from the optical axis given by Ym = ma lf b d (20) Et /E0 Figure 3 Transmission function of period d due to a Ronchi ruling, in which opaque and transmitting widths are equal. With halfwave voltage applied, the horizontally polarized beam from the laser cavity is rotated by 90° and is accordingly passed by the Glan-laser prism, allowing the beam to be backreflected from a high-reflectance mirror. That is, B21g1n¿21I>c2N2 RSt. Em. N2 = = RSt. Abs B12g1n¿21I>c2N1 N1 (14) Now the population densities in an assembly of atoms in thermal equilibrium are proportional to the likelihoods that a given atom will be in a particular energy state. 65 Optical Instrumentation prism in place. The first requirement is satisfied by an angle of scatter that is equal to the angle of incidence. This pencil is symmetrical about the axis OCI, where C is the center of curvature of the refracting surface, the wavefront GI is formed at the instant ray CF reaches I. To an observer in image space, the exit window seems to limit the area of the image in the same way as an outdoor scene appears limited by the window of a room. The band in which dn > dv 6 0 is said to be a region of anomalous dispersion. Consider a two-dimensional aperture (xy-plane) and its image (XYplane) formed by some intervening optical system. The minimum wavefront radius of curvature occurs at z = z0and has the value R1z02 = 2z0. Gain bandwidths are often expressed as wavelength spreads \$\epsilon in Figure 6a and plotted as curve (a) in Figure 6a and plotted as curve (a) in Figure 6a and plotted as curve (b) in Figure 6a and plotted as curve (b) in Figure 6a and plotted as curve (c) in Figure Figure 7. TE 100 TM 90 80 TE R (%) 70 60 TM 50 Single-crystal gallium: nR 3.7, nI 5.4 40 Solid sodium: nR 0.04, nI 2.4 30 20 10 Figure 10 Reflectance from metal surfaces by using Fresnel's equations. For normal dispersion, ¢n will be a small, positive quantity. L2: By ray diagram or by calculation, the image of lens L2, formed by L1 (as if light went from right to left), is L2¿, and is real. Then for B B v v0, P and E have the same sign and the dipoles are oscillating in phase B B with the field. Our equations show that their ratio is `tt¿r¿E0 E2` = `` = 1 - r2 E1 rE0 which is close to unity when r2 is small. Determine the peak-to-fringe ratio, in particular when a = 10b. We describe other means of producing pulsed laser output in the next section. This technique makes possible another application of interferometry with distinct advantages for spectroscopy. Once again we consider a case in which the small-signal gain coefficient exceeds the threshold gain coefficient, as shown in Figure 12a. (a) $12.5 \times$ (b) $15 \times$ (c) 0.13 cm, 3 mm, (d) 3.8° $34.5 \text{ SKIN DEPTH Before proceeding with the general case described by Eq. (53), we pause to consider the special case in which the frequency v of the incident radiation is small enough to allow as a good approximation to Eq. (53), we pause to consider the special case in which the frequency v of the incident radiation is small enough to allow as a good approximation to Eq. (53), we pause to consider the special case described by Eq. (53), we pause to consider the special case in which the frequency v of the incident radiation is small enough to allow as a good approximation to Eq. (53) k2 = ivsm0 Expressing i as eip>2 and taking the square$ root of each side, k = 11 + i2a sm0v 1 > 2 b 2 (54) 546 Chapter 25 Optical Properties of Materials Writing k in the complex form k = kR + ikI, as before, we can identify the real and imaginary coefficients by kR = kI = a sm0v 1 > 2 b 2 (55) and the real and imaginary refractive indices by nR = c2 sm0 1 > 2 c s 1 > 2 = a b b kR = a v 2v 2ve0 (56) c s 1 > 2 b kI = a v 2ve0 (57) and nI = The complex character of k, when introduced into the plane, harmonic wave equation, leads as in Eq. (29) to B B E = E0e -kIzei1kRz - vt2 The real exponential factor e -kIz describes absorption. Use a ray diagram to answer these questions by inspection. If the width w of slit and wire are equal, then there is an exact reversal of the transmitting and blocking zones of the wavefront. One sees that the amplitude, and so the irradiance, must decrease monotonically, as shown in Figure 4 Junction photodiode. A phasor A R from O to E then represents the contributions of half the unimpeded wavefront, the half above the axis SP in Figure 9a. Because of its axis of symmetry relative to rotation about an axis through its center, the lens treats (a) vertical and (b) horizontal fans of rays similarly, producing in each case a point image at the same location. Rossi, Bruno. The refraction by the first surface is, of course, unaffected by this change. focal length, placed just behind this mirror. They are also essentially different from the case of light waves. The operation of this lens is clearly asymmetric. The plasma frequency is a resonant frequency for the free oscillations of the electrons about their equilibrium positions. The result is less average astigmatism over the compromise focal plane. Thrierr, Atlas of Optical Phenomenon, Plate 12, Berlin: Springer-Verlag, 1962.) 3 VARIATIONS OF THE MICHELSON INTERFEROMETER Although there are many ways in which a beam of light may be split into two parts and reunited after traversing different paths, we examine briefly two variations that can be considered adaptations of the Michelson interferometer. Optical Instrumentation 67 Example 2 Determine the resolving power and minimum resolvable wavelength difference for a prism made from flint glass with a base of 5 cm. What is the wavelength associated with the photon energy required to populate each of the laser cavity (and subsequent focusing elements) that form the beam. (b) Sketch (not to scale) of the left side of the trough shown in the photo. What is the wavelength of a photon with this frequency? Myopic vision is routinely corrected with spectacles (or contact lenses) of negative dioptic power (diverging lenses) that effectively move both the Distinct vision Object at N.P. Lens Full accommodation (g) 430 Chapter 19 Optics of the Eye myopic far point and near point outward to normal positions. 475 8 a. A Bayer mask can be used in conjunction with a CCD array in order to record color images. 598 Chapter 27 Characteristics of Laser Beams spot size of the beam at the aperture location. Equation (20) becomes 1.33 1.33 - 11 + = 30 s; 15 giving s; 1 = +40 cm. In this case, Eq. (62) reduces to 0p > 0z = i > q, the defining equation for p obtained earlier. Most cameras are equipped with a depth-of-field scale from which values of s1 and s2 can be read, once the object distance and aperture are selected. Because the orientation of the surface curvature does not change in such a rotation, its optical behavior remains unchanged. The other ray is an arbitrary ray incident at P and refracting there according to Snell's law, n1 sin u1 = n2 sin u2 (17) The two refracted rays appear to emerge from their common intersection, the image point I. The effect of Energy>photon 3.58 * 10-19 J addition or removal of a single photon would perhaps be noticeable. This correction is handled by the obliquity factor to be discussed presently. What, approximately, is the irradiance at the point? Calculate the energy E1 and the first excited state energy E1 and th and skylight. By what factor is this fiber an improvement over a step-index fiber with n1 = 1.46 and n2 = 1.44? The first is included under the general heading of optical data imaging and processing and the second, Fourier-transform spectroscopy. With these modifications, Eq. 2 can be rewritten as dEP = a ELds i1kr0 - vt2 iks sin u be e r0 (3) The total electric field at the point P is found by integrating over the width of the slit. Reflecting or refracting surfaces that form perfect images are called Cartesian surfaces. RTE does not go to zero under this
condition, so reflected light contains only the TE mode and is linearly polarized, with RTE = 15%. If the values of the Fresnel integrals are plotted against the variable y, as real and imaginary coordinates on the complex plane, the resulting graph is the Cornu spiral (Figure 12). This process produces the population inversion of radiation. The image formed by the second surface is then the final image due to the action of the composite thick lens. A pair of plastic safety goggles inserted between crossed polarizers shows a higher density of color changes in those regions. Xenon Fluoride Krypton Fluoride Krypton Fluoride Gas, excimer Argon Fluoride Nitrogen Gas, molecular Carbon Dioxide Krypton Gas, ion Argon Helium Cadmium Gas, atomic Helium Neon Gain medium short-pulse electric discharge electric di nm 10.6 mm several from 350- 530 nm, main lines: 488 nm, 514.5 nm several from 350-800 nm, main line: 647.1 nm 325 nm, 441.6 nm, others 0.6328 mm, others 0. Power/Energy TABLE 1 LASER PARAMETERS FOR SEVERAL COMMON LASERS pulsed pulsed pulsed pulsed pulsed cw or long pulse pulsed cw (or modelocked) cw ((rectangular) 3-50 mm 0.6-2 mm 0.6-2 mm 0.6-2 mm 0.2-2 mm 0.5-2.5 mm Beam diameter 2-6 mrad 2-6 mrad 1-3 * 7 mrad 1-3 mrad 0.4-1.5 m gas water or forced air water or forced air air air Cooling 159 flashlamp, diode laser, doubled Nd:YAG flashlamp, diode laser Ti-sapphire InGaAsP Semiconductor Lasers, flashlamp, diode laser, flashlamp, diode laser, flashlamp, diode laser Ti-sapphire InGaAsP Semiconductor Lasers, flashlamp, diode laser, flashlamp, di Pump type Nd:glass Solid-State Nd:YAG Liquid Various Dyes Gain medium TABLE 1 Continued 1100-1600 nm, composition dependent 780-900 nm, composition dependent 780-900 nm, composition dependent 1.55 mm tunable, 660-1000 nm 1 mW to several watts, diode arrays up to 100 kW 1 mW to '1 W 1-100 W 0.1-100 J per pulse 6 100 W average power '2 W average power 1.06 mm tunable, 700-818 nm up to 10 kW (average) 20 mW-1W (average) Power/Energy 1.064 mm tunable 300-1000 nm Wavelength cw or pulsed cw or pu 0.7-10 mm 1-20 mm Beam diameter 200 * 600 mrad (oval in shape) a few mrad 3-10 mrad 0.3-25 mrad air or water water air or water dye flow or water Cooling 160 Chapter 6 161 Properties of Lasers PROBLEMS 1 The Lyman series in the line spectra of atomic hydrogen is the name for the light emitted from transitions from excited states to the n = 1 hydrogen is the name for the light emitted from transitions from excited states to the n = 1 hydrogen is the name for the light emitted from transitions from excited states to the n = 1 hydrogen is the name for the light emitted from transitions from excited states to the n = 1 hydrogen is the name for the light emitted from transitions from excited states to the n = 1 hydrogen is the name for the light emitted from transitions from excited states to the n = 1 hydrogen is the name for the light emitted from transitions from excited states to the n = 1 hydrogen is the name for the light emitted from transitions from excited states to the n = 1 hydrogen is the name for the light emitted from transitions from excited states to the n = 1 hydrogen is the name for the light emitted from transitions from excited states to the n = 1 hydrogen is the name for the light emitted from transitions from excited states to the n = 1 hydrogen is the name for the light emitted from transitions from excited states to the n = 1 hydrogen is the name for the light emitted from transitions from excited states to the n = 1 hydrogen is the name for the light emitted from transitions from excited states to the n = 1 hydrogen is the name for the light emitted from transitions from excited states to the n = 1 hydrogen is the name for the light emitted from transitions from excited states to the n = 1 hydrogen is the name for the light emitted from transitions from excited states to the name for the light emitted from transitions from excited states to the name for the light emitted from transitions from excited states to the name for the light emitted from transitions from excited states to the name for the light emitted from transitions from excited states to the light emitted from transitions f ' Ey = E0ye -i1vt - e2 The negative sign before e indicates a lag e in the y-vibration relative to the xvibration. Gerrard, A., and J. The high degree of directionality of a single-mode laser beam is due to the geometrical design of the laser cavity and to the fact that the stimulated emission process produces twin 155 Properties of Lasers Pinhole (a) (b) Filter (c) (d) Figure 18 A tungsten lamp requires a pinhole and filter to produce partially coherent light. for 20/100; 0.262 in. Notice that the angles A and B and the two right angles formed by the normals with the prism sides constitute such a quadrilateral. Determine the proper blaze angle. For optical wavelengths, the conduction paths analogous to the grid wires l dn a bd n dl (40) In regions of normal dispersion, dn>dl 6 0 and yg 6 yp . Solution Substituting directly into Eq. (53), we get R = c 11>1.48211.46>2.35212 + 1 d 2 or R = 99.1%. Optical Information Processing, Fundamentals. Calculator and watch displays often operate with ambient light. The intervening space is filled with oil of refractive index 1.65. In arriving at this result, Kirchhoff assumed as boundary conditions that the 1 This derivation requires mathematical ability that is beyond the stated level of this textbook but can be found in many places, for example, Max Born, and Emil Wolf. The useful aperture of this double-beam interferometer is such that all rays striking M1 and M2 will be normal, or nearly so. Enlarge the system to a distance x beyond the hemisphere and find the new system matrix as a function of x. It is interesting to note that the theoretical resolution just determined for a 2-mm-diameter pupil is consistent with the value of 1¿ of arc 129 * 10-5 rad2 used by Snellen to characterize normal visual acuity Solution Using Eq. (13), we have d = 45° * 60 min>° b = 2.68 cm VB 10.112 min>G-cm2 * 9000 G 5 THE ACOUSTO-OPTIC EFFECT Photoelasticity is the change in refractive index of a crystal due to mechanical stress. (Both photos are from M. No light is reflected through these pixels and so they appear dark. When R : q, the spherical surface becomes a plane refracting surface, and s_i = - a n2 bs n1 (21) where s_i is the apparent depth determined previously. 11 A hologram is constructed with ultraviolet laser light at 633 nm. Color displays can be made by placing a mask containing an array of red, green, and blue filters arranged in groups of three "subpixels." Controlling the brightness of the light transmitted through the different color subpixels allows for the generation of the complete range of "natural" colors. What is the absorption coefficient for tin, with an imaginary part of the refractive index of a transparent plate of glass, a microscope of "natural" colors. is first focused on a tiny scratch in the upper surface, and the barrel position is recorded. 32 Estimate the diffraction-limited far-field divergence angles of a beam output from the heterojunction laser diode illustrated in Figure 19. Example 3 A 5 cm focal length lens with an f/16 aperture is used to image an object 9 ft away. Indeed, the principles of holography do not depend on the transverse character of the radiation. The collimated beam length is arbitrarily defined as the distance between two symmetrical, transverse planes on either side of the waist. Each wavelength forms its own system of circular fringes according to Eq. (4). (uFF)1 brought to a focus with beam waist w02 located a distance from the line of symmetry to a point on the waveform. Determine the normal reflectance for sodium light of wavelength 10 = 589.3 nm. 102 Chapter 4 Wave Equations Equation 20 can therefore be generalized if the propagation constant, whose magnitude 2p>1 has already been determined in Eq. (4), is now considered to beBa vector quantity, pointing in the direction of propagation. How much larger is the image of the person using this telephoto lens? Referring back to Figure 11, it should be evident that both a change in frequency and a change in direction of the acoustic wave cause a change in the direction of the diffracted beam. Neglecting the obliquity factor for small angles u, Eq. (9) represents a spherical wave whose amplitude decreases with distance r. The interference term I12, in this case, takes the form, 2 2III28cos1k1s2 - s12 + f21t2 - f11t229 As stated, for real detectors and for all but those laser sources with state-of-theart frequency stability, the time average in the preceding relation will be zero. 11 You have been asked to design a Snellen eye chart for a test distance of 5 ft. Self-Phase Modulation and Cross-Phase Modulation In order to carry information in a fiber, the irradiance of the signal wave must vary in time at a given point in the fiber. Like X-rays, penetrating gamma rays find use in the medical area, often used in the visible and near-infrared regions; farthe out in the near-infrared region, the compounds lead sulfide (PbS) (0.8 to 3 mm) and lead selenide (PbSe) (1 to 5 mm) are popular. Show that the relation from part (b) agrees with Eq. (43) only if the survival fraction is close to 1. 452 Chapter 20 Aberration Theory P M O N I P (1) (2) (a) (b) (c) (d) Figure 11 (a) Effect of an aperture stop on the distortion of an image by a lens. At what distance from the objective is a point object viewed by the microscope? This result can be demonstrated by analyzing the Cornu spiral results associated with the slit and wire apertures of Figures 15 and 16. The maximum core index is 1.46 and the cladding index is 1.44. In Figure 4, a sample discrete set of coefficients, as might be calculated from Eq. (6), is shown together with a continuous distribution approximated by the coefficients, such as might result from Eq. (8). The nature of the beam inside the laser
cavity and its characteristics outside the transmission function for the Ronchi ruling is a periodic square function, it is represented by a discrete set of frequencies in a Fourier integral. Of this total power, 99.95% is wasted as heat energy. (a) 0.856 cm (b) 6.63 µm 7. In this case, the line image AB is longer than the axial length of the lens, CL. The degree of coherence can be observed by examining the interference fringe contrast in an amplitude-splitting instrument, such as the Michelson interference fringe contrast in an amplitude-splitting instrument, such as the Michelson interference fringe contrast in an amplitude-splitting instrument, such as the Michelson interference fringe contrast in an amplitude-splitting instrument, such as the tissue, the refractive index of the lens is not homogeneous. Since not all human eyes are identical, a standard response has been determined by the International Commission on Illumination (CIE) and is reproduced in Figure 2. The use of a symmetrical placement of lenses, or groups of lenses, with respect to the aperture is often a distinctive feature of such lens designs. Ch. 20. Both are included within a branch of physics referred to generally as Fourier transform, convolution, and correlation are central concepts of mathematical analysis. However, this technique soon requires impractically large and heavy prisms. 311 Fresnel Diffraction are central concepts of mathematical analysis. zero directly behind the opaque parts of the aperture, and that within the opening itself, they have the same value as they would in the absence of the aperture. The resultant wave may be written as a sum of the individual waves. It follows that the ExP is also conjugate with the EnP. Sketch the orientation of the two plates. The upper energy band is the conduction band and the lower energy band is the valence band. An astigmatic eye, for example, while it possesses predominantly spherical optics, might have a cylindrical axis component whose axis could be horizontal, vertical, or some angle in between. Thus, light amplification occurs during each pass through the gain medium. In such a case, the field radiated by the atom is composed of some photons originating from the spontaneous emission process. Interpret the result. 5 A ray of light makes an angle of incidence of 45° at the center of the top surface of a transparent cube of index 1.414. In such cases, the index is "stepped down" consistently from substrate to ambient. Multiple reflections in the region of 10 increase the total reflected intensity and the quarter-wave stack performs as an efficient mirror. A fringe pattern characterizing the surface contour is observed using He-Ne light of wavelength 632.8 nm. Mode spacings in a typical laser system using an etalon for mode suppression are shown in Figure 16b. Following convention, we call w(z) the spot size of the beam. Linearly polarized E-vector at 30 with x-axis y y E QWP SA Figure 12 x SA along x-axis Problem 10. That is, the nonlinear interaction can convert energy from the second harmonic wave into the fundamental wave. The double slit studied previously constitutes an obstruction to a wavefront in which light is blocked everywhere except at the two apertures. The refracted beam reflects again at the film-substrate interface B and leaves the film at C, in the same direction as the beam reflects again at the film-substrate interface B. and leaves the film at C. Using Eq. (41), nfsr = c. (a) 0.633, 1.898, 3.164 mm (b) 0.50 mm (c) 12.57, 1 37.70, and 62.83 cycles/mm (d) 1: 19: 25 2. 12 The small angle u between two plane, adjacent reflecting surfaces is determined by examining the interference fringes produced in a Fresnel mirror experiment. If instead B is transverse to the plane of incidence, a case to be considered later, the mode is a transverse magnetic (TM) mode. (b) Use of the Cornu spiral in analyzing straight-edge diffraction. Consistent with his conception, Huygens imagined each point of a propagating disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contributed to the disturbance as capable of originating new pulses that contrins that contrins that cont another, are required to read eye charts in a vision test, we limit our discussion of visual acuity to resolving powers associated with minimum legible resolution. Find the cardinal points for the lens and the position and size of the image formed. Some improvement results when the middle layer is of 1>2 thickness, as in Figure 6b and curve (b) of Figure 7. The functions f(x) and g(k) are said to be a Fourier-transform pair. 8 Write a computer program that will determine Ey-values of elliptically polarized light from the equation for the ellipse, Eq. (12), with input constants A, B, and C and variable input parameter Ex. Thus we seek solutions to the more tractable equation 0 2U 0U 0 2U = 0 + + 2ik 2 2 0z 0x 0y (9) 585 Characteristics of Laser Beams Equation (9) is a nontrivial partial differential equation with complex terms. Performance parameters of practical interest are then developed in discussions of the spectral range, dispersion, resolution, and blaze of a grating. (b) Image of a square grid by a positive lens. The phase of rTE may be investigated by expressing Eq. (34) in complex polar form, as rTE = e -ia = e -i12a2 eia where tan a = 2sin2 u - n2>cos u. Determine the beam divergence angle uFF for this laser. As explained in the previous section, amplification of a light wave or photon radiation field will occur only in a medium that exhibits a population inversion between two energy levels. Screen 630 nm Wire 0.37 mm S 3m 2m Figure 24 19 Calculate the relative irradiance (compared to the unobstructed irradiance) on the optic axis due to a double-slit aperture that is both 10 cm from a point source of monochromatic light (546 nm) and 10 cm from the observation screen. The light incident on the grating is rendered parallel by a primary slit and collimating lens. When the effect is enhanced by using an array of such junctions in series, the device is called a thermopile (Figure 1b). Equation (22) becomes m = -n1 1 1121 + 402 = -1 11.3321 + 302 R 5 n2 1.33 RI RO1 40 30 (a) n1 1 n2 1.33 n1 1 s2 9 RI2 RO1 Figure 20 Example of refraction by spherical surfaces. The base, or blank, itself must first be polished to closer than l>10 for green light. Rotator 1u : u + b2 Rotator c cos b sin b - sin b d cos b As an important example, consider the production of circularly polarized with a QWP. The phenomenon of beats provides a sensitive method of measuring the difference in frequencies of two signals of nearly the same frequency. The other, drawn as a double-headed arrow, lies in the plane of incidence, that is, the plane of the page, as in Figure 4b. Before focusing, a plane mirror is used to divert the converging rays to a secondary focal point, fs , near the body of the telescope, where an eyepiece is located to view the image. Its action on the incident linearly polarized light is to convert it to linearly polarized light perpendicular to the original direction, or at - 45° inclination with the x-axis. A small photocell is moved along the central axis, recording the power density of the diffracted beam. In Figure 11, we generalize Figure 3 by defining distances locating the six cardinal points relative to the input and output planes that define the limits of an optical system. (11) and (12), the irradiance is a maximum at u = 0 1y = 02 and drops to zero at values ym such that ym mlf b (13) The irradiance pattern is symmetrical about y = 0. Even the infrared radiation around 900 nm from a galliumarsenide semiconductor laser can be seen as a deep red. 3 Show that Eq. (16) follows from Eq. (15). The same is true for the off-axis point T and its image, T¿. Unpolarized light Air Water n 1.33 Glass block n 1.50 Figure 25 Problem 12. New York: Plenum Press, 1980. (See Figure 4.) 10 A signal of power 5 mW exists just inside the entrance of a fiber 100 m long, 14–16 San Francisco: W. 32. New York: John Wiley and Sons, 1983 Solid solutions of similar compound semiconductor materials produce output in a variety of spectral regions when the composition of the alloy is varied. Because of phase reversal, originally diverging rays—as those in EH2, which form a virtual
image—become converging and focus as a real image on the viewing side of the hologram. First, sources with a stable wavelength output at each of the wavelengths used in the different channels must be available. Fraunhofer Diffraction 289 (a) N 3 (c) N 4 (d) N 5 Figure 17 Diffraction fringes produced in turn by two, three, four, and five slits. The light power incident at the image plane (irradiance Ee in watts per square meter) depends directly on (1) the area of the aperture and inversely on (2) the size of the image. If the two planes are not orthogonal, a rather rare condition called irregular astigmatism, the surface anomaly is not so easily corrected. 17 A 5-cm focal length camera lens with f/4 aperture is focused on an object 6 ft away. CO2 lasers are typically pumped by an electric discharge. The B vector sum E executes oscillations along the x-axis as the EP- and E^c-vectors rotate clockwise, respectively, at equal rates. Combining this result with our understanding of the equivalence of Fourier transform and spatial frequency spectrum (or Fraunhofer diffraction function) of an aperture function, we can read Eq. (33) as follows: The spatial frequency spectrum of image irradiance is equal to the product of the spatial frequency spectrum of object irradiance and the spatial frequency spectrum of the point spread function. Fraunhofer pattern that results from more complicated aperture functions by using the convolution theorem. Each modification improves the coherence of the light given off by the source, but at the expense of a drastic loss of light energy. Copyright © Springer-Verlag GmbH & Co KG. At what wavelength? over a 10-cm grating width, determine (a) the minimum number of grooves/cm required; (b) the optimum blaze angle for work in this region (c) the angle of diffraction where irradiance is maximum (show both blaze angle and diffraction angle on a sketch); (d) the dispersion in nanometers per degree. Apparently then, the Gaussian beam is not brought necessarily to a focus in the focal plane of the lens, that is, at a distance f to the right of the lens. The Pump The pump is an external energy source that produces a population inversion in the laser gain medium. Take n = 1>1.5 to reproduce Figure 6 and then make similar plots for n = 1>2.42. Optics of Thin Films, an Optical Multilayer Theory. Thus the relation given in part (a) of Example 6, derived there for a Q-switched system, also applies for the mode-locked case. have supposed to be a minimum. The differential wave equation to be satisfied by the E-field is then §2E = a 1 0 2E s 0E b 2 + a 2b 2 0t c 0t e0c (53) Note that, compared with Eq. (51), the new wave equation densities of the different energy states in the medium determine the amount of attenuation or amplification that a given electromagnetic field will undergo. Figure 24 illustrates the working principle of the simple magnifier. A three-dimensional view of the object from all sides can be produced on a holographic film that is wrapped around the object on a cylindrical form, as shown in Figure 4. Extrinsic losses of a geometric nature include sharp bends in the fiber as well as microbends, both of which cause radiation loss because the condition for total internal reflection is no longer satisfied (see Figure 5). Nonlaser light primarily via the uncorrelated spontaneous emission action of many atoms. Suppose, however, that the model of the fish has undergone some small changes in shape, by thermal expansion, for example. Equation (7) describes the Cartesian ovoid of revolution shown in Figure 13a. (b) The first few zeroes and maxima of the normalized irradiance I>I0 = 12J11g2>g22. These angles are seen to be precisely complementary, as required by geometry and the definition of Brewster's angle. An Introduction to Coherent Optics and Holography, 2d ed. That stimulated emission produces a "twin" photon, which accounts for the unique degree of monochromaticity, directionality, and coherence associated with laser light. Any electromagnetic wave can be regarded as a superposition of plane electromagnetic waves with various frequencies, amplitudes, phases, and polarizations. With the active material in place, the optical activity is measured by the angle b required to reestablish extinction. (Courtesy of Burroughs Wellcome Co.) Parts of the Eye The basic parts of the Eye and using common trigonometric identities, the detected power can be written as P0 P0 P0 11 + cos 1dg > 22 Pdet = For small arguments, the sine function can be approximated by its arguments, the sine function can be approximated by its arguments, the sine function can be approximated by its arguments of the function can be approximated by its argument so that Pdet L P01dg > 22 Pdet = For small arguments, the sine function can be approximated by its arguments of the function can be approximated by its arguments of the function can be approximated by its argument so that Pdet L P01dg > 22 Pdet = For small arguments, the sine function can be approximated by its arguments of the function can be approximated by its argument so that Pdet L P01dg > 22 Pdet = For small arguments, the sine function can be approximated by its argument so that Pdet L P01dg > 22 Pdet = For small arguments, the sine function can be approximated by its argument so that Pdet L P01dg > 22 Pdet = For small arguments, the sine function can be approximated by its argument so that Pdet L P01dg > 22 Pdet = For small arguments, the sine function can be approximated by its argument so that Pdet L P01dg > 22 Pdet = For small arguments, the sine function can be approximated by its argument so that Pdet L P01dg > 22 Pdet = For small arguments, the sine function can be approximated by its argument so that Pdet L P01dg > 22 Pdet = For small arguments, the sine function can be approximated by its argument so that Pdet L P01dg > 22 Pdet = For small argument so that Pdet L P01dg > 22 Pdet = For small argument so that Pdet L P01dg > 22 Pdet = For small argument so that Pdet L P01dg > 22 Pdet = For small argument so that Pdet L P01dg > 22 Pdet = For small argument so that Pdet L P01dg > 22 Pdet = For small argument so that Pdet L P01dg > 22 Pdet = For small argument so that Pdet L P01dg > 22 Pdet = For small argument so that Pdet L P01dg > 22 Pdet = For small argument so that Pdet L P01dg > 22 Pdet = For small argument so that Pdet L P01dg > 22 Pdet = For s is the difference in path lengths traveled by the beams passing through the two arms of the interferometer. The other component, however, propagates with a refractive index ne = n 7 = c>y7. This equality of the resolution of the two components of the H-alpha doublet of the hydrogen spectrum, whose separation is 1.360 nm at 656.3 nm. Tolansky, Samuel. The film has been deposited on some substrate S. Because of the lens, however, the length of the lens, however, the length of the focused line image AB is no longer equal to the effective length CL of the lens. Linear Polarization (w mp) ~ E General: 0 ~ Vertical: E0 ~ At 45: E0 cos a sin a ~ 0110 Horizontal: E0 12 ~ 114545 II. What is the maximum frequency of input pulses on output due to this case of modal dispersion? Using an average wavelength of 570 nm, what is the angular diameter of the star? Figure 8 illustrates spectral absorption in silica and plastic fibers. The message source might be audio, providing an analog electrical signal from a video camera; or it might be digitally encoded information, like computer data in the form of a train of pulses. The calcium (Ca) atom is positioned at some distance above the carbon atom, at the apex of the pyramid. The root idea had been introduced by Hero of Alexandria, who lived in the second century B.C. According to Hero, when light is propagated between two points, it takes the shortest path. To form a faithful, detailed image of the external object, the eye relies on its visual acuity. For example, when a = 2b, then p = 2m = ; 2, ; 4, ; 6, A gives the missing orders of interference. Compare your answers with the values given in the table. In this case, the intermediate image I must be located outside the ocular focal length fe. The various parameters are k32 = 108 > s, k21 = 103 > s, sp = s31 = 3 # 10-19 cm2, s21 = 10-18 cm2 l31 = 400 nm121 = 600 nm NT = 1.5 # 1026>m3 1in free space2 a. All other field shapes see a high loss and so do not lase. Through lens L1: s1 = 3 cm, f1 = 6 cm so 13 + s11œ = 16 gives s1œ = -6 cm. To record sharp images under these conditions, the film must be shaped to fit the Petzval surface. L P S T 3 Optical Instrumentation INTRODUCTION The principles of geometrical optics are applied in this chapter in order to discuss several practical optical instruments. $f(x) = (4/)(\sin kx + 13 \sin 3kx + 15 \sin 5kx + \cdots) E E 2E f(t) = 0 + 20 \cos t + 30 \cos 2t 2 2 g() = h e(-)/2 \sqrt{2} 672$ (a) 32 million (b) 0.67 million (b) 0.67 million (c) 432 µm; 429 µm; 4 µm 12 and 120, counting both polarizations -70 db/km (0.80 mW 3.33 km; 10 km 0.136 db/km (b) -1.25 db, -6.02 db, -10 db, -20 db (a) 1.0069 km; 1 km (b) 4.900 µs; 4.867 µs 431 ns; 2.32 MHz 77.2 ns 14.6 ns/km 457 ps; 1/146 25 MHz (a) 4 ns (b) 0.4 ns 48.9 ns (b) 3.9 ps/km; 4.3 ps/km (a) 50.5 ns; 0.075 ns; 0. (a) No ΔL satisfies Eqs. r; Employing the Huygens-Fresnel principle, as in Fraunhofer diffraction, we seek to find the resultant amplitude of the electric field at P due to a superposition of all the Huygens wavelets from the wavefront at the aperture, each emanating from an infinitesimal region on the wavefront of elemental area dA. In this situation the ntype side of the junction will be at a higher voltage than the p-type side of the junction. That is, the standing wave normal modes of the cavity length. The focal points F1 and F2 are located at distances f1 and f2 from the principal points H1 and H2 and at distances p and q from the reference input and output planes, respectively. This wave phenomenon has its analogy in
the reflection of waves from the fixed end of a rope. The geometrical extensions denoted by the dashed lines in Figure 4, identifying triangle ACA2, make it evident that $\phi = AB + BC = A2B + BC = A$ = fr 2n1d cos w + p l Now, since fr ... p, the second term is 1 at most and is typically negligible compared with the first term. Irradiance fluctuations about the constant bias comprise the spectral distribution (interferogram) given by q 11x2 = L0 11k2cos1kx2 dk (41) which is the (cosine) Fourier transform of the spectral distribution (interferogram) given by q 11x2 = L0 11k2cos1kx2 dk (41) which is the (cosine) Fourier transform of the spectral distribution (interferogram) given by q 11x2 = L0 11k2cos1kx2 dk (41) which is the (cosine) Fourier transform of the spectral distribution (interferogram) given by q 11x2 = L0 11k2cos1kx2 dk (41) which is the (cosine) Fourier transform of the spectral distribution (interferogram) given by q 11x2 = L0 11k2cos1kx2 dk (41) which is the (cosine) Fourier transform of the spectral distribution (interferogram) given by q 11x2 = L0 11k2cos1kx2 dk (41) which is the (cosine) Fourier transform of the spectral distribution (interferogram) given by q 11x2 = L0 11k2cos1kx2 dk (41) which is the (cosine) Fourier transform of the spectral distribution (interferogram) given by q 11x2 = L0 11k2cos1kx2 dk (41) which is the (cosine) Fourier transform of the spectral distribution (interferogram) given by q 11x2 = L0 11k2cos1kx2 dk (41) which is the (cosine) Fourier transform of the spectral distribution (interferogram) given by q 11x2 = L0 11k2cos1kx2 dk (41) which is the (cosine) Fourier transform of the spectral distribution (interferogram) given by q 11x2 = L0 11k2cos1kx2 dk (41) which is the (cosine) Fourier transform of the spectral distribution (interferogram) given by q 11x2 = L0 11k2cos1kx2 dk (41) which is the (cosine) Fourier transform of the spectral distribution (interferogram) given by q 11x2 = L0 11k2cos1kx2 dk (41) which is the (cosine) Fourier transform of the spectral distribution (interferogram) given by q 11x2 = L0 11k2cos1kx2 dk (41) which is the (cosine) Fourier transform of the spectral distribution (interferogram) given by q 11x2 = L0 11k2cos1kx2 dk (41) which is the L0 q (42) Thus, detection of the interferogram output I(x), as a function of path difference x, at a point on the optical axis of the system enables one to calculate the spectral irradiance distribution I(k) as a function of wavenumber by the Fourier-transform integration indicated in Eq. (42). To aid a discussion of this evolution, consider Figure 16. A network of such corner reflectors ensures the exact return of a beam of light—a headlight beam from highway reflectors, for example, or a laser beam from a mirror on the moon. (15) and (16) that L1 = L2. Describe as completely as possible the line image of the point. The two dimensions are those of the page on which we have been drawing our ray diagrams. The coherence length of typical laser sources ranges from tens of centimeters to tens of kilometers. Formal proofs can be found in any standard textbook on matrices and determinants, for example, E. 8 A thin lens is used to image an object 1 m from the lens. It has the property that as u approaches 0, the function approaches a value of 1. Considering both TE and TM modes together, it follows that the reflected light is partially polarized with a predominance of the Es mode present. The redshift is the shift in wavelengths, due to a relative speed of the source away from us. Recalling that the ray represents plane waves moving up and down in the waveguide, it is evident that such waves overlap and interfere with one another. This leads to the Bragg equation for X-ray diffraction.14 In Eq. (16), the angles and optical wavelength are those measured within the medium. This is not, however, a fundamental physical distinction. For an off-axis object at infinity, the zones are straight, parallel interference fringes. Since such a relationship cannot depend on Br and t, must themselves be equal: 1k # Br - vt2 = 1kr # Br - vt2 = 0 of Figure 1, - vt = - vtt or v = vr = vt (5) so that all frequencies are equal. Another conclusion that is of some historic interest follows from a consideration of the effect at P when a round obstacle or disc just covering the first zone is substituted for the aperture. As another example, consider the superposition of vertically and horizontally linearly polarized light at an inclination of 45°. The visible spectrum of colors ranges from red (long-wavelength end) to violet (short-wavelength end) and is bounded by the invisible ultraviolet and infrared regions, as shown. For night viewing, when the pupils are somewhat larger, a rating of 7 * 50, producing an exit pupil diameter of 7 mm, would be preferable. We display this behavior by a double-headed arrow, as shown in Figure 2a. The small-signal gain coefficient, built while the cavity had a high loss rate, now exceeds a row, as shown in Figure 2a. the high-Q Q. In either case, nearly parallel rays of light from a distant object are collected by a positive objective lens, which forms a real image in its focal plane. Finally, computer ray-tracing methods for tracing a given ray of light through an optical system are briefly described. Show that the fringe visibility may be expressed by 12 Determine the linewidth in angstroms and hertz for laser light whose coherence length is 10 km. What is the maximum ratio of beam irradiance Radiant energy Radiant energy Radiant flux, Radiant power Radiant exitance Irradiance Radiant intensity Radiance Symbol (units) Defining equation Qe1] = W # s2 we1]>m32 f e1W2 Me1W>m22 Ee1W>m22 Ee move more than l>10 during the exposure? To achieve some measure of coherence with a nonlaser source, two modifications to the emitted light can be made. (a) (b) (c) (d) wave.) More complex filtering has also been used in image restoration, for example, in the deblurring of lunar photographs. The linewidth of a single mode in the output of a laser is typically governed by environmental noise such as mechanical vibrations, which change the cavity length, or index of refraction variations in the gain medium. Two common uses of the Fabry-Perot as a control element are as a means of limiting a laser to single-mode operation and as a component in a laser frequency stabilization system. Of course, a complete specification of the full electric field vectors of plane waves and Gaussian beams also requires knowledge of the polarization of the fields. 4 An equiconvex lens having spherical surfaces of radius 10 cm, a central thickness of 2 cm, and a refractive index of 1.61 is situated between air and water 1n = 1.332. In contrast, as mentioned, a laser source, by the very nature of its production of light via stimulated emission, ensures both a narrow-band output and a high degree of phase correlation. 22 Based on the plots obtained in problem 21, describe how an adjustable aperture can be used in a laser cavity to ensure that only the TEM00 cavity mode would be present in the laser output. molecule, and so also the crystal, is B symmetric with respect to this direction (from C to Ca), both E-vibrations interact with the electrons in the same way when traveling through the calcite. Thus f b f represents the magnitude of the phase difference, at point P, between waves from the center and either endpoint of the slit, where f s f = b>2. Emitting area m 0m 20 TABLE 1 LASER DIODE WAVELENGTHS Material Wavelength (nm) GaN AlGaInP GaAlAs InGaAsP Sb mixtures 400-480 630-690 750-900 1200-2000 2000-4000 579 Laser Operation of incident power that passes through a circular aperture (lens, diaphragm, etc.) of radius a, we revisit the expression for the Gaussian-beam irradiance I given in Eq. (25). The generation of LIGO interferometers under construction in 2005 is predicted to be sensitive to gravitational strains of less than 10-21, and the next generation of devices is predicted to have strain sensitivities of less than 10-22, both for signals with frequencies in the range of 100-1000 Hz. To detect these tiny gravitational strains, environmental signals due to seismic activity and a variety of other sources must be either reduced in size or filtered. The double sums represent all the cross products, excluding—by the use of notation j 7 i— index by K = n2 a. Mirror Film Holography 4 HOLOGRAM PROPERTIES As stated earlier, the entire hologram receives light from each object point in the scene. As v increases slightly, as shown in Figure 2. 6 Calculate the skin depth in copper for radiation of (a) 60 Hz and (b) 3 m. The incoming beam is highly, as shown in Figure 2. 6 Calculate the skin depth in copper for radiation of (a) 60 Hz and (b) 3 m. The incoming beam is highly as shown in Figure 2. 6 Calculate the skin depth in copper for radiation of (a) 60 Hz and (b) 3 m. The incoming beam is highly as shown in Figure 2. 6 Calculate the skin depth in copper for radiation of (a) 60 Hz and (b) 3 m. The incoming beam is highly as shown in Figure 2. 6 collimated so that its wavefronts are very nearly planar. With a lens separation somewhat less than f, however, the requirement on L that corrects for transverse chromatic aberration is to use two clean, glass microscope slides, wedged apart at one end by a thin spacer, perhaps a hair, as in Figure 15b. Recall that in this case the population of the lower lasing level N1 is negligible since we take t1 L 0. 23 What is the angular half-width (from central maximum to first minimum) of a diffracted beam for a slit width of (a) l; (b) 5l; (c) 10l? The temporal coherence, also called "longitudinal spatial coherence," is many orders of magnitude above that of any ordinary light source. To see that these equations represent the sequence in Figure 5, we take their real parts and set E0x = E0y = A and e = p>2, giving t T/4 Ey $\leq A$ Ex 0 (b) Ex = A cos vt y Ey = A cos avt - A p b = A sin vt 2 x E 2 = E 2x + E
2y = A21cos 2 vt + E 2 sin 2 vt 2 = A2 (8) To determine the normalized form of the vector, notice that 12 + fif 2 = 1 + 1 = 2, so that each element must be divided by 22 to produce unity. Experiment to find the range of distances over which you can detect the separation of lines placed 1 mm. When the reflecting surface is that of a homogeneous dielectric—the case we have been appreciated to the separation of lines placed 1 mm. When the reflecting surface is that of a homogeneous dielectric—the case we have been appreciated to the separation of lines placed 1 mm. When the reflecting surface is that of a homogeneous dielectric—the case we have been appreciated to the separation of lines placed 1 mm. When the reflecting surface is that of a homogeneous dielectric—the case we have been appreciated to the separation of lines placed 1 mm. When the reflecting surface is that of a homogeneous dielectric—the case we have been appreciated to the separation of lines placed 1 mm. When the reflecting surface is that of a homogeneous dielectric—the case we have been appreciated to the separation of lines placed 1 mm. When the reflecting surface is that of a homogeneous dielectric—the case we have been appreciated to the separation of lines placed 1 mm. When the reflecting surface is that of a homogeneous dielectric—the case we have been appreciated to the separation of lines placed 1 mm. When the reflecting surface is that of a homogeneous dielectric—the case we have been appreciated to the separation of lines placed 1 mm. When the reflecting surface is that of a homogeneous dielectric—the case we have been appreciated to the separation of lines placed 1 mm. When the reflecting surface is that of a homogeneous dielectric—the case we have been appreciated to the separation of lines placed 1 mm. When the reflecting surface is the separation of lines placed 1 mm. When the reflecting surface is the separation of lines placed 1 mm. The se discussing in this chapter—the conductivity s of the material is zero. Wolbarsht. Next, consider the first two members of Eq. (6), which govern the relationship between the incident and reflected waves. For example, lightbulbs spread their output uniformly in all directions so that the irradiance 1 m from a light power output of 10 W would be I = P>A = 10 W P = 4pr2 4p11 m22 = 0.796 W>m2 Irradiance 1 m from a 10-W lightbulb The output from a He-Ne laser, on the other hand, is concentrated in the thin beam of light emerging from the laser. The interferometer is therefore of the amplitudesplitting type. 3 471 Fourier Optics Aperture function for an array of slits Aperture function for a single slit Aperture function for a grating Figure 9 Symbolic representation of the convolution theorem for a grating. The special advantages of this technique have K (b) Figure 10 (a) Irradiance sinusoids of object and image, both of spatial frequency K. For a ray incident from the second medium, we define similar quantities, which we distinguish with prime notation, r¿ and t¿. A calculation similar to that carried out in Example 3 reveals that in this case I1st min = 0.78Iu. (6), (7), (10), and (11) to make use of those members previously ignored in first finding the transfer matrix. Of course, prisms alone cannot produce images. If the incident light is white and l0 is in the visible region, the reflected light is colored. Integrated Gain Using Eq. (37) in Eq. (36) results in a differential equation that can be integrated to provide a relation between the irradiance IL output from that gain medium. How does the polarization of the emergent light vary as a function of u? In this approximation, where we allow only such paraxial rays2 to form the image, the angles of incidence and refraction are both small, and the approximation sin u tan u 1 in radians2 is valid. By what percentage difference does the ratio of the film indices differ from the ideal? If such a resonance occurs in the visible range of frequencies, for example, the material absorbs a portion of the spectrum and appears colored, while transmitting the remainder. Below 100 nm, gold and platinum are often used. Equations (3) to (5) then take the simpler forms for photons: p = E c (6) l = h hc = p E (7) y = pc2 = c E (8) Thus, while nonzero rest-mass particles like photons must travel with the constant speed c. 13 Carry out the integration necessary to verify the claim that the total power carried in a TEM00 beam is £ tot = 10 pw20 2 14 Carry out the integrations necessary to show that the fraction of the power in a TEM00 beam that is transmitted through a 2 2 circular aperture of radius a is 1 - e-2a > w . 4 REFLECTION IN PLANE MIRRORS Before discussing the formation of images in a general way, we discuss the simplest—and experientially, the most accessible—case of images formed by plane mirrors. A pinhole does no focusing and actually blocks out most of the rays from each object point. Each view is complete, exhibiting both depth and parallax. 6 Determine the theoretical refractive index and thickness of a single film layer deposited on germanium 1n = 4.02 such that normal reflectance is zero at a wavelength of 2 mm. The quantity EA is the source strength, or amplitude per unit area of aperture, in the neighborhood of point O. What reflectance does the structure have for incident light of 550 nm? If the aperture is not uniformly illuminated or is not uniformly transparent, then EA = EA1x, y2 and it is called the aperture function. In general, harmonic waves are produced by sources that oscillate in a periodic fashion. New York: Academic Press, 1976. In any case, since the square brackets include quantities independent of h, we have shown that third-order theory predicts a wave aberration a(Q) that is proportional to the fourth power of the aperture h, measured from the optical axis, or a1Q2 = ch4 axial object points (19) where c represents the constant of proportionality. Thus gain will occur provided that a population inversion 1N2 7 N12 exists in steady state. Blazed grating 1 2000 Å N di u B N W 15 cm um Figure 16 Problem 14. Eventually, the irradiance grows sufficiently to reduce the population inversion to the point that the gain per round-trip. Radio waves have wavelengths ranging from meters. In Figure 9b, the rectangular strip zones are shown both above and below the axis SP. Thus, the image formed by a telescope with a round objective is subject to the diffraction effects described by Eq. (19) for a circular aperture. Rather, to restore clear vision of objects positioned anywhere from the eye to very far from the eye modes is 150 MHz. The plates are separated by an air gap and have a reflectance 1r22 of 0.999. All of the equations used in this chapter are linear in these quantities and so hold for both the real fields and displacements and their complex representations. transmits light at certain positions and blocks light at other positions. What is the reflectance if the layers are reversed? For the case of equal amplitudes (rather than the irradiances) simply add to produce a resultant E0 = NE01. Unfortunately, the standard symbol for irradiance, except for the subscript, is the same as that for the electric field. 1 CONVENTIONAL VERSUS HOLOGRAPHIC PHOTOGRAPHY We are aware that a conventional scene, bringing into focus every part of the scene that falls within the depth of field of the lens. 3 Find the Fourier transform of the Gaussian function given by f1t2 = he-t >2s 2 2 f(t) A t t0 2 Figure 17 t0 2 Problem 4. (New York: John Wiley & Sons, 1989), Ch. 7. What is its length? Calculate the far-field beam divergence angle for the laser beam that emerges from the focused beam divergence angle for the laser beam that emerges from the focused beam divergence angle for the laser beam that emerges from the focused beam divergence angle for the laser beam that emerges from the focused beam divergence angle for the laser beam that emerges from the focused beam divergence angle for the laser beam that emerges from the focused beam divergence angle for the laser beam that emerges from the focused beam divergence angle for the laser beam that emerges from the focused beam divergence angle for the laser beam that emerges from the focused beam divergence angle for the laser beam that emerges from the focused beam divergence angle for the laser beam that emerges from the focused beam divergence angle for the laser beam that emerges from the focused beam divergence angle for the laser beam that emerges from the focused beam divergence angle for the laser beam that emerges from the focused beam divergence angle for the laser beam that emerges from the focused beam divergence angle for the laser beam divergence angle for the laser beam that emerges from the focused beam divergence angle for the laser beam divergence angle for the lase material asymmetries along the propagation vector could B not alter the sense of the oscillating E-vector, and the physical mechanisms to be described here would have no polarizing or spatially selective effects on light beams. The first half-period zone is completed after a number of such phasors culminate in a subzone phasor opposite in direction to the first. To see this, recall that the incremental length dl along a curve in the xy-plane is given in general by dl2 = dx2 + dy2 In the case at hand, the x- and y-coordinates are the Fresnel integrals C1y2 and S1y2, respectively. The biprism is twice as far from a screen on which fringes are observed as it is from the slit. We can say that a one-to-one relationship exists between object and image points. Example 1 Show that the separation d of fringes in the formation of a holographic grating, as in Figure 7, is given by |>12 sin u2, where 2u is the angle between the coherent beams in the film, l = 10 > n is the wavelength of the beams in the film, l = 10 > n is the wavelength of the beams in the film, l = 10 > n is the wavelength of the beams in the film. wavefronts produced
by such an ideal point source is indicated in Figure 17. Let the electric field of this wave, at the B origin of the axis system, be represented, at a given time, by the vector E shown. 3 Repeat problem 1 for an object 2 cm high, with a 2-cm aperture stop and a thin convex lens of 6-cm focal length and 5-cm aperture. The general shape of an achromatic doublet is shown in Figure 13. With the seed photons of correct (resonant) energy accurately directed between the mirrors and many atoms still in the upper laser level E2, the stage for stimulated emission is set. The contribution due to pressure broadening \$nH,p is evidently \$nH,p = \$nH - \$nH,t = 1 GHz - 0.00161 GHz L 1 GHz g(n) gth nfsr n0 (b) Under the operating conditions leading to a linewidth of 1 GHz, this transition is predominantly pressure broadened. The special case of an electromagnetic wave that is circularly polarized is illustrated in Figure 12b. Determine the beam divergence angle u. Wavefront W1 is a spherical wavefront representing the Gaussian, or paraxial nsn21 b n0n22 + nsn21 2 (45) Zero reflectance is predicted by Eq. (45) when n0n22 = nsn21, or ns n2 = n1 n A 0 Air l 4 l 4 n0 1 CeF3 n1 1.65 Low index ZrO2 n2 2.1 High index Glass ns 1.52 Figure 3 Antireflecting double layer, using l>4-l>4 thickness films. Consider a wavefront moving towards Mirror 2 in Figure 6. Then, the gain coefficient takes the simple form g = sRp2>k2 1 + 1sI>hn¿2>k2 K g0 1 + I>IS (37) Here we have introduced two important parameters that describe gain media, the small-signal gain coefficient g0 and the saturation irradiance IS. Consider what happens to such light after reflection from a plane surface and transmission back through this optical device. B. The less numerous, wider cones in the macular region, by contrast, are individually activated. One, represented by a dot is perpendicular to the plane of incidence, as in Figure 4a. Adequate agreement with experimental observations is possible through an application of the Huygens-Fresnel principle. Objectives may be classified broadly in relation to the corrections introduced into their design. High reflectance in the visible spectrum is characteristic of metallic surfaces, as shown by the curves for solid sodium at a wavelength of 589.3 nm. 39 Geometrical Optics The second lens is concave: f2 = -15 cm. For the arrangements shown in Figure 17b and 17c, the rays 12b and 17c, the rays 12b and 17c a 2¿, and 3¿ appear to originate from a point of intersection (a virtual image point) located behind the mirror. Such overlapping of wavelengths can be avoided by observing the Nyquist criterion of sampled at a rate at least twice as high as its highest-frequency component. The effective friction due to interaction with lattice imperfections, for example, constitutes some dissipation of energy, which must attenuate the incident wave. In Figure 29, two vertical slices or sections are shown perpendicular to the axis of a convex cylindrical lens. The rate at which spectrogram data is sampled is 1.28 readings/s. The second grating also focuses the two-dimensional spectrum onto the photographic plate. Linear polarizers TA horizontal c 1 0 0 d 0 c TA vertical 0 d 1 0 0 TA at 45° to horizontal 1 1 c 2 1 1 d 1 II. Thus spherical aberration exists even for a single lens in Figure 6a. (27) and (28) can be conveniently substituted. Determine the irradiance (in terms of the unobstructed irradiance) at the screen (a) on axis and (b) at one edge of the geometrical shadow of the diffracting slit. In order to do this we use Maxwell's equations and the mathematical techniques of vector calculus, |R| 15 cm Figure 36 Problem 20 21 An evenies each of + 20-mm focal length, separated by a distance of 16 mm. The equilibrium separation of the two atoms in a diatomic hydrogen molecule H2 is about 0.074 nm. That is, the contribution to the total electric field at the position of a given dipole, due to B all the other dipoles in the medium, is given by P>3e0, where e0 is the permittivity of free space. Problem a. To this end, let us define a K ks1 + f1 and b K ks2 + f2 so that B B B B 2E1 # E2 = 2E01 # E02 cos1a - vt2cos1b - vt2 The identity 2 cos1A2cos1B2 = cos1A + B2 + cos1B - A2 helps us cast the B B time average of 2E1 # E2 = 2E01 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B B The first time average of 2E1 # E2 = 2E01 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B B The first time average of 2E1 # E2 = 2E01 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B B The first time average of 2E1 # E2 = 2E01 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B B The first time average of 2E1 # E2 = 2E01 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B B The first time average of 2E1 # E2 = 2E01 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B B The first time average of 2E1 # E2 = 2E01 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B B The first time average of 2E1 # E2 = 2E01 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B B The first time average of 2E1 # E2 = 2E01 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B B The first time average of 2E1 # E2 = 2E01 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B B The first time average of 2E1 # E2 = 2E01 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B The first time average of 2E1 # E2 = 2E01 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B The first time average of 2E1 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B The first time average of 2E1 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B The first time average of 2E1 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B The first time average of 2E1 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B The first time average of 2E1 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B The first time average of 2E1 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B The first time average of 2E1 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B The first time average of 2E1 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B The first time average of 2E1 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B The first time average of 2E1 # E02[8cos1a + b - 2vt9 + 8cos1b - a29] B B B The first time average of 2E1 # E02[8cos1a + b - 2vt9 + 8cos1b + a29] B B The first t defined by circles on the wavefront, spaced in such a way that each zone of area Sn is, on the average, l>2 farther from the field point P than 313 Fresnel Diffraction a1 A1 rn S Zonal area Sn O r2 r1 r0 P A Reference direction (a) (b) the preceding zone. In Table 1, these figures of merit are tabulated. Optical correlation techniques have been developed that allow recognition of a pattern independently of its size or orientation. Graphical methods of locating images, as with spherical mirrors in Figure 17, make use of three key rays. At some intermediate point M between E and I, a "best" focus is attained in practice. Any ray directed toward the first nodal point, N1, emerges from the optical system parallel to the incident ray, but displaced so that it appears to come from the second nodal point on the axis, N2 . dispersion and resolution attainable with large angles of incidence on a blazed plane grating. The optic-fiber cores are assumed to be homogeneous in composition, characterized by a single index of refraction n1 . If the amplitude at distance in composition attainable with large angles of incidence on a blazed plane grating. from the point source is A/r, then the irradiance 1W>m22 of the wave there is proportional to 1A>r22. Two of the most widely used transitions in gases are the 632.8-nm visible radiation from the CO2 molecule. Notice that at both normal and grazing incidence— angles of 0° and 90°, respectively—TE and TM modes have reflection coefficients of the same magnitude and transmission coefficients of the same magnitude. Because of dispersion, the light at frequency v. What plate spacing is required? Still, typical lasers have spatial and temporal coherences far superior to that for light from other sources. Figure 14 Fabry-Perot rings obtained with the mercury green line, revealing fine structure. Radial keratotomy. A 1-m focal length lens intercepts the light diffracted by the aperture and projects the diffraction pattern on a screen in its focal plane. The basic equation describing nonlinear behavior was given as Eq. (3), a relation between the polarization of the medium and the applied electric field. For many purposes, this treatment is sufficient. In 1821, Augustin Fresnel published results of his experiments and analysis, which required that light be a transverse wave. Butcher, and D. The thick lens can also be described in a way that allows graphical determination of images corresponding to arbitrary objects, much like the ray rules for a thin lens. Write the equation for the wave at t = 0. All objects in the object plane are precisely focused in the image plane, disregarding the usual lens aberrations. The amplitude of the electric field given in Eq. (9) is E0 = ELb sin b r0 b 271 Fraunhofer Diffraction Thus, we find the irradiance I to be I = a e0c e0c ELb 2 sin2 b b E 20 = a b r0 2 2 b2 or I = I0 a sin2 b b2 b K I0 sinc21b2 (10) where I0 includes all constant factors. Charged particles oscillating with a regular frequency emit harmonic electromagnetic waves. For example, a single pulse is a nonperiodic function but can be interpreted as a periodic function whose period extends from t = -q to t = +q. Thus, from Snell's law, sin uc = a n 2 n 2 b sin 90 = n1 n 1 or uc = sin - 1 a n 2 b n 1 (5) For angles of incidence u = -q to t = +q. Thus, from Snell's law, sin uc = a n 2 n 2 b sin 90 = n1 n 1 or uc = sin - 1 a n 2 b n 1 (5) For angles of incidence u = -q t - q t -
q t - q ttypically coupled directly into a fiber or collimated by a short focal length lens. 5 Prove the convolution in one dimension of two identical square pulses, of unit height and of 6 units length. Take the reflectances of the three mirrors M1, M2, and M3 to be R1, R2, and R3, respectively. Consider the Fraunhofer diffraction pattern due to an arbitrary aperture situated in an xy-plane, as shown in Figure 1. Rather, the eye views a virtual image formed by the corrective lens. Both waves have a period of 1 s. Next, consider the Fraunhofer diffraction pattern due to an arbitrary aperture situated in an xy-plane, as shown in Figure 28. As one such curve (dashed semicircle) is translated along the x-axis relative to the other, their autocorrelation £1B2 varies as a function of the parameter B, the displacement of their y-axes. Since the frequencies of the two modes are identical, angle b remains constant thereafter. The left mirror 1 f RM1 f = 2 m2 is 100% reflecting. Both UV and IR absorption decrease as wavelengths approach the visible region. In applications where fiber lengths are short enough, plastic fibers and LED 259 Fiber Optics sources may well represent the best compromise between performance and cost. 1 OPTICAL DATA IMAGING AND PROCESSING Fraunhofer Diffraction and the Fourier Transform We wish to show that the Fraunhofer diffraction pattern is, within certain apB proximations, the Fourier transform of the E-field amplitude distribution in the object plane. The first and second air separations between lens surfaces are d1 and d2. Although the values of the free spectral range and the FWHM of the transmittance peaks depend, of course, on the chosen independent variable. the ratio of these quantities (i.e., the finesse) depends only on the reflectivities of the mirrors and so is a useful figure of merit for the Fabry-Perot cavity. Strong absorption in the ultraviolet occurs due to electronic and molecular bands. From a packaging perspective, the main distinguishing feature of the diode laser is its size. Design bifocals that will allow this person to see clearly both faraway objects at a comfortable reading distance from the eye. Since irradiance at P is only 14 that due to the first-zone aperture alone. The formalism introduced in Section 5 can be used to determine the rate at which the light energy stored in an optical cavity decreases over time. A study of Figure 22, or the equations describing the set of reflected beams, shows that in the case of a reflected beams, shows that in the case of a reflected beams, shows that in the case of a reflected beam. In such a crystal, reversing the applied field should not—except for a change in sign—change any physical property, such as its polarization. 3 THE ELECTROMAGNETIC SPECTRUM We are concerned with the production of extremely short (ps-width) mode-locked pulses. With reference to Figure 14 and Eqs. After its final refraction by the crystalline lens, light enters the posterior chamber or the vitreous humor, a transparent jellylike substance whose refractive index (1.336) is again close to that of water. Determine size and location of the entrance and exit pupils. 118 Chapter 5 Superposition of Waves and by the Pythagorean theorem, N N 2 E20 = a a E0i sin ai b + a a E0i cos ai b i=1 2 (13) i=1 Eq. (13) may be cast into a form that looks more like a generalization of the cosine law in Eq. (9). Coma, like spherical aberration, may occur as a positive guantity 1he 6 hc2. The convex lens is replaced by a telephoto combination consisting of a 12-cm focal length convex lens and a concave lens. Find the distances of the m = 1 and m = 3 spots from the central DC spot in the diffraction pattern on the screen in the same medium, so that no further phase difference High Low High Low Substrate Figure 11 Multilayer dielectric mirror of alternating high and low index. That is, Eq. (26) encodes the familiar inverse square law of propagation for spherical wave disturbances. Suppose now that the transmission function is not a square wave but a sine wave. The diffraction pattern consists, in addition to the direct beam, of two pairs of light spots, each pair due to one of the spatial frequencies present. For a lower point P- on the screen, we must consider the zones relative to the new axis SO-P-, drawn from P- to the wavefront at the aperture. Furthermore, the two beams emerge linearly polarized in orthogonal orientations, as shown. As the story is told, a rather myopic Soviet lad, Boris Petrov, was engaged in a schoolyard fight in Moscow, mirror. In addition, the technique is capable of high resolution, limited in principle only by the sample width of the input data and the wavelength region under analysis. The same result y TA FA 45¹¹¹ x Unpolarized light HWP TA SA h Analyzer ≥45¹¹¹ SA Retarder Polarizer Figure 20 Light transmitted by cross polarizers when a birefringent material acting as a half-wave plate is placed between them. The large energy throughput that results from the use of a large aperture is called the Jacquinot advantage. As a result, the photograph lacks the perception of depth or the parallax with which we view a real-life scene. By using a double layer of quarter-wave-thickness films, however, it is possible to achieve essentially zero reflectance at one wavelength with available coating materials. Further, we will assume that an electric field suffers no absorption upon encountering the cavity mirrors, so that r2 + t2 = 1 lossless mirrors (16) A useful parameter associated with the Fabry-Perot interferometer is the cavity round-trip time t. Show that, for this case, lout = Isat 1g0 - gth2L b. Thus the lens can be considered as a series of concentric Comatic circle A xis cal a Opti C 1 D Zone 3 B Convex lens 4 2 (a) B A 4 2Re O hc he 2 Re 1 he hc 3 Image plane 5 (b) (c) sin u sin f PC r sin f sin u Seconding to Fermat's principle. A Bayer mask is an array of color filters, with each miniature 8 (a) and (b) Coma due to fans of parallel rays. To a first approximation, the optical path lengths of rays PQI and POI are identical, according to Fermat's principle. A Bayer mask is an array of color filters, with each miniature filter designed to cover one pixel of the CCD array. 20 A doublet telescope objective is made of a cemented positive lens 1n1 = 1.5736, f1 = 3.543 cm2 and negative lens 1n2 = 1.6039, f2 = 5.391 cm2. Estimate the diameter of this beam after it has propagated over a distance of 1 km. What is the minimum resolvable wavelength interval under these conditions? Figure 15b relates the four steps to the emission of the He-Ne 0.6328 mm laser line, but other transitions from the 3s to the 2s and 2p levels have also been made to lase. 7 OTHER HARMONIC WAVEFORMS Cylindrical Waves Another useful complex waveform represents a cylindrical wave in which the waveforms are outward-moving cylindrical surfaces surrounding a line of symmetry, as shown in Figure 8. There exists in the optical industry today many different practical optical systems, each with many choices available for the placement of apertures. Rays from intermediate points of the actual wavefront between O and B intersect the image screen at other points around I. producing a blurred image, the result of aberration. Electrons obey Fermi-Dirac statistics, whereas photons obey Bose-Einstein statistics. Thus as P is moved toward the plate, n = 2 when r0 = f1>2 for the same zonal radius R1. The linewidth en of the transition is the full width at half maximum of the lineshape function. apart. Parallel rays of light passing through the vertical axis (see Figure 27a) and through the horizontal axis (see Figure 27b) are handled identically by the lens, converging them to a common focus at F. At the location of vB 7, which must be perpendicular to aa, and the perpendicular component propagates along the direction of vB, which must be perpendicular to bb. The horizontal components of the original light have been removed by absorption. In this way, fiber-optic faceplates are made for use as windows in cathode ray tubes. Having originated from a single beam, the multiple beams are coherent. In more difficult situations, where the Petzval condition cannot be 451 Aberration Theory satisfied without sacrificing other requirements, a low-power lens is sometimes used near the image plane. 314 Chapter 13 Fresnel Diffraction The quantity 11>r02 is very small in most cases of interest. What is the ratio L>Lmin? Solution irradiance Ee = P>A = 100 W>4p12 m22 2 W>m2 From the CIE curve, V1650 nm2 = 0.1. Thus, illuminance Ev = K112 * irradiance = 685V112 * Ee Ev = 685 * 0.1 * 2 = 137 lm>m2 or lux Thus, whereas a radiometer with aperture at the surface measures 2 W>m2, a photometer in the same position
would be calibrated to read 137 lx, 383 Holography Ultrasonic Holograms The mention of ultrasonic holograms implies that the waves producing a hologram need not be electromagnetic in nature. Such light is said to be randomly polarized or, commonly, unpolarized or, commonly, u * 10-9 m = 3.58 * 10-19 J = 2.2 eV 6.63 * 10-16 J>s Power = 1850>s. At the point of superposition, calculate (a) the irradiances (d) the irradiances (d) the fringe visibility. For the case shown in Figure 17a, the three rays 12, 22, and 32 intersect at a real image point as they progress away from the mirror and toward the viewer. For gas lasers, such Pump M1 M2 Laser Medium Mirror Figure 13 Essential elements of a laser. However, prototype devices with arm lengths of 40 m have been operated with noise levels corresponding to strains of about 2 * 10-19 for signals at about 450 Hz.2 In the setup illustrated in Figure 17a, the end mirrors of the two FabryPerot interferometers and the beam splitter are mounted on freely suspended masses. The light is allowed to pass through a narrow, horizontal slit positioned 1 mm above a flat mirror surface. A Q-switched laser system, then, produces a series of irradiance pulses similar in character to the first pulse in a gainswitched system. v = 0.168c 22. If V112 is the luminous efficiency, as given on the CIE curve, then K112 = 685V112 (2) Photometric terms are preceded by the word luminous and the corresponding units are subscripted with the letter y (visual); otherwise, the symbols are the same. How large is a circular opening in an otherwise opaque screen if it transmits four Fresnel zones to a point 2 m away? Note that the half-angle beam divergence is larger for beams with smaller beam waists. Table 1 and Figure 24 provide a convenient summary of image formation in lenses and mirrors. If N is large, as in the case of unlimited aperture, a N approaches zero, and for either N even or odd, the resultant amplitude is half that of the first contributing zone, or a1>2. When thin lenses are placed together, in contact, the focal lengths f1, f2, Å of the individual lenses. However, not every light ray from an object point, directed toward or into an optical system, reaches the final image. For example, the green line of mercury at 546 nm may have a line width of around 0.025 nm, giving a coherence length of 1.2 cm. (30) and (31) into either of the Eqs. Since this myopic person can see clearly objects brought in as close as 15 cm from the eye, the virtual image of the print formed by the lens at 20 cm is seen without difficulty. Available values are 4 * to 25 *, corresponding to focal lengths of 6.25 to 1 cm or less. 277 Fraunhofer Diffraction J1 (g) g 5 10 Figure 7 A plot of the Bessel function J1 (the output of a laser. The required diameter for single-mode performance is found by imposing the condition mmax 6 2 on Eq. (10), giving 2 d 6 l p1N. The molecule 1Kr+F-2... is the upper state of the lasing transition. 27 A collimated light beam is incident normally on three very narrow, identical slits. For normally incident light of wavelength l + dl, and

principal maximum of order m, we have by the grating equation (2), a sin um = m11 + d12 (9) 297 The Diffraction Grating To satisfy Rayleigh's criterion, this peak in the same order, or a sin um = a m + 1 bl N (10) Equating the right members of Eqs. Solution lm fsr = 11 m 295 The Diffraction Grating Thus, l1fsr = 400 = 400 nm in first order2 1 l2fsr = 400 = 200 nm 1 from 400 to 600 nm in second order2 2 l3fsr = 400 = 133 nm 1 from 400 to 533 nm in third order2 3 3 DISPERSION OF A GRATING Higher diffraction orders grow less intense as they fall more and more under the constraining diffraction envelope. 31 Show that the minimum distance between an object and its image, formed by a thin lens, is 4f. Using this in Eq. (32) gives RM1 = -d11 + z20 > d22. The corrective contact lens of focal length f should form an image (recall the sign convention for image positions) at $s_c = -100$ cm of an object at infinity $1s = q^2$. In order that these modes add to a pulse, they must be locked to a common phase at a particular place that moves back and forth through the cavity at the speed of light. (a) 1.88 × (b) 6330 × 2. Indium gallium arsenide phosphide (InGaAsP) laser diodes can be engineered to emit near 1550 nm. Short-wavelength waves, corresponding to surface ripples, have a velocity given approximately by yp = a 2pT 1>2 b lr where r is the density and T is the surface tension. So the image is virtual, 12 cm to the right of L1, of half-size given by (3 cm) * A -ss; B = 13 cm2 A - -412 B = 9 cm. In this section we discuss three such procedures; radial keratotomy, corneal sculpting, and conductive keratoplasty. We are looking for the irradiance at a point like P; in Figure 15a. Victories for the wave theory continued up to the twentieth century. As discussed in Section 2, the maximum wavelength separation that can be resolved is the free spectral range of the device, so that \$\epsilon \lambda b = 1 fsr . V. Ch. 50. The latter property describes the resolution of the recorded spectrum. This is the content of Babinet's principle. which we express as EA + EB = Eu Figure 18 Fresnel shadow of a screw. Gravity waves propagating in other directions will also cause differing length changes in the two arms. In the case of ordinary fields, smaller than those now attainable with high-energy lasers, the net fields are assumed to be a linear superposition of the constituent fields. 16 Consider a myopic, presbyopic eye with a near point of 13 cm and a far point of 15 cm. We conclude from Eq. (59) that the wave propagates in the material at a wave speed c>nR and is absorbed such that the amplitude decreases at a rate governed by the ' exponential factor e -1vnIs>c2. Thrierr, Atlas of Optical Phenomenon, Plate 9, Berlin: Springer Verlag, 1962.) $r^2m = 2Rtm = 2R a ml b = mRl 2 r^21 = 11214.18421589.3 * 10-92 m^2 = 2.466 * 10-6 m^2 r^210 = 110214.18421589.3 * 10-92 m^2 = 24.66 * 10-6 m^2 r^210 = 110214.18421589.3 * 10-92 m^2 = 24.66 * 10-6 m^2 r^210 = 110214.18421589.3 * 10-92 m^2 = 24.66 * 10-6 m^2 r^2 = 24.66 * 10-6 m^2$ this case, the resultant wave can be formed as $ER = E1 + E2 = E01 \cos 1a1 - vt2 + E02 \cos 1a1 - vt2 = 1E01 + E022 \cos 1a1 - vt2$ Destructive Interference If two harmonic waves of the same frequency are "out of step" in the sense that the peaks of one always coincide with the troughs of the other, the waves are said to destructively interfere. A bit of analysis (see problem 17) indicates that decreasing the cavity losses not associated with the laser output irradiance. 22 Chapter 2 Geometrical Optics x introduced into the preceding condition, since sin ui = and 2 c - x $2a + x^2 \sin ut =$, giving $2b^2 + 1c - x^2 2 \sin ut \sin ut = 0$ yi yt dx Simplifying the equation set equal to zero, we obtain at once yt sin ui = yi sin ut . How many well-defined beams are broadcast and what are their angular half-widths? 4 Looking into a Michelson interferometer, one sees a dark central disk surrounded by concentric bright and dark rings. The line image is virtual at a distance of 65.2 cm on the object side of the lens and 5.65 cm long Further, it is difficult to limit a diode laser to stable single-mode output, and so diode devices generally have shorter coherent lengths than, for example, do Nd:YAG, He-Ne, or Ar+ laser systems. Boston: Academic Press, 1988. This analysis for the slab waveguide has served to elucidate the physical reasons for mode restriction. The family of spherical surfaces normal to the rays are the wavefronts, the locus of Real object space O Real image space Optical system I Figure 10 system. Here the solid angle dv = dA>r2. McDonald, Am. J. However, even very low level environmental noise processes lead to power signals of this and greater levels. n 401 Matrix Methods in Paraxial Optics Incorporating the paraxial form of Snell's law, nu = $n_{i}u_{i}$ we have $a_{i} = a y y y n n bu = a b aa + b n_{i} R n_{i} n_{i}$ or The appropriate linear equations are then $y_{i} = 112y + 102a a_{i} = c a n n 1 ba - 1b dy + a ba R n_{i} n_{i}$ or The appropriate linear equations are then $y_{i} = 112y + 102a a_{i} = c a n n 1 ba - 1b dy + a ba R n_{i} n_{i}$ or The appropriate linear equations are then $y_{i} = 112y + 102a a_{i} = c a n n 1 ba - 1b dy + a ba R n_{i} n_{i}$ or The appropriate linear equations are then $y_{i} = 112y + 102a a_{i} = c a n n 1 ba - 1b dy + a ba R n_{i} n_{i}$ or The appropriate linear equations are then $y_{i} = 112y + 102a a_{i} = c a n n 1 ba - 1b dy + a ba R n_{i} n_{i}$ or The appropriate linear equations are then $y_{i} = 112y + 102a a_{i} = c a n n 1 ba - 1b dy + a ba R n_{i} n_{i}$ or The appropriate linear equations are then $y_{i} = 112y + 102a a_{i} = c a n n 1 ba - 1b dy + a ba R n_{i} n_{i}$ or The appropriate linear equations are then $y_{i} = 112y + 102a a_{i} = c a n n 1 ba - 1b dy$ a ba R n $i_{i} n_{i}$ or The appropriate linear equations are then $y_{i} = 112y + 102a a_{i} = c a n n 1 ba - 1b dy$ a ba R n $i_{i} n_{i}$ or The appropriate linear equations are then $y_{i} = 112y + 102a a_{i} = c a n n 1 ba - 1b dy$ a ba R n $i_{i} n_{i} = 0$ or $i_{i} = 0$ or $i_{i} n_{i} = 0$ or $i_{i} n_{i} = 0$ or $i_{i} = 0$ or i_{i} familiar to you. Newton's second law, applied to the electron in the model of Figure 1b, then leads to the equation of motion, - KSBr - mg drB d2Br B - eE = m 2 dt dt (3) In Eq. (3), KS is the force constant of the effective spring, m is the electronic mass, and g is a frictional constant with dimensions of reciprocal time. 151 152 Chapter 6 Properties of Lasers Mirror 1 Gain medium (a) Mirror 2 Pump (b) Output Figure 16 Time development of the startup of laser oscillation in a typical laser cavity. The pump creates a population inversion in the laser medium. Figure 16 Two views of a packaged laser diode. We conclude P = a B F B bE 1 - F>3e0 (9) B The multiplier of E is Ne2>m F = 1 - F>3e0 1KS>m -Ne2>3me02 - v2 - ivg Let us define v20 as the quantity in parentheses, that is, v20 K KS Ne2 m 3me0 (10) Then, Eq. (9) becomes B P = Ne2>m V20 - v2 - ivg B E (11) Forming the magnitude of the applied field by the relation B fPf = B 21v20 Ne2>m B + 21v20 v2 + vg 2 2 2 ff Clearly, f P f can increase dramatically as v: v0, so that v0 represents a resonance frequency for the dipoles of the medium. fe 80 Chapter 3 Optical Instrumentation Substituting Eq. (41) into Eq. (40), M = 251fe + fo - d2 fofe (42) Based on an algebraic manipulation of the thin-lens equation, however, we can show that the ratio of image to object distance, soce > so, for the objective lens is d - fe - fo soce = so fo (43) where we have used the fact that soce = d - fe, evident in the diagram. Determine the waveguide dispersion in ps/km at l = 1.27 and 1.55 mm for a source with a spectral width of 1 nm. These values occur whenever sin kx = 0, or kx = 2px = mp, l m = 0, ; 1, ; 2, Å or l l 3l x = m a b = 0, , l, , A 2 2 2 (24) Such points are called the nodes of the standing wave and are separated by half a wavelength. The change to negative coordinates is required by the inversion of the real image relative to the object. B 11 By finding appropriate expressions for k # Br , write equations describing a sinusoidal plane wave in three dimensions, displaying wavelength and velocity, if propagation is a. Applications of OPC include aberration correction and pointing and tracking. Also, first and second focal lengths are equal in magnitude, and the usual thin lens equations, 1 1 1 + = so si f and m = - si so (6) are valid. Show that the phase delay of the diverging subject beam, at a point on the film a distance y from the axis, is given by py2>ld, where d is the distance of the point source from the film. V = 2 21112 f g1t2 f 111 + 122 b. Independent point sources S1, S2, and S3 are shown, all contributing to the intensity of the light at P. If the surface is instead concave, R is negative. Find and plot the steady-state small-signal population inversion N2 N1 as a function of the pump irradiance. The mass of each hydrogen atom is about 1.67 * 10-27 kg. The first laser, developed by T. Lens Sun dL 5 cm Image u fL 50 cm Figure 38 Problem 18. This mode is called left-circularly polarized (LCP) light. (9) and (10), we obtain l>dl = mN. Rotation of the polarizer now can produce zero intensity. Françon, M. Each curve corresponds to a different film index, but the glass substrate index has been chosen ns = 1.52 in all cases. In this case, all other coefficients vanish. We turn now to an important case of a multiple-beam instrument, the Fabry-Perot interferometer. Through which output port would light of wavelength 14 = 1548 nm exit? Its size, based on O¿P¿ is (- 1.5 cm) A - -105 B = - 3 cm. (b) Rochon prism. The result is a filter with a pass-band width of perhaps 15 Å and 40% transmittance. Equation (4) or (7) indicates that, as d is varied, a particular point in the fringe pattern 1u = constant2 will correspond to gradually changing values of order m
or p. This results because we have ignored spontaneous emission in the derivation of this rate equation. Since a phase difference is given in general by k¢, Eq. (7) indicates a path difference associated with b of $\psi = 1b>22$ sin u, shown in Figure 1. Without the pump energy, the light wave would be attenuated during each pass through the medium. Holographic optical elements are also used in optical systems to correct aberrations, in supermarket scanners, and in heads-up displays for aircraft pilots. 25. Nonlinear optics is a burgeoning field driven by the availability of high-power/short-pulse electromagnetic fields. Determine the mathematical expression for the resultant wave. With Kind Permission of Springer Science and Business Media.) 280 Chapter 11 Fraunhofer Diffraction Qumin u Figure 10 Rayleigh's criterion for just-resolvable diffraction patterns. Rays reflected from the top and bottom plane waves is responsible for the redirection of the light into the various regions of the twodimensional diffraction pattern. When squared, the reflectance as a function of wavelength is determined. Photometry and Radiometry for Engineers. The objective lens, being larger in diameter than the pupil of the eye, permits the collection of more light and makes visible those point sources such as stars that might otherwise not be detected. This general description of the instrument reflects the wide variety of designs and uses of interferometers. The direction of the electric field vector E is known as the polarization of the electric field vector end of the zonal contributions are distinctly shorter. After a moderate amount of algebra, one finds $s_1 = s_2 = s_0 f_1 + Ad_2 f_2 + Ad_s 0 s_0 f_1 - Ad_s f_2 + Ad_s f_1 + Ad_s f_1 + Ad_s f_2 + Ad_s f$ before the inversion can begin to grow again. The light waves interact with one another and with the medium. The real or apparent point of these rays. 20 Calculate the delay due to modal dispersion in a 1-km GRIN fiber with ap = 2. Parallel rays form a line image that is parallel to the cylinder axis. The array of blade edges effectively traps the incident light, resulting in almost perfect absorption. Benjamin, 1964. The frequency shift due to a moving observer is based physically on the change in speed of the sound waves relative to the observer. applied field, our analysis, thus far, would B apply only to the case of a single dipole oscillator. 2 It is awkward to refer to the energy levels of atoms with the understanding that the discussion at hand may also be applicable for molecules, liquids, and solids. 8 A lens has the following specifications: R1 = 1.5 cm = R2, d1thickness2 = 2.0 cm, n1 = 1.00, n2 = 1.60, n3 = 1.30. 14 Determine the length and base area of the cylindrical volume within which light received from the sun is coherent. In a color plasma display, gas cells are grouped into sets of three subpixels. What is the beat frequency between the incident and reflected light? The temporal coherence is perfect 5 See, for example, M. One meter from the output of a He-Ne laser the beam radius might be about 2 mm. 1 FOURIER ANALYSIS When a number of harmonic waves of the same frequency are added together, even though they differ in amplitude and phase, the result is again a harmonic waves of the same frequency are added together. of the given frequency. 16 In this problem and the following two problems, consider a ring cavity like the one depicted in Figure 8. (36) and (37). We have indicated that EM waves may lose and gain energy only in discrete amounts that are multiples of the energy associated with the energy quanta that have come to be called photons. New York: Academic Press, 1974. In Table 2, representative values of these figures of merit, as well as some other quantities, are listed for different mirror reflection coefficients. (c) Ellipsoid surface images object point O at infinity when O is at one focus and no 7 ni. The linear susceptibility for KDP can be found from the relation given earlier, n = e0x1 e c = = = 1x1 y A e0 A e0 Therefore, x1 = n2 = 1.52 = 2.25. In a Q-switched system, the population inversion grows to a value larger than that in the equivalent gain-switched system because the low-Q, high-loss cavity prevents the growth of the cavity field until the population inversion grows to a value larger than that in the equivalent gain-switched system because the low-Q, high-loss cavity prevents the growth of the cavity field until the population inversion grows to a value larger than that in the equivalent gain-switched system because the low-Q, high-loss cavity prevents the growth of the cavity field until the population inversion grows to a value larger than that in the equivalent gain-switched system because the low-Q, high-loss cavity prevents the growth of the cavity field until the population inversion grows to a value larger than that in the equivalent gain-switched system because the low-Q, high-loss cavity prevents the growth of the cavity field until the population inversion grows to a value larger than that in the equivalent gain-switched system because the low-Q, high-loss cavity prevents the growth of the cavity field until the population inversion grows to a value larger than that in the equivalent gain-switched system because the low-Q, high-loss cavity field until the population inversion grows to a value larger than that in the equivalent gain-switched system because the low-Q, high-loss cavity prevents the growth of the cavity field until the population inversion grows to a value larger than that in the equivalent gain-switched system because the low-Q. maximum in the interference pattern occurs at P if P lies on the perpendicular bisector of the two slits. If light represented by M1, M2, M3, Á, Mm, so that 1Mm Á M3M2M12V = MsV, then the system matrix is given by Ms = Mm Á M3M2M1. • Ray 2. As indicated in Figure 8, we will take the steady-state irradiance at the input end of the gain cell to be I0 and that at the output end to be IL. When using monochromatic light, the net shift x = 1.5x. In all cases, nH = 2.35, nL = 1.38, ns = 1.52, and n0 = 1.00. Find the (a) window width xw; (b) minimum resolvable wavelength interval at 400 nm; (c) minimum wavelength that is not subject to aliasing; (d) minimum sampling rate according to the Nyquist criterion. Discontinuities in the light is reflected or refracted. The Fresnel zones to which we shall refer are long, thin, rectangular regions as pictured earlier in Figure 9, rather than annular rings, as pictured in Figure 7. The lateral ray aberration by due to the rays from the neighborhood of P may then be approximated by by = as; = s; da n2 dy (2) where s; is the paraxial image distance from the wavefront and a has been taken from Eq. (1). When O is to the right, corresponding to a virtual object, s is negative. (a) Solution In this case, ¢ r = 1>2, so that Eq. (38) leads to an air-film thickness at the mth dark ring given by tm = ml>2nf. From the direction of the refracted beam (which may be calculated using B Snell's law), we conclude that the E-field within the isotropic dielectric material, and thus the axis of the dipole oscillations, is oriented perpendicular to the beam direction, as indicated by the double-headed arrows. Why is an initial single slit necessary? The Porro prism, Figure 18d, consists of two right-angle prisms, oriented in such a way that the face of one prism is partially revealed to output the refracted light. Still other practical solutions for double-layer antireflecting films become possible if the thicknesses of the layers are allowed to have values other in which the corresponding optical actions influence the light ray as it traverses the system. Birefringence indicates the possession of two refractive indices, whereas double refraction refers to the splitting of a ray of light into ordinary parts. As shown in Figure 9b, the output plane thus functions as the second focal plane. Thus the irradiance at the center of the shadow of the obstacle should be almost the same as with no disc present! When Fresnel's paper on diffraction was presented to the French Academy, Poisson argued that this prediction was patently absurd and so undermined its theoretical basis. If an electromagnetic field consists of the superposition of fields with many different polarized. The greater its coherence time, the more monochromatic the source. In optical fibers this frequency shift is typically too small to couple the different channels in a WDM fiber. For Snellen, the normal eye could just resolve a letter that subtended 5¿ of arc at 20 ft, with 1¿ of arc contained in the details of the letter. (a) Newtonian telescope. London: Microscope Publications Ltd., 1977. 5 Calculate the rectangular slit width that will produce a central maximum in its far-field diffraction pattern having an angular breadth of 30°, 45°, 90°, and 180°. In an ideal optical system, every ray from O intercepted by the system—and only these rays— also passes through I. Two important methods used to control the characteristics of laser light pulses are Q-switching and mode-locking. Locating the intermediate and final image ide of the lense approximately as a blackbody with a temperature of 6000 K at its center and 5000 K at its can also be seen from the same figure by reversing all rays and the roles played by object and image. If the light in the cavity, or by a pumped gain medium as in the cave of a laser, tp is the approximate time that a given portion of the light field remains in the cavity. (46) and (47) for the case in which the lens is placed at the waist of the incident beam. Any arbitrary beam can be expanded as a linear combination of HermiteGaussian beams, each of which has the same propagation law, q = q0 + z. 25 Thus, the line image B C 5 L 1 2 O 4 (plane) surface at exit, we obtain Parallel to cylinder axis 1.0 1.50 + = 0, which gives s₂ = 100 cm. 22 Determine the material dispersion in a 1-km
length of 4 nm and (b) a LD centered at 820 nm with a spectral width of 4 nm. The spectrum of spontaneous emission has the same frequency dependence as the lineshape function g1n2. The coherence length is the length along a wave train over which the phase of rays from far-distant objects and for plane surfaces of refraction. 25 A Newton's ring apparatus is illuminated by light with two wavelength components. The spectral radiation from a heated tungsten wire, for example, is close to that of a graybody with e = 0.4 - 0.5. Blackbody radiation is used to establish a color scale in terms of absolute temperature alone. Express this energy in J and in eV. Use a conservation of energy argument to show that the time-averaged energy density 809 associated with this field is related to the irradiance I of the field by 809 = I>c. Consider briefly the distinctive characteristics of this system. The points are then related as object and image points, as shown in Figure 9c, and the input and output planes correspond to y0 yf Axis Optical elements Input plane Optical system af Output plane a0 Input plane (a) Optical elements Optical system Output plane (b) y0 Optical elements Input plane Optical system (c) yf Output plane (d) Figure 9 Diagrams illustrating the significance of the vanishing of specific system matrix elements. Another situation in which the Doppler effect is of pivotal importance is the Doppler broadening of the spectral lines associated with the light emitted by the fast-moving atoms of a gas. Many optical applications depend critically on the nature and manipulation of the polarization of electromagnetic waves. The corresponding ranges of external angles of incidence at the first surface are 0° to 90° (TE mode) and 0° to up (TM mode). Recall that circularly polarized light consists of equal amplitude components with phases that differ by ; p>2. Calculate the irradiance at the surface. 5 A hollow glass sphere of radius 10 cm is filled with water. 474 Chapter 21 Fourier Optics yielding a resolving power of P K xw l = ¢l l (44) One sees that the resolution is improved by using large sample widths. (c) 2 In general, a paraxial ray is one that remains near the central axis of the image-forming optical system, thus making small angles with the optical axis. Research-quality gratings are usually of the reflection type. 553 Laser Operation Here n¿ is the center frequency of the spectral energy density of the electromagnetic field. This beam reconstructs the subject beam of Eq. (4) but with phase reversal, that is, with eiu replaced by e -iu. What is the absorption coefficient of seawater for red light of this wavelength? In this way the pulse builds from phase-matched spontaneous emission events. This technique of pattern recognition is applied, for example, to the recognition and counting of small particles with different shapes, as in the case of blood cells, or to the search for characteristic patterns in aerial photographs, medical X-rays, and fingerprint files. The normalized irradiance function I>I0 (dashed line) for single-slit Fraunhofer diffraction is the square of sinc1b2. Nussbaum, Allen. Thus, this wavelength, like 12 = 1552 nm, would predominately exit Output 2. The sun subtends an angle of 0.5° at the earth's surface, where the illuminance is about 105 lx at normal incidence. A blackbody, irrespective of wavelength or angle of incidence, is completely absorbed. (When describing theoretical resolution, it must be remembered that the Rayleigh criterion is somewhat arbitrary and that spectral line widths also enter into the actual resolution.) A grating with 10,000 grooves/cm and 20 cm width provides a resolving power of 1 million in fifth order. In the latter application, instrument readings are projected so that they seem to be floating in space, allowing the pilot to retain a clear "heads-up" view of the scene in front of the aircraft. In either case, the light is refracted by the eyepiece in order to produce parallel, light rays. Chromatic aberration is eliminated by making use of multiple refracting elements of opposite power. Thus, to determine whether a given function of x and t represents a traveling wave, it is sufficient to show either that it is of the general form of Eq. (1) or that it satisfies Eq. (2). Of course, such a system does not really stabilize the absolute frequency of the Fabry-Perot. When unpolarized light is input into such a fiber, the output light will be linearly polarized along the low-loss direction, and the fiber functions as a linear polarizer. Take the transmission coefficients of the beam split- ters to be real. Light that is more monochromatic suffers less distortion due to material dispersion. The grooves ruled on a concave grating are equally spaced relative to a plane projection of the surface, not relative to the concave surface itself. n=1 due to the action of the prism as a whole is the sum of the angular deviations d1 and d2 at the first and second faces, respectively. Thus, if each beam spot size 1D = 3w2, nearly 99% of the beam gets through. 10, 11. First, consider a transparent, distorting medium like frosted glass, which is placed in the path of a light wave on its way to a PCM. Also find the minimum length d of an etalon that could be used to limit this laser to single-mode operation. Quite reasonably, fine features in the given f(t), such as the corners of the square waves, require waves of smaller wavelength, or higher frequency components, to represent them. When y V c, Eq. (44) is approximated by y l₂ = 1 c l (45) 2 Robert Resnick, Basic Concepts in Relativity and Early Quantum Mechanics (New York: John Wiley and Sons, 1972), Ch. 2. It is helpful to break the distances AB and BC into parts and rearrange terms, resulting in ¢ = [nf1AE + FC2 - n0AD] + nf1EB + BF2 (29) The quantity in square brackets vanishes, as we now show. Modern Optical Engineering. Refraction due to the thin glass walls is negligible for paraxial rays. Screen 20 Two microscope slides are placed together but held apart at one end by a thin piece of tin foil. A numerical aperture of 0.6, for example, corresponds to an acceptance slides are placed together but held apart at one end by a thin piece of tin foil. A numerical aperture of 0.6, for example, corresponds to an acceptance slides are placed together but held apart at one end by a thin piece of tin foil. cone of 74°. In optometric notation, the horizontal axis is referred to as the 180° axis, or simply "* 180," and the vertical axis as " * 90." Figure 7 indicates the optical conditions associated with irradiance, is given by Ie = d£ dv (10) Differential solid angle dv measured in steradians (sr) is defined in Figure 2. For the identical optical system, already partially analyzed, a. Notice that a = 0 in the reverse direction. Abramovici et al., Phys. Let the axial progress of the ray be L, as shown, such that at point 1, the elevation and direction of the ray are given by "coordinates" y1 and a1 respectively. If crosshairs or a reticle with a scale is used with the eyepiece to make possible quantitative measurements, then to be in focus with the image formed by the ocular EL, the crosshairs must be placed in the focal plane of RI, conveniently attached to the field or aperture stop placed there (Figure 27). With the reference beam also present, however, the resultant 377 Holography amplitude EF at each point of the film—subject to the scalar approximation— is given by EF = ER + ES so that the scaled irradiance on the film is, $IF = f EF f 2 = 1ER + ES 21E \dots R + ER E \dots S P$ (6) The last two terms now incorporate the important function u1x, y2. Notice that if longitudinal chromatic aberration for difference in magnification for difference in magni Figure 6 Spherical aberration of a lens, producing in (a) different image distances and in (b) different focal lengths, depending on the lens aperture. In this graph, the component of the electric field 109 Wave Equations y t0 t p 4v x E y 3p 4v x E y p t v x E t y 3p 4v x $sin(kz \ge vt)x 0$ (a) y t0 t p 4v E y E y 3p 4v p t v y x 3p 2v y x x t y 5p 4v x x E E t p 2v E x t t y t 7p 4v E y E E x y 2p t v x x ^ \leq E $sin(kz \ge vt)x^{-}$ E $sin(kz \ge vt)x^{-} \leq$ E $sin(kz \ge vt)x^{-} =$ E sin(kzcavity is naturally Q-switched when the irradiance due to spontaneous emission reaches a value large enough to saturate the absorber. A = 0.93935; B = 22.2212; C = -0.009284; D = 0.8448; r = v = 16.72 mm; $f = -f^2 = -107.71$ mm; the film plane is a distance q = 101.2 mm behind the last lens surface. The lens is used in air and has an axial thickness of 3 cm. 312 Chapter 13 Fresnel Diffraction and similarly, for the diffracted wave curvature in Figure 2b, ¢ h2 7 l 2q (10) Combining Eqs. 22-24. 1 0 y0 2 6 3 4 5 a0 T y7 x
a7 7 x0 x7 18 Matrix Methods in Paraxial Optics INTRODUCTION This chapter deals with methods of analyzing optical systems elements in trainlike fashion. Stimulated Emission As shown in Figure 11b, when a photon of energy hn L E2 - E1 = hn0 encounters an atom initially in an excited state E2, it can "stimulate" the atom to drop to the lower state, E1. The ad hoc assured to the lower state in the atom initially in an excited state E2, it can "stimulate" the atom to drop to the lower state, E1. The ad hoc assured state E2 is a state in the state E2 is a state in the state E2 is a state in the state E2. become complex, involving a number of refracting and/or reflecting shown by Kirchhoff to follow naturally by arguing from Green's integral theorem, whose functions are scalar function formula, given by EP = - ikES -ivt eik1r + r2 e dA F1u2 2p rr2 O (7) In Eq. (7), the factor - i = e -ip>2 represents the required phase shift, and the obliquity factor F1u2 = 1 + cos u 2 limits the amplitude, ES. This is suggested by the schematic separation of the two components on the optical axis, although of course both y TA x Unpolarized light Linear polarizer z Figure 8 Operation of the two components on the optical axis, although of course both y TA x Unpolarized light Linear polarizer z Figure 8 Operation of the two components on the optical axis, although of course both y TA x Unpolarized light Linear polarizer z Figure 8 Operation of the two components on the optical axis, although of course both y TA x Unpolarized light Linear polarizer z Figure 8 Operation of the two components on the optical axis, although of course both y TA x Unpolarized light Linear polarizer z Figure 8 Operation of the two components on the optical axis, although of course both y TA x Unpolarized light Linear polarizer z Figure 8 Operation of the two components on the optical axis, although of course both y TA x Unpolarized light Linear polarizer z Figure 8 Operation of the two components on the optical axis, although of course both y TA x Unpolarized light Linear polarizer z Figure 8 Operation of the two components on the optical axis, although of course both y TA x Unpolarized light Linear polarizer z Figure 8 Operation of the two components on the optical axis, although of the two components on the optical axis, although of the two components on the optical axis, although of the two components on the optical axis, although of the two components on the optical axis, although of the two components on the optical axis, although of the two components on the optical axis, although of the two components on the optical axis, although of the two components on the optical axis, although of the two components on the optical axis, although of the two components on two components on two components on two componen position of zero path difference between arms? We have I1 = 12 e0cE201 = 12 e0cE201 = 12 e0cE202 = 25,640 W>m2 II = 12 e0cE201 = 12 e0cE202 = 12 331802 = 65,034 W>m2 Imin = I1 + I2 - 22I1I2 = 5309 + 33180 - 2215309 * 331802 = 11,945 W>m2 The visibility is then given by Eq. (17), or visibility = 65,034 - 11,945 = 0.690 65,034 + 11,945 If the amplitudes of the two waves were equal, then Imax = 4I0, Imin = 0, and the visibility would be 1. What frequencies appear in the polarization wave? Wavelets emerging from each slit arrive in phase at angular deviation u from the axis if every path difference like AB 1 = a sin u2 equals an integral number m of wavelengths. One sees that the reflectance quickly approaches 100% for several double layers. Inhomogeneously broadened laser systems in which many different cavity modes lase are commonly mode-locked. Solution Using Eq. (37), s 6 10.221546 * 10-92 rl = = 1.1 mm ls 1 * 10-4 Now suppose that the source slit in the example is made exactly 1.1 mm in width and that the separation between slits S1 and S2 is adjustable. Finally, the important differences between internal and external reflection are clarified. According to Snellen, the letters on the eye chart are constructed so that the overall block size of a letter, from top to bottom, or side to side, subtends an angle of 5¿ of arc at the test distance. The portion of the wavefront that must pass through the thicker region is delayed relative to the other portions. Reynolds, George O., John B. This situation is typical of interference and diffraction phenomena: If the power density falls below the average at some points, it rises above the average at other points in such a way that the total pattern satisfies the principle of energy conservation. In 301 The Diffraction Grating another configuration, the light is introduced instead along the normal N to the grating itself. Thus, polychromatic light from a point object images not as a point but as a series of points, one for each distinct wavelength. In addition, the output irradiance from laser diodes can be easily modulated by varying the injection current that pumps the diode. If such a single-mode fiber were perfectly uniform, both polarization modes would travel through the fiber with the same speed. Diffraction-limited optics is good optics indeed. 69 Optical Instrumentation (b) (a) 112.5 necessarily, purifies the transmitted beam of this component. Ch. 3. Notice that a cone of violet light will form a halo around the red focus at R. While examining the inside of the eye with bright light, doctors often use drugs, such as atropine, to maintain the condition of an enlarged or dilated pupil. 13 Calculate the percent reflectance and transmittance. for both (a) TE and (b) TM modes of light incident at 50° on a glass surface of index 1.60. (a) 50.0° (b)1/55.5 (c) A = 1.6205, B = 6073.7 nm2; $4.297 \times 10-5$ nm-1 (d) 1.12 m 10. Let the mirrors be separated by 20 cm and let each mirror have a radius of curvature of 100 cm. Thus, 96% of the cancellation occurs between the first two reflected beams alone and the two-beam treatment is well justified. 12 Light is incident on a water surface at such an angle that the reflected light is completely linearly polarized. Principal points and nodal points coincide, that is, r = y and s = w, when the initial and final media have the same refractive indices. This simplified form is the normalized form of the vector. We have placed the origin of the time frame, Figure 5, so that the wave train is symmetrical about it. The grating can replace the prism in a spectroscope. Focusability Nonlaser sources must have a significant transverse extent in order to produce a significant transverse extent in ord angular magnification of detail increases with proximity to the eye, the myopic eye enjoys "superior" vision of objects held close to the eye. The entire device constitutes a linear polarizer. In such a case, the superposed incident and reflected wave may be written profitably as the sum of a standing wave (which transmits no energy) and a traveling wave that carries the energy that is absorbed by or transmitted through the boundary. Viewed from off-axis points, the light is partially polarized. In general, image size is proportional to focal length. Example 1 Consider two interfering beams with parallel electric fields that are superposed. More recently this problem has been minimized by the addition of a halogen vapor (iodine, bromine) to the gas in the quartz-halogen or tungsten-halogen lamp. Then positions to the left of the beam waist (like Mirror 1 in Figure 6) have negative z-coordinates, and positions to the right of the beam waist (like Mirror 1 in Figure 6) have negative z-coordinates. Although free charge exists in 545 Optical Properties of Materials the metal, the internal free-charge volume density rf is zero. (51) and (52). (Adapted from Melles Griot, Optics Guide 3, 1985.) OA u OA u u Figure 15 Glan-Air prism. The Cooling System Overall efficiency is an important operating characteristic of a laser system. This phenomenon makes possible the AO or acousto-optic effect—the interaction of optical and acoustic waves—in which a longitudinal acoustic
wave launched by means of a piezoelectric transducer produces a periodic mechanical stress in the rods, the photoreceptor cells become insensitive to further light signals and a regeneration of pigment in the rods must occur before they can respond again. System B has a lower frequency limit than system C, but better performance at lower frequencies. Nevertheless, the Schmidt camera, as it is often called, has been highly successful and has spawned a large number of variants, including designs to flatten the field near the focal plane. The operating linewidth of a single-mode He-Ne laser is 1000 to 1 million times narrower than the fluorescence linewidth associated with the neon transition. In practice, Fresnel diffraction does not produce amplitudes Eu = 0 without an aperture. Do this by determining the composite transfer matrix for the three quarter layers and using the matrix elements in the calculation of the reflection coefficient in Eq. (36). 8 Use the constant phase condition to determine the velocity of each of the following waves in terms of the constants A, B, C, and D. If a camera is attached to the microscope, a real final image is required. In practice, of course, S is always an extended source, so that rays reach A and B from many points of the source. Cornu spiral are v1 and v2. Converging lenses are real and virtual, respectively. For the fortuitous case at hand, this turns out to be the case since Eq. (21) gives m = 1.5001801350 nm2 n cm L = 775.0 ll 1551 nm In general, the procedure used here to solve for ¢L only ensures that Eqs. 8 PULSED OPERATION In this section we turn to a discussion of the means of producing laser output pulses. Further, T1 is the time of flight for the light field propagating along path 2. What is the amplitude of the resultant when (a) all waves are in phase (coherent sources) and (b) the waves have random phase differences? To determine the actual path of individual rays of light through an optical system, each ray must be traced, independently, using only the laws of reflection and refraction together with geometry. If, as in Figure 21, the aperture is circular with diameter D and the energy of the light is assumed to be distributed uniformly over a corresponding image circle of diameter d, then Ee r area of aperture D2 = 2 area of image d (25) 71 Optical Instrumentation D d Figure 21 Illumination of image. the yttrium (Y) atoms in the host crystal, yttrium aluminum garnet (YAG). These waves can be represented by the complex fields ' E = E0ei1kz - vt + f2 r Spherical wave (5) Here, r = 2x2 + y2 + z2 is the distance from the source of the spherical waves, and in each waveform k = nv > c. 248 Chapter 10 Fiber Optics and at a point like F, sin wc = n2 n1 œ Using the geometrical fact, um = 90° - wc, and the trigonometric identity, 2 2 sin wc + cos wc = 1, these relations combine to give the numerical aperture, N. When illuminated by the reference beam, the hologram, due to its transmittance function, modulates both the amplitude and the phase of the beam. In these detectors, photons absorbed into thin films or bulk material produce additional free charges in the form of electron-hole pairs. 7 Using Figure 12b and c, verify the expressions given in Table 2 for the distances q, f2, s, and w. z Waist z0 589 Characteristics of Laser Beams Beam Spreading Let us further investigate the spreading of a Gaussian beam as it propagates from the beam waist. Plot the four curves on the same set of axes. A, Vol. Reflectance curves are shown in Figure 4. In this section, we have discussed but a few of the many and varied optical engineering challenges encountered when developing a high-bit-rate fiberoptic communications system. It can be shown, however, that when the transmittance profile of the grooves or zones is not sharp but varies continuously, these general remarks concerning orders have to be modified. Whereas a spherical lens produces a point image of a point s of ho ho F F x Figure 26 Construction used to derive Newton's equations for the thin lens. (a) 0.01 cm (b) 1000 Hz (c) and 628.3 cm-1 (d) 6283 s-1 (e) 1 ms (f) 10 cm/s (g) 10 cm 8.7 TELESCOPES Telescopes may be broadly classified as refracting or reflecting, according to whether lenses or mirrors are used to produce the image.) : Cavity finesse Diffraction order N: Number of grooves in grating Three useful figures of merit that describe scanning Fabry-Perot interferometers as well as diffraction gratings are the resolving power P, the minimum wavelength separation ¢lmax that can be unambiguously resolved. Compute the resultant line width ¢l, bandwidth ¢n, and coherence length. If the blackbody is a 1-mm diameter hole in a cavity radiator at this temperature, find the power radiated through °. 47 Geometrical Optics 2.25 cm uc Light 7.6 cm Figure 33 8 Show that the lateral displacement s of a ray of light penetrating a rectangular plate of thickness t is given by t sin1u1 - u22 s = cos u2 where u1 and u2 are the angles of incidence and refraction, respectively. For monochromatic light incident normally on the film, determine (a) reflectance from the air-film surface; (b) reflectance from the combination. Consequently, we write k = kR + ikI (28) Inserting this form into the expression for a harmonic wave, we have B B B E = E0ei1kRz + ikIz - vt2 = E0e -kIzei1kRz - vt2 (29) The exponential factor in kI represents a depth-dependent absorption of an otherwise harmonic wave, and kI measures the amplitude attenuation of the wave. (a) 0.113 nm-1 21. In most cases, the selectivity is not 100% efficient, so that the transmitted light is partially attenuation of the wave. polarized. Figure 2 shows both nR and nI calculated from Eqs. When sin uc 7 n, the radical 2n2 - sin2 u is negative and both rTE and rTM are complex. If the distance between the lenses is 16.4 cm, find the magnification of the microscope. By contrast, the quantum efficiency of photographic film is about 2%. E0 1 mm 45 🔅 Laser beam n 1.414 Film Figure 2 shows both nR and nI calculated from Eqs. When sin uc 7 n, the radical 2n2 - sin2 u is negative and both rTE and rTM are complex. If the distance between the lenses is 16.4 cm, find the magnification of the microscope. 30 Problem 27. Pulse broadening becomes zero at 1.27 mm and is negative as wavelength increases further. Leith and Upatnieks introduced an off-axis technique, using one or more mirrors to bring in the reference beam from a different angle so that the directions of the reconstructed real and virtual wavefronts are separated. Of course, the dimensions of the diffraction pattern also depend on the wavelength, as indicated in Eq. (14). Let us be a bit more specific. As shown, the incident vertically polarized light is rotated 45° counterclockwise by the Faraday rotator and in this orientation is fully transmitted by the analyzer. To determine which is your dominant eye, try the following simple test. From the results of (b), calculate the image distance and lateral magnification for an object 20 cm to the left of the lens. M. Compared with modal distortion and material dispersion, waveguide dispersion is a small effect that becomes important only when the other pulse-broadening effects have been essentially eliminated. The quantitative treatment that allows us to make such calculations follows. As another example, consider a multilayer stack of alternating high-low index dielectric films (Figure 11). For other values of applied voltage, the beam incident on the analyzer is elliptically polarized and is only partially transmitted. Of course, the subject is now absent. Alternatively, the Es mode is called the TE (transverse electric) mode, and the Ep mode is called the TM (transverse magnetic) B mode, since the B-component of the vave is transverse to the plane of incidence. Determine the dispersive power of the prism. A simple example of such a field stop is the opening directly in front of the film that outlines the final image in a camera. Explain. In Example 3 we consider one such dependence. E E0 k B0 B (a) 4 Wave Equations INTRODUCTION In this chapter we develop mathematical expressions for wave motion in general but concentrate on the most useful special case, the harmonic wave. The total number of propagating modes mutor is the value of m when cos wm has its maximum value. This is sensible since for normal incidence there is no distinction between the two cases. 1 In practice, measured reflection and transmission coefficients also depend on scattering losses from a nonplanar surface. Higher-order 1m 7 12 spots represent higher harmonics given by mnY1. If the path length difference is as found from part (a), through which output port would light of wavelength 13 = 1551.6 nm exit the interferometer? When two transparencies back-to-back in the aperture plane, how must the combined transmission function relate to the individual transmission functions? The uncoated surfaces of the slab have a reflectance 1r22 of 0.90. Each component produces an interference term with 1 7 E2 B B (E1 parallel to E2). At what depth is 99% of normally incident sodium light absorbed in tin? Knittl, Z. In the area of nonlinear optics, however, the controlled scattering of light from active media, exemplified by stimulated Raman, Rayleigh, and Brillouin scattering, provides much vital research in modern optics. The arrangement of prisms in Figure 16a, combined so that the dispersion is additive, providing double dispersion. For the purpose of the present discussion, Eq. (13) is most relevant. Find the approximate group velocity in glass whose dispersive power is 1>30 and for which nD = 1.50. With these relationships it is easy to show the equivalence of the following common forms for harmonic waves: sin y = Acos[1kx; yt2](7) y = Acos[1kx; yt2](7)cosine, which depends on space and time, is called the phase, w. (b) Σi (ti tan i) 33. We seek a relationship between s and s; that depends only on the radius of curvature R
of the mirror. 1 DIFFRACTION FROM A SINGLE SLIT We first calculate the Fraunhofer diffraction pattern from a single slit, a rectangular aperture characterized by a length much larger than its width. Let us compare the peak power in a mode-locked, multimode laser to the average power in the same multimode laser system with CW output. Sources we call "monochromatic" emit light that can be represented as a sequence of harmonic wave trains of finite length, as suggested in Figure 7, each separated from the others by a discontinuous change in phase. In other applications, apertures may be introduced to produce a sharp border to the image, like the sharp outline we see looking into the eyepiece of an optical instrument. Of course, the real fields are given ' ' B B by E^c = Re 1E^c2 and E^P = Re 1E^A2. For the case at hand, the gain contribution is found by noting that each stimulated emission event decreases the population of level 2 by 1 and increases the number of photons in the cavity by 1. The Wadsworth spectrograph (Figure 12) uses a concave grating, and a plate holder. f1x, t2 = A1Bx + Ct + D22 c. Guenther, Robert D. There is no conservation law for photons as there is for the charge associated with particles. 18 Consider again the ring laser described in problem 16. Next'suppose that the phase difference between orthogonal vibrations ' E0x and E0y is still p>2, but E0x Z E0y . If the spontaneous emission grows to a value large enough to saturate the absorber, the cavity will suddenly become low loss. The assumption is made to allow discussion of the fringe pattern in a concrete (and common) situation. In any case, apertures are inevitably present because every lens or mirror has a finite diameter that effectively introduces an aperture into the system. The solid curve represents the population inversion Ninv as a function of time. Perhaps the oldest source of this kind is the carbon arc, still widely used in searchlights and motion picture projectors. 3 BANDWIDTH AND DATA RATE The more complicated the signal to be communicated, the greater is the range of frequencies required to represent it. Starting with the maximum aperture setting, supply the next three f-numbers that would allow the irradiance to be reduced to 13 the preceding at each successive stop. 178 Chapter 7 Interference of Light D ui ui ui no G A C ut ut F E nf t ut Figure 12 Single-film interference with light incident at arbitrary angle ui . The free spectral range and FWHM of the transmittance T through a variable-input-frequency FabryPerot interference with light incident at arbitrary angle ui . The free spectral range and FWHM of the transmittance T through a variable-input-frequency FabryPerot interference with light incident at arbitrary angle ui . scanning Fabry-Perot interferometer of the last section. What is the wavelength of the other light? In each case, from the meanings of A, B, C, deduce the possible values of phase difference between component vibrations. The narrow range of electromagnetic waves from approximately 380 to 770 nm is capable of producing a visual sensation in the human eye and is properly referred to as "light." It is not surprising that this visible region of the spectrum corresponds to the frequencies of electromagnetic radiation that predominate in the output of the sun. That is, !!! E¿F + GE = E¿E - FG (40) The irradiance at point P is then found as !! IP = IO C E¿F + GE D 2 When different field points like P¿ are considered, the omitted spiral interval ψ slides along the spiral as did the contributing interval ψ for the case of S(y) 1.5 2.5 E 0.5 1.0 2.0 P v \ge 0.5 F \bigcirc y 0 \ge 0.5 F \bigcirc 0.5 F \bigcirc y 0 \ge 0.5 F \bigcirc 0.5 F population densities of these states N1 and N2. The problems associated with transverse vibrations of a wave in a fluid thus vanished. In some lasers, the amplifying medium consists of two parts, the laser host medium and the laser atoms. fringes are seen. Energy may be transferred from one excited species to the other species in a process whose net effect can be symbolized by the relation A* + B : A + B*. t1 t2 t3 t4 t5 231 Coherence is conventional to take both ¢n and ¢l to be positive. The appearance of a second harmonic in the polarization is expected from the following mathematical argument. By making the reference beam stronger than the signal beam, the minimum irradiance on the emulsion can be raised to the level of its linear response characteristics. Both are very small effects and will not be discussed further here. The width of the incident beam, finally, is assumed to be large compared with its lateral displacement due to the many reflections that contribute significantly to the resultant reflected and transmitted beams. A similar effect is produced by wrapping glossy cellophane tape around a microscope slide, allowing for regions of overlap. The narrow portion occupied by the visible spectrum is highlighted. Thus both E1 and E2 average to zero over very short time intervals. (a) $8.75 \times 10-3$ W/m2, 2.57 V/m (b) 2×1013 W/m2, 1.23×108 V/m, 0.410 T 21. Javan, Ali. In the case of the thick lens just calculated, the input plane was chosen at its right surface. The linewidths of different atomic transitions vary over a wide range of values but a linewidth in the range 106 - 109 Hz for a transition associated with a photon of nominal frequency 1014 - 1015 Hz is typical. For N large, the diagram shows clearly that the resultant amplitude A R approaches a value of a 1>2, or half of that of the first contributing zone. Introducing the refractive indices of the media through the relation y = c>n, we arrive at Snell's law: ni sin ui = nt sin ut Fermat's principle, like that of Huygens, required refinement to achieve more general applicability. The output from a laser is primarily stimulated emission, which produces photons of nominally identical frequencies. A pinhole in the screen allows some light to enter a spectrograph of high resolution. Hot gasses, in which some of the atoms are ionized, also constitute a system that can have a continuous emission spectrum. 7 Let us suppose that as a theoretical limit, 1 bit of information can be stored in each l3 of hologram volume. O., and M. Verrier, Optical Fibre Devices (Bristol and Philadelphia: Institute of Physics Publishing, 2002). Since the dawn of modern science in the sixteenth and seventeenth centuries, light has been pictured either as particles or waves—seemingly incompatible models—each of which enjoyed a period of prominence among the scientific community. 6 During the construction of a hologram, a beam splitter is selected that makes the amplitude of the reference beam eight times that of the signal beam at the emulsion. This effect begins to be important at signal powers of only a few mW. The best values for the grating resolving power P are in the range of 105 to 106, which is one or two orders of magnitude less than the resolving powers of Fabry-Perot interferometers. The T T F W F d d d G b (a) X W W a s a b (b) Figure 15 Constructions used to determine chromatic resolving power of a prism. New York: Halsted Press, 1987. It will be more efficient, in the general treatment that follows, to consider all transmitted or reflected beams as already summed in corresponding electric fields that satisfy the general boundary conditions required by Maxwell's equations. 24. In this way, the crossover point of the two peaks will be not more than one-half of the maximum irradiance of either peak. Thus it may be represented by f1t2 = c e -iv0 t, 0, - t0 t0 6 t 6 2 2 elsewhere (11) f (t) eiv0t Figure 5 Finite harmonic wave train of lifetime t0 and period 2p>v0. If B tion, r = r0 cos1vt2, is proportional to the square of the frequency. Its refractive index is 1.50 and its central thickness is 5 cm. The presence of apertures in an optical system influences its image-forming properties in two important ways—by limiting the field of view and by controlling the image brightness. The surfaces are generated by rotating the field of view and by controlling the image brightness. shown in Figure 14 illustrates the high-resolution performance of a Fabry-Perot instrument operated in the mode illustrated in Figure 7a. Assume, for example, that the refractive power in the vertical meridian of the cornea is greater by 1 diopter than the power in the vertical meridian. Notice also in Eq. (12) that object distance and image distance appear symmetrically, implying their interchangeability as conjugate points. If the path difference ¢ is much less than the coherence length 1¢ V lt2, interference fringes are poorly defined or absent altogether. 4 Due to quantum fluctuations, laser fields have an inherent uncertainty ¢n in the number of photons n contained in the field. When a certain thickness of optically active material is inserted between analyzer and polarizer, the condition of extinction no longer exB ists because the E-vector of the light is rotated by the optically active medium. s¿ = - 1n1>n22s, and b. It is predicted that in order to detect gravitational radiation from astronomical sources, sensitivities to strains of less than 10-21 (over a detection time of about 1 ms) are required. 4 FUNCTIONS OF THE EYE To operate as an effective optical system, the eye must form a retinal image of an external object or scene, either distant or nearby, in bright as well as dim light. Only in the unattainable limit of geometrical optics, where l: 0, would diffraction effects disappear entirely. Since the phase difference is unchanged in this process, the new vector represents the same polarization mode. Assumed values are v0 = 1 * 1016 s-1, g = 1014 s-1, and N = 1 * 1028 m-3. r11 r21 (1) where the radii of curvature are designated in Figure 13. Figure 6 shows a minimum of absorption at around 1.3 mm. Recall that when waves are out of phase, so that various contributions
effectively cancel one another. The angular width of the central maximum is defined as the angle ¢u between the first minima on either side. Equation (13) shows that the blaze angle depends on the angle of incidence, ui so that various geometries requiring different blaze angles are possible. If a second neighboring wavelength component l¿ is now also present in the incident beam, such that l2 - l = ¢l, the component l2 will be associated with a different refractive index, n_i = n - ¢n. Losses can include mismatch of coupled fiber ends, involving core diameter and lateral and angular alignment. First, consider Eq. (46). As a result, an assembly of atoms in thermal equilibrium will always be a net absorber of incident radiation. Determine first which element (A, L1, or the image of L2 in L1) subtends the smallest half-angle from rim to point O. The wave direction B is given by the vector k along the x-axis in (a) and an arbitrary direction in (b). Finally, we should point out that, because two independent polarizations are possible for the propagating plane wave, the total number of modes is twice that given by Eq. (9). Recall that the appearance of distinct shadows influenced Newton to assert that the apparent rectilinear propagation of light corpuscles rather than a wave motion. The sensitivity of this technique has been dramatically demonstrated in holographic recordings of convection currents around a hot filament, compressional waves surrounding a speeding bullet, and the wings of a fruit fly in motion. In Figure 8b, a vertical fan of rays (numbered 1, 2, 3, 4, and 5) is shown passing through the center and two outer zones of the lens. According to the sampled at a rate at least twice as high as its highest-frequency component in order to be faithfully represented Technically speaking, visual acuity is defined as the reciprocal of the minimum angle of resolution. This type of obstruction is typical in many optical instruments that utilize only the portion of a wavefront passing through a round lens. Incorporating Eq. (45) in Eq. (45) in Eq. (46) E20i = E20r + n a bE0t cos u Dividing the equation by the left member, it becomes 1 = r2 + n a cos ut 2 bt cos u (47) where the reflection and transmission coefficients r and t have been introduced. Now three half-period zones are contained in each of the original zones in Figure 7. Optical activity is described as a mechanism that modifies polarized light. If the angle is large enough, two distinct images will be clearly seen, as shown in the photograph of Figure 9b. 16 A medium is disturbed by an oscillation described by y = (3 cm) sina px 50p b cos a tb 10 cm s a. If the input power? In the intermediate case, the lineshape function does not have a simple closed form. (b) Thermopile made of couples in series. A close examination of Figures 5f and 5g shows that the corrective negative lens provides clear vision for objects located anywhere from infinity to the normal near point, N.N.P. To gain some insight into the degree of negative lens power required to correct myopic vision, consider Example 2. Then, since each stimulated emission event creates one photon and each stimulated absorption event removes one photon from the field, the rate of change of the number of photons in the volume V (see the last term in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 - N12 \xi V \xi t$ hn; Using this in Eq. (21) leads to $\xi I = sI1N2 + N12 \xi V \xi t$ hn; Using this in coefficient a appearing in Eq. (20): a = - s1N2 - N12 (23) Note that the loss coefficient has a dimension of inverse length. As kx and ky vary, the slopes of these lines vary. At what depth is red light reduced to 1% of its original energy density? The plasma frequency for metals falls in the visible to near-ultraviolet regions, so that they are opaque to visible and transparent to ultraviolet radiation at sufficiently high frequency. (a) Determine its relativistic momentum, de Broglie wavelength, and speed. At the field point P on the axis SOP, the edge of the primary image that the eyepiece can cover, in the range of 6 to 30 mm. The fringe system established under these conditions is monitored as the gas is gradually pumped out of the Bessel function J11x2 is that, for large x, a closed form exists, given by J11x2 = Find the angular separation of diffraction minima far from the axis of a circular aperture. That is, even a field containing no photons still has an effect on an atom in an excited state. F2 58 Chapter 3 Optical Instrumentation Find the image of in with light traveling right to left so that 1 s = 4 cm, f = 6 cm. The ellipse is oriented with its major axis along the x- or y-axis, as in Figure 6, depending on the relative magnitudes of E0x and E0y. When laser light is incident on such a medium a significant population density can accumulate in an excited state only if the 3 More generally, sabs = 1g2>g12s, where g2 and g1 are the degeneracies of the upper and lower levels, respectively. If the receiving screen contains a hole with diameter 5 cm, how much radiant flux gets through? Experimentally, one finds that the optimum pinhole size is around 0.5 mm when the pinhole-to-film distance is around 25 cm. Next, consider the consequences of assuming n^c Z n^P. 16 Show that Rmax in Eq. (53) approaches 1 when either N approaches infinity or when the ratio nL>nH approaches zero. According to this argument, moving the source B even farther should bring the fringe system into coincidence again, so that the degree of coherence f g f between P1 and P2 is a periodic function. The average of the functions sin2 u or cos2 u over a periodic function. The average of the function sin2 u or cos2 u over a periodic function. forms of Eq. (42) are expressed for the case of free space. For example, according to Eq. (53), when I = IS, g = g0 > 22 L 0.71g0 rather than p may also be represented as an angle lag of less than p. For example, an external scanning Fabry-Perot interferometer provides a means of investigating the mode structure of the output of a multimode laser. Note that in order to achieve the desired sensitivity, the LIGO interferometers in that it contains a Fabry-Perot cavity in each of the two arms of a Michelson interferometer. The focal length of the objective is 20 cm. Finally, notice from Figure 13 that M actually passes through zero at around 1.27 mm, so that material dispersion can also be reduced by finding light sources that operate in this spectral region. The step in the metal film will usually be somewhat sloped, but the total step will be the same as the thickness of the film to be measured. Incorporating Eq. (43) into Eq. (42), M = -a soce 25 ba b so fe (44) showing that the total magnification of the evepiece 125>fe2 when viewing the final image at infinity. Mirror Slit Entrance slit Grating Mirror Exit slit Mirror Figure 10 Czerny-Turner spectrometer. (Take care to ensure that your solution nearly satisfies both Eqs. What rotation would you expect for violet light? If the number of distinct states that have energy Ei is gi and the ground state of the system is not degenerate, then the likelihood that the system will be in any of the states with energy Ei is gi and the ground state of the system is not degenerate, then the likelihood that the system will be in any of the states with energy Ei is Pi = giP1e-1Ei - E12>kBT. A fourth of a period later, Ex is zero and Ey = + A, and so on. New York: Van Nostrand Reinhold Co., 1971. The light reaching P is now due to all zones except the first. What is the corresponding range of distances over which such an eye can detect the separation of objects 1 mm apart? Recall that the different energy states of interest in an atom correspond to different configurations of the charge cloud associated with one of the outermost 549 550 Chapter 26 Laser Operation E2 r(n) hn0 E1 Figure 1 Electromagnetic field spectral energy density r1n2 incident on a two-level atom. Upon passing through a
1-mm-thick quartz plate, red light is rotated about 15°. Excited states of higher energy correspond to the electron in "orbits" further from the nucleus. In addition, the oscillation of the free electrons is not entirely free. 14 Investigate the behavior of Eq. (32), giving the dependence of the depth of field on aperture, focal length, and object distance. Hawkes, Optoelectronics: An Introduction (London: Prentice-Hall International, 1983). Accordingly, optical systems often employ plano-convex lenses (with the convex side facing the parallel incident rays) to reduce spherical aberration. Objects closer to 1s12, and farther 1s0æ + x2 from and closer 1s0æ + x resonator—work together to produce the laser output? Its refractive index varies with wavelength, as given in the table: nm n 656.3 587.6 486.1 1.634611 a. Radiometry. The surface is oriented perpendicular to a line from the bulb to the surface. What is the refractive index of the glass? The superposition of colors that form the white-light fringes creates a pattern whose center at m = 0 is unique, serving as an unambiguous index of fringe location. 25 Compare pulse broadening for a silica fiber due to the three principal causes—modal distortion, material dispersion, and waveguide dispersion—in a step-index fiber. The damping term in the denominator in this case is not negligible, and the division by B- i, equivalent to multiplication by i, indicates a p>2 phase shift beB tween E and P. Peters, and G. Further, let mirror M3 be the output mirror with a transmittance T3. The wave train may be characterized by an average lifetime, the coherence time t0. Instead of using an extended source, this interferometer uses a point source together with a collimating lens L1, so that all rays enter the interferometer parallel to the optical axis, or cos u = 1. When illuminated from the reference beam direction with white light, for instance, the developed hologram partially reflects light from each silver layer, but only light of the wavelength used in making the hologram is reinforced by such multiple reflections. Such a standard interferometer is depicted in Figure 16a. n0 1 n1 1.38 | 4 n2 2.02 n3 1.8 | 4 n1 1.38 ns 1.52 The procedure just outlined can be used to calculate the spectral reflectance of three-layer films as well. How do the calculations for the exact formulas and approximate formulas compare? In particular, Eq. (21) can be adapted and used to develop an expression for the cavity loss rate. Referring to Figure 8, we see that the slope of the dispersion curve, dn>dv, is negative—or "anomalous"—over a certain frequency interval. If d = 1 cm and L = 3 cm, what half-wave voltage is needed? Here r is the end mirror reflection coefficient, T is the Fabry-Perot transmittance, R is the resolving power of the Fabry-Perot with an input field of nominal wavelength l whose mirror spacing d is varied, 2 cn1>2 is the FWHM of a transmittance peak when the frequency of the input is varied around frequency n, ≠ is the decay rate of the light within the Fabry-Perot cavity, tp is the photon lifetime of the cavity, and FSR stands for free spectral range. For example, if a particular (1) Light Figure 7 Schematic used to define the absorption coefficient for a glass fiber. The object is 10 cm in front of the lens and the stop is 2 cm in front of the lens. Since we can control the beam-waist radius w0 by laser cavity design and "select" the wavelength by choosing different laser media, what lower limit might we expect for the beam divergence? The dispersion. In this section, we wish to concentrate on the effects of such spatial limitations of light beams in an optical system. The resultant amplitude A R is seen to oscillate between magnitudes that are larger and smaller than the limiting value of a1>2, depending on whether it represents an even or an odd number N of contributing zones. The first of these corresponds to the usual case of an object in air. Wavefront-division interferometers sample different portions of the same wavefront of a coherent beam of light, as in the case of Young's double slit, or adaptations like those using Lloyd's mirror or Fresnel's biprism. Thus the spectrum broadens as the original Gaussian narrows, and vice versa. The fast axis (FA) and slow axis (SA) directions of the plate are also indicated. In the infrared regions, silver and gold coatings are both effective. Using the equivalence of optical paths through the center and edge of the lens, determine the thickness of the lens, determine the thickness of the lens at its center. The bright light is then processed efficiently by the less-sensitive cones. 19 Make a rough sketch for the irradiance pattern from seven equally spaced slits having a separation-to-width ratio of 4. Then dEP = a EA dx dy ivt - ik[r0 - 1xX + yY2 > r0] be e Z (13) so that, upon integration over the area of the aperture, we have EP = c ei1vt - kr02 d EA1x, y2eik1xX + yY2 > r0 dx dy Z O (14) If we are interested in the relative amplitude distribution of the electric field in the spectrum plane, it is convenient to define the relative amplitude function AP = ZEPei1vt kr02 = EA1x, y2eik1xX + yY2 > r0 dx dy O (15) Next, introducing the angular spatial frequencies, kX K kX r0 and kY K kY r0 (16) corresponding to each point (X, Y) in the spectrum plane, Eq. (17) may be expressed as A P1kX , kY2 = EA1x, y2ei1xkX + ykY2 dx dy O (17) In this form, Eq. (17) may be compared directly with Eq. (7), and our goal is established Prove that the proper orientation is with light incident on the spherical side by comparing the Coddington shape factor for each orientation with the value giving minimum spherical aberration. 22 A rectangular aperture of dimensions 0.100 mm along the x-axis and 0.200 mm along the x-axis is illuminated by coherent light of wavelength 546 nm. Figure 14 Components of a ruby laser system. A small air bubble in the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 cm from the glass is located on the central axis through the hemisphere 5 show next that the radiance has the same value at any point along a ray propagating in a uniform, nonabsorbing medium. Incandescent Sources by an electric current are called incandescent lamps. At what point is their superposition always zero? Find the pump irradiance Ip required to sustain a small signal gain coefficient of 0.01/cm. The maxima coincide with maxima of the sinc function, which occur at points satisfying b cos b - sin b d sin b a b = = 0 db b b2 or b = tan b. The Galilean telescope, illustrated in Figure 32, produces an erect image by means of an eyepiece of negative focal length. Resolving Power The minimum wavelength difference, ¢lmin, that can be determined in this manner is limited in part by the width of the transmittance peaks associated with the two wavelength components. Unpolarizer 1 Polarizer 1 Polarizer 2 Figure 22 Problem 3. Pneumatic or Golay A Golay cell measures the thermal expansion of a gas induced by radiation incident on the gas enclosure. Human ingenuity is nevertheless an essential component in the design task, since there 74 Chapter 3 Optical Instrumentation is more than one optical solution to a given set of specify the electromagnetic wave, it is sufficient to specify the electric field since the magnetic field and Poynting vector can be determined B once E is known. 25 a. Approximating the sine of the angles in radians, we may write n 1A + d2>2 A>2 or d A1n - 12, minimum deviation, small A, prism in air (16) n For A = 15°, the deviation given by Eq. (16) is correct to within about 1%. For the case shown, a p phase shift has occurred upon reflection so that a node (zero displacement) will exist at the mirror. In this process, therefore, both idler and signal waves can be amplified, drawing power from the pump wave. Shortly thereafter, in 1958, A. This shape could be deduced by precisely tracing a sufficient number of rays, using the laws of reflection and refraction, through the optical system. Thus, the images formed by plane refracting surfaces have the same lateral dimensions and orientation as the object. In such
placements, one group may reverse the aberrations introduced by the other, reducing overall image degradation due to factors Single meniscus lens Achromatic double meniscus lens net lateral displacement of the ray from point of incidence to point of emergence. (d) Problem 5, parts (a)-(d). Thus, ER = E0eivt a r + tt;r;e-id b 1 - r; 2e-id Making use next of the Stokes relations, Eqs. As a result, linearly polarized light launched into one end of a fiber evolves into light that is a mixture of two orthogonal linear polarizations as the light progresses through the fiber. The propagation of this sound wave alters the air pressure P as it passes. If the light from Paths 1 and 2, of Figure 16b, happens to constructively interfere upon combination into Output 1, it will destructively interfere upon combination into Output 2. If the fiber is very long, it may be necessary to amplify the signal at several positions along the fiber. KDP has an index of refraction of about 1.5 and a second-order nonlinear susceptibility x2 of about 10-12 m>V. We then examine the essential elements of a laser system, describe the basic operation of the laser. reduces the coupling between orthogonal polarization modes of the fiber. An additional aberration, chromatic aberration, results from the wavelength dependence of the imaging properties of an optical system. When the muscles are relaxed, the lens assumes its flattest shape, providing the least refraction of incident light rays. of two functions and is nonzero only at those (x, y) points where both functions have nonzero values. Even higher resolutions are available for professional use. (b) Incoherent radiation from a thermal source is "focused" to a demagnified image of size hi W l. Both x- and y-components of E are simultaneously present. ©f 0 Figure 4 Lissajous figures as a function of relative phase for orthogonal vibrations of unequal amplitude. The lens provides the fine-tuning in the final light-focusing process, changing its own shape appropriately to transform an external scene into a sharp image on the retina. The aperture function EA1x, y2 may thus be formed by any photographic negative. In a typical laser cavity, about 1 million halfwaves fit into the length of the cavity. It should be noted that even monocular vision is not without some depth perception. (a) 320 × (b) 0.516 cm 24. EviB dently, the superposition of the vertical E-vibrations of an incident electromagnetic wave with the radiation of these electron oscillators leads to cancellation in the forward direction Taking wx = 0, wy = e, E0x = A, and E0y = b (with A and b positive), the Jones vector is ' E0xeiwx A d E0 = c iwy d = c E0ye beie Using Euler's theorem, we write beie = b 1 cos e + i sin e2 = B + iC The Jones vector for this general case is, then, ' E0 = c A d B + iC counterclockwise rotation, general case (9) Here the identification of this form with counterclockwise rotation requires that A and C have the same sign. We find ¢n from Eq. (7), which, for small changes, can be approximated by d11>n22 = rE. The rotation. In such cases, the scattered light is modified by the resonant frequencies of the

medium. Determine the thickness of the layers and the normal reflectance for light of 550 nm. 7 REFLECTION AT A SPHERICAL SURFACE Spherical mirrors may be either concave or convex relative to an object point O, depending on whether the center of curvature C is on the same or opposite side of the reflecting surface. Their positions are determined by the grating equation, in which angles are measured relative to the plane of the grating. Since energy propagates in the direction of energy flow, the extraordinary ray with velocity vB intermediate between vB and vB 7 shows the unusua refraction of Figure 12. In either case, the line image is parallel to the cylinder axis. Consider Figure 15a, in which a monochromatic parallel beam of light is incident on a prism, such that it fills the prism face. Actual resolutions may be somewhat less than the theoretical value due to grating imperfections. (e) Gain saturation continues. If enough plates are assembled, the transmitted beam approaches a linearly polarized condition. In particular, a screen placed perpendicular to the OX axis, as in Figure 3, intercepts hyperbolic arcs that appear as straight-line fringes near the axis. 9 In an interference experiment of the Young type, the distance between slits is 0.5 mm, and the wavelength of the light is 600 nm. Notice that a lag of p>2. Evidence of phase changes and of a polarizing, or Brewster's, angle may also be seen here. Matrix Methods in Paraxial Optics Example 2 Find the system matrix for the thick lens of Figure 8, whose matrix before multiplication is expressed by Eq. (15), and specify the thick lens exactly by choosing R1 = 45 cm, R2 = 30 cm, t = 5 cm, nL = 1.60, and $n = n_c = 1$. The configuration now permits rapid traversal of the beam back and forth through the laser cavity, and stimulated emission occurs, producing an energetic pulse of laser radiation. Notice the direction of the OA in this assembly. 108 Chapter 4 Wave Equations 9 LIGHT POLARIZATION As we have noted, the fields associated with electric field, and the direction of energy propagation are mutually perpendicular, with B B the direction of energy propagation being the direction of E * B. The gain medium is a 10-cm-long Nd:YAG crystal with a saturation irradiance of 2300 W>cm2. 392 Chapter 17 Figure 8 CRT display. Leighton, and Matthew Sands, The Feynman Lectures on Physics, vol. This pulse sequence provides a record of the local irradiance measured by each pixel in that row. Note that a beam traveling in the z-direction described by Eq. (24) is uniquely specified if the amplitude E0, phase constant f, wavelength l, spot size at the beam waist (z = 0 plane) are known. Such a convenient device is called a compensator. 'The expression for Emn1x, y, z, t2 given in Eq. (66) with v = 2pnmnq describes the Hermite-Gaussian modes of a laser cavity with two spherical mirrors. What is the power of the corrective lens? Collimated light in this instance reaches the plates at a fixed angle ut (ut = 0 is shown) and comes to a focus at a light detector. Equation (11) has the same form as the equation of motion of a driven harmonic oscillator with damping. In this case, application of the field produces some reorientation of the molecules so that, on the average, the positive end of the dipole is in the direction perpendicular to the plane of incidence. The first term produces astigmatism, and the second, which is symmetrical about the optical axis, is called curvature of field. The source of the electrons may be a heated cathode (thermionic emission), or the impact of positive ions on the cathode (thermionic emission), a strong field applied at the cathode (thermionic emission), or the impact of positive ions on the cathode (thermionic emission), a strong field applied at the cathode (thermionic emission) zero.) The pattern is symmetrical about the optical axis through the center of the circular aperture and has its first zero when g = 3.832, as indicated in Figure 8a and b. The difference in cavity lengths associated with the transmittance peaks of the two wavelength components for the same mode number m is $d = ml^2 + ml^2 +$ in cavity lengths associated with adjacent transmittance peaks for wavelength component 11 is the free spectral range of the variable-length Fabry-Perot interferometer, $dfsr = 1m + 12l_{2} - ml_{2} = 122$ The transmittance peak with mode number m associated with 12 if ¢d = dfsr. In Example 2 we explore the quantization conditions for the electromagnetic field and the hydrogen atom. When the light irradiance becomes great enough, linear optics is not adequate to describe the situation. 200 Chapter 8 Optical Interferometry cavity. When the arc is enclosed in an atmosphere of vapor at high pressure, the lamp is a compact short-arc source and the radiation is divided between line and continuous spectra. In this case, Figure 5 Transmittance curve for the Pockels cell modulator. What is the slit separation? Assume the film is in air and light is incident at near-normal incidence. 4 RESOLUTION In forming the Fraunhofer diffraction pattern of a single slit, as in Figure 5. 1, we notice that the distance between slit and lens is not crucial to the details of the pattern. 2 A transverse wave pulse, described by y = a. Even before developing, the emulsion contains a latent image, a distribution of reduced silver atoms determined by the variations in radiant energy received. Thus, repeated forward traversals of the material by a light beam has a cumulative effect on the angle of rotation b. We turn now to cases where this constitutes an unwarranted approximation, cases in which either or both source and observation screen are close enough to the approximation. -labeled E and E7—have dissimilar effects on the electrons in the oxygen base plane. Solution Using Eq. (23) together with Eq. (20), fn = r0l r0 R21 = = n nl nl so that f1 = 30>1 = 30 cm, f3 = 30>3 = 10 cm, f5 = 30>5 = 6 cm, and so on. The image points due to all of the azimuthal fans that pass through the same annular region lie on a comatic circle. If a star is regarded as an extended, incoherent source with light emanating from a continuous array of points extending across a diameter s of the star (see Figure 15b), then the spatial coherent width ls in Eq. (38) becomes ls 6 1.22l u (38) Here the factor 1.22 arises from the circular shape of the source, as it does in the Fraunhofer diffraction of a circular shape of the source star (see Figure 15b), then the spatial coherent width ls in Eq. (38) becomes ls 6 1.22l u (38) Here the factor 1.22 arises from the circular shape of the source star (see Figure 15b), then the spatial coherent width ls in Eq. (38) becomes ls 6 1.22l u (38) Here the factor 1.22 arises from the circular shape of the source star (see Figure 15b), then the spatial coherent width ls in Eq. (38) Here the factor 1.22 arises from the circular shape of the source star (see Figure 15b), then the spatial coherent width ls in Eq. (38) Here the factor 1.22 arises from the circular shape of the source star (see Figure 15b), then the spatial coherent width ls in Eq. (38) Here the factor 1.22 arises from the circular shape of the source star (see Figure 15b), then the spatial coherent width ls in Eq. (38) Here the factor 1.22 arises from the circular shape of the source star (see Figure 15b). aperture. If the effective length of the cylindrical lens is CL, then by similar triangles it follows that s + s¿ AB = s CL 6 To be more precise, we are speaking of a plano-concave cylindrical lens as shown in Figure 28. As the analyzer is rotated, the light transmitted by the pair increases, reaching a maximum when their TAs are aligned. The average power is thus Pav = Ep>T, so that Pav = Pp ¢tp T Finally, setting Pav = PCW and solving for the peak power gives 5.625 cm. 6 It is gives 5.625 cm. 6 It is important to distinguish the "order" of an electro-optic process as determined from Eq. (7) for 1>n2 or ¢n. We now repeat the description of the buildup towards steady-state laser action with emphasis shifted to the evolution of the light field within the optical cavity. Show how this effect might be used to correct dispersion broadening in an optical fiber. We have determined the minimum wavelength separation that can be resolved with a Fabry-Perot interferometer. (a) Lens L2
of diameter 6 cm (b) The entrance window is 12 cm to the right of L1 and has radius 9 cm. Solve for w1 to get w1 = 4.38 * 10-4 m. The integral shift of fringe patterns is then easily seen and can be combined with the monochromatic measurement of ¢x described previously. Assume a substrate index of 1.50 and normal incidence. The letters R and V refer to real and virtual, O and I to object and image. 9 MULTIPLE-BEAM INTERFERENCE IN A PARALLEL PLATE We return now to the problem of reflections from a thin film, already considered in a two-beam approximation in Section 4. (a) (b) M1 199 Optical Interferometry be used to test the optical quality of another optical quality of another optical component, such as a prism, situated as shown in Figure 4b. 310 Chapter 13 Fresnel Diffraction such, EA should be proportional to the complex amplitude of the electric field originating with the real point source at S. The curve shows that again at l = 510 nm, in the blue-green, the brightness has dropped to 50%. Without proof we state that the lineshape function, $g_{12} = a 4 \ln 122 p c - 4 \ln 122 [1n - n02 > cnD] 2$ (51) Here, n0 is the center frequency of the emission from the atoms in their rest frame and ¢nD is the full width at half-maximum of the Doppler-broadened lineshape function. (b) Huygens' construction to prove the law of refraction. 1 DICHROISM: POLARIZATION BY SELECTIVE ABSORPTION B A dichroic material. The point object is 15 cm from the lens. Each bundle enters at the aperture, which is located at the center of curvature of the primary mirror. (17), (21), and (22), that the term in parentheses is given by 1 il 1 0w = q w 0z pw2 (54) If we use Eq. (54) and a change in variable, j = 22x > w, in Eq. (53), we obtain immediately the Hermite differential equation, 0 2q 0j2 - 2j 0q C1w2 + q = 0 0j 2 (55) This equation is known to have a solution only if C1w2 = 2m 2 where m = 0, 1, 2, A (56) The solutions to Eq. (55) are the well-known Hermite polynomials, g1j2 = Hm 1j2 = Hm 1j2602 Chapter 27 Characteristics of Laser Beams Solution of Eq. (58) for m = 0, 1, 2, Å gives m = 0: H01j2 = 1 m = 1: H11j2 = 2j = m = 2: H21j2 = 4j2 - 2 = 222x w (59) 8x2 - 2 w2 Applying the second condition and solving for the h-expression in Eq. (52), in a manner identical to that for the g-expression, we obtain, using the change of variable h = 22y > w, 12w2 0h 0 2h 2h + h = 0 0h 2 0h2 (60) for which the solutions are again the Hermite polynomials: h1h2 = Hn 1h2 = Hn 1 thickness provide a sensitive optical means for measuring thin films. At first glance, this sensitivity would seem unachievable since it implies that length changes ¢L smaller than the size of an atomic nucleus 1 ' 10-15 m2 would need to be measured in a device Quadrupole gravity wave Mirror ot er P y- y br vit Fa ca Arm 1 Mirror Fabr y-Pe cavit rot y Arm 2 Mirror P1 P0 /4 Mirror P0 Beam P2 P0 /4 splitter Photodetector Laser Figure 17 (a) Schematic of the LIGO interferometer. This separation of the original light into two parts, preliminary to recombination and interferometer. This separation of the original light into two parts, preliminary to recombination and interferometer. interference from a film. The cell is filled with carbon disulfide and linearly polarized sodium light is transmitted through the cell, along the B-field direction. This is shown by the black dots. Mosby Company, 1980. Let's see how an optometrist might calculate the spectacle power required to correct hyperopic vision. An eyepiece viewing the primary image and providing further magnification merely enlarges the details of the diffraction pattern formed by the lens. The optical system of Figure 1b is now equivalent to the case of interference due to a plane, parallel air film, illuminated by an extended source. 19 To what diameter spot should a He-Ne laser of power 10 mW be focused if the irradiance in the spot is to be the same as the sun's irradiance at the surface of the earth? If a corrective lens is placed in front of (or on) the eye, the eye no longer views a real object directly. The contribution of each original zone, now subdivided into three half-period zones, adds, at the observation point P for r0 = f1>3, to provide one amplitude A given by 1st zone 2nd zone 10 paque 2 3rd zone removed a 7 A = 5 a1 - a2 + a3 - 5 a4 + a5 - a6 + 5 a7 - a8 + a9 - Á a1 (22) Comparing the amplitude of Eq. (22) at r0 = f1, the entire first zone (made up, effectively, of 318 Chapter 13 Fresnel Diffraction a1, a2, and a3) contributes, whereas at r0 = f1>3, only one of the three does so. In Figure 9, a concave mirror collimates the light incident on the echelle, located near the slit and oriented with grooves horizontal. One of the most commonly used is the Glan-air prism, shown in Figure 15. After multiple reflections, the ray will have lost a large part of its energy. This may happen, for example, if the film thickness and, therefore, the spatial separation of two interfering beams—such as (a) and (b)—are increased, while the pupil of the eye viewing the reflected light is limited in size. If the source of light is a laser, the fringe pattern is clearly visible on a screen placed anywhere in the vicinity of the film. What is its resolution in wave number? Equations (12) and (14) are correct for B B the E and B vectors as chosen in Figure 5. (9) and (10), implies that the ratio of the overall rate of stimulated emission to that of stimulated emission to that of stimulated absorption is the ratio of the overall rate of stimulated emission to that of stimulated emission to the stimulated emission levels. The E of the elliptical wavefront is intermediate between E and E7. To do this, we need to consider the case of an off-axis object point. As indicated in the sense that both classical waves (i.e., light) and classical particles (i.e., electrons) are seen to have the same basic nature, which is neither wholly wave nor wholly particle. In certain situations, wavelike attributes may predominate; in other situations, particle-like attributes stand out. Overlapping occurs because in the grating equation, the product a sin u may be equal to several possible combinations of ml for the light actually incident and processed by the optical system. Of course, the emulsion must itself possess a high-resolution potential to record faithfully such detail. The ray passes through the optical axis of a V and then Q M u a P u N a u a B R Q Optical axis of a V and then Q M u a P u N a u a B R Q Optical axis of a V and then Q M u a P u N a u a B R Q Optical axis of a V and then Q M u a P u N a u a B R Q Optical axis of a A R C u a a A R C u a a A R C u a a A R C u a a a V a h a u a B R Q Optical axis of a A R C u a a A R C u a a a V a h a u a B R Q Optical axis of a A R C u a a V a h a u a B R Q Optical axis of a A R C u a a V a h a u a B R Q Optical axis of a A R C u a a a V a h a u a B R Q Optical axis of a A R C u a a V a h a u a B R Q Optical axis of a A R C u a a V a h a u a B R Q Optical axis of a A R C u a a V a h a u a B R Q Optical axis of a A R C u a a V a h a u a B R Q Optical axis of a A R C u a a V a h a u a B R Q Optical axis of a A R C u a a V a h a u a B R Q Optical axis of a A R C u a a V a h a u a B R Q Optical axis of a A R C u a a V a h a u a B R Q Optical axis of a A R C u a a V a h a u a B R Q Optical axis of a A R C u a a V a h a u a B R Q Optical axis of a A R C u a a V a h a u a B R Q Optical axis of a A R C u a a V a h a u a B R Q Optical axis of a A R C u a a V a h a u a B R Q Optical axis of a A R C u a a V a h a u a B R Q Optical axis of a A R C u a a V a h a u a B R Q Optical axis of a A R C u a A A R C u a a A R C u a programs. (d) Diffraction fringes from a straight line. For simplicity, we shall assume a lateral magnification of 1. For the fully tensed eye, the front surface of the lens sharpens its curvature from a radius of R = 6 mm. When the hologram is developed, it consists of grooves in the surface of the material. SUMMARY OF TERMS Brightness Aperture stop AS: Entrance pupil EnP: Exit pupil ExP: The real element in an optical system that limits the size of the cone of rays accepted by the system from an axial object point. The magnitude of b can be determined by noticing that the resultant E that determines the angle b is always the diagonal of an equal-sided parallelogram, so that u^c - b = uP b (a) or y b = 121u^c - uP2 (9) Using Eq. (8) in Eq. (9) leads to E u b u E b = 121k^c - kP2z x E Finally, using k^c = k0n^c , kP = k0n^c members of the Laser Interferometer Gravitational Observatory (LIGO) project are building, at two different sites within the United States, interferometers designed to detect and study gravitational waves. Assuming that the overall efficiency of this laser system is 3%, find the pump power required to operate this laser system. A summary of radiometric quantities and units and the corresponding photometric quantities and units are given in Table 1. New York: John Wiley and Sons, 1967. Determine the value of the high-frequency components in a Fourier series when synthesizing the fine features of a function, like the corners of a square Figure 5 Optical filter. For n = 1.50, the angle should be u = 53°. In a semiconductor, the band-gap energy is between 1 and 2 eV. Because of coma, an off-axis object point images as a blurred shape that resembles a comet with a head and a
tail—hence the name "coma." Figure 8 illustrates the formation of a comatic image. In this case the contributing zones range from z = - w>2 to z = w>2 for a field point P along the SOP axis. For a resultant with amplitude A, the perpendicular component amplitudes are E0x = A cos a and E0y = A sin a. (a) 1 2 n 2 1 0 P 1 2 n (b) Fresnel Diffraction 319 now gives the endpoints of a curve called the Cornu spiral. By Eq. (2), the zeroth order of interference, m = 0, occurs at um = - ui, the direction of the incidence u 0 90 up 0 0 30 60 Angle of incidence u 0 90 up 0 0 30 60 Angle of incidence u 0 90 (b) TE mode, internal reflection (glass to air) Phase shift on reflection f 0 (a) TE mode, external reflection (air to glass) Incident light up 0 uc 30 60 Angle of incidence u 90 0 90 (d) TM mode, external reflection (glass-to-air) (c) TM mode, external reflection (air-to-glass) Example 2 What is the phase shift on reflection f 0 (a) TE mode, external reflection (glass-to-air) (c) TM mode, external reflection (glass-to-air) (c) TM mode, external reflection (air-to-glass) Example 2 What is the phase shift on reflection (glass-to-air) (c) TM mode, external reflection (glass-t externally and internally for the situation discussed in Example 1? As shown in Figure 1, the waves do not arrive at P in phase. P = - NerB (2) where N is the magnitude of the electronic charge. Notice also the distinction between the analogous terms irradiance (radiometric) and illuminance (photometric). By suppressing the gain of the higher-order modes— those with intense electric fields near the edges of the beam—the laser can be made to operate in a single fundamental mode, the TEM00 mode. We take the waves, at the superposition point P, to have the forms E1 = E01 cos1ks1 - vt + w12 E2 = E02 cos1ks2 - vt + w22 (1) (2) Here, s1 and s2 represent the directed distances measured along the propagation directions of each light wave from the reference planes at which the phases of the individual waves are w1 and w2 at time t = 0. The photopic response (rods completely bleached out and inactive) operates between light sunlight. M = 10 might be a set which the phases of the individual waves are w1 and w2 at time t = 0. The photopic response (rods completely bleached out and inactive) operates between light sunlight to bright sunlight. 12.5a 1 1 + b f1 f2 22 A magnifier is made of two thin plano-convex lenses, each of 3-cm focal length and spaced 2.8 cm apart. When the real image falls in the focal plane of the eye located at the exit pupil. That is, the viewer "sees" the tip of an image at point P¿. The wavefronts, having been apart. shaped by the optical system, exist in image space with refractive index n2. (Therefore, it can be an advantage for a watchmaker to be myopic, at least during working hours!) In short, then, the nearsighted person has a contracted, drawn-in field of vision, a less-remote far point and a closer near point than a person with normal vision. On the other hand, when $\cos d = -1$, destructive interference yields the minimum, or background, irradiance Imin = I1 + I2 - 2 2I1I2 (16) a condition that occurs whenever d = 12m + 12p. Here we read from the curve the value y -1.2 at this point. On a viewing screen placed beyond the hole, the circle of light may show complex edge effects. When a small bias voltage is applied in the forward direction, optical energy is produced by the recombination of electrons and holes in the vicinity of the junction. Accordingly, if the widths of the square waves were allowed to diminish, 100 terms 3 terms 10 terms 4 to 2000 plate, 0.0182 mm thick, when placed in a 45° orientation between crossed polarizers? Notice that the new wavefront is tangent to each wavelet at a single point. Undepleted Pump Approximation It is often true that the laser pump does not significantly empty the ground state of the four-level system so that N0 W N3 and N0 L NT. (b) Light rays in a side view of the vertical (focusing) section of the lens in Figure 31. Where is the far field for this laser if one uses the criterion zFF U 50z0? Phillips. (a) $A \sin(2/)(\sqrt{2x \pm vt})$ (c) $A \sin(2/)(\sqrt{2x \pm vt})$ (c) observe the wave at z = 0 and choose wx = 0 and wy = e, so that wy 7 wx. Lens Design Fundamentals. Total Magnification When the final image is viewed by the eye, the magnification of the microscope may be defined as in the case of the simple magnification. The fields Eb and Bb are then related to the fields Ec and Bc at the back boundary of the second film layer by a second transfer matrix. Show that in a double-slit Fraunhofer diffraction peak to the central interference fringe is 2(a/b), where a/b is the ratio of slit separation to slit width. These carefully numbered and carefully positioned lesions act like a tightening, contracting belt that causes the cornea to bulge or steepen in the center, increasing the refractive power of the eye. 12 The attenuation of a 1-km length of RG-19/U coaxial cable is 10 mW and the receiver sensitivity is 1 mW. The holographic plate is situated in the Fourier-transform plane—the spectrum plane. Oil n 1.65 n 1.5 24 A convex thin lens with refractive index of 1.50 has a focal length of 30 cm in air. 15 Production of the lens determines the nearest distance of objects that can be handled by the camera. New York: John Wiley and Sons, 1976. 18 Consider the transmittance of the variable-input-frequency Fabry-Perot cavity shown in Figure 15. A prism design useful in spectrometers is one that produces a constant deviation for all wavelengths as they are observed or detected 590 Chapter 27 Characteristics of Laser Beams Wave fronts Transverse plane (x, y) O z Figure 4 The surfaces of constant phase for spherical waves are concentric spheres radiating outwardly from a point source O. (Photo by Sheri Trbovich.) Metal contact Electrical lead Cleaved end Heat sink and Output electrical contact e p-type p n-ty 1 mm Junction Figure 17 Simple p-n junction, laser diode pumped by an injection current. The factor ei12w2, when compared with the phase term in Eq. (3), indicates an angular displacement of the image direction by 2a relative to the normal to the film plane. The most important gas-molecular laser is the carbon dioxide 1CO22 laser that emits radiation of wavelength 10.6 mm. The choroid, in turn, serves as the backing for the retina. Lifetime Broadening Classically, an atom driven by a nearly resonant electromagnetic field oscillates at the frequency of the driving field. Refractive indices are given for sodium light of 589.3 nm. No amount of magnification of the images can produce a higher resolution or enhancement of the ability to discriminate between two such closely spaced spectral lines. If the two meridional planes are orthogonal to one another, one horizontal and the other vertical, say, the defect is referred to as regular astigmatism, a condition that is correctable with appropriate spectacles. A section of the plane that includes the relevant points and defines the distances r_{i} , b, and r is also shown in Figure 5 (detail). The net path difference for waves from successive slits is then $c = c_1 + c_2 = a$ sin ui + a sin um (1) The two sine terms in the path difference for waves from the difference may add or subtract, depending on the difference for waves from the difference may add or subtract, depending on the difference may add or subtract, depending on the difference for waves from successive slits is then $c = c_1 + c_2 = a$ sin ui + a sin um (1) The two sine terms in the path difference may add or subtract, depending on the difference for waves from successive slits is then $c = c_1 + c_2 = a$ sin ui + a sin um (1) The two sine terms in the path difference may add or subtract. eye will allow this person to view objects at infinity with a relaxed eye. A given source can be characterized by an average wave train lifetime t0, called its coherence time. \Leftrightarrow wc l1 n1 \Leftrightarrow \Leftrightarrow wc l1 B A \Leftrightarrow wc \Leftrightarrow L (fiber modes) travel different distances in arriving at the output. The correct approximation for a thin lens is then made by allowing t : 0. Then, by Eq. (5), the corresponding Jones vector is ' E0xeiwx 0 0 d = Ac d E0 = c iwy d = c E0ye A 1 y x (b) y a x linear polarization along y (c) Furthermore, when only the mode of polarization is of interest, the amplitude A may be set equal to 1. The preceding integral can then be rewritten, leading to R EP = 2EA i1kr0 - vt2 e eisk sin u 2R2 - s2 ds r0 L-R The integral takes the form of a standard definite integral upon making the substitutions y = s R and g = kR sin u: 2EA R2 i1kr0 - vt2 e eigy 21 - y2 dy = pJ11g2 g where J11g2 = 1g>225 1g>223 g + 2 2 - Å - 2 2 1 #2 1 #2 1 #2 #3 As can be verified from this series expansion, the ratio J11g2>g has the limit 12 as g: 0. Problem 11. In many typical cases the spectrum of light emitted by a gas has a continuous background overlaid with a line spectrum of light emitted by a gas has a continuous background overlaid with a line spectrum of light emitted by a gas has a continuous background overlaid with a line spectrum corresponding to particular transitions between discrete energy levels. In the case of the TV channel with a bandwidth of 6 MHz, this means that 2 * 6 MHz or 12 * 106 samples must be taken each second. Brecha, Physics Department, University of Dayton.) a. Typically the extra loss for the TE mode will prevent it from lasing and so the laser output will consist only of the TM mode. The measured values for calcite are n = 1.658 and n 7 = 1.486 for l = 589.3 nm Although the wave amplitude decreases rapidly beyond TABLE 1 CHARACTERIZATION OF SEVERAL OPTICAL FIBERS Core/cladding n0 n1 n2 wc umax N. Figure 3 is a photograph showing the distortion of fringes of equal thickness produced by a candle flame when situated in one arm of a Michelson interferometer. The measured coherence length of
barium titanate at 10 = 1.06 mm is 5.8 mm. (b) Geometrical relationships illustrating the transfer between Q and a after one refraction by a single spherical surface. Figure 26 6 Two slits are illuminated by light that consists of two wavelengths. 257 Fiber Optics monochromatic, the light propagating in the fiber is characterized by a spread of wavelengths determined by the light source. The zone plate radii are thus given approximately by Rn = 1nr0l (20) Evidently, the radii of successive zones in Figure 7 increase in proportion to 1n. In most cases of interest, the correct answer is given by the superposition principle: The resultant displacement is the sum of the separate displacements of the constituent waves: c = c1 + c2 (1) 113 114 Chapter 5 Superposition of Waves Using this principle, the resultant wave amplitude and irradiance 1W>m22 can be calculated and verified by measurement. Assume that the film is nonabsorbing. (47) and (49) yield IR = c IT = c 4r2 d Ii 11 + r222 11 - r22 11 + r22 (52) 2 d Ii (53) It is easily verified that IR + IT = Ii . 1 2 Chapter 1 Nature of Light The evolution in our understanding of the physical nature of science. Show that if KR and KI are the real and imaginary parts of the dielectric constant, then nR = c KR + 1K2R + K2I21>2 d 1>2 and nI = c - KR + 1K2R + K2I21>2 2 d 1>2 b. Hence the use of these lasers, in holography experiments, for example, still requires some care in equalizing optical ths. In a conductor, on the other hand, one or more electrons per atom in the solid are not tightly bound to a given atom but rather are relatively free to roam about the solid as a whole. The gain bandwidth of an EDFA is about 35 nm, which is enough to amplify some 35>0.8 = 45 wavelength channels separated by 0.8 nm. Of course, such losses also occur at the output end, where the light from the fiber is fed to a detector. For example, nonlinear optical processes involve the exchange of two or more photons with matter at a given time. The scaled population inversion density Ninv>NT = 1N2 - N12 > NT is also shown. By the lensmaker's formula, for lenses made of the same glass, $1 \ 1 = 1n - 12k2$ f2 R21 R22 (37) and where the expressions in parentheses involving the radii of curvature of the lens surfaces are symbolized by constants K1 and K2, respectively. Show that the numbers of photons striking the surfaces per second for the two beams are in the same ratio as their wavelengths. Amplification is to occur on the 2-to-1 transition. This process also weakens the filament and increases its electrical resistance. Detection of light, then, corresponds to the detection of a differential length change in the arms of the interferometer. By combining matrices that represent individual refractions, and translations, a given optical system may be deduced. Smith, Howard Michael. Light is propagated through them by multiple total internal reflections. Equivalently, in such cases there is a p-phase shift of E on reflection, as the following mathematical argument demonstrates: B # B B # B Er = $-\int r \int E = eip \int r \int E eip f r \int$ mode and for u 6 up for the TM mode. The Keplerian telescope in Figure 31 is often referred to as an astronomical telescope since inversion of astronomical when it is written in complex form: OTF = 1MTF2ei1P TF2 Omax - Omin Omax + Omin and gI = Imax - Imin Imax + Imin PTF = £ 1/K Omin Imax Imin (a) MTF 1.0 A (35) B 0.5 Then the MTF and OTF are given, simply, by MTF = gI>g0 and Omax (34) where MTF is the modulus and PTF is the phase. 458 459 Fourier Optics Fourier-transform spectroscopy capitalizes on the fact that the spatial or temporal variations of an irradiance pattern due to polychromatic radiation - a c b 0 0 dc d = c d d 1 1 This matrix equation-according to the rules of matrix multiplication-is equivalent to the algebraic equations a102 + b112 = 0 c102 + d112 = 1 from which we conclude b = 0 and d = 1. Their surfaces are generally polished to a flatness of better than l>50 and coated with a highly reflective layer of silver or aluminum. "Faraday Rotation in the Undergraduate Advanced Laboratory," Am. J. To produce a field that is both temporally and spatially coherent, neighboring point sources of light must produce light of the same frequency and correlated phase. Thus, cot ov 1 b B2 m0 A k Figure 11 Energy flow of an electromagnetic wave. A shows three possible paths from A to B, including the correct one, ADB. The effective pump rate density Rp1 is less in an atom for which k31 is small. According to Huygens, however, these are ignored and the new wavefront ends abruptly at points P and P₄, precisely where the extreme wavelets originating at points S and S₄ are tangent to the new wavefront. These processes are known as stimulated emission, and spontaneous emission. How many dark fringes appear between the edge and the wire? What is the energy (in J and in eV) of an X-ray of wavelength 0.1 nm? The Coddington shape factor, Eq. (27), which results in minimum spherical aberration, is close to that producing zero coma, so that both aberration, is close to that producing zero coma, so that both aberration aberration, is close to that producing zero coma, so that both aberration aberr 2phc2 1 b a hc > lk T 5 B l e - 1 (5) The spectral exitance Ml is the power per unit area per uni 1, 2, 3 Å (2) n2 These allowed energies are often displayed in an energy level diagram like the one shown in Figure 1. The link between UV-B radiation and skin cancer is a primary reason for the concern related to ozone depletion, which is believed to be in part caused by human use of so-called chlorofluorocarbon (CFC) compounds. In a thick lens or an optical system of lens combinations, the second principal planes for different wavelengths may not coincide as they do in a thin lens. Photometric units, in terms of their definitions, parallel radiometric units, in terms of their definitions, parallel radiometric units. voltage (a) Light Reverse- store biased voltage Load resistor (b) Figure 5 Two modes of operation of a junction photodiode. If a different angle, reflect as parallel rays from the film at a different angle, reflect as parallel rays from the various source points are incident on the film at a different angle. according to the conditions expressed by Eqs. Thin Film Optical Filters. Why is this reasonable? We adopt a pragmatic point of view in formulating appropriate matrices. 13 A thick lens presents two concave surfaces, each of radius 5 cm, to incident light. adb = 110 db>km2 log1011 - f2 where f is the overall fractional power loss from input to output over a 1-km-long fiber. For example, to reduce the reflectance of lenses employed in optical instruments handling white light, the film thickness of 1>4 is determined with a l in the center of the visible spectrum or wherever the detection system is most sensitive. The spherical surface has a radius of 1 m. The usual rays, determined by the focal points, change direction at their intersections with the principal planes, as in Figure 1. 28, 29. The reflected wave is also a plane wave. The usefulness of these Jones vectors will be demonstrated after Jones matrices representing polarizing elements are also developed. tank is a plane mirror, 25 cm from the window. It is different from Figure 1a in that the aperture is placed inside the focal length of the lens. (Oriel Corp., General Catalogue, Stratford, Conn.) Photoemissive detector. Unlike the prism, a grating produces greater deviation from the zeroth-order point for longer wavelengths. 25,000 ft 36. The number of standing wave modes that will likely be present in the laser output Solution 12 * 0.3 m2 2d L = 948,166. Atom A originally receives its excitation energy from a free electron or by some other excitation process. Suppose that the linear dispersion at the screen is 20 Å/mm. If the object in the aperture plane is a photographic image of the block letter A and the mask in the image plane contains a pattern of similar shape, a high degree of correlation should be obtained when the objects are properly positioned. Nonlinear Optics and the mask in the image plane contains a pattern of similar shape, a high degree of correlation should be obtained when the objects are properly positioned. Fibers The stimulated Raman effect can be used to amplify the signal in an optical fiber, thus counteracting attenuation and increasing the length of fiber that can carry a usable signal. For both arrangements, the rays from object point O fail to converge at a single image point. If the frequency is originally adjusted to give maximum transmittance, a frequency change of $\xi n = \xi n 1 > 2 = 50$ MHz would cause the transmittance to fall by a factor of 2. In addition to the information given in the example note that the spontaneous emission rate for the transmittance to fall by a factor of 2. In addition to the information given in the example note that the spontaneous emission rate for the transmittance to fall by a factor of 2. In addition to the information given in the example note that the spontaneous emission rate for the transmittance to fall by a factor of 2. In addition to the information given in the example note that the spontaneous emission rate for the transmittance to fall by a factor of 2. In addition to the information given in the example note that the spontaneous emission rate for the transmittance to fall by a factor of 2. In addition to the information given in the example note that the spontaneous emission rate for the transmittance to fall by a factor of 2. In addition to the information given in the example note that the spontaneous emission rate for the transmittance to fall by a factor of 2. In addition to the information given in the example note that the spontaneous emission rate for the transmittance to fall by a factor of 2. In addition to the information given in the example note that the spontaneous emission rate for the transmittance to fall
by a factor of 2. In addition to the information given in the example note that the spontaneous emission rate for the transmittance to fall by a factor of 2. In addition to the information given in the example note that the spontaneous emission rate for the transmittance to fall by a factor of 2. In addition to the information given in the example note that the spontaneous emission rate for the transmittance to fall by a factor of 2. In addition to the information given in the example note that the spontaneous emission rate for the transmittance to fall by a factor of 2. In addition to the information given in the example note that the spontaneous emission rate for the transmittance to fall case of linearly polarized light that reduces to the vertically polarized mode when a = 90° and to the horizontally polarized mode when a = 0°. Additionally, in contrast with metallic conduction techniques, communication by light offers the possibility of electrical isolation, immunity to electromagnetic interference, and freedom from signal leakage. RP2 Figure 13 Optical system consisting of two thin lenses in air, separated by a distance L. With the stop located at the lens, the image is free from distortion. Knowing that a Nd:YAG laser emits photons of wavelength 1.064 mm, determine the quantum efficiency associated with each of the four pump levels. Thus, for example, the vector C 2 D = 2 C 1 D and so represents linearly polarized light making an angle of 45° with the x-axis and with amplitude of 2 22. Since the relative distances traveled by the two beams will, in general, differ for different observation points. The light polarization rotates so as to be aligned along the long axis of the liquidcrystal molecules and so that vertically polarized light. They may be written in matrix form as Ea i sin d Eb g1 C S = C S SC Ba ig1 sin d cos d Bb cos d (24) The 2 * 2 matrix is called the transfer matrix of the film, represented in general by M = c m11 m21 m12 d m22 (25) 480 Chapter 22 Theory of Multilayer Films If boundary (b) is the interface of another film layer, rather than the substrate, Eq. (24) is still valid. Let the magnetic field be produced by winding a solenoid directly onto the ZnS crystal at a turn density of 60 turns/cm. The pump energy and rate is sufficiently high to excite a large number of atoms from the ground state E0 to several excited states, collectively labeled E3. Furthermore, the variable y represents the length along the Cornu spiral itself. Notice that for a photon, because of its zero rest mass, there is no distinction between its total energy and its kinetic energy. Assume that the dopant density (number of atoms per distance p to the left of the input plane. In this case, aperture A is imaged through L2 to form A2¿. Accepting this result for the moment and combining it with the temporal or longitudinal coherence length lt, we conclude that there exists at any point in the radiation field of a real light source a region of space in which the light is coherent. That is, E1+1t 12/(s - 6); m = 23 - s' /6 (c) s' = 6 47 cm; m = -0.429 (d) s' = 4 cm corresponds to second focal plane; s = 6 cm corresponds to first focal plane; analogously, for the irradiance, as in Eq. (10), I = I0 a sin a 2 b a k where a K a b a sin u 2 (17) The two-dimensional pattern now gives zero irradiance for points x, y satisfied by either ym = mlf b or xn = nlf a where both m and n represent nonzero integral values. (This corresponds to a typical DWDM system.) 265 Fiber Optics 3 a. It is important to distinguish dispersion from deviation. Note the dimensions of the cavity region. In this state, the eye forms clear images of distant objects on the retina. The light field to be amplified is taken to have irradiance I and frequency n¿ and should be taken to have a negative radius of curvature if its reflecting surface faces the beam waist, and a mirror to the right of the beam waist. Find the values of b for which the fourth and fifth secondary maxima of the single-slit diffraction pattern occur. If instead the incident waves are spherical, from an axial point source at distance p from the aperture, show that the necessary modification yields Rn = 2nLl where q is the distance from aperture to the axial point of detection and L is defined by 1>L = 1>p + 1>q. Variations in film thickness, as well as angle of incidence, determine the wavelength region reinforced by interference. (a) $6.6 \times 10-34$ m (b) 3.9 Å $3.6 \times 10-17$ W 3.27 and 1.61 eV 0.024 Å; $2.7 \times 10-22$ kg-m/s 0.511 MeV 1.422 MeV/c (a) $1.49 \times 10-16$ m (c) $4.22 \times 10-16$ m (c) $4.22 \times 10-16$ m 2.77×1017 3.9×1014 Hz to 7.9×1014 Hz to 7.10-8 sr (c) 76.4 W/m2 (d) 8.75 × 1010 W/(m2 · sr) Chapter 2 1. Let us consider, somewhat arbitrarily, that "good" coherence will exist over an area that is 10% of the maximum area of coherence. 519 520 Chapter 24 Nonlinear Optics and the Modulation of Light y x Unpolarized light TA Pockels crystal Linear polarizer Analyzer Figure 4 The effect of halfwave voltage to a Pockels cell when the system includes a crossed polarizer and analyzer. Referring to Figure 6e and making use of the thin-lens equation, with f = 11>3.5 dipoters2 = 0.286 m = 28.6 cm and s_i = -148.5 cm, one can solve for the object distance corresponding to the near point of the corrected eye: 1 1 1 + = s s_i f or 1 + s s s_i f or 1 + s s s_i f or 1 + s s_i f or 1 + s s s s_i f or = s -148.5 28.6 Calculation gives s = 24.0 cm. An atom can be raised from an initial state with energy Em to a final state medium, the general form of the gain coefficient given as the rightmost member of that equation holds for a wide range of homogeneously broadened gain media (see Section 5), but with definitions of g0 and IS different image, as shown. Because a 7 b, the cos2 a factor varies more rapidly than the 1sin2 b2> b 2 factor. In Figure 11c, the parallel reflected rays are said to form an image "at infinity." In each case, one can show that Fermat's principle, requiring isochronous rays between object and image points, leads to a condition that is equivalent to the geometric definition of the corresponding conic section. Plot the pulse at t = 0, t = 2 s, and t = 5 s. Most detectors may be classified as being either a thermal detector. With that ' convention a positive imaginary part C of E0y indicates that the Jones vector 339 Matrix Treatment of Polarization represents counterclockwise rotation. In the Littrow mount, incident light is brought in along or close to the groove face normal N¿, so that ub = ui and um = - ui , as is clear from Figure 6 and Eq. (13). Identify the state of polarization corresponding to the Jones vector c 2 d 3eip>3 and write it in the standard, normalized form of Table 1. Spherical-mirror Fabry-Perot cavities are easier to align and fabricate and have greater light-gathering power than do flat-mirror cavities. The radiant intensity Ie from a sphere radiating £ e watts (W) of power uniformly in all directions, for example, is £ e>4p (W>sr), since the total surrounding solid angle is 4p sr. The Nd:YAG system provides laser output at 1.064 mm. (a) 0.164 µm (b) 5.1 × 10-6 Chapter 24 1. Thus it controls the brightness of the image.
Feldott.) 184 Chapter 7 Interference of Light fringe systems, made through a microscope. The condition for interference is just that of the two-source interference of Light fringe systems, made through a microscope. The condition for interference is just that of the two-source interference is just that of the two-source interference is just that of the two-source interference of Light fringe systems, made through a microscope. The condition for interference is just that of the two-source interference is just that of y-axes, a vertically polarized light wave E0 incident on the crystal along the field direction has equal amplitude components on FA and SA. One's own resolution (visual acuity) can easily be tested by viewing two lines drawn 1 mm apart at increasing distances until they can no longer be seen as distinct. The light is of wavelength 541 nm with a line width of 1 Å, and the path difference is 1.50 mm. +40 cm, +30 cm, -40 cm 35. In part (b), assume that the fully accommodated eye differs in the following ways: The front surface of the lens is more sharply curved, having a radius of +6 mm, but the back surface remains at - 6 mm. Such a situation can occur in solids and liquids in which the myriad modes of interaction between neighboring atoms lead to a nearly continuous range of possible energies of the atoms or molecules in the material. M1 (1) (1) M3 (1 ≤ 2) (2) BS (2) M2 Figure 5 Mach-Zehnder interferometer. 15 Standing waves are produced by the superposition of the wave y = (7 cm) sin c 2p a t 2x bd T p cm and its reflection in a medium whose absorption is negligible. As an example of the latter case, consider light propagating from one focus to the other inside an ellipsoidal mirror, along any of an infinite number of possible paths. Second, in using this description one assumes that the left- and right-circularly polarized components move through an optically active material with different velocities, y^c and y^p, respectively. Rays contributing to the image that do not pass through the optical axis are called skew rays and require three-dimensional geometry in their calculations. Referring to Figure 28, where the object lies outside the focal length fo of the objective, a real image I is formed within the microscope tube. This area, which we call the correlation, clearly depends on the choice of 1qx, qy2. If the lens index is 1.60, determine its radii of curvature. a(Q) for spherical aberration in Eq. (18) vanishes. 3 Nature of Light by the experimental fact that when two beams of light intersected, they emerged unmodified, just as in the case of two water or sound waves. In a time ¢t, the energy transported through a cross section of area A (Figure 11) is the energy associated with the volume V of a rectangular volume of length c t. The electric and magnetic fields in this figure can be written as $E = 1E \cos uxN + Er \sin uzN$ 2ei1kr r - vt2 B B # B Er = 1Er cos uxN - E sin uzN 2ei1kr r - vt2 B B # B Er = 1Er cos uxN vt2 B B # B y n2 Interface kt Bt O r kr Et ut Plane of incidence P Br ur n1 z Figure 2 Defining diagram for incident, reflected, and transmitted rays at an xyplane interface when the magnetic field is perpendicular to the plane of incident, reflected, and transmitted rays at an xyplane interface kt Bt O r kr Et ut Plane of incidence P Br ur n1 z Figure 2 Defining diagram for incident, reflected, and transmitted rays at an xyplane interface when the magnetic field is perpendicular to the plane of incident, reflected, and transmitted rays at an xyplane interface kt Bt O r kr Et ut Plane of incidence P Br ur n1 z Figure 2 Defining diagram for incident, reflected, and transmitted rays at an xyplane interface when the magnetic field is perpendicular to the plane of incident, reflected, and transmitted rays at an xyplane interface when the magnetic field is perpendicular to the plane of incident, reflected, and transmitted rays at an xyplane interface when the magnetic field is perpendicular to the plane of incident, reflected, and transmitted rays at an xyplane interface when the magnetic field is perpendicular to the plane of incident, reflected, and transmitted rays at an xyplane interface when the magnetic field is perpendicular to the plane of incident. expression for z0 gives z0 = d2 -1 - RM1>d = 11 m22-1 - 1-2>12 = 1 m. Since the detected power is to be zero in the absence of a strain caused by a gravitational wave. 8 HIGH-BIT-RATE OPTICALFIBER COMMUNICATIONS In previous sections we have discussed some of the limitations to high-bit-rate transmission through optical fibers. In the nearfield approximation, the situation is more complicated. In addition, generation and recombination noise due to statistical fluctuations of current carriers occurs in photoconductors. Angles are considered positive for all rays pointing upward, either before or after a reflection; angles for rays pointing downward are considered negative. Notice that the shorter the wave train of Figure 5, that is, the smaller the lifetime t0, the wider is the central maximum of Figure 5, that is, the smaller the lifetime t0, the wider is the central maximum of Figure 5, that is, the smaller the lifetime t0, the wider is the central maximum of Figure 5, that is, the smaller the lifetime t0, the wider is the central maximum of Figure 5, that is, the smaller the lifetime t0, the wider is the central maximum of Figure 5, that is, the smaller the lifetime t0, the wider is the central maximum of Figure 5, that is, the smaller the lifetime t0 are considered negative. can show that w = again using the fact that Det 1M2 = AD - BC = n0>nf. Fringes of a different kind are nonetheless formed. Thus, even though we are at present interested in a single thick lens, the following description is applicable to an arbitrary optical system that we can imagine is contained within the outlines of the thick lens. In order for an assembly of atoms to amplify an incident electromagnetic field, pump energy must be supplied to the atom out of thermal equilibrium and preferentially populate the upper energy level so that N2 7 N1 and RSt. Em. 7 RSt. Abs. On closer inspection of Eq. (27), we find that the irradiance is just a product of the irradiances found for double-slit interference and single-slit diffraction. Using Eq. (26): nm + 1 - nm = 1m + 12 c c c - m = 2d 2d 2d 3 * 108 m > s = 5 * 108 Hz 210.3 m2 d. Do this for the profile parameter ap = 2 and repeat for ap = 10. By the law of reflection, the reflected ray PQ remains within the plane of incidence, making equal angles with the normal at P. The Verdet constant is both temperature and wavelength dependent. The total number density of gain atoms is NT = N1 + N2 + N3. (c) Image of a pair of incoherent point sources at the limit of resolution. Further, when the cavity in a Q-switched system is far above the lasing threshold and so the irradiance grows more rapidly and to a larger value than in the gain-switched system. If the grating in our previous example, with 5000 grooves/cm, has a width of 8 cm, then N = 40,000 and the resolving power in the first order is 40,000. Sliding the upper wedge to the left increases the thickness of the first order is 40,000 and the resolving power in the first order is 40,000. variable retardation up to a maximum, in position (b), of perhaps two wavelengths, or 4p. The presence of cladding of sufficient thickness prevents leakage, or, to put it more obliquely, negates the frustration of total internal reflection. Aberration contributes to the formation of the image because, beyond a first approximation, the ray path PQI depends on the position of point Q along the spherical surface. (20) through (23), if Er is eliminated instead of Et, similar steps lead to the following equations describing the transmission coefficient t = $Et 2 \cos u = 2 E n \cos u + 2n^2 - \sin^2 u$ (30) Eqs. The most immediate benefits of this modification are (1) an increase in the brightness of the image due to the focusing of all the rays of light from each object point and (2) an increase in sharpness of the image point and (2) an increase in sharpness of the image due to the focusing power of the lens. To a first approximation, Q-switching a laser system does not change the overall
efficiency of the system. What percentage of the incident light energy is transmitted by the pair when their transmission axes are set at 0° and 90°, respectively? A variable-spaced Fabry-Perot interferometer is used to examine the doublet. t 227 Coherence so that the individual squares approached spikes, one would expect a greater contribution from the high-frequency components for an adequate synthesis of the function. 18 Fresnel diffraction is observed behind a wire 0.37 mm thick, which is placed 2 m from the light source and 3 m from the screen. Photoconductive Detectors are used. 15 The gain bandwidth of the lasing transition (that is, the width of the atomic lineshape g1n2 associated with the transition) in a Nd:YAG gain medium is about ¢n = 1.2 * 1011 Hz. Express this bandwidth as a wavelength range ¢l. Consider Figure 9. Boston: Academic Press, 1990. Relationships Between A and B Coefficients The spectral energy density in an electromagnetic field in thermal equilibrium with its surroundings at temperature T takes the form r1n2 = 8phn3 1 3 hn>kBT c e - 1 (6) [See problem 1.] In thermal equilibrium at temperature T the population densities N1 and N2 of the atoms satisfy a Boltzmann relation, N2 = e -1E2 - E12>kBT = e -hn0>kBT N1 (7) These relations can be compared to the requirements imposed by the rate equations. Eqs. (a) Frontal view showing radial cuts. Let us use as a reasonable criterion for successful discrimination between neighboring pulses that their separated in the figure to clarify its action. The configuration is sketched in Figure 4a, which shows an emerging spherical wavefront centered at S. Although there are numerous other pumps or excitation processes, we cite one more process which has some historical significance. The central maximum is a circle of light, the diffracted "image" of the circular aperture, and is called the Airy disc. (19) (21), and (22) to determine R(z) and w(z) at z = 50 m. In the last two sections of this chapter, we wish to introduce only the most basic characteristics of electromagnetic waves. The lateral magnification of an extended object is simply determined by inspection of Figure 19. 9 A positive thin lens of focal length 10 cm is separated by 5 cm from a thin negative lens of focal length -10 cm. (a) Equal focal lengths result in residual longitudinal chromatic aberration. The two endpoint corrective measures, with the appropriate positive spectacle lens in place, are indicated in Figure 6d and e. What is the other wavelength? The photon lifetime, tp , of the cavity. What should be its focal length? At any wavelength, the index for the ordinary ray is a constant, given by the lower curve, whereas the incident ray relative to the crystal axis. Malacara, Zacarias H., and Morales R. Returning to Eq. (34), some insight is gained by examining Figure 16, which shows representative slits of a grating illuminated by plane wavefronts of monochromatic light. Nevertheless, Kerr cells find application as high-speed shutters and as a substitute for mechanical light choppers. The waves are redirected at S1 and S2 by various means, including reflection, refraction, and diffraction. If the angle u represents the angular separation of the sources from the plane of the slits, then from the diagram, ¢ /u, where r is the distance between slits, and u s>r, where r is the distance to the sources. The integration specified by Eq. (7) is over a closed surface including the aperture but is assumed to make a contribution only over the aperture itself. An effective refractive index neff for the guided wave is defined by neff = c>yg, where yg is the group velocity. Verify that the reconstructed wavefront from the hologram of a point source produces both the real and virtual images shown in Figure 10. At the input end of the fiber-optic cable, the information to be transmitted is converted by some type of transducer from an electrical signal to an optical one. X-ray diffraction serves as a probe of the lattice structure of crystalline solids and X-ray telescopes provide important information from astronomical objects. Alternatively, the aberration may be described in terms of the deviation of the deformed wavefront from the ideal at various distances from the optical axis. Fiber Optics Communications, Experiments and Projects. This instrument, probably the most adaptable of all interferometers, has been used, for example, in precision wavelengths. The image of a given object, formed by refraction at the first surface, becomes the object for refraction at the second surface. 2 THE MATRIX METHOD When the optical system consists of several elements—for example, the four or five lenses that constitute a photographic lens.—we need a systematic approach that facilitates analysis. When the slits are very close together 1a V ls2, they fall within a high coherence region and the fringes in the interference pattern appear sharply defined. Field of view formed by Eq. (9) and g(z) are general functions, as yet undetermined, that are subject to constraints imposed by Eq. (9) (27) and (28) becomes imaginary, and the equations may be written in the form rTE = rTM = cos u + i 2sin2 u - n2 cos u + i 2sin2 u given by E1 = E2 = Write the resultant wave form expressing their superposition at the point x = 5 cm and y = 2 cm. Let the light so transmitted be intercepted by an additional lens L4, as shown in Figure 7. We consider for simplicity the spectral resolution of a pulse that is, while it exists at some point, a harmonic wave. 3p p 3l a (b) presented graphically in Figure 15 is precisely described by the following set of equations and conditions: pp , p = 0, ; 1, ; 2, Å ; N Å ; 2N Å N principal maxima occur for p = all other integer values A practical device that makes use of multiple-slit diffraction is the diffraction grating. In this "strained" state, the eve is able to form clear images of nearby objects on the retina. The impressive ability of dichroic materials to absorb light strongly with B B E along one direction and to transmit light easily with E along a perpendicular direction can be understood by reference to a standard experiment with microwaves, illustrated in Figure 3. The experimental observation that light can be polarized is, therefore, clear evidence of its transverse nature. Then for times t 7 t0, Eq. (21) simplifies to 213 214 Chapter 8 Optical Interferometry + + E01 1t + t2 = r2E01 1t2 (44) If, during one round-trip time t the change in the complex field amplitude + E01 is small compared to the amplitude itself, a Taylor series approximation can be used, + + E01 1t + t2 L E01 1t2 + td + E 1t2 dt 01 Using this in Eq. (44) and rearranging terms gives d + 1 + E011t2 = -11 - r22E01 1t2 t dt One can verify by direct substitution that the solution to this differential equation is + + E01 1t2 = -11 - r22E01 1t2 t dt One can verify by direct substitution that the solution to this differential equation is + + E01 1t2 = -11 - r22E01 1t2 t dt One can verify by direct substitution that the solution to this differential equation is + + E01 1t2 = -11 - r22E01 1t2 t dt211 - r22 = 2t2. points such that each ray contacting a wavefront represents the same transit time of light from the source. This is amply demonstrated in Table 1. (c) General superposition; the amplitude of the resultant wave is neither the summary and comparison provided in Table 1. (c) General superposition; the amplitude of the resultant wave is neither the summary and comparison provided in Table 1. (c) General superposition; the amplitude of the resultant wave is neither the summary and comparison provided in Table 1. (c) General superposition; the amplitude of the resultant wave is neither the summary and comparison provided in Table 1. (c) General superposition; the amplitude of the resultant wave is neither the summary and comparison provided in Table 1. (c) General superposition; the amplitude of the resultant wave is neither the summary and comparison provided in Table 1. (c) General superposition; the amplitude of the resultant wave is neither the summary and comparison provided in Table 1. (c) General superposition; the amplitude of the resultant wave is neither the summary and comparison provided in Table 1. (c) General superposition; the amplitude of the resultant wave is neither the summary and comparison provided in Table 1. (c) General superposition; the amplitude of the resultant wave is neither the summary and comparison provided in Table 1. (c) General superposition; the amplitude of the resultant wave is neither the summary and comparison provided in Table 1. (c) General superposition; the amplitude of the resultant wave is neither the summary and comparison provided in Table 1. (c) General superposition; the amplitude of the resultant wave is neither the summary and comparison provided in Table 1. (c) General superposition; the amplitude of the resultant wave is neither the summary and comparison provided in Table 1. (c) General superposition; the amplitude of the resultant wave is neither the summary and comparison provided in Table 1. (c) General superposition; the amplitude of the resu photometric guantities, then, we are measuring the properties of visible radiation as they appear to the normal eve, rather than as they appear to an "unbiased" detector. In general, however, two rays incident at the interface, as in Figure 21b, each result in a reflected and a transmitted ray, all of which are shown, with appropriate amplitudes, in Figure 21c. 4 Assume that aluminum has one free electron per atom and a static conductivity given by 3.54 * 107> Æ-m. New York: McGraw-Hill Book Company, 1972. Microwaves, with wavelengths from 1 mm to 30 cm or so. Interference fringes are seen in the overlap region on the screen. In this introduction we limit ourselves to a basic description of how apertures can affect both image brightness and field of view. In such a case we say that the sources are mutually incoherent and
the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = I1 + I2 Mutually incoherent and the detected irradiance will be I = laser, do not interfere with each other. A glucose solution of unknown concentration is contained in a 12-cm-long tube and is found to rotate linearly polarized light by 1.23°. Some rays leaving O do not reach I due to reflection strong surfaces, and scattering by inhomogeneities in transparent media. In a high-power laser, the cooling system is an essential part of the system. 28 Consider a Mach-Zehnder fiber demultiplexer depicted in Figure 16b. If the maximum irradiance on this scale? The reverse-biased external voltage increases the electric field in the junction region, which in turn increases the rate at which the electrons and holes generated by absorption of the junction region. 251 Fiber Optics A more careful analysis indicates that single-mode performance results even when 2.4 d 6 (11) l p1N. Solution Substituting into Eq. (12), VHW = 0.01 212212.4 * 10-12210.032 = 26.4 kV Thus the Kerr cell behaves as a half-wave plate at a voltage of around 26 kV, considerably higher than for a typical Pockels cell. (b) 7.50 ×; 8.70 × 29. Determine the radii of the first and tenth dark rings. Objective Ocular ExP VO as a fe fo E nP Figure 32 Galilean telescope. Because of this periodicity, increasing all x by I should reproduce the same wave. In Figure 1a, the ExP is the real image of the EnP; in Figure 1c, it is the virtual image. For any one mode, the angle of propagation is a function of the wavelength. 9 What minimum thickness should a piece of guartz have to act as a guarter-wave plate for a wavelength of 5893 Å in vacuum? The compromise surface between the S and T surfaces is indicated by the dashed line. Macleod, H. We consider several applications of Eq. (22), beginning with the following example. (Here m = 2d>1, where d is the length of the Fabry-Perot interferometer.) t1 9 t2 t3 t4 t5 Coherence INTRODUCTION The term coherence is used to describe the correlation L- q 2p L-t0>2 g1v2 = Integrating, we have g1v2 = c g1v2 = +t0>2 ei1v - v02t d 2pi1v - v02t d 2pi1v - v02t d 2pi1v - v02t d 2pi1v - v02 i or, after using the identity, eix - e-ix K 2i sin x g1v2 = sin[1t0>221v - v02] t 0 sin[1t0>221v - v02] = e f p1v - v02 2i or, after using the identity, eix - e-ix K 2i sin x g1v2 = sin[1t0>221v - v02] t 0 sin[1t0>221v - v02] = e f p1v - v02 2i or, after using the identity, eix - e-ix K 2i sin x g1v2 = sin[1t0>221v - v02] t 0 sin[1t0>221v - v02] u2>u]. To treat the initial growth of the laser field, Eq. (55) can be rectified by replacing the factor NpVc + 12>Vc. Treating the cornea as a thin surface (whose own refraction can be neglected), bounded by air on one side and aqueous humor on the right with the factor 1NpVc + 12>Vc. surface. Interference fringes appear in the region of overlap. In addition, there can be environmental factors that cause the center frequencies of each of the atoms in an assembly of atoms to differ from one another. The circle of light at the center frequencies of each of the atoms in an assembly of atoms to differ from one another. object and the holographic image are slightly different, and the light forming the two images interferes, producing fringes that measure the extent Figure 7 Example 1. In Eq. (20), when Rn is fixed, n increases as r0 decreases. Of course, the films must be thin enough to be partially transmitting. The schematic eye shown corresponds to its relaxed state. The directed distances s1 and s2 are the perpendicular distances from the reference planes to the point of superposition. The object is first defined mathematically by specifying its coordinates and the intensity of all its points. Virtual fringes of equal inclination may be seen by looking into the beam splitter along ray 4, with the eye or a telescope focused at infinity. The first three orders of diffraction are most commonly used. 557 Laser Operation b. The anastigmat camera objective is designed to take advantage of this. In each case, after reflection, this ray is labeled 37. Excessive vignetting may make the image of a point appear astigmatic. Even though object points are imaged as points, distortion shows up as a variation in the lateral magnification for object points at different distances from the optical axis. 236 Chapter 9 Coherence we may now delineate the following special cases: 1. 685 lm 650 700 750 V(): Luminous efficiency spectrum. Take into account the results of problem 5. Note that the inversion is always negative and decreases in magnitude as the irradiance of the light incident on the medium increases. Of course, for the straight edge depicted in Figure 14a, only those zones above the physical edge contribute light to a given field point. The figure 4 a given field point. The figure 4 a given field point are straight edge depicted in Figure 4 a given field point. fringes satisfy Eq. (36), ¢ p + ¢ r = 2nt + ¢ r = ml where t represents the thickness of the air film at some point. For our present purposes, it will be sufficient to show how the appropriate equations for meridional ray tracing can be developed and how they can be repeated in stepwise fashion to follow a ray through any number of spherical refracting surfaces that constitute an optical system. The scattered light at v is elastic or Rayleigh scattering. The diagram defines quantities used in applying boundary conditions to write Eqs. The left member is 1nR + inI22 = 1n2R - n2I2 + i12nRnI2 (35) The right member can also be written as the sum of a real and imaginary part. In this so-called photovoltaic mode of operation, depicted in Figure 5a, a change in the amount of incoming light leads to a change in the open-circuit voltage across the p-n junction. The fibers of a bundle of such fibers, end-equipped with objective lens and evenies of a bundle of such fibers. the cavity mirrors. Determine its cardinal points and make a sketch to scale. Thus an electric field directed from the n-type to the p-type material is created in the junction region. Still, the presence of anisotropic binding forces along the x- and y-directions leads to, for light propagating along the z-direction, different dispersion curves (like that of Figure 8) for refractive index nx corresponding to Ex-vibrations. Harmonic wave functions are then adapted to represent electromagnetic waves, which include light waves. The first good replica grating usually serves as a submaster for the routine production of other replicas. According to the notion A A A vt vt B B B B Figure 2 Illustration of Huygens' principle for (a) plane and (b) spherical waves. On the basis of spreading due to diffraction alone, how far must it travel to double its diameter? The direction of polarization is the z-direction alone, how far must it travel to double its diameter? rather than an average. A phase-conjugate mirror handles all cases and also responds to instantaneous changes in the incident wavefront. In this case, the light wave is diffracted in a way similar to that of X-rays from crystalline planes in Bragg scattering (the Bragg regime). The beam splitter in this position enables light to strike the film at normal incidence, while at the same time providing for the transmission of part of the reflected light into the detector (eye). Portions of other conversations can be carrying capacity of the system. 8 LASER TYPES AND PARAMETERS To this point we have examined the basic processes involved in the interaction of light with matter, identified the essential parts that make up a laser, described in a general way how a laser operates, and studied the characteristics that make up a laser, described in a general way how a laser operates, and studied the characteristics that make up a laser. equation of the ellipse is E 2y E 2x + - 0.267ExEy = 0.2 9 5 When Ex lags Ey, the phase angle e becomes negative and leads to the Jones vector (with A and C positive numbers) representing a clockwise rotation instead: 'E0 = c A d B - iC E0y a E0x Ex Figure 7 Elliptically polarized light oriented at an angle a relative to the x-axis. In the present discussion we B B choose to write the fields E1P and E2P being superposed at point P in terms B of the field ES at the
sourceBpoint S. We close this chapter with an introductory glance at the electromagnetic spectrum and a survey of the radiometric units we use to describe the properties of electromagnetic radiation. Table 1 is meant to serve as a convenient summary that can be referred to when needed. These fringes reveal imperfections in the optical system that cause variations of all six cardinal points are indicated in Figure 3. Photography by holography is a twostep process. Know that some techniques used in near-field microscopy allow one to surpass the diffraction. limited resolution just discussed. 23 Newton's rings are formed between a spherical lens surface and an optical flat. Note that gth characterizes the cavity losses. Some of the fibers function as light pipes, transporting light from an external source to illuminate inaccessible areas internally. Wavelengths extending further into the infrared can be handled by prisms made of salt (NaCl, KCl) and sapphire 1Al2O32. The central ray makes angles of u1 and u2, respectively, relative to the area normals, as shown. In making a hologram with a microscope, the specimen is illuminated by laser light, part of which is first split off outside the microscope and routed independently to the photographic plate, where it rejoins the subject beam processed by the microscope optics. What is the maximum crystal thickness useful in generating second harmonic light? The thick lens can be treated by methods you should already be familiar with. constructing the wavelets that determine the reflected wavefront. Check your results against Figure 3. In view of the unique role played by the eve in human vision, it is not treated in this chapter. Then, by Eq. (41), EA = - EB and IA = IB at the point. If the crystal is rotated about the incident ray direction, the extraordinary image is found to rotate around the ordinary image, which remains fixed in position. With the stop located between object (far right) and lens, barrel distortion occurs in the image. The diffracted light is observed on a screen at 15 cm farther along the x-axis at uniform speed y relative to a fixed coordinate system, O(x, y), as in Figure 1b. Light from a point object is incident on the concave, cylindrical surface from a distance of 25 cm to the left of the lens. If this region is illuminated with monochromatic light, the light diffracted from the deformations can be photographed and converted into a visual image of the underwater object. The points P represent the position of the resultant. That is, an energy of 13.6 eV must be given to an electron in the ground state of hydrogen atom. Kingston, R. We do so in the following subsections. This discussion should make it clear that high-quality microscopes today are designed as a whole and usually for a specific use The image provided by the hologram may be viewed by focusing at leisure on any depth of an unchanging field. Since a cylinder has no curvature along its axis of symmetry, the surface has no power in the horizontal meridian. For the case of arbitrary N, there will be N - 1 zeroes and N - 2 secondary peaks between principal maxima. The oscillating dipoles, consisting of electrons accelerating in harmonic motion, are tiny radiators—antennas that reradiate or scatter energy is a detector. 35 An airplane is used in aerial surveying to make a map of ground detail. Find the equation of the intersection of the oval with the xy-plane, where the origin of the coordinates is at the object point. Rather when this condition holds, the cavity loss per round-trip and no irradiance builds up in the cavity loss per round-trip and no irradiance builds up in the cavity. For longer distances, this leads to a modified dependence of the form, dt r 2L. The "negative" of a hologram alters neither fringe contrast nor spacing and hence does not modify the stored information. Example 4 Suppose that each lens on a pair of binoculars has a diameter of 35 mm. (b) Equivalent optics for the Michelson interferometer. The mean wavelength is 6328 Å. Now the phases B B of the ^c- and P-components, E^c and E^P respectively, are not equal. In this chapter, we first describe the basic processes involved in the interaction of light with matter and discuss the nature of light emitted by nonlaser light sources. (What is the ratio of a/b in this case? The image of the object in the aperture plane is thus superimposed over the pattern on the partially transparent mask. Consider a 1200-groove/mm grating to be blazed for a wavelength of 600 nm in first order. The slits are 0.04 mm in width and separated (center to center) by 0.25 mm. The lens refractive index is 1.50. Sources operating at or near this wavelength are thus ideal in reducing pulse broadening and increasing transmission rates. (7) and (11), as follows: Eb = Et1e - id + Ei1eid = Et2 (18) Bb = g11Et1e - id - g12 (18) Bb = g12 (Ei1eid2 = gsEt2 (19) Disregarding for the moment the rightmost members, these equations may be solved simultaneously for Et1 and Ei1 in terms of Eb and Bb, yielding Et1 = a g1Eb + Bb id be 2g1 (20) Ei1 = a g1Eb + Bb id be 2g1 (21) Finally, substituting the expressions from Eqs. The displacement at the nodes is always zero. In this section we discuss

two such effects, the Pockels effect and the Kerr effect, and show that these effects can be used in light modulators. Determine the wavelength of the light. The rate of spontaneous emission is, of course, still given by Eq. (3). An Introduction to Modern Optics. Notice that since EnW and ExW are both images of the FS, they are conjugate planes. Since the ellipse is the locus of all points whose combined distances from the two foci is a constant, all paths are indeed of equal time. Since rays from O, directed toward this virtual aperture, make a smaller angle 1N¿ON2 than rays directed toward this virtual aperture, make a smaller angle 1N¿ON2 than rays directed toward the lens edge 1L¿OL2, this virtual aperture, make a smaller angle 1N¿ON2 than rays directed toward the lens edge 1L¿OL2, this virtual aperture, make a smaller angle 1N¿ON2 than rays directed toward the lens edge 1L¿OL2, this virtual aperture, make a smaller angle 1N¿ON2 than rays directed toward the lens edge 1L¿OL2, this virtual aperture, make a smaller angle 1N¿ON2 than rays directed toward the lens edge 1L¿OL2, this virtual aperture, make a smaller angle 1N¿ON2 than rays directed toward the lens edge 1L¿ON2 than rays directed toward the lens edge 1L²ON2 than rays directed toward t (13), p p p 2 E20 = c7 sin a b + 12 sin a - b + 20 sin a b d 3 4 5 p p p 2 + c7 cos a b + 12 cos a - b + 20 cos a b d 3 4 5 or E20 = 9.3332 + 28.1662 and E0 = 29.67. According to Eq. (35), the phase difference between successive reflected beams is given by d = kc, where c = 2n ft cos ut (44) If the incident ray is expressed as E0eivt, the successive reflected beams is given by d = kc, where c = 2n ft cos ut (44) If the incident ray is expressed as E0eivt, the successive reflected beams is given by d = kc. rays can be expressed by appropriately modifying both the amplitude and phase of the initial wave. The scattering is called Brillouin scattering is called Brillouin scattering and is another third-order effect that does not require a medium possessing inversion symmetry. resultant field, together with the stronger first-order field at the fundamental frequency v. Photographs of diffraction fringes produced by 2, 3, 4, and 5 slits are shown in Figure 17. It must provide a large field of view, in the range of 35° to 65° for normal lenses. Notice that in this case six cavity modes are at frequencies that have gain larger than the threshold value. Calculate the reflectance R for the TE mode when the light is incident from air onto glass of n = 1.50 at the polarizing angle. As the aperture approaches the lens, it permits a shorter average distance to the lens. 22 A quasar near the limits of the observed universe to date shows a wavelength that is 4.80 times the wavelength emitted by the same molecules on the earth. When the film is developed, straightline fringes appear. As with the Pockels cell, a modulation by the polarizer-analyzer pair. Let the actual irradiance over the image plane be given by the same molecules on the earth. Ii1X, Y2. In this discussion we are content to present briefly the radiometric quantities or physical terms used to characterize the energy content of radiation. In this form, show that the superposition of the waves is the standing wave given by Eq. (22). Gamma Rays This type of EM radiation has its origin in nuclear radioactive decay and certain other nuclear reactions. This description rests first on the fact, demonstrated in the previous chapter, that linearly polarized light can be assumed to consist of equal amounts of leftand right-circularly polarized light can be assumed to consist of equal amounts of leftand right-circularly polarized light can be assumed to consist of equal amounts of leftand right-circularly polarized light. example. Notice that rays from O, directed toward the edges of EnP, are in fact first refracted by the lens so as to pass through the edges of the real aperture stop. The single hole, used to illuminate the double slit. 20 18 n1 2 16 14 n1 1.8 R (%) 12 10 8 n1 1.6 6 4 n1 1.4 2 n1 1.2 0.1 22 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 Path difference/wavelength Theory of Multilayer Films, in its essentials, should already be familior to you. If the point object is only 6 cm from the lens, describe the line image. Let f1 = 15 cm, f2 = 15 cm, and their separation be 60 cm. What focal length for the negative lens gives a flat Petzval surface? Show that a(Q) also vanishes for s_i = R and for rays intersecting with the spherical surface? Show that a(Q) also vanishes for s_i = R and for rays intersecting with the spherical surface? out of phase with respect to the incident wave, and complete cancellation of the forward wave does not occur. Formation of constructive fringes is shown in Figure 15a. Find the irradiance of these optical electromagnetic B waves and the amplitude of their E-field at a distance of 10 m from the lamp. We content ourselves for purposes of this discussion with pointing out that optically active materials possess molecules or crystalline structures that have spiral shapes, with either left-handed or right-handed or right-handed or right-handed or right-handed or right-handed screw forms. maximum? Example 4 a. Typically, the record of the irradiance of each pixel is stored digitally. (1) through (3), we have dEP = a a ES ik1r + r2 -ivt be e dA rr2 (5) The field at P due to the secondary wavelets from the entire aperture is the surface integral of Eq. (5), EP = aESe -ivt O a 1 ik1r + r2 be dA rr2 (6) Aperture Equation (6) is incomplete in two ways. Spectral reflectance curves for N = 2 and N = 6 double-layer stacks have been calculated and plotted in Figure 9. Adding Eqs. H., ed. In the case of solutions, the specific rotation due to a 10-cm thickness and concentration of 1 g of active solute per cubic centimeter of solutions. Consider the first coherence time interval to 1. in which the pulse function may be expressed by w1t2 - w1t + t2 = e 0, H1, 0 6 t 6 1t0 - t2 6 t 6 t0 235 Coherence In successive intervals, the expression is similar, except for the value of H1. The disadvantages of this restriction can be overcome if the photograph is a hologram, which in a single snapshot contains potentially all the ordinary photographs that could be made after successive refocusings throughout the depth of the living specimen. To take advantage of the maximum resolution, the light must cover the entire ruled width of the grating. Where must a small object be positioned so that light from the object is rendered parallel by the combination? If the two refracted rays, linearly polarized perpendicular to one another, can be physically separated, then double refraction can be used to produce a linearly polarized beam of light. The use of the Fabry-Perot cavities in the interferometer arms increases the sensitivity of the device by a factor roughly equal to the number of round-trips in a photon lifetime of the Fabry-Perot cavities. What is its beam-spread angle in the far field? We summarize his approach in what follows. The order of the interference pattern is indicated by m, with integral values of m determining positions of fringe maxima. We wish now to introduce some of the mathematical formalism and terminology commonly used to discuss Fourier transformations in another approach to imaging. Forces are exerted on the charges by the electric field of the waves and, because of the motions of the charges, also by the magnetic field of the waves. (2) Polarizing angles exist for both external reflection 1n2 7 n12 and internal reflection 1n2 7 n12 and internal reflection 1n2 6 n12 and are clearly not the same. THE NONLINEAR MEDIUM Nonlinear phenomena are due ultimately to the inability of theBdipoles in the optical medium to respond in a linear fashion to the alternating E-field associated with a light beam. Finally, we will assume that the four-level system is closed, in the sense that all atoms in the sample exist in one or the other of these four levels so that NT = N0 + N1 + N3 + N45 See problem 7 for another common arrangement involving three levels. The angle of inclination is determined from tan 2a = (10) E 20x - E 20y E0y = 2B2 + C 2, and e = tan-1 a C b B (11) Example 1 Analyze the Jones vector given by c 3 d 2 + i to show that it represents elliptically polarized light. The Q of the cavity is rapidly switched to a high value so that the loss rate of the cavity is reduced to a low value. 100 Chapter 4 Wave Equations 4 HARMONIC WAVES AS COMPLEX FUNCTIONS Using Euler's formula, it is possible to express a harmonic wave as the real (or imaginary) part of the complex function ' y = Re 1y2 = A cos1kx - vt2 or y = Im 1y2 = A sin1kx - vt2 (19) ' Note that any equation that involves only terms that are linear in y and its de' ' rivatives will also hold for y = Re 1y2 or y = Im 1y2. Example 4 Convex (a) A thin plano-cylindrical lens in air has a radius of curvature of 10 cm, a refractive index of 1.50, and an axial length of 5 cm. The coherence length of this radiation, by Eq. (17), is 78 cm! Laser radiation has far surpassed even the coherence of this gas-discharge source. "Optical Interferometry of Surfaces." Scientific American, July 1991: 66. The peak response at 5500 Å closely matches the response of the human eye. With the appropriate cylindrical surface ground on the rear of the spectacle lens, the correction of -1.00 D reduces the power in the vertical meridian from 46.00 D to 45.00 D, thereby equalizing the refracting powers in the two meridians and negating the corneal astigmatism. This is accomplished by exciting (or pumping) more atoms into the higher energy level than exist in the lower level. How many half-period zones are contained in an aperture with a radius 100 times larger? The construction makes clear the equivalence between the angles of incidence and reflection, as outlined in Figure 4a. s1 To simplify notation we introduce the constant phases, $a_1 = ks_1 + w_1$ (3) $a_2 = ks_2 + w_2$ (4) The
time variations of the EM waves at the given point can thus be expressed by E1 = E01 cos1a1 - vt2 (5) E2 = E02 cos1a2 - vt2 (6) Two such waves, intersecting at the fixed point P, differ in phase by a2 - a1 = k1s2 - s12 + 1w2 - w12 due to a path difference, given by the second term. 1pR2a22>4 pa2 = , independent of the value of R. A change from low-level light or scotopic vision to high-level light or photopic vision in the process of adaption consists of a rapid bleaching out of rod pigment and a resulting insensitivity of the rod receptors. Such asymmetry leads to different refractive powers and, consequently, to image formation at different distances from the cornea, resulting, of course, in blurred vision. The refractive index of the lens is 1.52. Where does the fish appear when viewed through the lens? The last term depends on an interaction of the waves and is called the interference term, I12. The retardation action due to an applied voltage V is suggested by an on-axis separation of the polarized components transmitted by the fast and slow axes of the crystal. Diffraction is often distinguished from interference on this basis: In diffraction phenomena, the interfering beams originate from a continuous distribution of sources; in interference in fB and fR results in a difference of lateral magnifications, and lateral chromatic aberration remains. If it is known that the adjacent peaks in Figure 12 have the same mode number m, then the wavelengths must satisfy the relations $l1 = 2d_1 > m l2 = 2d_2 > m d l dfsr l1/2$ Transmittance 0.8 l1 0.6 l1 l2 l2 0.4 0.2 0 0 0.05 0.1 0.15 0.2 0.25 Change in cavity length (mm) 0.3 0.35 0.4 Figure 12 Fabry-Perot scan used to determine the difference in wavelength of two closely spaced wavelength components of the input field. Returning now to the problem at hand, notice that two angular relationships may be obtained from Figure 15, because the exterior angle of a triangle equals the sum of its interior angles. At what observation point on the axis does $\psi = 2.5$? 14 A source slit at one end of an optical bench is illuminated by monochromatic mercury light of 435.8 nm. How long does it take for the soprano's voice to reach the listener? This source of imperfect image formation, discussed further in the sections under diffraction, represents a fundamental limit to the sharpness of an image that cannot be entirely overcome. What is the free spectral range for first and second orders in each case? San Francisco: W. Note that this condition under which one can consider the diffraction pattern to be in the far field. in diameter has a core of index 1.53 and a cladding of index 1.39. Describe the polarization mode of the product light. The spectral radiant exitance is seen to increase with absolute temperature at each wavelength. Since n = c>y and y 6 y7, we conclude that n 7 n 7. The center of curvature is located on the side of the higher index. since the information-carrying capacity of the carrier wave increases directly with the width of the frequency band available. 9. The relative response or sensation of brightness for the eye is plotted versus wavelength, showing that peak sensitivity occurs at a "yellow-green" wavelength near 550 nm. The rate equations governing population densities of the four levels shown in Figure 5, due to the indicated processes, take the form spIp dN3 = k3N3 + k21N2 - k10N1 + 1N - N12 dt hn; 2 (27) dN1 sI = k31N3 + k21N2 - k10N1 + 1N - N12 dt hn; 2 (28) spIp dN0 1N3 - N02 = k30N3 + k20N2 + k10N0 + dt hnp (29) Here we have replaced the spontaneous emission A coefficients with decay rates k in order to account for any decay process that causes a downward transition in the atom, including spontaneous emission and, for example, inelastic collisions with other atoms, molecules, or particles. The locations of the pulse following the axial path reaches point B. (Note: The reflection coefficient for the external surface of the cavity mirror must be - r if that from the internal surface is r and the transmission coefficients t are real.) b. (57) and (58) are explored in problems 27 through 31. The HWP may be used in this way as a "laser-line rotator," allowing the polarization of a laser beam to be rotated without having to rotate the laser. The possibility of polarizing light is essentially related to its transverse character. We shall say more about coherent radiation later. Nonideal images are formed in practice because of (1) light scattering, (2) aberrations, and (3) diffraction. Each diffraction spot now helps to illuminate the image of the aperture in the image plane. Angular Deviation of a Prism The top half of a double-convex, spherical lens can form an image of an axial object point within the paraxial approximation, as shown in Figure 8. Determine the radiance of this laser light source in units of W. What is the irradiance at a height of 1 mm above the axis SOP at the screen? Compare this with the resolving power obtained from the theoretical grating resolving power formula, Eq. (11). Consider the specular reflection of a single light ray OP from the xyplane in Figure 7a. Each loop of the standing wave envelope is of length l>2. The mirror translation rate is 71.5 nm/s. The peak exitance also shifts toward shorter wavelengths with increasing temperature, falling into the visible spectrum (between dashed vertical lines) at T = 5000 and 6000 K. Extend Malus' law by calculating the irradiance transmitted by a pair of such polarizers with angle u between their TAs. Assume initially unpolarized light of irradiance I0. Let R1 = R2 = 0.99 and A3 = 0.01. This requires that there be available energy states which differ by a continuous range of energies. Use the result for Np in (a) to form the following expression for the steady-state output irradiance from the distance beam waist, z, exceeds the Rayleigh range z0 by a factor of 20 to 50. This case is much like the previous one. (33) and (34) into Eq. (37) gives P = 1n1 - 12K1 + 1n2 - 12K2 (38) Chromatic aberration is absent at the wavelength lD if the power is independent of wavelength lD if the power is independent of wavelength, or 10P>012D = 0. Gain saturation occurs because large irradiances cause more stimulated emission, which depletes the steady-state population density of the upper lasing level, thus reducing the likelihood of a stimulated emission event. The plot shows the difference in air pressure from its equilibrium value as a function of x at t = 0, and several planar wavefronts associated with the sound wave are depicted at the same time. In CW operation the phases of these modes are independent from each other and wander randomly since the fields are not perfectly coherent. Find (a) its momentum, (b) its de Broglie wavelength, and (c) the wavelength of a photon with the same total energy. It can be shown 8 that for this case, pulse broadening is given approximately by modal distortion 1GRIN fiber, ap = 22: d a n1 2 t b = ¢ L 2c (16) Comparing with modal distortion in the step-index fiber, Eq. (14), we can write da ¢ n1 t ¢ t b a ¢ b = da b = L GRIN 2 c 2 L SI The factor ¢>2 thus represents the improvement offered by a GRIN fiber. Assume the original light to be linearly polarized vertically. 466 Chapter 21 Fourier 0 (a) Video be a GRIN fiber. image of a diatom frustule imaged in dark field illumination with a superimposed sawtooth pattern. a Summarizing, a Jones vector C b D with both a and b real numbers, not both zero, represents linearly polarized light at inclination angle a = tan-11b>a2. In Figure 6, the cell is used as a Q-switch that allows 10 J. The gain coefficient is increased by reducing the decay rate from level 2. 8 Chapter 1 Nature of Light displayed in terms of both frequency n and wavelength, l. Tuning these lasers to emit in specific stable wavelength, l. Tuning these lasers to emit in specific stable wavelength, l. Tuning these lasers to emit in specific stable wavelength, l. Tuning these lasers to emit in specific stable wavelength and wavelengt DWDM in long-haul fibers was the discovery and development of erbium-doped fiber amplifiers (EDFA's). What path difference corresponds to a shift in the fringe pattern from a peak maximum to the (same) peak halfmaximum? The terms group velocity and phase velocity are introduced in the next section. Imagine two spectral lines formed on a photographic film in a prism spectrograph. Commercially available blackbody sources consist of cavities equipped with a small hole. 20 Single-slit diffraction is produced using a monochromatic light source (435.8 nm) at 25 cm from the slit. In later chapters, we will have occasion to further discuss optical communications systems and the use of fiber-opti components as optical switches and modulators. Figure 6 Diffraction pattern due to an opaque, circular disc, showing the Poisson spot at the center. Computer techniques have made routine the rather detailed calculations involved in the analysis of multilayer film performance. This is left as an exercise for the student. The square of the length of chord from y1 to y2 on the Cornu spiral is proportional to the irradiance at the point P2. An electron beam emitted by a heated cathode is steered by electric and magnetic forces to a particular point on a screen covered with a phosphorescent material that emits light when struck by electrons. The Summary of Terms that follows is provided as a convenient reference for a subject that requires patience, and experience with many examples, to master. What is the quantum efficiency of this detector? 3 A collimated light beam is incident on the plane side of a plano-convex lens of index 1.50, diameter 50 mm, and radius 40 mm. This is not a problem in the Ramsden eyepiece, Figure 26, in Huygenian eyepiece Eye lens Reticle RI Retaining ring VO F2 Field lens EL FL Exit pupil Field stop Ramsden eyepiece Eye lens Figure 25 Huygens eyepiece. 17 Consider again the ring laser described in problem 16
but now take the small-signal gain coefficient to be 0.01/cm, R3 = 0.95, and T3 = 0.05. sees the lens directly but sees the AS through the lens. From the point of view of optical filtering, then, it should be clear that a diaphragm, which blocks all but those frequencies near the direct beam, functions as a low-pass optical filter. At normal incidence, the grating equation can be incorporated with the angular dispersion relation to give \supset = a sin um 1 m = a ba b a cos um l a cos um l a cos um l (7) Thus, the dispersion \supset is actually independent of the grating constant a at a given angle of diffraction um and increases rapidly with um. Davis, Christopher C. The total number density of gain atoms is NT = N0 + N1 + N2 + N3. When this is done, the problem is treated as a diffraction problem. (a) r11 = -4.5770 cm, r22 = 53.1840 cm (b) f1D = -4.5770 cm, r22 = 53.1840 cm (b) f1D = -4.5770 cm, r22 = 53.1840 cm (cm) r22 = 53.1840 = 8.4399 cm (c) fD = -10.0000 cm, fC = -10.0050 cm, fF = -10.0050 cm Chapter 21 1. E b. The dashed lines depict the envelope of the resulting wave disturbance. The path difference ¢ is much smaller than r0 and so (to lowest order) can be ignored in the amplitude factor. These initiate the stimulated emission process. Then, for example, at l = 610 nm, in the range where the luminous efficiency is 0.5 or 50%, 1 W 423 Optics of the Eye TABLE 1 RADIOMETRIC TERMS Term Radiant energy Radiant 1W > m22 Ee 1W > m22 Ie 1W > sr2 f e = dQe>dt Me = df e>dA Ee = y 1lm2 My 1lm>m22 Ey 1lm>m22 or (lx) Iy 1lm>sr2 or (cd) f y = df y>dA Ey = df y>dA intercepted. The interference factor peaks at N 2 = 82 = 64. Even when the viewing angle u2 is not small, a reasonably good retinal image of an underwater object is formed because the aperture or pupil of the eye admits only a small bundle of rays while forming the image. 2 511 512 Chapter 24 Nonlinear Optics and the Modulation of Light small spots with wavelength dimensions, producing electric field strengths exceeding 1010 V>m—on the order of the strengths of the fields binding electro-optic effects discussed to this point, the Faraday effect is a first-order (i.e., ¢n r B) magneto-optic interaction.11 When a transparent material is placed in a magnetic field and linearly polarized light is passed through it along the direction of the magnetic field B, according to the empirical relation, b = VBd (13) Here V is the Verdet constant for the material, usually expressed in minutes of angle per Gauss-cm (G-cm). In (b), the concave lens forms a virtual image. A variety of multiplexing schemes exist: Here we discuss one based on the Mach-Zehnder interferometer. That is, the TE mode will experience more loss per round trip through the cavity than will the TM mode. b 2 l (10) Notice that, as for the slab waveguide, the number of possible modes increases with the ratio d>l. The limiting points have the coordinates 1C1y22, S1y222 = 10.5, 0.52, A = (1 +)1/2, B = 2(c/0)2(1 + 1) - 1/2, C = 2(c/0)4(3 + 4)(1 + 1) - 3/2 where = Ne2 / m0201. Ultraviolet On the short-wavelength side of visible light, this electromagnetic region spans wavelengths ranging from 380 nm down to 10 nm. = ng sin aa = sin aaœ and when an oil-immersion objective is used, N. Show also that reversal of the phase angle produces a converging spherical wavefront associated with the real image on reconstruction. Unless the E-field amplitude is very large, the x-coefficients of the higher-power E-terms are too small to allow these terms to influence the polarization appreciably. In this case, E0y is a negative number, what is the radius of curvature of the lens surface? Verdeyen, J. Thus, the circular image begins to dim as its radius increases. Due to fiber nonlinearities, this irradiance variation induces a time-varying index of refraction at this given point. Example 3 Calculate the reflectance R and transmittance T for both TE and TM modes of light incident at 30° on glass of index 1.60. Thrierr, Atlas of Optical Phenomenon, Plate 5, Berlin: Springer-Verlag, 1962.) Here we discuss chromatic aberration. When object or three-dimensional scene, each point of the scene produces its own Gabor zone pattern on the plate. 18 One side of a fish tank is built using a large-aperture thin lens made of the scene produces its own Gabor zone pattern on the plate. glass 1n = 1.502. The gain coefficient becomes larger by reducing Rp1 . Assume laser irradiation of 632.8 nm and a 50-cm focal length lens. (37) and (38) balance the small prefactors containing the mass. The hologram, itself a product of the interference of light, has been used as an alternative technique in interferometry, the science of using the wavelength of light and interference to measure very small opticalpath lengths with precision. a b 2 a 5 DOUBLE-SLIT DIFFRACTION The diffraction pattern of a plane wavefront that is obstructed everywhere except at two narrow slits is calculated in the same manner as for the single slit. Such a wave takes the form, c = A i1kr; vt2 e 1r (27) Slite states the form of a plane wavefront that is obstructed everywhere except at two narrow slits is calculated in the same manner as for the single slit. Incident plane waves Emerging cylindrical waves Figure 8 Plane waves incident on a slit generate cylindrical waves. The velocity of the wave may be found from $y = \ln = 12>325$ m>s = 3.33 m>s in the positive x-direction (due to the negative sign in the phase). An excellent example of a blackbody is the surface formed by the series of sharp edges of a stack of razor blades. The plastic triangle is 16 in. This is the usual form in which the gratings are made commercially available. Thus Eq. (24) can be written as, IP = I1P + I2P + e0ce 0ce 8E1E...2 + E...1E29 = I1P + I2P + e0ce 1 b 2Re8E1t - T12E...1t - T229 where, for simplicity, we have taken b 1 and b 2 to be real. 26. (a) $1.01 \times 10 \text{ V/m}$, $3.37 \times 10-6 \text{ T}$ (b) $4.76 \times 1021/\text{m2-s}$ (c) $E = 1010 \sin 2(1.43 \times 106 r + 4.28 \times 1014 t)$, r in m, t in s 18. Thus, if the direction of the incident light is fixed, say at normal incidence, a bright or dark fringe will be associated with a particular thickness. for which ¢ satisfies the condition for constructive or destructive interference, respectively. 13 In each of the following cases, deduce the nature of the light that is consistent with the analysis performed. So long as the gain per round-trip, the irradiance in the cavity continues to grow. Now, since in the far field the spot size grows linearly with z, the far-field divergence angle3 uFF, shown in Figure 2, satisfies the relation uFF L tan uFF = w1z W z02 l = z pw0 (28) From Eq. (28) we draw the important conclusion that a beam with a smaller beam-waist spreads more rapidly than a beam with a larger beam-waist. Reading, MA: Addison-Wesley Publishing Company, 1975. Thus, in this case, the reflected ray is linearly polarized only in the Es mode. Figure 14 Refractive indices of crystalline quartz versus wavelength at 18°C. These dips are the result of selective absorption by specific elements in the sun's outer layers and the earth's atmosphere. That is, cn = f - 1c > 122 cl f. Most fiber-optic communications systems in use today use semiconductor sources that emit near 1550 nm in order to minimize the attenuation of the optical signal. f f L2 Optical filter f f L3 f f L4 Spectrum analyzer 467 Fourier Optics the image of the object in the aperture plane coincides with the transmission pattern on the mask, then maximum light throughput occurs, a case of maximum correlation. In this mode, illustrated in Figure 5b, the n-type side of the junction is connected to the positive terminal of an external voltage source. The lens has a refractive index of 1.50 and is used in air. (b) x 321 Fresnel Diffraction Thus, r q and similarly, It follows that $r + r_i$ 1p + q2 + a 1 1 h2 + b p q 2 If we abbreviate, using D K p + q 1 1 1 K + p q L and (25) we have h2 2L r + r_i D + (26) Then Eq. (24) becomes EP = C1e -ivt eik1D + h > 2L2 dA 2 O If the elemental area dA is taken to be the shaded strip in Figure 11a, dA = W dz, h = z, and z2 EP = C1Wei1kD - vt2 Lz1 eikz > 2L dz 2 O If the elemental area dA is taken to be the shaded strip in Figure 11a, dA = W dz, h = z, and z2 EP = C1Wei1kD - vt2 Lz1 eikz > 2L dz 2 O If the elemental area dA is taken to be the shaded strip in Figure 11a, dA = W dz, h = z, and z2 EP = C1Wei1kD - vt2 Lz1 eikz > 2L dz 2 O If the elemental area dA is taken to be the shaded strip in Figure 11a, dA = W dz, h = z, and z2 EP = C1Wei1kD - vt2 Lz1 eikz > 2L dz 2 O If the elemental area dA is taken to be the shaded strip in Figure 11a, dA = W dz, h = z, and z2 EP = C1Wei1kD - vt2 Lz1 eikz > 2L dz 2 O If the elemental area dA is taken to be the shaded strip in Figure 11a, dA = W dz, h = z, and z2 EP = C1Wei1kD - vt2 Lz1 eikz > 2L dz 2 O If the elemental area dA is taken to be the shaded strip in Figure 11a, dA = W dz, h = z, and z2 EP = C1Wei1kD - vt2 Lz1 eikz > 2L dz 2 O If the elemental area dA is taken to be the shaded strip in Figure 11a, dA = W dz, h = z, and z2 EP = C1Wei1kD - vt2 Lz1 eikz > 2L dz 2 O If the elemental area dA is taken to be the shaded strip in Figure 11a, dA = W dz, h = z, and z = Z P = C1Wei1kD - vt2 Lz1 eikz > 2L dz 2 O If the elemental area dA is taken to be the shaded strip in Figure 11a, dA = W dz, h = z, and z = Z P = C1Wei1kD - vt2 Lz1 eikz > 2L dz 2 O If the elemental area dA is taken to be the shaded strip in Figure 11a, dA = W dz, h = z, and z = Z P = C1Wei1kD - vt2 Lz1 eikz > 2L dz 2 O If the elemental area dA is taken to be the shaded strip in Figure 11a, dA = W dz, h = z, and z = Z P = C1Wei1kD - vt2 Lz1 eikz > 2L dz 2 O If the elemental area dA is taken to be the shaded strip in Figure 11a, dA = W dz, h = z, and z = Z P = C1Wei1kD + Z P = Z P = C1Wei1kD + Z P = Z P = C1Wei1kD + (27) The exponent kz2>2L = pz2>Ll. Making a change of variable, we let IL A 2 z = y or 2 y = z A
Ll (28) whereby EP is y y 2 2 Ll 2 2 C1ei1kD - vt2 eipy >2 dy A 2 Ly1 Ly1 EP = W Here, AP is a complex scale factor with dimensions of electric field amplitude. It is the only term in the third-order wave aberration a(Q) that does not depend on h¿. 9 By working with the appropriate transfer matrix, show that a quarter-wave layer alone. 8 The plates of a Fabry-Perot interferometer have a reflection coefficient of r = 0.99. 21 A narrow beam of light 11 = 546 nm2 is rotated through 90° by TIR from the hypotenuse face of a 45°-90°-45° prism made of glass with n = 1.60. (b) 20 cm right of L2 (c) both at L1 (d) 8.57 cm beyond L2 and 47 cm in diameter (e) field stop at A, entrance window in object plane with 1 cm diameter (f) 2.86° 5. If s2 - s1 = 1m + 122l, the requisite condition for destructive interference or darkness is met. 330 Chapter 13 Fresnel Diffraction Figure 17 Fresnel diffraction c y3 y d = M1 c 0 d a1 a0 for the first refraction c y3 y d = M3 c 2 d a1 a0 for the first refraction c y3 y d = M3 c 2 d a3 a2 for the second refraction and Telescoping these matrix equations results in c y y3 d = M3M2M1 c 0 d a3 a0 Evidently the entire thick lens can be represented by a matrix M = M3M2M1 . g. As the irradiance grows, the gain saturates and the gain coefficient is reduced. Ch. 13. The laws of geometrical optics that describe the subsequent direction of the rays are the Law of Reflection and the Law of Reflection. The greater the angle between these wavefronts, the finer the spacing of the interference is d = k¢ = 12p>102 ¢. This pencil is certainly not symmetrical about the axis OI; in the absence of the limiting aperture EnP, its axis of symmetry would be 443 Aberration Theory EnP y I by O I C O Figure 4 Comparison of axial and oblique pencils of rays from an object, defined by passage through entrance aperture EnP. Together with the fiber-optic and semiconductor optoelectronic devices, the laser has revolutionized optics industry. In this case the primary photoelectrons are accelerated, so that as a result of a sequence of collisions, each multiplying the current by the addition of secondary electrons, an avalanche of electrons becomes available at the output corresponding to each primary photoelectron. When the T surface falls to the left of the S surface, as shown, the astigmatic difference is taken as positive; otherwise it is negative. Using these values in Eq. (36), the result is r = g22g0 - gsg21 (44) g22g0 + gsg21 Incorporating the refractive indices through the use of Eqs. 4 Determine the wavelength and momentum of a photon whose energy equals the rest-mass energy of an electron. 7 A small source of light at the bottom face of a rectangular glass slab 2.25 cm thick is viewed from above. In such cases, B B both the E- and B-fields satisfy a differential wave equation of the form B B §2E = a 1 0 2E b c2 0t2 (51) We have written harmonic waves satisfying Eq. (51) in the form B # B E = E0ei1k r - vt2 (52) Now if the material is metallic or has an appreciable conductivity, the fundamental Maxwell equations of electricity and magnetism lead to a modification Bof Eqs. The output pulse at the other end suffers, in general, from both attenuation and distortion. 2 ABSORPTION Light may either be attenuated or amplified as it propagates through a medium. Goodman, Douglas S. (27) through (30) and a computer program or a computer algebra system, reproduce Figures 3 and 5. Use the geometry of Figure 11 and the Bragg condition. The use of Q-switching and mode-locking to produce pulsed output fields is then considered. In LASIK, a microkeratome (sharp blade) is first used to create a corneal flap, 160 to 180 mm thick. This condition is shown satisfied in Figure 11. As the gain coefficient is reduced, the number of cavity modes above above threshold decreases. Similarly, the speed of light in the lower medium is c>nt. Thus, just as the direction of energy flow in the crystal is about to switch so as to cause attenuation of the second harmonic field, the sign of x2 changes. The function f is any function whatsoever, so that, for example, y = A sin1k[x - yt]2 y = ek1x - yt2 all represent traveling waves. As the slits are moved farther apart, the degree of coherence f g f decreases and the fringe contrast begins to degrade. Explain why, even when every pump event leads to an output photon, the efficiency of the image and therefore determines the image brightness, point by point. New York: Barnes and Noble, 1970. 23 Show that the loss rate \neq for a ring cavity with round-trip survival factor S and perimeter P is \neq = c 11 - S2 P 30 Use the relation," American Journal of Physics, Vol. 6 Consider an assembly of atoms that have two energy levels separated by an energy corresponding to a wavelength of 0.6328 mm, as in the He-Ne laser. The new wavefront, which must now be tangent to these wavelets at points M and N, and include the point I, is shown as KI in the figure. Atoms occupying the upper laser level (state E2 of Figure 15a) are shown by empty circles. Determine both the net rotation of the light and the circular dispersion of CS2 at this wavelength. For the case n = 1.50 used in Figure 20 Problem 9. Since light frequencies are of the order of 1014 Hz, while acoustic frequencies are generally less than 1010 Hz, both v and v¿ are much greater than vS , that is, k Figure 12 Wave vector triangle in the apB B proximation f k ¿ f = f k f = k. Hariharan, P. Explain why a more economical silver-plated brass component will work as well. to an integral value of order m. The rhombohedron (Figure 9b) has only two corners where all three face angles (each 102°) are obtuse. (Note that 5E7 = 5 * 107.) 138 Chapter 6 Properties of Lasers under the blackbody radiation curve at temperature T is found to be q M = L0 Ml dl = sT4 (7) This relation is known as the Stefan-Boltzmann law, and s, the Stefan-Boltzmann constant, is equal to 5.67 * 10-8 W/(m2 # K4). In the more general case of the interaction with an electromagnetic field with spectral energy density r1n2, these relations must be generalized as q RSt.Em. = B21N2 (3) 0 q RSt.Abs. Only the wavelength and velocity of a light beam in a transparent material are required to describe its behavior. In humans, the optic nerves 1 Signals containing fewer than 100 photons can trigger a visual response in humans. The result, after simplification, is 1nR + inI22 = 1 + v20 - v2 vg Ne2 a 2 + i 2 b 2 2 2 me0 1v0 - v22 + v2g2 (36) 542 Chapter 25 Optical Properties of Materials Now by comparing the right members of Eqs. Let c = P - P0 = 110 N > m22 sin[12p > m2x - 1680p > s2t] represent the difference in the air pressure from its equilibrium value 1P0 L 105 N>m22. By rearranging Eq. (40), we may recast Eq. (41) as !!!! E¿F + FG + GE = E¿E !! Now, E¿F + GE is proportional to the electric field amplitude EA at screen ! point P due to the slit, and E¿E represents the unobstructed amplitude Eu. The modulated signal driving the piezoelectric crystal is transferred to the output beam in zero order. A layer of resin is then spread over the combination, and a substrate for the future replica is placed on top. All the energy in the wave goes into sustaining the oscillations between nodes, at which points forward and reverse waves cancel. 7 How many modes can propagate in a step-index fiber with n1 = 1.461 and n2 = 1.456 at 850 nm? 12.5 cm; 75 cm 10 cm behind the glass, 87 actual size (b) 6.4 cm behind the glass, 87 actual size (convex) and R < 0 (convex) and Rwindow, twice the object size 13.0 cm +20 cm or -20 cm 22.5 cm behind the lens; 1.50 times the actual size (a) -6.7 cm (b) -10 cm or -60 cm -50 cm (a) 3.33 mm in front of the objective (b) erect and magnified Final image between lens and mirror at 21/34 f from lens, virtual, inverted, and 171 the original size 23. 8 LASERS AND THE FABRY-PEROT CAVITY Laser cavities typically consist of two highly reflecting spherical mirrors and so have the same basic structure as spherical-mirror Fabry-Perot cavities. Since, for this waveform, the wave disturbance at an arbitrary point in space, defined by the vector Br in Figure 6a, is the same basic structure as spherical-mirror Fabry-Perot cavities. 40,000 f Figure 14 Problem 6. This characteristic is exploited in a liquid-crystal display (LCD). This state of total darkness is referred to as the electromagnetic vacuum. Depending on the relative magnitudes of the refractive indices, the appropriate refracting surface is either a hyperboloid 1ni 7 no2 or an ellipsoid 1no 7 ni2, as shown. When conditions of enhancement, or constructive interference, and diminution, or destructive interference, alternate in a spatial display, the interference is said to produce a pattern of fringes, as in the double-slit interference, alternate in a spatial display, the interference is said to produce a pattern. 40. 278 Chapter 11 Fraunhofer Diffraction I I0 g \geq 5 k D sin u 2 5 (a) (c) 1st Maximum st 1 Zero 2 I/I0 (2 J1 (g)/g)2 0 1 3.832 0 nd Maximum 5.136 0.0175 nd Zero 7.016 0 rd 3 Maximum 8.417 0.00416 rd 3 Zero 10.173 0 4th Maximum 11.620 0.00160 4th Zero 13.324 0 2 (b) Figure 8 Circular aperture diffraction pattern. This situation is illustrated in Figure 6. We look for a procedure that will allow us to calculate the height and slope angle of the ray at any point in the optical system, for example, at point T, a distance x7 from the mirror. When the two systems come to a common temperature, the rates of energy flow between the systems become equal. These fringes will be straight, oriented parallel to the line that represents the intersection of M1¿ and M2. We see that the size of the field imaged by the optical system is effectively determined by the entrance window and, actually, by the size of the field stop. Let us adopt again the ring cavity model used earlier. Thus, 10 + s11ce = -110 yields s2ce = -5 cm. Subscripts 1 and 2 refer to refractions at the first and second surfaces, respectively. Let us set r =
r0 for the wave from the center of the slit (at s = 0). At the critical angle, sin used to be adopted as the first and second surfaces. = n and cos ut = cos190°2 = 0. Today, Vol. Thus optical phase conjugate mirror (PCM). High-pressure and high-current operation generally results in a continuous spectral output, in addition to spectral lines characteristic of the vapor. Here, k = k2v - 2kv. A = n RL t + 1, B = nnt, L 1 L 616 Answers to Selected Problems C = nL - n' n' R2 - nL'R - n - n 1' (nL - n)(nL - n') n' nL t, R 1 R 2 D = nn' + (nL'R) nnt 2 L 21. The result is a wave train of finite length, such as the one pictured in Figure 5. Instead, external fields can be used to perform a periodic police police of the vapor. Here, k = k2v - 2kv. A = n RL t + 1, B = nnt, L 1 L 616 Answers to Selected Problems C = nL - n' n' R2 - nL'R - n - n 1' (nL - n)(nL - n') n' nL t, R 1 R 2 D = nn' + (nL'R) nnt 2 L 21. The result is a wave train of finite length, such as the one picture of the vapor. Here, k = k2v - 2kv. A = n RL t + 1, B = nnt, L 1 L 616 Answers to Selected Problems C = nL - n' n' R2 - nL'R - n - n 1' (nL'R) nnt 2 L 21. The result is a wave train of finite length, such as the one picture of the vapor. Here, k = k2v - 2kv. A = n RL t + 1, B = nnt + (nL'R) nnt 2 L 21. The result is a wave train of finite length, such as the one picture of the vapor. Here, k = k2v - 2kv. A = n RL t + 1, B = nnt + (nL'R) nnt 2 L 21. The result is a wave train of finite length, such as the one picture of the vapor. Here, k = k2v - 2kv. A = n RL t + 1, B = nnt + (nL'R) nnt 2 L 21. The result is a wave train of finite length, such as the one picture of the vapor. Here, k = k2v - 2kv. A = n RL t + 1, B = nnt + (nL'R) nnt 2 L 21. The result is a wave train of finite length, such as the one picture of the vapor. Here, k = k2v - 2kv. A = n RL t + 1, B = nnt + (nL'R) nnt 2 L 21. The result is a wave train of finite length, such as the one picture of the vapor. Here, k = k2v - 2kv. A = n RL t + 1, A = n RL t + 1, A = n RL t + 1, A = n RL t + 1. A = n RL t + 1, A = n RL t + 1, A = n RL t + 1, A = n RL t + 1. A = n RL t + 1, A = n RL t + 1, A = n RL t + 1, A = n RL t + 1. A = n RL t + 1, A = n RL t + 1, A = n RL t + 1. A = n RL t + 1, A = n RL t + 1, A = n RL t + 1, A = n RL t +of a nonlinear ferroelectric material or a nonlinear polymer. When v v0, near resonance, the vibrations are large. The variation of lmax, the wavelength at which Ml peaks, with the temperature can be found by differentiating Ml with respect to l and setting this equal to zero. Figure 8 shows the basic Littrow mount, where a single focusing element is used both to collimate the light incident on the plane grating and, in the reverse direction, to focus the light onto the photographic plate placed near the slit. Finally, since n and ut are related to u through Snell's law, sin u = n sin ut, ut may be eliminated using n cos ut = n 21 - sin2 ut = 2n2 $E \cos u + 2n2 - \sin 2 u$ (27) 496 Chapter 23 Fresnel Equations rTM = Er - n2 cos u + 2n2 - sin2 u (28) Returning to Eqs. In fact, it is the stimulated emission rate A 21. Note that the rate of stimulated emission rate A 21. Note that the rate of stimulated emission rate A 21. the lineshape function evaluated at the frequency of the input field g1n¿2, and the population density N1 of the lower of the two levels involved in the transition. As the driving frequency v0 of the oscillator, the amplitude of the vibrations becomes very large and subsides again as the frequency v0 of the second v0 Harmonic wave disturbances emanating from a point source in a homogeneous medium travel at equal rates in all directions. 0.01909 11. The cardinal points are located, approximately to scale, in Figure 15. Thus the beam waist is at Mirror 2. (12) and (14) appear with a change of signs. Short sections of pumped erbium-doped fiber can be placed at widely spaced (100 km) sections of a long-haul fiber-optic communications system. When all constant (or approximately constant) terms are taken out of the Huygens-Fresnel principle. A = 0. Tiny bubbles or imperfections in a glass lens, for example, produce undesirable diffraction patterns when transmitting laser light. Individual phasors are shown in (a) and the resultant phasors at each step in (b). Here yf = Ba0 implies that yf is independent of y0, so that all rays departing the input plane. Modal distortion can be lessened by reducing the number of propagating modes. Widths of energy levels in atoms vary greatly but a typical value is on the order of 10-7 eV. The plane portion of the wavefront in the slit opening represents a continuous array of Huygens' wavelet sources. The reflected and transmitted waves in Figure 1 can be expressed, single, representative step in the ray-tracing analysis. To produce this wave with ordinary mirrors, we would need to construct a mirror surface that matched exactly the wavefront of the instant of reflection. The diffraction pattern is observed q = 30 cm from the slit. Sketch the setup. In constructing ray diagrams, as in Figure 22. observe that, except for the central ray (ray 3), each ray refracted by a convex lens bends toward the axis, for t gravitational force is so weak, gravitational waves coming from even the most dramatic astronomical events like the collision of black holes or the explosion of supernovae lead to extraordinarily small effects on earth. v = -0.917c 1. The central ray arrives at point O in the image plane. When specimens of cells or microscopic particles are viewed conventionally under high magnification, the depth of field is correspondingly small. Rather, the photon energy must be within a very small range of energies, near the nominal energy difference of two levels, in order to interact with the atom. At a given instant, the surfaces of constant phase for a spherical wave are given by the simple relation kr = constant Spherical wave (29) u1 w01 z w02 u2 z0 3 Note that the far-field divergence angle, as we define it, is the half-angle spread of the beam. What is the thickness of the etalon? S(y) 1.5 2.5 0.5 E 2.0 1.0 y $0.5 \ge 0.5 C(y) \ge 0.5 E 4.0 1.0 y = 0.5 E 4.0 1.0 y = 0.5 E 4.0 z =$ situations in which the wavefront at the diffracting aperture may be considered planar without appreciable error. A simpler but equivalent optical axis, can be drawn by working with virtual images of source S and mirror M1 via reflection in the BS mirror. The rest mass energy is mc2 = 19.11 * 10-31 kg213 * 108 m>s22 = 8.19×10^{-14} J. (2) and (3) in Eq. (1) gives, for the complex field E, 'E = E0xei1kz - vt + wx2xN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN + E0yei1kz - vt + wy2yN which may also be written ''E = [E0xeiwxxN wave. Note that the far-field angular radius (i.e., the angular half-width) of the Airy disc, according to Eq. (20), is very nearly ¢u1>2 = 1.221 D (21) In Example 3, the beam spread from a circular aperture is compared with that from a single slit. 1 ENERGY QUANTIZATION IN LIGHT AND MATTER Electromagnetic fields result when charged particles are accelerated. 6 Determine the half-wave voltage for a longitudinal Pockels cell made of ADP (ammonium dihydrogen phosphate) at 1 = 546 nm. Since 4 pixels are used to record the color information, the irradiance is recorded with higher resolution than is the color of the image. In the more general case of complete reflection with an arbitrary phase shift, the positions of the nodes will be shifted from the case depicted in Figure 5b but the nodes will still be separated by l>2. The slit allows only the modulated zero-order beam to be transmitted. A typical reaction might be Kr... + F2 : 1Kr+ F-2... + F The production of the excited rare-gas species is accomplished by electric discharge or e-beam pumping. Gerard, A., and J. Equation (20) represents a traveling wave moving along the + x-direction. Interference of Mutually BIncoherent Fields B In practice, for electric fields E1 and E2 originating from different sources, the time average in Eq. (13) is zero. The laser linewidth ¢nL is the full width at half maximum (FWHM) of the spectral irradiance associated with the radiation.
Recognizing the significance of what he had witnessed, Fyodorov replicated, under controlled conditions, what nature and a first had accomplished so haphazardly. 13 One eye of a person has a far point of 50 cm and a near point of 50 cm. It does not affect the validity of results like Eq. (8), for example, because measurements depend on the net motion of the fringe pattern, not on precisely where it is dark and where it is bright. That is, C-15C-1f1x226 = C-15g1k26 = f1x2 (5) in accordance with Eqs. Find the pump irradiance Ip required to sustain a steadystate population inversion. Note that the image position does not depend on the position of the eye. b indices of various parts of the schematic eye, as well as radii of curvature of surfaces, may not agree with values of the biological eye itself. 9 Show that if the irradiance IS, the output irradiance IL is related to the input irradiance IL is related very large input irradiance, the irradiance exhibits linear growth. If the curved grating surface is tangent at its center to the Rowland circle, which has a diameter equal to the radius of curvature of the concave grating, then a slit source placed anywhere on the circle gives well-focused spectral lines that also fall on the circle. In this chapter we discuss chiefly the Michelson and the FabryPerot interferometers and suggest only a few of their many applications. (This virtual image is shown as L2œ M 9>30 = 0.3 rad Comparing half-angles, element A subtends the smallest half-angle and so serves as the aperture stop AS. (a) A typical standing wave situation occurs when a wave E1 and its reflection E2 exist along the same medium. O Tank n 存 4/3 5 cm 30 cm n 1.50 Figure 34 Problem 10 11 A concave mirror forms an image on a screen twice as large as the object. (b) Construction used to relate distances q, s, and f2 to matrix elements. = ng sin ao = no sin aoœ The maximum value of the numerical aperture when air is used is unity, but when object space is filled with a fluid of index n, the maximum numerical aperture may be increased up to the value of n. What actual material could be used? After re-collecting constants, we get n = A + C B + 4 + A 2 l l This is the Cauchy relation introduced earlier to describe normal dispersion. Still, the advantages of the diode laser design make them the preferred choice in an ever-increasing array of devices, including laser pointers, optical pumps, and optical data storage and read-out. Assume that the lens diameter D is related to the focused beam waist w0 by the equation D = 4.5 A 22w0 B. (d) When C = 0, a parallel bundle of rays at the input plane is parallel at the output plane and D is the angular magnification. Photons interact directly with the electrons in the detector material. Using P as a center, let an arc S1Q be drawn of radius s1 so that it intersects the line S2P at Q. The argument may, of course, be extended to an observation point at r0>5, when the original zone of radius R1 includes five half-period zones and the irradiance is 1/25 that at r0, and so on. Assume that the interferometer is set to a null (no detected power) in the absence of the gravitational strain. These matrix elements are then used in Eq. (36) for the reflection coefficient. gravitational wave. What is the focal length of the mirror? Verify your results dimensionally. The focal line T lies in the sagittal plane, and the focal line S falls in the tangential plane. Consider Figure 12, which shows the behavior of the gain coefficient during the buildup to steady state in such a medium. Correction for presbyopia is similar to that for hyperopia in that a converging lens is needed to form clear images of nearby objects on the retina. Verdeyen, Laser Electronics, 3d ed. Scanning and readout is performed by charge transfer along each pixel row of such a device. Determine the minimum angle of deviation for sodium light of 589.3 nm. This method of cooling is sometimes used in carbon dioxide and dye lasers. 384 Chapter 16 Holography recording. As soon as the c mode arrives, however, the two modes superpose to fix the direction of vibration at an angle b in a linear mode. To emphasize this requirement, we write z0 = f z0I f and q1z2 = z - iz0 (14) 1 A more detailed derivation is given in Anthony E. (b) Rhombohedron of calcite, showing the optic axis, which passes symmetrically through a blunt corner where the timedependent term in the exponent is negative. The variation of refractive index and light speed with wavelength is called dispersion and is discussed later. For this m 20 Lamp Filter Slits m0 0.1 mm Screen 1m Figure 18 18 A Michelson interferometer forms fringes with cadmium red light of 643.847 nm and linewidth for distances less than the equilibrium length of fiber (see footnote 10). In this case, the design aims to minimize the angular spread of the diffracted light; when used as a spectrum analyzer, the design aims instead to maximize it. Tuning the cavity is accomplished by varying the refractive index of the cavity through control of temperature or an applied DC field. The notion of a group velocity is sensible only so long as the pulses "hold together" as the constituent harmonic waves propagate. Although the calculations can be tedious, they are easily done using a wavefront-splitting device, such as the double slit. Whether the errors of refraction occur singly or in some combination (as they often do), they are generally correctable with appropriately shaped external optics (eyeglasses or contact lenses). 22. Thus the z and y values for the center of the spiral length ¢y become increasingly negative. 10 VERGENCE AND REFRACTIVE POWER Another way of interpreting the thin-lens equation is useful in certain applications, including optometry. While achievable this is a very large irradiance. In most cameras, the aperture is variable and is coordinated with the exposure time (shutter speed) to determine the total exposure of the film to light from the scene. Special cases of electromagnetic waves with elliptical polarization include linearly polarized waves in which the electric field vector always oscillates back and forth along a given direction in space and circularly polarized waves in which, over time, the tip of the electric field vector traces out a circle. We desire solutions to the wave equation, Eq. (3), 584 Chapter 27 Characteristics of Laser Beams 1 irradiance e2 profile lines Figure 1 An external laser beam, confined essentially to regions within the 1>e2irradiance guidelines, is focused by a converging lens. If the two holes are equal in size, light waves emanating from the holes have comparable amplitudes, and the irradiance at any point of superposition is given by Eq. (18). In general, however, responsivity is not independent of wavelength. This width in the allowed energy levels in turn relaxes the restriction that a photon must have a precise energy that just matches the difference in discrete allowed energy levels. Referring to Figure 22, these are E1 = 1rE02ei1vt - 2d2 E4 = 1tt;r; 5E02ei1vt the normalized correlation function and the visibility of the resulting fringes. Cotter, The Elements of Nonlinear Montinear medium A2 Pump beam Nonlinear medium A2 Pump beam A4 A1 A2 A3 Figure 15 Conventional geometry for phase conjugation by four-wave mixing. The nature of these wavefronts that we are about to investigate is illustrated in Figures 2 and 3. Before pursuing Fresnel's quantitative treatment of such cases, consider qualitatively what we might expect by using again the concept of Fresnel half-period zones. From the power conservation requirement, as expressed by Eq. (47), show that for an external reflection the transmission coefficient t must be less than 1, but for an internal reflection t¿ may be greater than 1. By the resolution of a grating, we mean its ability to produce distinct peaks for closely spaced wavelengths in a particular order. If the lens is the objective of a microscope, as indicated in Figure 11, the problem of resolving nearby objects is basically the same. The beams interfere at a point P where the phase difference due to path is p>3 (the first beam having the longer path). The product of the sine and cosine factors may be considered a modulation of the interference fringe pattern by a single-slit diffraction envelope, as shown in Figure 14b. Rayleigh scattering explains why a clean atmosphere appears blue: Higher-frequency blue light from the sun is scattered by the atmosphere down to the earth more so than is the lower-frequency red light. Examination of Figures 4 and 5 shows that, for the case of internal reflection, both RTE = r2TE and RTM = r2TM reach values of unity before the angle of incidence u reaches 90°. 202 Chapter 8 Optical Interferometry We choose not to include electric field changes caused by reflection from or transmission through mirrors in the definition of the propagation factor, but rather we will include these factors explicitly when we track changes to an electric field that encounters mirrors. He suggested, in fact, that a particle with momentum p had an associated wavelength of l = h p (2) where h was, again, Planck's constant. Determine the radius of their Petzval surface. The last defect, astigmatism, is due to unequal or asymmetric curvatures in the corneal surface. The last defect, astigmatism, is due to unequal or asymmetric curvatures in the corneal surface. eyepiece cannot be used as an ordinary magnifier. What aperture diameters correspond to these f-numbers? 7 Research and describe the manner in which a nematic liquid crystal placed between transparent glass sheets with the electric field in free space is uE = 1 e E2 2 0 (32) and the energy density associated with the magnetic field in free space is uB = 1 1 2 B 2 m0 (33) These expressions, easily derived for the static electric field of an ideal capacitor and the static electric field of an ideal capacitor and the static electric field of an ideal capacitor and
the static electric field of an ideal solenoid, are generally valid. below) is made up of a positive thin lens L1 of diameter 6 cm and focal length f1 = 6 cm, a negative thin lens L2 of diameter 6 cm and focal length f2 = -10 cm, and an aperture A of diameter 6 cm and focal length f1 = 6 cm, a negative thin lens L2 of diameter 6 cm and focal length f2 = -10 cm, and an aperture A of diameter 6 cm and focal length f1 = 6 cm, a negative thin lens L2 of diameter 6 cm and focal length f2 = -10 cm, and an aperture A of diameter 6 cm and focal length f1 = 6 cm, a negative thin lens L2 of diameter 6 cm and focal length f1 = 6 cm, a negative thin lens L2 of diameter 6 cm and focal length f1 = 6 cm, a negative thin lens L2 of diameter 6 cm and focal length f1 = 6 cm, and f1 = 6 cm and focal length f1 = 6 cm and focal length f1 = 6 cm and focal length f2 = -10 cm, and f1 = 6 cm and focal length f1 = 6 cm and focal lengt 2d1/2 0.2 0.1 0 0 0.05 0.1 0.15 0.2 0.25 Change in cavity length (mm) 0.3 0.35 0.4 (a) Spherical mirrors d Focusing lens Piezoelectric Aperture spacer Driving voltage source Figure 11 (a) Transmittance T as a function of the change in cavity length ¢d, for a monochromatic input field. Then at the instant Ex has reached its maximum displacement— + A, for example—Ey is zero. If the maximum diameter of the circle of confusion is taken to be 0.05 mm, determine the depth of field of the photograph. One rarely finds a He-Ne laser 11 = 632.8 nm2 has a beam waist w0 (at z = 0) of 0.5 mm and a beam divergence of uFF = 0.4 mrad. The concern that CFCs and other similar chemicals may contribute to the depletion of the ozone layer and thus increase the risk of skin cancer led to protocols calling for the reduction of the use of refrigerants, aerosol sprays, and other products that release these chemicals into the atmosphere. (b) Twyman-Green interferometer used in the testing of a prism and a lens (inset). The variation of um with 1 is described by the grating Eq. (2), from which we may conclude \mathcal{D} = m a cos um (5) If a photographic plate is used in the focal plane of the lens to record the spectrum as in Figure 2a, it is convenient to describe the spectrum as in Figure 2a, it is convenient to describe the spectrum as in Figure 2a, it is convenient to describe the specad of wavelengths on the plate. property is precisely described by the angular dispersion, \supset , defined by \supset K dum dl (4) which gives the angular separation per unit range of wavelength. we have, $r = r0 c 1 - 1xX + yY2 r^{20} d$ (12) In Eq. (9), the distance r appears in both the amplitude and the phase. Finally we describe several current surgical procedures that can restore visual acuity in less-thanperfect eyes. The short-term stability of commercially available CO2 lasers, for example, is such that line widths of around 1 * 10-5 nm are attainable at the infrared emission wavelength of 10.6 mm. Using Eq. (12) with m = ; 1 and approximating sin u by u, we get $\psi u = 2l b$ (14) From Eq. (14), it follows that the central maximum will spread as the slit width is narrowed. The distance between the fifth minima on either side of the zeroth-order maximum is measured to be 34.73 mm. If the stars are near the center of our galaxy, a distance, d, of around 30,000 light-years, then their actual separation s is approximately s = d ¢umin = 130,000211.92 * 10-52 = 0.58 light-years To get some appreciation for this distance, consider that the planet Pluto at the edge of our solar system is only about 5.5 light-hours distant. 3 a. Real, nonlocalized fringes are formed in reconstruction. Gratings with more slits produce brighter and narrower principal maxima. These missing orders are expected when the slit separation is twice the width of the slit opening, precisely the case in the Ronchi ruling. Making use of the defining equation for radiance Le in Table 1, we ob¢Ie, where we have replaced the differentials dIe and tain Le = ¢A S cos u £ dAs by the small quantities ¢Ie and ¢A s. The sine and cosine terms can be interpreted as harmonic waves with amplitudes of bm and am, respectively, and frequencies of my. Furthermore, they produce higher-order images of the same wavelength component, which can be dumped by the polarizing prism. 2 80 (1) See, for example, Christopher C. Various stages in solving the lens design problem are illustrated in Figure 23a, from the single-element Tessar lens. 14 A thin, plano-convex lens with 1-m focal length and index 1.60 is to be used in an orientation that produces less spherical aberration while focusing a collimated light beam. This process is known as gain saturation. An inelastic process leading to scattered light at frequencies different from the incident light is known as spontaneous Raman scattering. Note that the wavefronts associated with adjacent maxima are separated by one wavelength. The design of a multilayer stack that will meet arbitrary prespecified characteristics, however, remains a formidable task. Example 4 Consider a homogeneously broadened transition in a carbon dioxide 1CO22 laser. We wish to determine the image distance x and the lateral magnification m. Neighboring dark fringes decrease in order outwards from the center of the pattern, as cos u decreases from its maximum value of 1. For a fixed ratio of 1sin um2>l, however, the grating equation also fixes the ratio m/a. At a given place in the constant frequency separation of the modes. On the other hand, for object points along radial lines in the object circle, sharp radial images are produced only in the S surface, where the elongated radial images merge to produce well-focused radial lines. Long-wavelength waves, traveling deep in the ocean, have a speed given approximately by yp = a gl 1>2 b 2p 130 Chapter 5 Superposition of Waves where g is the acceleration of gravity. The thin-lens equation, in terms of the focal length, is then 1 1 1 = + s s; f (29) Wavefront analysis for plane wavefronts, as shown in Figure 21, indicates that a lens thicker in the middle causes divergence, and one thinner in the middle causes divergence. produce erect final images also permits the distance between objective lenses to be greater than the interpupillary distance, enhancing the stereoscopic effect produced by ordinary binocular vision. For the example of glass 1n = 1>1.52 used in Figure 5, upce = 33.7° and uc = 41.8°. These atoms bond in the solid lattice in such a way that each atom sees a full outer shell (eight electrons) with some of these electrons shared with neighboring atoms. Subsequent principal maxima are less bright since they are limited by the diffraction envelope, sin2 b>b 2 (dashed line). Solution The reflection and transmission coefficients for this situation are given in the solution to Example 1. Example 5 Estimate the linewidth of an Ar+ gain medium. Light from the text to be searched is passed through a hologram of the letter or word to be identified in an appropriate optical system. 6 (a) express the relation in terms of n and v and (b) determine whether the group velocity is greater or less than the phase velocity in a medium having a normal dispersion. For this reason, temporal coherence is also called longitudinal coherence. The depth of field, MN = s2 - s1 , can be expressed as depth of field = 2Ads01s0 - f2f2 f4 - A2d2s20 (32) Acceptable values of the circle diameter d depend on the quality of the photograph desired. For the case of a plane refracting surface, Eq. (21) may 34 Chapter 2 Geometrical Optics n1 n2 ho u1 C I V O hi u2 Figure 19 Construction to determine lateral magnification at a spherical refracting surface. 7 The rate of decay of an assembly of atoms with population density N2 at excited energy level E2 when spontaneous emission is the only important process is a dN2 b = - A21N2 dt spont Show that an initial population density N20 decreases to a value N20>e in a time t equal to 1>A21. Since the state of polarization of the light is completely determined by the 1 R. In this case, I = 410 cos2[p10.00022y>1658 * 10-9211m2] = 410 cos2[p10.00022y>1 shown in Figure 5. Matrix Methods in Paraxial Optics 411 If input and output reference planes are located at the lenses, the system matrix includes two thin-lens matrices, A and B, and a translation matrix P for the distance L between them. Using the expression given earlier, Ep = Pp ctp = 14 * 104 W210.25 * 10-6 s2 = 0.01 J = 10 mJ P T Pp Otp Figure 14 Construction showing a rectangular pulse approximation to Q-switched pulses used in Example 6. The conditions are frequency dependent. Example 6. The conditions are frequency dependent. Example 6. The conditions are frequency dependent. points coincide at a distance given by r = y = 1D - 12>C from the first lens, and the second principal points and nodal points coincide at a distance given by s = w = 11 - A2>C from the second lens. ym mlL a ym S 3 DOUBLE-SLIT INTERFERENCE WITH VIRTUAL SOURCES Interference fringes may sometimes appear in arrangements when only one light source is present. Two calcite prisms with apex angle u, as shown, are combined with their long faces opposed and separated by an air space. This radiation is believed to have originated early in the development of the universe, when the universe, when the universe was hot and dense. If the object in the aperture plane is shifted by an arbitrary translation given by components 1qx, qy2, for instance, its transmission function must reflect a translation of origin within the xy-plane, and Eq. (26) is expressed more generally by q C[E11- x, - y2E21x, y2]DC = O E11qx - x, qy - y2E21x, y2]DC = O E11qx - x, qy - y2E21x, y2]DC = O E11qx - x, qy - y2E21x, y2]DC = O E11qx - x, qy - y2E21x, y2]DC = O E11qx - x, qy - y2E21x, y2]DC = O E11qx - x, qy - y2E21x, y2]DC = O E11qx - x, qy - y2E21x, y2]DC = O E11qx - x, qy - y2E21x, y2]DC = O E11qx - x, qy - y2E21x, y2]DC = O E11qx - x, qy - y2E21x, y2]DC = O E11qx - x, qy - y2E21x, y2]DC = O E11qx - x, qy -
y2E21x, y2]DC = O E11qx - x, qy - y2E21x, y2]DC = O E11qx - x, qy y2f21x, y2 dx dy (28) 468 Chapter 21 Fourier Optics If the transmission function possesses inversion symmetry, that is, if f11- x, -y2 = f11x, y2 then the negative signs, and the integrand of Eq. (28) may be written as positive signs, and the integral is instead the correlation function, £ 121qx, <math>y2f21x, y2f21x, y2f21x, y2f21x, y2f21x, y2 = O f11x + qx, y2 = O f1+ qy2f21x, y2 dx dy - q Further, when f1 and f2 are merely shifted versions of the same function, q f 111qx, qy2 = 0 - q f1x + qx, y + qy2f1x, y2 dx dy (30) Transmission functions with inversion symmetry are imaged in such a way that the actual image inversion due to the lens is not apparent. Thus, /t = 0 $l^2>$ (1) $l^2>$ (2). No interaction at V = 0. Before wavelengths of spectral lines appearing in a region of overlap can be assigned, the actual order of the line must first be ascertained so that the appropriate value of m can be used in Eq. (2). No interaction at V = 0. Before wavelengths of spectral lines appearing in a region of overlap can be assigned, the actual order of the line must first be ascertained so that the appropriate value of m can be used in Eq. (2). No interaction at V = 0. Before wavelengths of spectral lines appearing in a region of overlap can be assigned, the actual order of the line must first be ascertained so that the appropriate value of m can be used in Eq. (2). No interaction at V = 0. Before wavelengths of spectral lines appearing in a region of overlap can be assigned, the actual order of the line must first be ascertained so that the appropriate value of m can be used in Eq. (2). No interaction at the appropriate value of m can be used in Eq. (2). all would make y = c. Peter Franken and his associates are credited with the first nonlinear coherent optics experiment, 3 conducted at the University of Michigan in 1961. 526 Chapter 24 Nonlinear Optics and the Modulation of Light application of the Faraday rotator as an optical isolator. n2 \Leftrightarrow w c l1 n1 \Leftrightarrow w c \Leftrightarrow L 10 Fiber Optics INTRODUCTION The channeling of light through a transparent conduit has taken on great importance in recent times. The photoresist is spread evenly over the surface of the glass blank to a thickness of 1 mm or less by rapidly spinning the blank. Solution The atomic mass of an argon atom is M = 6.64 * 10-26 kg. In this context it is important to distinguish between specular reflection from a perfectly smooth surface and diffuse reflection from a granular or rough surface. As a consequence, only the first-order diffraction, m = 1, occurs in the acousto-optic effect. To deal with cylindrical lenses and astigmatism in a general way, then, we must be able to determine the effect of combining cylindrical lenses having arbitrary orientations with each other and (bb) perpendicular to the OA and (bb) perpendicular to the OA and (bb) perpendicular to the other and with spherical aberration agrees with Eq. (19), derived for axial imaging, where h represents the aperture. Solution The grating constant or groove separation a is a = 1 = 2 * 10-4 cm 5000 cm-1 Clearly, for zeroth order, there is no dispersion. Determine the Rayleigh range z0 for the Gaussian beam generated by this cavity. In dispersion. Determine the Rayleigh range z0 for the Gaussian beam generated by this cavity. or far-field) may be applied to the diffraction problem when the detector is at 50 cm, 1 m, and 5 m from the aperture? The values of the parameters M and M_d are 43 ps/nm-km and 3 ps/nm-km, respectively. Example 2 A ring laser cavity system like the one shown in Figure 8 uses mirrors with reflectances R1 = R2 = 0.99 and R3 = 0.95. Find the diameters of the first three clear zones such that the plate focuses parallel light of wavelength 550 nm at 25 cm from the plate. If three sources of light, respectively, are observed visually, the yellow, and red light, respectively, are observed visually, the yellow source will appear to be far brighter than the others. (See problems 24 and 25.) Note that, as shown in Figure 13, in the approach to steady state a laser system can produce pulses of intracavity photon number densities Np that far exceed the steady-state photon number density. 3 The ratio of the amplitudes of two beams forming an interference fringe pattern is 2/1. If all 100 W is emitted from a red bulb at l = 650 nm, calculate also the illuminance at the surface. 182 Chapter 7 Interference of Light fringes by reflected light. The myopia itself causes an overall blurring in one meridian than another. The diffraction pattern due to this function may be quite complicated, but the raster lines, like a Ronchi ruling, produce a series of diffraction spots along the vertical direction in the spectrum plane. 25 Geometrical Optics The image point occurs at the vertical distance s? below the surface given by s? = a n2 bs n1 (4) where s is the corresponding depth of the object. plane wave propagating along the positive z-direction with the electric field varying along the x-direction and the magnetic field varying along the x-direction. Siegmund, "Fiber Optics," in Handbook of Optics, edited by Walter G. A photograph that freezes motion of the specimen captures in a focused image a very limited depth of field within the specimen. Find (a) the equivalent focal length and (b) the magnifying power for an image formed at the near point of the eye. Situated in the aqueous humor is the iris, a diaphragm that gives the eye its characteristic color and controls the amount of light-emitting diodes and is illustrated in Figure 18a. (36) and (37), is 2nft + ¢ r = e ml, A m + 12 B l, bright dark (38) where ¢ r is either l>2 or 0, depending on whether there is or is not a relative phase shift of p between the rays reflected from the top and bottom surfaces of the film. (From M. Thus, as the pinhole is reduced in size, the image improves in clarity, until a certain pinhole size is reached. When h is taken as the maximum extent of the aperture in either direction or as the radius of a circular aperture, Eq. (9) or Eq. (10) may also be expressed approximately by the condition near field: d 6 A l (12) where d represents either p or q and A is the area of the aperture. The green line of mercury at 546.07, which lies neared to the center of the luminosity curve, is also used. Such fibers are called step-index fibers because the refractive index changes discontinuously between core and cladding. What wavelength is minimally reflected when the light is incident instead at 45°? This inexpensive method for artificially flattening the field has been used in simple box cameras. Siegman, Lasers (Mill Valley, Calif.: University Science Books, 1986), Ch. 16. Once the virtual image separation a is related to the tilt angle u and to the distance d from actual source to the intersection of the mirrors at O, the fringe pattern may again be described by Eq. (22). (Handbook data for copper: s = 5.76 * 107>Æ-m.) 7 Compare the skin depth of (a) aluminum, with conductivity of 3.54 * 107>Æ-m and (b) seawater, with conductivity of 4.3> Æ-m, for radio waves of 60 kHz. 8 Calculate the skin depth of a solid silver waveguide component for 10-cm microwaves. Thus, the spatial coherence of light at Double slit A B S P1 Michelson interferometer P2 Figure 11 Wavefront and amplitude division of radiation from source S, illustrating the practical requirements of spatial and temporal coherence. Figure 2 Golay pneumatic infrared detector. For a sound wave while it is traversed by a light wave. 23 Consider the transmittance through a Fabry-Perot interferometer as a function of the variable wavelength l of its input field. Sample ray diagrams for converging (or convex) and diverging (or convex) and diverging (or convex) and the image screen moved until it again receives a focused image. Here the coordinate y could, for example, represent the transverse displacement from equilibrium of a string stretched out along the x-direction. The proper expression for kinetic energy is no longer simply EK = 12 my2, but rather is EK = mc21g - 12, where g = 1 > 21 - 1y2 > c22. The word laser is an acronym that stands for light amplification by the stimulated emission of radiation. As

you follow through the steps in the solution, be sure to verify the correct use of the sign convention related to the object distance s, image distance s, image distance s, image distance s, image of frequencies of the sign convention related to the object distance s, image distanc of 6 GHz. That is, the gain bandwidth of the laser output. A more precise statement of Fermat's principle, which requires merely an extremum relative to neighboring paths, may be given as follows: The actual path taken by a light ray in its propagation between two given points in an optical system is such as to make its optical path equal, in the first approximation, to other paths closely adjacent to the actual one. We take the half-width of the central maximum, or 2p>t0, to indicate in a rough way the range of dominant frequencies required. 9 A zone plate is to be produced having a focal length of 2 m for a He-Ne laser of wavelength 632.8 nm. Such a system must meet several stringent design considerations. The corresponding composite phasors A n are shown in Figure 5b. As a result, the electronic oscillators reemit radiation in all diB rections. The high-current arc is formed between two carbon rods in air. Incident, reflected, and refracted rays are shown in the plane of incidence. 144 Chapter 6 Properties of Lasers light is shown in Figure 12b. The converging lens reshapes the wavefronts and focuses the beam—forming a beam waist—to the right of the lens. The refracted rays are shown in Figure 12b. discussed in the preceding paragraph are the Gabor zone plate and holographic grating, corresponding to point objects at a finite distance from the plate, respectively. The E-vibration in light reflected from a horizontal surface into the eye is preferentially polarized along the horizontal direction. A signal cannot be extracted from noise unless the mean signal Optical Detectors and Displays photon number n exceeds the uncertainty in photon number 2n. Analyzer the rotator mechanism involved in rotating the direction of vibration of linearly polarized light is distinct from the action of phase retarders, such as half-wave plates discussed in Section 4, which may produce the same result. On returning to the beam 3 is reflected by the semitransparent film so that they come together again and leave the interferometer as beam 4. Determine the irradiance at (a) 2 mm inside and (b) 1 mm outside the edge of the geometrical shadow. These electrons are said to be in the conduction band of electron energy states in the solid. The resulting geometry is shown in Figure 1b. In that case, light of free-space wavelength 11 will constructively interfere in the direction of Output 1 if the difference in path lengths of Path 1 and Path 2, ¢L, is given by ¢L = ml1>n m = 0, ; 1, ; 2 Å (21) Under this condition, light of wavelength 11 will not be present in Output 2. This arrangement is used because the eye is more sensitive to green light than to either red or blue light and doubling the information obtained in the green portion of the spectrum allows for the longest and shortest trajectories as "true" color. 15 Determine (a) the length and (b) transit time for the longest and shortest trajectories as "true" color. in a step-index fiber of length 1 km having a core index of 1.45. Such polarized light patterns for a beam under light and heavy stress is shown in Figure 21. on the screen. The resulting air layer between the slides are illuminated by monochromatic light. Solution According to Eq. (18), with object distance s very large, there remains $a = -h4 n2 1 1 2 c a - b d dh 2 s_i s_i R$ To calculate by and then bz, one needs the derivative da/dh: h3 n2 1 1 2 c a - b d dh 2 s_i s_i R The image distance s_i, also the focal length of the surface, is found from the paraxial equation, giving 1 1.6 0.6 + = q s_i 4 or s_i = 10.667 cm Then da/dh and the spherical aberrations are, da 1 1.6 1 1 2 = - c a - b d = - 0.001831 dh 2 10.67 10.67 4 by = s; da 10.667 s; da = = 1 - 0.0018312 = - 0.0122 cm n2 dy n2 dh 1.6 bz = s; s; 10.667 1 - 0.01222 = - 0.130 cm by = by = r h 1 Figure 6b shows spherical aberration when the object is at infinity. In addition, solids and liquids can have energy levels associated not with individual atoms and molecules, but with the entire solid. The broadened image there is called, descriptively, the "circle of least confusion." Using Eqs. Of course, any obstruction placed inside the telescope reduces the cross section of the incident light waves contributing to the image. 552 Chapter 26 Laser Operation population densities should be zero Pulse distortion limits transmission frequency and information rate in a way that we can roughly estimate. 2 YOUNG'S DOUBLE-SLIT EXPERIMENT The decisive experiment performed by Thomas Young in 1802 is shown schematically in Figure 3. Calculate the minimum resolvable wavelength difference in the second order. The multiplied current is collected at the anode. As a result, free electrony to express nonlinearity of the refractive index n by an equation5 analogous to Eq. (2) for the susceptibility: 1 1 = 2 + rE + RE 2 2 n n0 (7) where r and F are the linear and quadratic electro-optic coefficients, 6 respectively, and we assume that there is no other effect present (like crystal strain) that can modify n. Suppose, for example, that the aperture function is the superposition of two sine waves that are produced by backto-back sinusoidal gratings with parallel rulings but different line spacings or spatial frequencies. You will learn the coherence time of a source is inversely proportional to the range of frequencies, ¢n, of the components that make up the electric field. An arbitrary polarization direction represents some linear combination of these two special cases. problems at the end of this chapter. The Resonator Given a suitable pump and a laser medium that can be inverted, the third basic element is a resonator, an optical "feedback device" that directs photons back and forth through the laser (amplifying) medium. (a) Refraction of monochromatic light. x2 lack inversion symmetry, the resulting crystal will have a second-order susceptibility that changes sign each coherence length of the crystal, as shown in Figure 2b. Changes in elevation of the horizontal lines suggest the magnification in the various regions. The light is assumed to be emerging from the page. Thus it is in the local variations of fringe contrast and spacing across the hologram that the corresponding variations in amplitude and phase of the object waves are encoded. The mathematical treatment, however, is more complex and is almost always handled by approximation techniques, as we will see. 8 Derive the Wien displacement law from the Planck blackbody spectral radiance formula When both dimensions of 1 A laser beam usually does not have constant irradiance across its diameter. Thus, from Eq. (12), we conclude that $\lim g_{1}v_{2} = v : v_{0} t_{0} 2p$ (13) Furthermore, the sinc function (sin u)/u vanishes whenever sin u = 0, the case already described by Eq. (13). At each of the minima, the phasor diagram forms a closed figure, so that cancellation is complete. The center frequency of the transition is n0 = 1En - Em2>h. Blackbodies are approached in practice by blackened surfaces and by tiny apertures in radiating cavities. If some birefringent material is inserted between them, light is generally transmitted in beautiful colors. In many cases, the precise phase of the wave is not of interest. The solutions to this problem are illustrated in Figure 13b and c. These waves exert forces on charged particles in the wave path. 256 Chapter 10 Fiber Optics The variation of refractive index with fiber radius is given, 7 in general, by n1r2 = n1 r ap 1 - 2a b ¢, a B 0 ... r ... a (15) where ¢ 1n1 - n22>n1 and n1 = [n1r2]max. As the observation point P- moves from P to lower points on the screen, the representative phasor endpoint B slides along the Cornu spiral away from O, with its other end fixed at E. This term is important primarily in gas media. Englewood Cliffs, NJ: Prentice-Hall, 1976. The fraction of light removed from the zero-order diffracted beam depends on the magnitude of the induced stress and so on the amplitude of the modulating RF signal. Even if individual spiral-shaped molecules confront the light in random orientations, as in a liquid, there will be a cumulative effect that does not cancel, as long as all or most of the molecules are of the same handedness. 5 Refer back to the extended example in the text involving both a positive and a negative lens, of focal lengths 6 cm and - 10 cm, respectively. Most often, as in the case of the thick-lens example, n0 and nf both refer to air, and Det (M) is unity. Adaptation The ability of the eye to respond to light signals that range from very dim1 to very bright, a range of light irradiances that differ by an astonishing factor of about 105, is referred to as adaptation. This simple and versatile instrument was used, for example, to establish experimental evidence for the validity of the special theory of relativity, to detect and measure hyperfine structure in line spectra, to measure the tidal effect of the moon on the earth, and to provide a substitute standard for the meter in terms of wavelengths of light. Example 1 The cross section s, for a transition from the ground state to an excited state that is resonant with an electromagnetic field of wavelength 808 nm, for a neodymium (Nd) atom doped into a YAG (yttrium aluminum garnet) crystal4 is about 3 * 10-20 cm2. Light from a monochromatic (temporally coherent) point source (spatially coherent) is collimated by lens L1 and illuminates, in the input or aperture plane, a two-dimensional pattern whose transmittance varies across the aperture. Wavelengths of microwaves range roughly from 1 mm to 1 m. approached as b increases. The calculations lead to new values of a, Q, and s (now primed), which prepare for the next refraction
in the sequence. A linearly polarized wave traveling in the x,y-plane in a direction making an angle of 45° relative to the x-axis. Thrierr, Atlas of Optical Phenomenon, Plate 36, Berlin: Springer-Verlag, 1962.) (41) with A and B representing any two complementary apertures. Figure 13 illustrates one means of achieving AM modulation using Nonlinear Optics and the Modulation of a light beam by an acousto-optic grating in the RamanNath regime. Regular astigmatism can be corrected with a lens that has cylindrical surfaces ground on the back surface of the required spectacle lens. (b) Wavefronts for a (linearly polarized) plane electromagnetic wave. In Figure 3c, the locations of the stops, pupils, and windows are shown in a more complex optical system consisting of two lenses and two apertures. Of course, there are also cubic crystals such as salt (NaCl) or diamond (C) that are optically isotropic and possess one index of refraction Letting P represent a refraction matrix and P represent a translation matrix, the matrix for the thick lens is, by Eq. (14), the composite matrix M = P2PP1 or 1 M = C nL - n¿ n2R2 0 1 nL S C 0 n¿ t 1 S C n - nL 1 nLR1 0 n S nL (15) For the case where t is negligible 1t = 02 and where the lens is surrounded by the same medium on either side 1n = n², 1 n M = C L - n nR2 1 0 nL S C 0 n 0 1 n nL S C 1 nLR1 0 n S nL (16), 1 M = C nL - n a 1 - 1 b n R2 R1 0 1S (17) The matrix element in the first column, second row, may be expressed in terms of the lens, by the lensmaker's formula, nL - n 1 1 1 b = a n f R1 R2 so that the thin-lens ray-transfer matrix is simply 1 M = C - 1 f 01S (18) Progress of a ray through a thick 404 Chapter 18 Matrix Methods in Paraxial Optics As usual, f is taken as positive for a convex lens. Accordingly, a section of a sine wave is pictured in Figure 2. Thus we define the aberration at Q as a1Q2 = 1PQI - POI2opd (5) where opd indicates the optical-path difference. Conservation of momentum in a collision between a photon and a phonon requires B B b that k c = k - kS, as indicated in the inset vector triangle. Contemporary Optics for Scientists and Engineers. The optical-path difference between the emerging beams is, then, c = nf1AB + BC2 - n01AD2 where nf and n0 are the refractive indices of film and external medium, as shown. Notice that this nonoverlapping spectral region is smaller for higher orders. One wavelength is known to be 33°33¿. As an example, Figure 8, we have chosen as a function the top half of a circle. 5 THE REFLECTION MATRIX Finally, consider reflection at a spherical surface, illustrated in Figure 7. Ozone 1032 is formed when UV-C radiation that reaches the earth's surface. 498 Chapter 23 Fresnel Equations 100 90 80 70 R (%) 60 External reflection (air-to-glass) 50 40 30 Internal reflection (glass-to-air) 20 TE TE 10 TM 10 Figure 4 Reflectance for both external and internal reflection when n1 = 1 and n2 = 1.50. Take the mirror separation to be d and see the note given in part (a) of Problem 15. This can be understood by resolving the incident light into equal orthogonal orthogonal orthogonal orthogonal problem 15. This can be understood by resolving the incident light into equal orthogonal o components along the FA and SA (slow axis) and with a p phase difference between them. The negative sign implies a virtual image for a real object. X-ray holograms could provide strikingly detailed three-dimensional images of microscopic objects as small as viruses and DNA molecules. g21/2 R21/2 pw21/22 e. In many common applications the source is a laser, in which case the lenses shown in Figure 7b may not be needed. Consider the superposition of two such waves of different frequency and wavelength but with the same speed through the medium; $E1 = E0 \cos 1k^2 x \cdot v^2 t^2$ (28) The superposition of these waves, which are traveling together in a given medium, is ER = E1 $+ E2 = E0[\cos 1k1x - v1t2 + \cos 1k2x - v2t2]$ Making use of the trigonometric identity, $\cos a + \cos b K 2 \cos 121a + b2\cos 121a - b2$ and identifying a = k1x - v1t b = k2x - v2t(29) Now let vp = v1 + v2, 2 kp = k1 + k2 2 (31)vg = v1 - v2, 2 kg = k1 - k2 2 (32) and Then, ER = 2E0 cos1kpx - vpt2cos1kpx - vpt2cos1kpx - vpt2(33) Equation (33) represents a product of two cosine waves. The total energy is a multiple n of the photon energy hn = hc>l. To record different regions of the spectrum, the grating can be rotated and higher orders can be used. 175 Interference of Light inclined at a small relative angle u. Optical filter (Figure 5). (Refer to the discussion in Problem 4.) 395 6 Discuss how a twisted nematic liquid crystal between crossed polarizers can be used as a voltage-controlled irradiance modulator. The design of a complex lens system, such as a photographic lens with four or five elements, is a combination of science and skill. Using the method that is valid for a linear cavity, one can show (see problem 23) that the cavity loss rate \neq for the ring cavity is \neq = c 11 - S2 P Note that Eq. (55) predicts a zero-growth rate if there are no photons in the cavity. In either case, the B dipole moment p due to each atom or molecule is given by the product of the magnitude of the displaced charge q and the vector Br that locates the effective negative charge center relative to the effective positive charge center in the dipole, or E ≤ q ≥ q r p (a) B p = - qrB (1) ≥ mgv ≥ KS r e r v F ≥ eE E as indicated in Figure 1a. Unfortunately, this equation is, in general, difficult to solve. Time-division multiplexing is an information encoding scheme that ensures that all time slots in a stream of bits of information are used to full capacity. As a consequence, a cylindrical lens has asymmetric focusing properties, as will be seen later in greater detail. Apparently, the single type of visual pigment in rods is much more sensitive to light than is any of the three pigments in cones. As in the example of Figure 20, two refractions at spherical surfaces are involved. The reflection at B, on the other hand, occurs for light going from a higher index nf toward a lower index ns, a condition called internal reflection. Fiber Optics Devices and Systems. (Recall that "small signal" is code for "set I = 0.") c. If means are provided for recording the spectrum, for example, with a photographic film in the focal plane of the telescope objective, the instrument is called a spectrograph. For example, an opaque screen with a round hole represents such an obstruction. The angular separation of the two beams is shown as 2u, and the constructive fringes (vertical dashed lines) formed in the emulsion are labeled as G. Nevertheless, determine the distance above the axis at which single-slit Fraunhofer diffraction predicts the first zero in irradiance. Incorporating Eq. (23), p = -y0 D = a0 C (24) Similarly, a0 = yf>1 - f12, and thus f1 = f1 = - 1Ay0 + Ba02 - yf AD = = - B a0 a0 C Det1M2 n0 1 AD - BC = = a b nf C C C (25) Finally, using Eqs. Since the degree of birefringence induced is proportional to the strain, prototypes of mechanical parts may be fabricated from plastic and subjected to stress for analysis. Comparing this matrix with the general form in Eq. (5), we determine that E0x = A = 1 and E0y = 2B2 + C 2 = 1. Shifting the time origin by T1 and defining the difference in the times of flight for the two paths to be t = T1 - T2, the irradiance at point P can be written as, I = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + 1T1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + 1T1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + 1T1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T2 + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T229 = I1P + I2P + e0cb 1 b 2 Re8E1t2E...1t + IT1 - T229 = I1P + I2PI2P + e0cb 1 b 2 Re8E1t2E...1t + t229 The remaining time average has the form of a correlation function. For an aperture diameter 4.5w = 2 cm, the collimated beam length becomes 98 m for the He-Ne laser and 5.8 m for the CO2 laser, increasing as the square of the aperture diameter. Equation (20) should be compared with the analogous equation for the narrow rectangular slit, ml = b sin u. This intermediate image, located at or near the focal point of the ocular, serves as a real object (VO) in the case of the Galilean telescope and a virtual object (VO) in the case of the Galilean telescope. The initiation of such a pulse can be viewed as the fortuitous spontaneous emission into the different cavity modes in such a way that the fields in these modes happen to constructively interfere at the gate is open. Even
with the narrowest of slit widths, however, the spectral line image is found to possess a width, directly traceable to the limitation that the edges of the collimating lens or prism face impose on the light beam. As a result, the near point of an eye tends to move further from the eye ages. In step 1 of Figure 15a, energy from an appropriate pump is coupled into the laser medium. Solution The longitudinal cavity modes are separated by the free spectral range of the laser medium. would be given by # of lasing modes L 6 GHz = 40 0.15 GHz To ensure single-mode operation, the free spectral range of the etalon must exceed the gain bandwidth. Modern Optics. Essential distinctions between photons are removed and both are subject to the same general principles. 1973): 1703. The object and image positions are separated by a distance L that is more than four times the focal length of the lens. This fourth beam, pictured with complex amplitude A 4 in Figure 15, will be the spatial complex conjugate of the signal beam, A 3. The chart is to include rows of letters to test for visual acuities of 20/300 (same as 5/75), 20/100, 20/20, and 20/15. 111 Wave Equationsistic effective effect The Doppler effect is especially important when used to determine the speed of astronomical sources emitting electromagnetic radiation. The light scattered in various directions from the milk molecules, when examined with a polarizing filter, is found to be polarized, as shown in Figure 7. The detail shows how to relate a change da in wave aberration to a change dy in the aperture dimension. If the doublet is to be used in air, determine (a) the system matrix elements for input and output planes adjacent to the lens surfaces; (b) the cardinal points; (c) the focal length of two lenses in contact. The arrow shows the direction of light through the compensator. The radiation from real surfaces is always less than that of the blackbody, or Planckian source, and is accounted for quantitatively by the emissivity, e. This condition occurs most frequently when one or the other of the oppositely directed waves experiences a reflection at some point along its path, as in Figure 5a. Third Edition Introduction to Optics FRANK L. m mmax 100 p mmax m 0 Figure 2 Alternate orderings of fringes. Here, "a brief period" means a fraction of a round-trip time. Townes and co-workers developed a microwave amplifier based on stimulated emission of radiation. What minimum thickness is required to produce a quarter-wave path difference for sodium light of 589 nm? IO IO/2 l ©l Because the optical fiber is dispersive, we describe the speed of propagation of a pulse by its group velocity, yg. Many radiometric terms have been introduced and used in the optics literature; however, we include here only those approved International System (SI) units. Again, this requirement places a limitation on the frequency of input pulses or the rate at which bits of information may be sent. 27 The gain bandwidth (in nm) and the transition wavelength for three different laser systems are given below. Looking along the axis into the plane surface, one sees two images of the bubble. The irradiance is plotted as a function of b in Figure 2. That rot is, find Erot 1 -E0. Let us introduce a wave number or "normalized" form Eq. (21) and for Y from Eq. (21) and for Y fr spatial frequency nY = 0, the DC component, in analogy with electrical frequencies. Employing Fermat's principle, the ray FTW is isochronous with ray GX, since they begin and end on the same plane wavefronts, GF and XW, respectively. Within the metal wires, the mobile free electrons are set in oscillatory motion by the oscillations of the electric field of the incident radiation. The noise is that part of the signal or output not related to the desired input. Here, S is the survival fraction in the linear polarization of the emergent light is rotated by 90° relative to the linear polarization of the incident light. Thus, a biological 82 Chapter 3 Optical Instrumentation objective compensates for the beam. Use the matrix approach and analyze the final Jones vector to describe the product light. 2 FOURIER-TRANSFORM SPECTROSCOPY Fourier-transform spectroscopy represents an elegant alternative to traditional methods of spectrum analysis. This embosses the hologram onto the mylar, which is then attached to the credit card. r $\diamond 2 \ge 1$ 2 Path 2 Path 2 BS2 Input 1 l1, l2 Path 2 Pat the port marked Input 1. In this case, the polarization of the light does not change as it progresses across the cell and so vertically polarizer, which has a horizontal transmission axis. 10 White light does not change as it progresses across the cell and so vertically polarized light entering the twisted nematic cell is blocked by the second polarizer, which has a horizontal transmission axis. 10 White light (400 to 700 nm) is used to illuminate a double slit with a spacing of 1.25 mm. The rates of stimulated emission and absorption are equal, and so the "downward" (2 to 1) rate always exceeds the "upward" (1 to 2) rate; thus a steady-state population inversion cannot occur in a two-level atomic system. A circular fringe pattern like the one shown may be photographed at the screen. To see this more clearly, refer to Figure 3, which shows a spherical wave disturbance originating at O and incident upon an aperture with an opening SS₂. The photons scattered in the spontaneous Raman processes. Assuming that the laser beam has cross sectional area $A = 0.1 \text{ cm}^2$, find the output power of the laser. Note that one of the elements of the Jones vector in Eq. (9) is now a complex number having both real and imaginary parts. In that event there is a steady increase in the incident resonant photon population and lasing continues. Estimate the final width W of the beam due to diffraction spreading. Stimulated Brillouin Scattering In Section 5 we discussed ordinary Brillouin scattering in which light is scattered by an acoustic wave. (From H. In each case distinguish between polarization modes. Curve (a) is rather steep on both sides of its minimum at 550 nm. Without emphasizing this, we have been using meridional rays in all our diagrams. If the manufacturer provides rulings a. In Figure 6c, it is clear that for distinct vision, the hyperopic near point is farther away than the normal near point. z The linear electro-optic tensor pij is defined by the relation \$\phi1>n22i = @ jpijEj , with i = 1, 2, 3, A , 6 and j = x, y, z. Notice that the result is independent of wavelength. Nevertheless, the Kirchhoff theory suffices to yield accurate results for most practical diffraction situations. This fluid has a refractive index of 1.336, almost equal to that of water (1.333). This phenomenon is essential in the transmission of light along glass fibers by a series of total internal reflections. For the highest spectral purity, particular isotopes of the gas are used. A right-elliptically polarized wave traveling in the y-direction. 18 A soap film is formed using a rectangular wire frame and held in a vertical plane. If c1 and c2 are independently solutions of the wave equation, $s_{2c} = 102cy_{2}0t_{2}$ then the linear combination, $c = ac_{1} + bc_{2}$ where a and b are constants, is also a solution. We shall take the equivalent focal length of the two-lens system to be feq = $f_{2} = -1 > C$. The overall transfer-matrix elements are first determined by forming the product of the transfer matrices of the individual layers. Until the technique of making replicas—relatively inexpensive copies of the masters—was developed, few research scientists owned a good grating. It is this last arrangement that we will discuss in the following sections. The radius of curvature of the spherical surface is 7.5 cm, and the glass has an index of 1.50. The combination v = 2pn is called the wavelength k = 1 > l is called the wave number. For concreteness, we consider the case of a parallel plate of thickness t and index of refraction nf surrounded by air on both sides. The interpretation is based on two considerations. 444 Chapter 20 Aberration Theory Applying the cosine law to the triangle BOQ in the geometric detail shown in Figure 5, we have $r_{z}^{2} = r^{2} + b^{2} + 2rb \cos u + 4rb^{2} \cos u^{2} + 4r^{2}b \cos u + 4rb^{2} \cos u^{2}$ (23) From similar triangles OBC and SCP₂ in Figure 5, we have $r_{z}^{2} = r^{2} + b^{2} + 2rb \cos u + 4rb^{2} \cos u^{2}$ (23) From similar triangles OBC and SCP₂ in Figure 5, we have $r_{z}^{2} = r^{2} + b^{2} + 2rb \cos u + 4rb^{2} \cos u^{2}$ (23) From similar triangles OBC and SCP₂ in Figure 5, we have $r_{z}^{2} = r^{2} + b^{2} + 4r^{2}b^{2} \cos u^{2}$ (24) From similar triangles OBC and SCP₂ in Figure 5, we have $r_{z}^{2} = r^{2} + b^{2} + 4r^{2}b^{2} \cos u^{2}$ (25) From similar triangles OBC and SCP₂ in Figure 5, we have $r_{z}^{2} = r^{2} + b^{2} + 4r^{2}b^{2} \cos u^{2}$ (27) From similar triangles OBC and SCP₂ in Figure 5, we have $r_{z}^{2} = r^{2} + b^{2} + 4r^{2}b^{2} \cos u^{2}$ (28) From similar triangles OBC and SCP₂ in Figure 5, we have $r_{z}^{2} = r^{2} + b^{2} + 4r^{2}b^{2} \cos u^{2}$ (29) From similar triangles OBC and SCP₂ in Figure 5, we have $r_{z}^{2} = r^{2} + b^{2} + 4r^{2}b^{2} \cos u^{2}$ (29) From similar triangles OBC and SCP₂ in Figure 5, we have $r_{z}^{2} = r^{2} + b^{2} + 4r^{2}b^{2} \cos u^{2}$ (29) From similar triangles OBC and SCP₂ in Figure 5, we have $r_{z}^{2} = r^{2} + b^{2} + 4r^{2}b^{2} \cos u^{2}$ (29) From similar triangles OBC and SCP₂ in Figure 5, we have $r_{z}^{2} = r^{2} + b^{2} + 4r^{2}b^{2} \cos u^{2}$ (29) From similar triangles OBC and SCP₂ in Figure 5, we have $r_{z}^{2} = r^{2} + b^{2} + 4r^{2}b^{2} \cos u^{2}$ (29) From similar triangles OBC and SCP₂ in Figure 5, we have $r_{z}^{2} = r^{2} + b^{2} + 4r^{2}b^{2} \cos u^{2}$ (29) From similar triangles OBC and SCP₂ in Figure 5, we have $r_{z}^{2} = r^{2} + b^{2} + 4r^{2}b^{2} \cos u^{2}
+ 4r^{2}b^{2} + 4r^{$ we see that the distance OB = b is proportional to the height h¿ of the paraxial image P¿ above the optical axis. Lens L2 acts as a Fourier transform lens. This technique is utilized in the Fresnel rhomb (Figure 7). Aperture Spectrum Image S L1 L2 f 21 L3 f f Fourier transform lens. This technique is utilized in the Fresnel rhomb (Figure 7). hout most of this text we use the symbol I, rather than Ee, to represent irradiance.) Notice that the SI unit of luminous energy is the talbot, the unit of luminous incidence is the lux (lx), and the unit of luminous energy is the talbot. although, necessarily, somewhat cursorily. Also, throug Determine the radii of curvature of the outer surfaces of the lens, as well as its resultant focal length for the D, C, and F Fraunhofer lines. The free spectral range in order m may be determined by the following argument. We are interested here in describing the modulation that is accomplished by varying the refractive index of a material through the use of an applied electric field. When two or more light fields of very large amplitude mix together in a material, the resultant light field may not be simply the superposition of the individual fields. A series of such double layers increases the reflectance further, and the structure is called a high-reflectance stack, or dielectric mirror. Distances are directed, positive or negative, by a sign convention that makes distances to the left negative and distances to the right positive. Many photodiodes used in the visible to near infrared region of the spectrum use p-i-n junctions. No other light source, with or without the help of lenses or mirrors, generates a beam of such precise definition and minimum angular spread. Notice that the yB component of B must reverse on reflection. The exponential term in Eq. (6) merely reflects the "more-or-less" plane wave nature of the solution. With a given gain medium one can increase the output irradiance by increasing the pump density Rp2 , since this increases the small signal gain coefficient g0 . The situation is sometimes described by referring to the reference wave as a carrier wave that is modulated by the signal wave from the scene. For example, the C coefficient 1C31 accompanies the term h¿r3 cos u, where h¿ is to the first power, r is cubed, and cos u is to the first power, r is cubed. origin at the center of the central slit. voltage across the cell. We note that wavelength separations larger than l>m can be measured with a Fabry-Perot cavity provided that one has additional knowledge of the wavelength separation so that the difference in mode number associated with adjacent transmission peaks can be unambiguously determined. A conservative estimate2 of fiber resolving power, RP, is given by RP 1 lines>mm2 = 500 d1mm2 (1) Thus, a 5-mm fiber, for example, can produce a high resolution of about 100 lines/mm. For a shift of fringes of magnitude x (Figure 20b) the change in m is given by $x = \frac{1}{x} x^2$. ¢x can be measured with a stable microscope—or from a photograph like that of Figure 20—the film thickness d is determined. 133 Properties of Lasers Solution The output power P is the rate of energy emission. The holograph ic grating, operates as a dispersing element. 16 A small, monochromatic light source, radiating at 500 nm, is rated at 500 W. (Hint: The spectral energy density in (a) includes the energy in field components moving in all directions while the spectral exitance accounts for the power moving normally away from the blackbody surface.) 2 Consider a monochromatic electromagnetic field traveling with speed c in a given direction. Here, b is a constant of dimension m 1. Points of maximum strain are made visible by light transmitted through crossed polarizers. For example, if p = q = 20 cm, L = 10 cm, and l = 500 nm, then $\psi = 0.632$ for a slit width of 0.01 cm. Recall that in the Littrow configuration, light is incident along the normal to the groove faces. To understand the interaction of light with individual atoms and molecules, it is important to keep in mind that EM waves gain and lose energy in discrete amounts proportional to the frequency of the radiation. Hernandez, G. Thus rays spread out radially in all directions from object point O, as shown, in real object space, which precedes the first reflecting or refracting surface of the optical system. What is the phase difference between the TE and TM modes after both reflections, when the angle is 5% below and above the correct value? Only the first, however, represents the important case of a periodic wave. In the GRIN fiber, a process of continuous refraction bends rays of light, as shown. b 5.625 cm 2m Figure 19 Problem 3. This service is performed by a semiconductor device, most commonly a PIN diode, an avalanche diode, or a photomultiplier. Only electromagnetic fields that have frequency of the cavity (and so experience low loss) will be present in the laser output. Regions may overlap, as in the case of the continuum from X-rays to gamma rays. When the function I(x) is such a discrete set of sample points, the continuum from X-rays to gamma rays. geometric relations simplify in this case. In the ideal polarizer, the transmitted light is linearly polarized in the same direction as the transmission axis. The lifetime broadened spectrum. These waves would seem to disappear at the right node and be generated at the left node of each pulse. In Figure 16f the steady-state operation of the laser is illustrated. As mentioned, a good Fabry-Perot interferometer may have, overall, a resolving power of a good diffraction grating is in the range 105 - 106, an order of magnitude smaller. It is nevertheless helpful in some cases to think of a prism as functioning approximately like one-half of a convex lens. Before investigating the effects that the Hermite functions g1j2 and h1h2 have on the transverse nature of the beam irradiance, let us examine the consequences of the third condition imposed on Eq. (52), 0p 2ik = C1 + C2 - 2k q 0z (62) where C1 = 4m>w2 and C2 = 4n>w2. Stereoscopic Vision The ability to judge depth or position of objects accurately in a threedimensional field is called stereoscopic vision. A notable example is the He-Ne laser, where the laser-active neon (Ne) atoms are excited by resonant transfer of energy from helium (He) atoms in a metastable state. cm2 # sr Solution a. Describe the line image by length and location if the lens has a radius of curvature of 5 cm, a refractive index of 1.60, and an axial length of 7 cm. For oblique incidence, however, results must be the temperature of a graybody with emissivity of 0.45 if it is to have the same total radiant exitance as a blackbody at 5000 K? This example shows how optical filtering is applied to the extraction of desired periodic signals from background noise or, on the other hand, to the elimination of periodic noise from a desirable signal. If optical fiber is used instead, with a loss rated at 4 db/km, how long can the transmission line be? A QWP is allowed to intercept the beam first with its OA parallel to the TA of the polarizer. Determine the radiant flux delivered to the film. (c) Diffraction pattern due to a single slit. Snell's law, which now takes the form n1 sin u1 = n2 sin u2 (2) y x (b) Figure 7 Geometry of a ray reflected from a plane. At a certain point in the pattern, the fringes are observed to shift laterally by 3.4 mm. Calculate (a) the wavelength spread of the line of the lin and (b) the coherence time of the source. Assume that 5% of the lamp energy is converted to light may be emitted by an absorbing medium, but this light is emitted in any direction and with any frequency within the linewidth of the transition. The more massive nuclei can be considered stationary since they are unable to respond to the rapid changes in the field representing an electromagnetic wave in the optical region of the spectrum. In its simplest form, the instrument consists of two positive lenses, an objective lens of small focal length that faces the object and a magnifier functioning as an eyepiece. For low magnifications, with focal lengths in the range of 8 to 64 mm, achromatic objectives are generally used. The net phase change is made up of two parts, the optical-path difference ¢ and the phase change is made up of two parts. B product of the orthogonal vectors, E and B, we can write, finally, B B S = e0c2E * B (40) Note that since this relation involves the product of two waveforms, it does not hold for waveforms, it does not hold for waveforms, it does not hold for waveforms written in complex form. If the film is of varying thickness t, the optical-path difference \$\epsilon = 2\$ of t cos ut varies even without variation in the angle of incidence. 304 Chapter 12 The Diffraction Grating Plate Concave grating Echelle grating Figure 9 Side view of the echelle spectrograph. When the signal is internally amplified by secondary electron emission, the detector is a photomultiplier; see Figure 3. 21 Show that one can arrive at Eq. (32) by taking the origin of coordinates at the midpoint of the central slit in an array where N is odd. 16 The reflectance R (see Problem 15) of a Fabry-Perot etalon is 0.6. Determine the ratio of transmittance of the etalon at maximum to the transmittance at halfway between maxima. Figure 27 Construction of Huygens and Ramsden eyepieces. interferometer, first introduced by Albert Michelson in 1881, has played a vital role in the development of modern physics. Thus, in this case z varies from a certain negative value to q. First, find the irradiance at the film due to the superposition of a plane and a spherical wave. Laser systems with moderate or high power outputs also typically require a cooling system. And the amplitude of the resultant wave is simply the sum 1E01 + E022 of the amplitudes of the individual waves. Since E-oscillations in the oxygen plane B 1E OA2 interact more strongly
with the electrons, the speed y of these component waves is reduced most, that is, y 6 y7. Representing J with the help of Eq. (47), we conclude B B 1 $0 2E 1 s 0E a b \S E = 2a 2b + 21 - iv > g 0t c 0t e0c 2B B (52)$ B For plane, harmonic waves given by E = E0ei1kz - vt2, the appropriate space and time derivatives required by Eq. (53) where we have also made use of the fact that e0m0 = 1 > c2 with m0 the permeability of vacuum. (a) $46.7 \times (b)$ 8.68 cm 25. The indices are n400 = 1.5255 + 14825 nm 22 > 1400 nm 22 = 1.5353 b. Wavelength-division multiplexing (WDM) is a means of combining 40 or more signals, carried in different wavelength channels, so that they propagate together through the same fiber. 196 Chapter 8 Optical Interferometry This means that the fringes are more widely separated when optical-path differences are small. Laser systems with gas or liquid gain media can be cooled by this same mechanism, or by flowing the lasing medium itself through the cavity where it is same mechanism. again pumped. The same conditions may lead to the enhancement of one visible wavelength interval or color at the expense of the others, in which case interference colors are produced, as in oil slicks and soap films. pz 1n - nP2 10 c (10) Notice that the linearly polarized light is rotated through an angle that is proportional to the thickness z of the active medium, as verified experimentally. This turns out to be another way of arriving at the Doppler effect for light. Other interferometric systems, such as that shown in Figure 7b, are essentially those used to produce holograms. Once at these levels, the atoms spontaneously decay, through various chains, back to the ground state E0. Determine the radiant exitance, radiant intensity, and radiance of the object. Notice that this relationship produces the correct sign of s2, as in Figure 20, and also when the intermediate image falls inside or to the left of the lens. A measure of this bending is the Coddington shape factor s, defined by $s = r^2 + r^1 r^2 - r^1 (27)$ where the usual sign convention for r1 and r2 is assumed. There is one relative motion between them that determines the frequency shift in the Doppler effect for light. Inspection of Eq. (52) indicates that for a given z, that is, for a given transverse plane, the first bracketed series of terms, the g-expression, is a function of x alone; the second, the h-expression, is a function of y alone; the third is independent of both x and y; and the fourth is identically zero, since q = q0 + z is the propagation law that we continue to take to be valid. Gamma rays have very short wavelengths in the range from 0.1 nm to 10-14 nm. Optical Image Formation and Processing. Film Laser beam Figure 4 Cylindrical film surrounding the subject records a 360° hologram The allowed energies of electrons in the wide variety of types of atoms and molecules cannot be summarized in a simple formula. 32 A ray of light traverses successively a series of plane interfaces, all parallel to one another and separating regions of differing thickness and refractive index. Thrierr, Atlas of Optical Phenomenon, Plate 40, Berlin SpringerVerlag, 1962.) (b) 369 Production of Polarized Light change in thickness d. When etched, the interference pattern is preserved in the form of transmission gratually across the groove in a sinesquared profile. One is an axial ray, normal to the surface at its vertex and so refracted without change in direction. These nonlinear phenomena require an extension of the linear theory that allows for a nonlinear response of optical materials to the electromagnetic radiation. This permanent periodic poling produces the alternating sign of x2 needed for QPM. That is, ETOT = nhn = nhc>l The number of photons n emitted in 1 s is therefore n = ETOT 1J l = 15 * 10-7 m2 = 2.5 * 1018 hc 16.63 * 10-34 J # s213 * 108 m>s2 For this light source, one photon more or less is unlikely to be noticed. (2) and (4) for lateral aberration by and longitudinal aberration bz, the corresponding spherical aberration by and longitudinal aberration bz, the corresponding spherical aberration by and longitudinal aberration bz, the corresponding spherical aberration bz, the corresponding spherical aberration by and longitudinal aberration by and longitudinal aberration bz, the corresponding spherical aberration by and longitudinal aberration by and longitudinal aberration bz, the corresponding spherical aberration by and longitudinal aberration bz, the corresponding spherical aberration by and longitudinal aberration bz, the corresponding spherical aberration by and longitudinal aberration bz, the corresponding spherical aberration by and longitudinal aberration bz, the corresponding spherical aberration by and longitudinal aberration bz, the corresponding spherical aberration by and longitudinal aberration bz, the corresponding spherical aberration by and longitudinal aberration bz, the corresponding spherical aberration by and longitudinal aberration bz, the corresponding spherical aberration bz, the corresponding sphereical abe n2 and bz = s¿by y s¿by = r = 40C40s¿ 2 2 r n2 Example 1 Axially collimated light enters a glass rod through its end, a convex, spherical surface of radius 4 cm. The second prism serves to reorient the transmitted ray along the original beam direction. In Example 4 we consider the effect of using reading glasses on the vision of a person with presbyopic eyes. The distances L and L₂ are related, as suggested by the geometry in Figure 9, by sin wc = n2 / L = n1 /₂ L₂ Thus, the times of flight for the two rays taking the extreme paths between points A and B differ by the time interval dt, given by dt = tmax - tmin = L₂ L L n1 - 1b = a y y y n2 where y is the speed of light in the fiber core. Figure 10 illustrates the principal b B I E E L Plane of polarization rotates inside material Incident polarization (horizontal) Exit polarization (the plane of polarization. Equating Eqs. To project a larger image on the retina, the simple magnifier is inserted and the object is moved physically closer to position (b), where it is at or just inside the focal point of the lens. A particularly elegant means of Q-switching involves the insertion of a saturable absorber into the cavity. Perry, and Richard W. There exist values of x for which A1x2 = 0, and thus ER = 0 for all t. Notice that (b) OA OA (c) Figure 16 Polarizing prisms. For example, zinc has two outer-shell electrons. In (b), the incident and reflected beams are separated for clarity. high $f_1 = -1.15$ cm; r = 0.400 cm; s = -1.16 cm; v = 4.20 cm; w = 2.64 cm; $s_i = 18.9$ cm from H2; $h_i = -1.18$ cm (a) $f_1 = -20.15$ cm = -r/2; r = 10 cm = -w (b) Image is inverted, real, 61.38 cm from H2; $h_i = -1.18$ cm (a) $f_1 = -20.15$ cm = -r/2; r = 10 cm = -r/2; r = 10 cm = -w (b) Image is inverted, real, 61.38 cm from H2; $h_i = -1.18$ cm (b) $f_1 = -1.18$ cm = -1.16 cm; v = 4.20 cm; w = 2.64 cm; $s_i = 18.9$ cm from H2; $h_i = -1.18$ cm = -1.18 cm = sphere center and $m = -2.05 \times (a) \ y = 1 \ cm; = -5.73^{\circ} (b) \ A = 1 - x/10; B = 10/3 + 2x/3; C = -1/10; D = 2/3 \ (c) \ x = 10 \ cm, p = -4.17 \ cm, q = +2.17 \ cm, f1 = -3.33 \ cm, f2 = 4.33 \ cm, f1 = -20 \ cm, f2 = +20 \ cm, p = -10 \ cm, s = -10 \ cm, s = -10 \ cm, f1 = -16.7 \ cm, f2 = +23.3 \ cm, q = +18.7 \ cm, p = -18.3 \ cm, r = -18.3 \ cm, r = -10 \ cm, s = -10$ -1.67 cm, s = -4.67 cm 1 (a) A = -12, B = 0, C = -10, D = -2 (b) Input and output planes fall at conjugate object and image positions; A is identical with the linear magnification. Figure 16 Three examples of a phasereversed replica of an incident wavefront produced by an ordinary mirror. To take this into account formally, Eq. (34) is usually generalized to include a number of terms summed over the resonant frequencies v_j , given by $n_2 = 1 + f_j$ Ne2 a 2 me0 j v_j - v_2 - igjv (39) where f_j , called the oscillator strength for the resonant frequency. If the top edge of the beam strikes the film at x = 0, then w is a linear function of distance x along the film plane, since w = a 2p 2p b ¢ = a b x sin a l l (2) Thus the phase angle w relates only to the tilt of the film plane relative to the reference beam were not present, the film would be illuminated only by the subject beam, ES = sei1vt + u2 (4) where s(x, y) is the amplitude of the reflected light at different parts of the subject. The incident beam of roughly collimated function due to the variations in phase of the light reaching the film from different parts of the subject. The incident beam of roughly collimated light is divided into two beams at beam splitter BS. It was the double-slit experiment, in which an opaque screen with two small, closely spaced openings was illuminated by monochromatic light from a small source. Sketch the arrangement, showing the orientation of the telescope. A detector is situated on axis at a distance of 20 cm from the aperture plane. It can always be answered, however, by determining which of the actual elements in the given system—in this case, A, L1, or L2— has an entrance pupil that confines rays to their smallest angle with the axis, as seen from the object point. Since from Eq. (4), n1 cos wc = 2n21 - n22 = N. Consider a 1-meterlong linear cavity with a mode spacing nfsr = 1.5 * 108 Hz. Let this cavity contain a gain medium of bandwidth 1 GHz pumped so that at the frequency of the transition line center n0 the small-signal gain coefficient g01n02 is twice the threshold gain coefficient g01n02 is twice the thresh relation ut = 90 - up, we arrive at Brewster's law, up = tan-1 a Figure 5 Pile-of-plates polarizer. In this and following chapters, several such applications, considered under the general heading of interference, are presented. Mirror PQOMNQP(a) PQMOQNP(b) Figure 6 Spherical aberration (exaggerated) in (a) a spherical mirror and (b) a thin lense It is sufficient in what follows, therefore, to treat
only one of these functions. Arguing from the Fourier series required to represent this kind of aperture function, it is clear that orders in the diffraction spectrum higher than m = 1 do not appear. Chapter 4 Ghatak, Ajoy K. and the ray-transfer matrix representing the entire optical system is M = MNMN - 1 Á M2M1 (14) We apply this result first to the thick lens of Figure 8, whose index is nL and whose thickness for paraxial rays is t. See for example, Ammon Yariv, Optical Electronics, 3d ed. 382 Chapter 16 Holography of the change at specific locations, as in the case of Newton's rings. Figure 8 illustrates the operation schematically. Principal and nodal points coincide. The relationship of crystalline asymmetry with refractive index and the speed of light in the medium may be understood a bit more clearly by considering the case of calcite. Plastic fibers are used to aid the eye in viewing images formed by prior components of an optical system, they are called oculars, or eyepieces. (Ignore possible state degeneracies.) 4 The allowed energies Evib k = 1k + 1>22hf Here, k is the vibrational quantum number and can take the values k = 0, 1, 2 Å and f is the resonant frequency of the vibration. c_{1y} , $t_2 = A sin_1ky + vt_2 + A sin_1ky + vt_$ of the eye or its minimum angle of resolution of two closely spaced objects or points. Over this range, the energy density function is nearly constant and can be taken to be r1n02. The narrow region where nR decreases with frequency is contrary to the usual dispersion. We shall use the term free spectral range to refer to the separation between adjacent transmittance peaks regardless of the choice of independent variable but take care to symbolically differentiate between the free spectral ranges in the different adjacent transmittance peaks regardless of the choice of independent variable but take care to symbolically differentiate between the free spectral ranges in the different modes of operation. must leak out of the cavity. It has also been suggested that robots could identify and be directed toward appropriate objects in the same way. James, J. The line spectrum of the gas. Vectors in Table 1 have all been multiplied by prefactors, when necessary, 2 1 to put them in normalized form. Show that at z = 0, E1 + E2 = 2E0 at times given by t = n > dn, where n is an integer. 5, 6. The requirement that the component of the electric fields associated with the electric fields of Figure 1 have the form, B = 1B cos uxN - B sin uzN 2ei1kr - vt2 B B # B Continuity of the parallel components of the magnetic field requires that the field amplitudes be related by B cos u - Br cos u = Bt cos ut (14) where we have made use of Eq. (8) In this case, the total irradiance Iu at point P is proportional to the square of the length of the phasor drawn from E; to E, as shown in Figure 13. The presence of the third term I12 is indicative of the mass m in the denominator of these equations shows that electronic oscillations are more important than ionic oscillations in determining the index of refraction. How many pixels would be to pulse the pump—that is, turn the source of these equations are more important than ionic oscillations are more important than ionic oscillations in determining the index of refraction. laser energy on and off. In this case, no light is transmitted, or c a c 0 b 1 dc d = c d 0 d 0 The corresponding algebraic equations are now a112 + b102 = 0 c112 + d102 = 0 from which a = 0 and c = 0. The simplification we make is to neglect the thickness of the lens in comparison with the object and image distances, an approximation that is justified in most practical situations. In these cases, wR>2 = p>2 and the resultant field takes the form ER = 12E0 sin kx2cos vt (23) As shown in 5b, Eq. (23) represents a standing wave. Thus, LC = p> ¢k When L = LC, the sinc-squared intensity factor is reduced to about 0.4 of its maximum value and so represents an estimate of the useful length of a crystal 4 Ammon Yariv, Optical Electronics, 3d ed. 7 Determine the conditions on the elements A, B, and C of the general Jones vector (Eq. 9), representing polarized light, that lead to the following special cases: (a) linearly polarized light, that lead to the following special cases: (a) linearly polarized light, that lead to the following special cases: (b) elliptically polarized light, that lead to the following special cases: (c) circularly polarized light. The transmittance of the output mirror is T3 = 0.04. 32 Chapter 2 Geometrical Optics trace, depending on the object location before or after points C and F, and on the geometry of the mirror surface, concave or convex. Parallel plates, such as the one studied here, can be used as Fabry-Perot interferometers. The method of pattern recognition just described is perhaps the simplest to understand, but many other techniques with various advantages have been developed. 4 Plane waves of monochromatic (600-nm) light are incident on an aperture. The results of Example 4 indicate that a large number of equally spaced wavelength channels could be demultiplexed by a system of Mach-Zehnder interferometers. More generally factor S should include factors describing each process that reduces the irradiance as the beam traverses the ring. The coefficients A 21, B21, and B12 are characteristic of the two energy states. Beyond resonance, however, when v v0, P and E have opposite signs, indicating a phase difference of p. For the normal ray, on the other hand, due to the B E-component perpendicular to the OA, everything is normal; the ray obeys B B B Snell's law, the Huygens' wavelets are spheres, k E, k 7 S, and the ray is perpendicular to its wavefront. (a) Converging lens (positive focal length). Phase-locking the fields in the cavity allows for the formation of a narrow pulse centered on the positions of commor phase. Show that the attenuation db/km is given by n 2d 2n21 - n22 b. The Faraday effect can be used for light modulation, although it is difficult, practically speaking, to modulate a magnetic field at very high frequencies. (1) ' Ex = E0xei1kz - vt + wx2 (2) ' Ey = E0yei1kz - vt + wx2 (3) and ' ' Here, Ex = Re 1Ex2 and Ey = Re 1Ey2. To understand this unusual effect, consider Figure 20, where polarizer and analyzer TAs are crossed and at 45° and - 45°, respectively, relative to the x-axis. The corrected far point of each eye is 15 cm and the corrected far point of each eye is 15 cm and the corrected far point of each eye is 15 cm and the corrected far point of each eye is 15 cm and the corrected far point of each eye is infinity. (a) 0.218 cm (b) 0.218 cm (b) 0.218 cm (b) 0.218 cm (c) 0.218 through shaping of their surfaces, to produce a net power of the doublet that may be either positive or negative. In Figure 12, three experimental sample interferograms are shown, produced by a Michelson interferograms are shown, produced by a Stadow a structure not explainable in terms of the rectilinear propagation of light. Recall that a laser system converts pump power. Figure 13 shows that M for material dispersion becomes zero at around 1.27 mm and then becomes negative for longer wavelengths. The state of polarization of the light can most easily be tested by a second dichroic polarizer, which then functions as an analyzer, shown in Figure 1. It is from this axis that the displacement y¿ of the rays of the oblique pencil would have to be measured to determine the degree of aberration described by Eq. (19). Figure 20a shows a typical photograph of the x (a) x (b) Figure 20 (a) Photograph of interference fringes produced by the arrangement shown in Figure 19. Thus the total average power, for the CW laser, is simply the sum of the powers in the individual fields. When it does, laser amplification begins. In summary, the small-signal gain coefficient g0 must exceed the threshold gain coefficient gth for the laser field to grow in the cavity. Thus other maximum intensity points along the axis are to be found at R21, nl fn = n odd (23) Example 2 What are the focal lengths for the zone plate described in the preceding example? The light in the cavity makes repeated passes through the windows, on its way to and from cavity mirrors positioned beyond alternate ends of the gas tube. Again, if the source is small, then real, nonlocalized fringes appear in the light emerging from the interferometer, as if formed by the entrance window at the center of the entrance pupil. 331 Fresnel Diffraction PROBLEMS 2 A 3-mm-diameter circular hole in an opaque screen is illuminated normally by plane waves of wavelength 550 nm. (20) and (22). Calculate the degree of polarizers and with monochromatic light official to the transmitted beam, given by 20 When a plastic triangle is viewed between crossed polarizers and with monochromatic light official to the transmitted beam, given by 20 When a plastic triangle is viewed between crossed polarizers and with monochromatic light official to the transmitted beam. 500 nm, a series of alternating transmission and extinction bands is observed. Coherent sources are the virtual images S1 and S2 of source S, formed by refraction in the two halves of the prism. t = (i ni xi)/c 1/2 1.25(x2 + y2) + 70(x2 + y2) - 135x + 800 = 0 4.00 mm 3 ft, with top edge of mirror at a height halfway between the person's eye level and the top of the person's head The ray emerges from the bottom at 45°. With these relations and since ' the beam irradiance is proportional to the square of the magnitude of Emn, Imn = I0 a 8 w 20 w 1z2 2 b H 2m1xs2H 2n1ys2e -1xs 2 + ys22 Amnon Yariv, Quantum Electronics 3d ed. In such a case, d is a constant 167 Interference of Light and the interference term takes the form, 2211128cos1k1s2 - s12 + f11t2 - f11t2 - s12 = 2 21112 cos1k1s2 - s122 = 2 21112 cos1k1s2 time, t0, of the source. A photograph of the pattern is given in Figure 14d. Referring to Example 2 in which the external beam waist is focused at / 0.06 m with a
waist size w1/2 = 0.54 mm, use Eqs. The plot clearly shows that intersection points approach the vertical lines defining midpoints more closely as b increases. (Oriel Corp., General Catalogue, Stratford, Conn.) (a) (b) Figure 7 High-intensity, compact shortarc light source. In the region of 1 to 8 mm, the semiconductor compounds PbS, PbSe, and PbTe (lead telluride) possess a large photovoltaic effect and greater sensitivity than the thermocouple or the ordinary bolometer. So the exit pupil ExP is located 5 cm to the left of L2 or 1 cm to the left of L1. Equation (1) gives the energy of a photon as hn. If the quality of the image is to be improved, however, ways must be found to reduce the everpresent aberrations that arise from this ideal assumption. Indeed, requiring energy conservation in a Mach-Zehnder interferometer is one way to prove that beam splitters with real transmission coefficients have reflection coefficients from opposite surfaces that differ by a factor of - 1. Conceptually, account for the missing pump events. This matrix is A B C D D 1 Z2 0 1 1 TD T = D Z2 f = D 1 f 1 - - 1 f 0 1 Z1 0 1 TD T = D Z2 f = D 1 f 1 - - 1 f 0 1 Z 0 1 TD T = D Z2 f = D 1 f 1 - - 1 f 0 1 Z 0 1 TD T = D Z f = D 1 f 1 - - 1 f 0 1 Z 0 1 TD T = D Z f = D 1 f 1 - - 1 f 0 1 Z 0 1 TD T = D Z f = D 1 f 1 - - 1 f 0 1 Z 0 1 TD T = D Z f = D 1 f 1 - - 1 f 0 1 Z 0 1 TD T = D Z f = D 1 f 1 - - 1 f 0 1 Z 0 1 TD T = D Z f = D 1 f 1 - - 1 f 0 1 Z 0 1 TD T = D Z f = D 1 f 1 - - 1 f 0 1 Z 0 1 TD T = D Z f = D 1 f 1 - - 1 f 0 1 Z 0 1 TD T = D Z f = D 1 f 1 - - 1 f 0 1 Z 0 1 TD T = D Z f = D 1 f 1 + - - 1 f 0 1 Z 0 1 TD T = D Z f = D 1 f 1 + - - 1 f 0 1 Z 0 1 TD T = D Z f = D 1 f 1 + - - 1 f 0 1 + a Z1 + Z2 b f f Z1 1 - q1 + a 1 b f f (45) Making use of Eq. (17) and noting that the radius of curvature of the beam waist is infinite, we find q1 = -i pw201 at Z1 l and q2 = -i pw202 at Z2 l Using these relations in Eq. (45), we obtain a rather complicated equation that contains the desired unknowns, Z2 and w02. Thus, a wavelet of radius JN = JH centered at J is drawn above the reflecting surface. 250 Chapter 10 Fiber Optics where m is an integer. The sharpness of the image of a distant point object—a star, for example—is, then, limited by diffraction. Turning on the acoustic wave deflects the beam outside the laser cavity and initiates cavity dumping. Grayscale images can be formed by either varying the 394 Chapter 17 Optical Detectors and Displays voltage across a pixel, so that the length of the transmission pulse leads to differences in perceived brightness of the pixel. 4 Using the Fourier transform, determine the power spectrum of a single square pulse of amplitude A and duration t0. Notice also that pulse broadening due to material dispersion is much smaller than that due to model distortion. This pattern may be manipulated in turn, using masks or filters to modify the final image produced by a second lens in a process called spatial filtering. The two wave vectors and as well as S B the wave vector k ¿ of the diffracted light beam, are also shown in Figure 11. Letters, 7, 1961: 118. Example 1 should be regarded as an "order-ofmagnitude, back of the envelope" estimation. In addition, microwaves play an important role in radar systems both on the ground and in the air, in telecommunications, and in spectroscopy. M1(f 12) M2 f 4 2 10 12 Figure 41 Problem 34. some of this beam, which we call the subject beam, also strikes the film, where it interferes with the reference beam and produces the hologram. The Balmer series refers to the light emitted from transitions from excited states with n Ú 3 to the n = 2 energy state. Presbyopia can be remedied in some patients by using CK to correct the refractive power of one of the eyes for near vision while the other eye is left untreated and is used by the patient for middle-todistant vision. In each case, the light is propagating in the positive z-direction. The final form of U(x, y, z) can then be used in Eq. (6) to give a manageable form for the Gaussian beam solution to the wave equation, 'w0 2 2 2 -1 be -r >w 1z2eikr >2R1z2e -i tan 1z>z02ei1kz - vt + f2 E = E0 a w1z2 (24) where R(z), z0, and w(z) are given by Eqs. This pattern simply repeats for p from N to 2N and so on, thereby accounting for all of the principal and secondary peaks. The chief ray, from point P to conjugate point P-, is shown in the final drawing. A simple model in which electrons are held by springlike forces to a fixed nucleus is therefore applicable. Gain Saturation in Homogeneously Broadened Media It is important to note that the expression for the gain coefficient given in Eq. (37) is valid only for homogeneously Broadened Media It is important to note that all atoms participating in the interaction with the light are of the same type. A linearly polarized wave traveling in the x-direction. The halogen vapor functions in a regenerative cycle to keep the bulb free of tungsten. Thus, the wave-particle duality came full circle. At the center of the pattern projected on a screen, the irradiance is Imax. The dashed lines are merely added to assist in analyzing the operation of the prism, a single structure. The result is that point objects are not imaged as points but rather as small blurred lines. For the situation shown in Figure 12, d L dfsr > 8 = 500 * 10-8 m = L a b = 6.25 # 10-7 l d 0.05 m That is, this Fabry-Perot interferometer easily resolves a fractional difference in wavelength of less than one part in a million. In an inhomogeneously broadened system pumped so that g0 = 2gth, all modes within cn>2 of linecenter will be above threshold (see, for example, Figure 12a). A list of useful refractive indices is given in Table 1. To understand his design refer to Figure 36. Entrance Pupil EnP: There are no optics to the left of the aperture stop A, so it serves also as the entrance pupil EnP. Since U depends only on r and z, it is cylindrically symmetric about the z-axis. This region has lateral dimensions of ls and longitudinal dimensions of ls and longitudina around the point P. The rates associated with these processes are valid for the case of interaction with a nearly monochromatic laser field of frequency n/. Let us express the situation more precisely in mathematical terms. 3 Write out the second-order terms of the polarization for three-beam interaction, where the beams are plane waves having amplitudes E01, E02, and E03 and frequencies v1, v2, and v3, respectively. What are the diameters of the holes that produce (a) the first two maxima and (b) the first two maxima and (b) the first two maxima and (c) the be discussed is not one of the Seidel aberrations, which are all monochromatic aberrations. 2 If image and object distance for a spherical refracting surface—in addition to satisfy the relation $1 - n2 n2 n1 = s c_c R$ —also satisfy the relation $1 - n2 n2 n2 n1 = s c_c R$ —also satisfy the relation $1 - n2 n2 n2 n2 = s c_c R$ —also satisfy the relation $1 - n2 n2 n2 n2 = s c_c R$ —also satisfy the relation $1 - n2 n2 n2 n2 = s c_c R$ —also satisfy the relation $1 - n2 n2 n2 n2 = s c_c R$ —also satisfy the relation $1 - n2 n2 n2 = s c_c R$ —also satisfy the relation $1 - n2 n2 n2 = s c_c R$ —also satisfy the relation $1 - n2 n2 n2 = s c_c R$ —also satisfy the relation 1 - n2 n2 n2 =displacement at the origin is zero at time zero.
Similarly, the image distance MP¿ is less than the distance NP¿. J.: Prentice Hall, Inc., 1998). Rn Problem 2. There we found that the two product functions could be interpreted separately as diffraction from a single slit and interference from multiple (negligible width) slits. To model real sources, Eqs. These possibilities have already been discussed in the previous chapter, where we treated the various interference fringes that can be formed by illumination of a film. For example, $y_1 = 2 2 z_1 = 1-0.9 * 10-32 = -5.19615 A Ll A 10.1221500 * 10-92 329$ Fresnel Diffraction Similarly, $y_2 = 0.57735$. The same principle can be stated more formally as follows. Figure 13 depicts extreme cases illustrating the distinction. The ability of different wavelengths in different wavelengths in different directions finds use in several other applications. The ability of different wavelengths in different directions finds use in several other applications. The ability of different wavelengths in different directions finds use in several other applications. The ability of different wavelengths in different directions finds use in several other applications. frequency wave serves as an envelope modulating the high-frequency wave, as shown in Figure 7b. Treating this system as an ideal four-level system, estimate the saturation irradiances It>10, which we have called the transmittance. 539 Optical Properties of Materials B B The dependence of P on E, as given in Eq. (11), can now be used to discover the conditions under which plane waves are able to propagate in a dielectric. Assume an average wavelength of 550 nm. Dispersion The minimum deviation of a monochromatic beam through a prism is given distinguished by the vibrational and rotational state of the molecule. The beam can be scanned back and forth across the screen, covering the entire screen 30 times each second. Still, the sum of a larger number of closely grouped harmonic components can still be characterized both by a phase velocity, the average velocity of the individual waves, and by the group velocity, the velocity of the modulating waveform itself. How much does 1n - n 72 vary between transmission bands to satisfy successive conditions for HWP retarda1 tion? What is the net optical density of the combined layers? Thus, AC = A/C and the distance traveled by the ray of light from A to B via C is the same as the distance from A/ to B via C. A more complete analysis of this experiment must take into account the finite size of the slits. The energy of a photon is not a function of its speed but rather of its frequency, as expressed in Eq. (1) or in Eqs. Notice that a free electron that has been stripped from the hydrogen atom can have any energy. s + s_c bCL s together with the sign convention—positive for real objects and images, negative for virtual objects and images, positive R for convex surface. Using the result from (a) and Eq. (24) (or an equivalent form), show that the sum of the irradiances reflected by and transmitted through the Fabry-Perot cavity is equal 222 Chapter 8 Optical Interferometry the first set of dual peaks of Figure 20a over a smaller length scale in order to allow a closer examination of the structure of the overlapping peaks. In sharp contrast to the response of the rods, the cones are sensitive to bright light and color but do not function well in dim light. Notice that to produce the 'vibration shown in Figure 3a, the two ' resultant perpendicular vibrations E0x and E0y must be in phase. In Figure 13, M ranges from about 165 to - 30 ps>nm-km over the spectral range of 0.7 to 1.7 mm. The electric field vector in the z = 0 plane is shown every eighth of a period over one period, T = 2p>v. A special case of frequency mixing is the process known as parametric amplification. They are capable of response to frequencies in the range of 1010 Hz and they can often be found operating as Q-switches in pulsed lasers. The groove profiles of normal interference gratings. Find the near and far points for each unaided eye. Fourier analysis of such a wave train must regard it as a nonperiodic function. 14 Chapter 1 Nature of Light u1 dA1 Figure 6 General case of the illumination of one surface by another radiating surface. The irradiance I (in W>m2) is then proportional to the square of this result. When u 7 uc = sin-11n2, the radical in Eqs. (a) (b) A P S O S P Figure 3 Huygens' construction for an obstructed wavefront. These are discussed next. (16) and (17), we may eliminate the fields Ei2 and Er2 in the boundary conditions at (b), expressed by Eqs. 9 Two beams of planar wavefront, 633-nm coherent light, whose directions are 120° apart, strike a photographic emulsion of index 1.6. a. The new wavefront KI includes point I on the interface and is tangent to the two wavelets at points M and N, as shown. Schawlow and C. The two effects are physically distinct and described by different equations. 13 Show that a wave function, expressed in complex form, is shifted in phase (a) by p>2 when multiplied by i and (b) by p when multiplied by i and (c) by p when multiplied by p when mu when viewing white-light fringes, formed in the same way. Other instruments dispense with secondary focusing lenses or mirrors and rely on concave gratings both to focus and to disperse the light. Some of the waveferont (arc SS;), however, overlap into the region of shadow. Land. For equal positive and negative fields, the response of the optical medium is not symmetrical in the case of the nonlinear (curved line) response. In traversing the Faraday rotator a second time, the polarization vector of the reflected light is rotated an additional 45° in the same rotational sense, so that it emerges horizontally polarized and encounters the polarizer at an angle of 90° with the polarization direction of the original beam. At the fiber input end there are losses due to the restrictions of numerical aperture, as well as losses due to inevitable reflections at the interface, the so-called Fresnel losses. 7 HIGHER-ORDER GAUSSIAN BEAMS The solution for the cylindrically symmetric Gaussian beam, derived earlier and displayed in Eq. (24), represents the lowest order—that is, fundamental—transverse electromagnetic mode that exists in the open-sidewall laser cavity. 7 Using Eqs. The ultraviolet radiation from excited mercury atoms is converted to visible light by stimulating fluorescence in a phosphor coating on the inside of the glass-envelope surface. 588 Chapter 27 Characteristics of Laser Beams Irradiance Profile The irradiance I carried by a harmonic electromagnetic wave is proportional ' to the square of the magnitude of the complex electric field strength E. The virtual mirror M₂ is constructed by imaging M through the beamsplitter reflecting plane. Thus Gaussian beams are modes of spherical mirror cavities. The aperture function EA1x, y2, involving amplitudes, may also be called the transmission function. Thus the virtual image of the print held at s = 25 cm is formed by the contact lens at a distance of 20 cm in front of the eye. Lasers and Electro-Optics, Cambridge: Cambridge essentially uniform irradiance over its cross section. Show that the rotational inertia of the hydrogen molecule about an axis through its center of mass is about I = 4.6 * 10-48 kg # m2. (b) Hyperbolic surface images object point O at infinity when O is at one focus and ni 7 no . 346 Chapter 14 Matrix Treatment of Polarization TABLE 2 SUMMARY OF IONES MATRICES I. When taken as a whole, however, the optical values that describe the schematic eve do faithfully represent the optical performance of a living, biological eve. In this position, the lens forms a virtual image subtending a larger angle aM at the eve. A special aperture, functioning as a field stop, is placed at the position of the intermediate image I. One means of creating a liquid-crystal display is illustrated in Figure 9. The photodetectors in CCD arrays have a quantum efficiency of as much as 80%. Layers are 1>4 thick at 1 = 550 nm. 105 Wave Equations due to a sound wave propagating in a gas—as mentioned earlier. By incorporating a sign convention, the equations developed from this diagram can be made to apply to any ray and to any spherical refracting surface. From either diagram, the angles subtended by object and image at the center of the lens are seen to be equal. Using the definitions for the refraction and translation matrices, set up the ABCD matrix for this element as follows: A CC B 1 = C n n¿ DS R3n¿ 0 1 n SC 0 n¿ t 1 n - n¿ 1S C R2n¿ 0 nS n¿ Pay particular attention to the sign conventions. As a result, a large population inversion grows in the gain medium. So, O¿P¿ is inverted, 1.5 cm long, and 5 cm to the right of L2. The aperture is placed directly in front of a lens of focal length 2 m. A camera uses a convex lens of focal length 15 cm. What radii of curvature lead to minimum spherical aberration? Compare the visibility when observing the interference of the two emerging from M3 along a direction at 90° relative to the first (not shown). The composite wave amplitudes A n at P (see Figure 4a) from n halfperiod zones can be expressed as A n = a1 + a2eip + a3ei2p + a3slightly increasing zonal areas, (2) a gradual decrease with n due to the inverse-square law effect as distances from P increase, and (3) a gradual decrease with n due to the obliquity factor. 9 Use a computer to calculate and plot the phase shifts on reflection as a function of angle of incidence for u 7 uc. Determine the location and size of the field stop, FS.

I (b) Irradiance function I = I0 a: b: sin u: p 2p l a 2l a b2 sin 2 a for the multiple slit of (a). 601 Characteristics of Laser Beams the defining equation for U, leads to 2iky 1 2ikx 1 1 0w g; 1 h - 1 0w h; 1 g - b + b + + 2 a a 2 g w q w 0z g w q w 0z h w w h (""")""* 1 2 + 0q 0p 2ik k2 2 b = 0 1x + y22a1 - 2k 2 q 0z 0z q (")"* (""")"* 3 4 (52) where the primes denote differentiation with respect to the arguments of g and h. Beam expander 2z0 2pw20 l Characteristics of Laser Beams 597 distance is the Rayleigh range z0. At lower pressure and current, sharper spectral lines appear to be nearer the surface than they actually are, since in this case $s_{\ell} = 11 > 1.332$ s = (3/4) s. Level 1 is the ground state and the nominal energy difference between the levels is E2 - E1 = hn0. A detailed analysis of this interaction 15 shows that the phase conjugate output beam has an amplitude that is proportional to the product of the amplitudes of the pump beams and the complex conjugate of the amplitude of the signal beam: (20) A 4 r A 1A 2A *3 Now, since the two pump beams are oppositely directed, the complex amplitudes on the right-hand side of Eq. (20) can be written as B # B A 1 = f A 1 f eik1 r, B # B B # B A 3 = f A 3 f eik3 r A 2 = f A 2 f e -ik1 r, so that B # B A 4 = f A 1 f f A 2 f f A 3 f e -ik3 r B B Thus, $k_4 = -k_3$ and A 4 is proportional to the complex conjugate of A 3 . Holography alternating between minimum and maximum, then multiple diffracted images are virtual, localized fringes and cannot be projected onto a screen. The use of finite sampling intervals across a finite total sample width or window leads to limitations both in the resolving power of the instrument and in the minimum wavelength that is unambiguously handled by the transform calculation. Equations, giving reflected and transmitted B B E-field amplitudes to the incident E-field amplitudes to the incident E-field amplitudes to the incident E-field amplitude by the transform calculation. Recently, the relation between the group and phase velocities of light signals has gained prominence as researchers have succeeded in preparing propagation media approaches zero.2 The dependence of index of refraction on wavelength can take a variety of forms, depending upon the nature of the medium through which the signal is propagating. The corresponding field amplitude at P_{ℓ} is then proportional to DE 7 OE and so IP_{ℓ} 7 IP. In a dielectric where B rf = 0, Jf = 0 also. Find the threshold gain coefficient if R1 = R2 = 1, R3 = 0.95, and T3 = 0.05. On the other hand, as t0 : 0, approximating a harmonic "spike," ¢v: q. The sum of all these contributions is the phasor A 1. The radius R of the surface is also shown, passing through the center of curvature at C. TABLE 2 STANDARD RELATIVE APERTURES AND IRRADIANCE AVAILABLE ON CAMERAS A = f-number 1 1.4 2 2.8 4 5.6 8 11 16 22 1A = f-number 22 1 2 4 8 16 32 64 128 256 512 Ee E0 E0>2 E0>4 E0>8 E0>16 E0>32 E0>64 E0>128 E0>256 E0>512 72 Chapter 3 Optical Instrumentation D a M O M N s0 s0 s1 Figure 22 Construction illustrating depth of field MN. The wire grid polarizes microwaves much as a dichroic absorber polarizes optical radiation. Information is not lost, as would be the case in other memory devices, where every bit of information has its own unique storage coordinates. Fringe distortion over the surface is found to be less than onefourth the fringe separation at any point. Consider again the wave represented in Eq. (20). In this configuration, the LCD transmits light. (Here, we have 11 632.8 * 10-9 m rounded down to an integer.) a. Recalling that the multiplication of matrices is associative but not commutative, the descending order must be maintained. 3.6 mm (a) 0.81 µm; 0.525 µm; 0.585 µm; 0.5 infinity and (b) for a near point of 30 cm. Similarly, if the wavefront radius of curvature R1z12 at Mirror 1 is equal to RM1, the left-going beam will reflect from Mirror 1 without distortion and retrace its path to Mirror 2. Example 1 Find the approximate number of photons emitted in 1 s from a source that emits 1 W of light power at a wavelength of 500 nm. Electro-Optical Devices and Systems. For an object at infinity, incident rays are parallel and s₂ = - R>2, as illustrated in Figure 16a and b for both concave 1R 6 02 and convex 1R 7 02 mirrors. Stroke, George W. The use of three or more layer coatings makes possible a broader, low-reflectance region in which the response is flatter. If the original reference beam and the reconstructing beam are both collimated, what is the magnification of the holographic image, compared with the original subject? Field and Irradiance variation for several of the lower-order modes—small m and n— and thus predict the nature of the "burn" pattern. TABLE 3 KERR CONSTANT FOR SELECTED MATERIALS Material (l = 589 nm, room temperature) K (pm > V2) Nitrogen (STP) Glass (typical) Carbon disulfide 1CS22 Water 1H2O2 Nitrotoluene 1C5H7NO22 A * 10-6 0.001 0.036 0.052 1.4 2.4 523 524 Chapter 24 Nonlinear Optics and the Modulation of Light Kerr cells can be used as modulators in the manner described for Pockels cells. This ray leaves point P as a ray parallel to the optical axis, strikes the mirror, reflects and passes through the focal point F of a concave mirror—as in Figure 17a and b. Solution According to Eq. (22), 1¢u2min = 1.221550 * 10-9215 35 * 10-3 = 1.92 * 10-5 rad or about 4- of arc, using an average wavelength for visible light. Determine the percentage of light energy reflected in air from a single surface separating a material of index 1.40 for light of l = 500 nm. Many, however, preferentially start the trip back by a very fast (usually radiationless) decay from pump levels E3 to a special level, E2. 603 Characteristics of Laser Beams The Hermite-Gaussian Beam Solutions Now, collecting our results for p, q, g1j2, and h1h2, and putting them all to' gether in the general expression for the electric field E1x, y, z, t2 as initially introduced in Eq. (6), we obtain finally 'w0 22y 1-x2 + y22>w21z2 22x Hm a b Hn a be Emn1x, y, z, t2 = cE0 d * w1z2 w1z2 w1z2 ('''''')'' """* (66) amplitude ceik1x + y 2>2R1z2ei[kz - 1m + n + 12arctan1z>z02]e-ivteif d (""""")""* phase 2 2 It is standard to refer to the various waveforms distinguished by the different values of m and n as TEMmn modes. Assume a refractive index of 1 for the emulsion. The right side should be recognizable as the square of the sum of the individual amplitudes. As the screen is moved away from the aperture, the image of the aperture passes through the forms predicted in turn by geometrical optics, near-field diffraction, and far-field diffraction. These spontaneous emission events are then amplified by the action of stimulated emission within the gain medium. (Canrad-Hanovia, Inc.) 100 100 Mercury-xenon cathode tip 90 Relative spectral emission 142 90 80 80 70 70 60 60 50 50 40 40 30 30 20 20 10 10 0 0 240 260 280 300 320 340 360 380 400 420 440 460 480 500 520 540 560 580 600 620 Wavelength (nm) Figure 9 Spectral emission for Hg-Xe arc lamp. Consequently, the best solution is to use a single-mode fiber, 6 Actual values are somewhat better than predicted by Eq. (14) due to mode coupling or mixing (rays may switch modes in transit due to scattering mechanisms that, on the average, shift power from higher and lower modes to intermediate ones) and due to preferential attenuation (higher modes taking longer paths suffer greater attenuation and so contribute less to overall pulse spreading). If light corresponding to each orthogonal vibration travels with a different speed through such a retardation plate, there will be a cumulative phase difference, ¢w, between the two waves as they emerge. Along directions marked B, wave crests (or wave valleys) from both slits coincide, producing maximum irradiance. Typically blurred vision is a result of astigmatism mixed with myopia or hyperopia. When the diffracted rays are on the side of the grating normal. If the average irradiance on the entire screen is lav, what is the ratio IP>lav at the central maximum? As indicated in the figure, the inner surface of each glass plate. Alternatively, as discussed at the end of the next section, the change in the transmittance through a fixed-length Fabry-Perot cavity induced by a change in the frequency of the laser input field can be used as a feedback signal to stabilize the frequency of the laser source. Since the pulses is T = 1 ms. Let us ask for the equation of the appropriate refracting
surface that images objective. point O at image point I, as illustrated in Figure 12. The g() Properties of Lasers 0 Figure 2 Lineshape function by a prism under the condition of minimum deviation is most often utilized in practice. The radius of curvature R is positive when C is to the right of V, corresponding to a convex mirror, and negative when C is to the left of V, corresponding to a concave mirror. We also describe a quantitative measurements of interference take place. Far from resonance, vg V v20 - v2, and so the damping term in the denominator of the expression on the right-hand side of Eq. (11) can be ignored. Let us examine the factor 1sin Na>sin a22, which evidently describes interference between slits. From Eq. (25): m = 123 Superposition of Waves b. (b) Section of a sine wave at a fixed point. The dotted-line envelope moves with the group velocity and the high-frequency carrier wave moves with the phase velocity. Francon, and J. Frequency Mixing When two or more incident beams with different frequencies are allowed to interfere within a nonlinear displays—the CRT, the LCD, and the plasma display. What is the radius at which overlap takes place and the thickness of the air film there? a ls (a) s u r Figure 15 Michelson stellar interferometer (b). 6 PLASMA FREQUENCY Returning to the general case of Eq. (53) and introducing there the complex refractive index, we write 2 isc2m0 c n2 = a k b = 1 + v v11 - iv>g2 After multiplying to the general case of Eq. (53) and introducing there the complex refractive index, we write 2 isc2m0 c n2 = a k b = 1 + v v11 - iv>g2 After multiplying to the general case of Eq. (53) and introducing there the complex refractive index, we write 2 isc2m0 c n2 = a k b = 1 + v v11 - iv>g2 After multiplying to the general case of Eq. (53) and introducing there the complex refractive index, we write 2 isc2m0 c n2 = a k b = 1 + v v11 - iv>g2 After multiplying to the general case of Eq. (53) and introducing the end to the general case of Eq. (53) and introducing the end to the general case of Eq. (53) and introducing the end to the general case of Eq. (53) and introducing the end to the general case of Eq. (53) and introducing the end to the general case of Eq. (53) and introducing the end to the general case of Eq. (53) and introducing the end to the general case of Eq. (53) and introducing the end to the general case of Eq. (53) and introducing the end to the general case of Eq. (53) and introducing the end to the general case of Eq. (53) and introducing the end to the general case of Eq. (53) and introducing the end to the general case of Eq. (53) and introducing the end to the general case of Eq. (53) and introducing the end to the general case of Eq. (53) and introducing the end to the general case of Eq. (53) and introducing the end to the general case of Eq. (53) and introducing the end to the general case of Eq. (53) and introducing the end to the end the second term on the right-hand side of this equation by ig>ig, this becomes $n^2 = 1 - m^{0}s^2$ where we have made the square of a plasma frequency given by $v^2p = m^{0}c^2g = m^{0$ use of both Eq. (46) and the relation e0m0 = 1>c2. When a = b, the resulting pattern is, of course, that of a single slit. For concreteness, consider the situation shown in Figure 5a in which a wave traveling in the negative x-direction (solid line) encounters a barrier and is reflected (dashed line). This behavior contrasts with that exhibited in the closely related phenomenon of optical activity. The two slits S1 and S2 must fall within the lateral coherence width ls due to the primary slit of width s. If we imagine two coherent point sources of light radiating in all directions, then the condition given by Eq. (19) for bright fringes, s2 - s1 = ml (24) defines a family of bright fringe surfaces in the space surrounding the holes. Chopra, Kasturi L. In such a case, the system and its surroundings can be characterized by a common temperature, T. The spectacular improvement in three-dimensional photography made possible by the holography made possible by the h today also include its use in art and advertising. Figures 9a and b illustrate the astigmatic images of an off-axis point P due to a tangential fan of Circle of least confusion S Principal ray T ical Opt t axis s s to P (a) (b) T P S S F T Object plane S (c) (d) T Figure 9 (a) Astigmatic images T and S of an off-axis point P due to a tangential fan of Circle of least confusion S Principal ray T ical Opt t axis s s to P (a) (b) T P S S F T Object plane S (c) (d) T Figure 9 (a) Astigmatic line images T and S of an off-axis point P due to a tangential fan of Circle of least confusion S Principal ray T ical Opt t axis s s to P (a) (b) T P S S F T Object plane S (c) (d) T Figure 9 (a) Astigmatic line images T and S of an off-axis point P due to a tangential fan of Circle of least confusion S Principal ray T ical Opt t axis s s to P (a) (b) T P S S F T Object plane S (c) (d) T Figure 9 (a) Astigmatic line images T and S of an off-axis point P due to a tangential fan of Circle of least confusion S Principal ray T ical Opt t axis s s to P (a) (b) T P S S F T Object plane S (c) (d) T Figure 9 (a) Astigmatic line images T and S of an off-axis point P due to a tangential fan of Circle of least confusion S Principal ray T ical Opt t axis s s to P (a) (b) T P S S F T Object plane S (c) (d) T Figure 9 (a) Astigmatic line images T and S of an off-axis point P due to A standard devices a stand axial point P due to tangential 1tt/2 and sagittal 1ss/2 fans of light rays through a lens. 486 l 4 Chapter 22 Theory of Multilayer Films the film thickness is determined by the l>4 or l>2 requirement at a single wavelength. The integration of the spectral energy density over all frequencies gives the time-averaged energy density 80% of the electromagnetic field, [] r1n2 dn = 8u9 q r(n0) 0.5 0.035 0 g(n) 0 n n0 0 (a) 0.035 0 r(n0)g(n) n0 n (b) Figure 2 Broadband spectral energy density. Experimental confirmation of de Broglie's hypothesis appeared during the years 1927-1928, when Clinton Davisson and Lester Germer in the United States and Sir George Thomson in England performed experiments that could only be interpreted as the diffraction of a beam of electrons. Rate Equations for Monochromatic Light When the frequency width of the lineshape function g1n2, as is typically the case for laser light, the stimulated emission and absorption rates appearing in Eqs. The familiar fluorescent lamps use low-pressure, low-current electrical discharges in mercury vapor. Example 1 An electron is accelerated to a kinetic energy EK of 2.5 MeV. If the beams of 488-nm wavelength and the angle between the beams is 120°, how many grooves per centimeter are formed in a plane emulsion oriented perpendicular to the fringes? Thus, a flat film, situated at distance s0œ from the lens, intercepts circles of confusion corresponding to such object points. (a) 2.8 cm (b) 10 × 23. The antennas are separated by a distance of 23 km and each antenna radiates equally in all horizontal directions. Thus the boundary conditions for the electric field at the two interfaces become Ea = E0 + Er1 = Et1 + Ei1 (6) Eb = Ei2 + Er2 = Et2 (7) Corresponding equations for the magnetic field are $Ba = B0 \cos ut1 - Br2 \cos ut1 = Bt2 \cos ut1 - Br1 \cos ut1 = Bt2 \cos ut1 - Br1 \cos ut1 = Bt2 \cos ut1 - Br2 \cos ut1 = Bt2 \cos ut1 - Br1 \cos ut1 = Bt2 \cos ut1 - Br2 \cos ut1 = Bt2 \cos ut1 - Br1 \cos ut1 = Bt2 \cos ut1 - Bt1 \cos ut1 = Bt1 \cos ut1 - Bt1 \cos ut1 = Bt2 \cos ut1 - Bt1 \cos ut1 = Bt1 \cos ut1 - Bt1 \cos ut1 = Bt1$ one fringe! For a mirror translation ¢d, the number ¢m of fringes passing a point at or near the center of the pattern is, according to Eq. (4), ¢m = 2¢d l (8) Equation (8) suggests an experimental way of either measuring l when ¢d is known or calibrating the micrometer translation screw when l is known. 4 For what refractive index are the critical angle and (external) Brewster angle equal when the first medium is air? m = 801350 nm ¢L = = 776.502 L 776.5 114>n2 11548 nm2>11.5002 is very nearly an integer + 1>2. Consider the reflection grating of Figure 6, where a beam is incident on a groove face at angle ui and is diffracted at arbitrary angle u, both measured relative to the grating normal N. Thus, it is appropriate to seek approximate solutions, to Eq. (7), that vary slowly with z so that the following condition holds: `0 2U 0U 2k `i` 2 `V 0z 0z (8) That is, we are motivated to drop the term 0 2U>0z2 from the left side of Eq. (7). fly, t2 = A1y - Bt2 b. 1 A 1-mm-diameter hole is illuminated by plane waves of 546-nm light. Let the cavity mirrors M1 and M2 have reflectances R1 = R2 and let mirror M3 have reflectance R3 = 1 - T3 - A 3, where A 3 characterizes the output mirror absorption. The Elements of Nonlinear Optics. (10) and (9) for N such harmonic waves of the same frequency. We consider next the guantitative details of this design. The finesse, F, of the cavity. The plane of incidence is the plane containing the incidence is the plane containing the incidence of the principal interference maxima of orders 1, 2, 3, 4, and 5 relative to the central fringe of zeroth order. (See footnote 3.) b. As we define it, the propagation factor is the ratio of an electric field E(z, t) associated with a traveling monochromatic plane wave at position z = z0 + cEmbossed Holograms Rainbow holograms, sometimes referred to as "embossed holograms," are commonly used on credit cards and in other similar security applications. Thrierr, Atlas of Optical Phenomenon, Plate 19, Berlin: Springer-Verlag, 1962.) PROBLEMS 1 A collimated beam of mercury green light at 546.1 nm is normally incident on a slit 0.015 mercury green light at 546.1 nm is normally incident on a slit 0.015 cm wide. Englewood Cliffs, NJ: Prentice-Hall, 1964. y y TA1 along x x TA2 y 45 FA x TA2 at 45 to x ' 3 d E0 = c 2 + i SA along x x QWP 9 Specify the polarization mode for each
of the following Jones vectors: a. Cambridge: Cambridge abounding in nerve cells. What is the position and diameter of the exit pupil? Reading MA: Addison-Wesley Publishing Company, 1978. Nonlinear first order: P1 = e0x1E Nonlinear first order: P1 = e0x2E2 Nonlinear third order: P3 = e0x3E3 Classical optics: Materials lacking inversion symmetry: Second harmonic generation Four-wave mixing Kerr effect Raman scattering Brillouin scattering Optical phase conjugation Reflection Refraction Birefringence Absorption Second harmonic generation is not the only nonlinear phenomenon that results from the quadratic dependence of the polarized at 45° to the plane of incidence, two internal reflections produce equal-amplitude TE and TM amplitudes with a relative phase of p>2, or circularly polarized light. A Fabry-Perot etalon of length d can be inserted into a laser cavity of length 1 7 d in order to suppress all but a single laser mode. Thus the Fourier-transform spectrometers, by the presence of narrow slits that restrict both the wavelength interval and irradiance available at any one time. The h2 term is proportional to the expression a n1 n2 - n1 n2 b - a b + s s? R When this expression is set equal to zero, it reproduces the Gaussian formula for imaging by a spherical surface. Along each beam the E-field is shown—by the usual dot notation—to be pointing out of the page 1 - z-direction2, and the B B-field is shown in a direction consistent with Eq (1). The function (sin u)/u, often called simply sinc (u), shows up frequently. As long as we restrict our analysis to paraxial rays, this systematic approach is well handled by the matrix method. A sketch of these and several others of the comatic circles is shown in Figure 8c. The primary advantage of a pinhole camera (other than its elegant simplicity!) is that, since there is no focusing involved, all objects near and far are in focus (a) (b) Figure 19 Imaging by a pinhole camera. If a Schmidt-type correcting plane of refractive index 1.40 were installed to correct the spherical aberration, what would be the required difference in thickness between the center and edge of the plate? 13 What is the length of a half-wave dipole antenna designed to broadcast FM radio waves at 100 MHz? Another application involves a prism face brought near to the surface of an optical waveguide so that the evanescent wave emerging from the prism can be coupled into the waveguide so that the evanescent wave emerging from the prism can be coupled into the surface of an optical waveguide so that the evanescent wave emerging from the prism can be coupled into the surface of an optical waveguide so that the evanescent wave emerging from the prism can be coupled into the surface of an optical waveguide so that the evanescent wave emerging from the prism can be coupled into the surface of an optical waveguide so that the evanescent wave both attenuation (loss of amplitude) and distortion (change in shape) due to several mechanisms to be discussed. The polarizer easily B transmits light with E-vibrations along a transverse direction of absorption. This effect can be considered a special case of two-wave mixing, where one of the waves is the incident optical wave is the incident optical wave for the direction of absorption. and the other a field of zero frequency. 1 THE THICK LENS Consider a spherical thick lens, that is, a lens whose thickness along its optical axis cannot be ignored without leading to serious errors in analysis. This is most easily accomplished with the help of Eq. (23) which indicates that the amplitudes of E1P and E2P are b 1E0 and b 2E0 respectively. Thus an oblique pencil of rays due to off-axis object points is far more susceptible to aberration than corresponding axial points. This is due to visual clues like parallax, shadowing, and the particular perspective of familiar objects. (17) and (18) to make the following conclusions: 1. Suppose the compensator is constructed of quartz and provides a maximum phase retardation of two full wavelengths of green mercury light (546.1 nm). The tendency toward alignment is counteracted by the thermal motions of the other? Equation (32), describing the atomic population density N2, then becomes dN2 sI = Rp2 - k2N2 N dt hn; 2 We wish to develop a rate equation governing the photon number density Np in the cavity. In fact, it is possible that more cavity modes could be present in the output, but only if these modes utilize different spatial portions of the gain medium. The aperture (not shown) determines the useful diameter D of the lens. The dips in the gain curve have a frequency width roughly equal to the homogeneous gain bandwidth \$nH of the atoms whose center frequency corresponds to the cavity-mode frequency. If one of these pairs is blocked, that frequency is eliminated, or filtered from the illumination. In analogy with the holographic grating, it corresponds to zeroth-order diffraction. In Figure 1a, this is simply the aperture stop itself, so in this case, AS and EnP are identical. Light incident on this structure is scattered to a greater extent from regions of higher refractive index. (b) Propagation of a typical light ray through an optical fiber. Photographic Optics, 15th ed. Astigmatism The astigmatic eye suffers from uneven curvature in the surface of the refracting elements, most significantly, the cornea. Geometrical and Physical Optics, 2d ed. 0 vm1 vm Frequency of input field v Optical Interferometer is explored in problem 22. At what wavelength in first order does the grating direct the maximum energy when used with the incident ligh normal to the groove faces? Therefore, the frequencies of the modes of such a cavity are nm = m c 2d (15) As we have noted, one of the mirrors in a laser cavity must be partially transmitting in order to allow for laser output. Figure 10 shows the GRIN fiber profile, together with the profile of the ordinary step-index fiber for comparison. Although R = r2, T Z t2. As a dispersing element, the grating is superior to a prism in several ways. In the limit of very large irradiances, the inversion tends to zero. This partial shielding of the outer portion of the image by the aperture for off-axis object points is called vignetting. Basic Concepts in Relativity and Early Quantum Mechanics. The superposition of electromagnetic (EM) waves may be expressed in terms of their electric or magnetic fields by the vector equations, B B B = B1 + B2 In general, the orientation of the electric or magnetic fields must be taken into account. Of the incident wavelengths, only one will refract at the precise angle that conforms to the case of minimum deviation, as shown, with the light rays parallel to the prism base AE. Today digital cameras typically use CCD arrays with resolutions ranging from 1024 * 768 pixels to 3032 * 2008 pixels. (Reproduced by permission from "Atlas of Optical Phenomena", 1962, Michael Cagnet, Maurice Franco and Jean Claude Thrierr; Plate 10(top). If no change has occurred since recording the hologram, the view appears as if the subject or the hologram alone was in place. In the latter case, the spectrum may be scanned by rotating the spherical surface provides, in fact, about 73% of the total refractive power of the eye. Using the spherical surface refraction equation (see Table 1), n1 n2 n2 - n1 + = s s R and AB = a Concave (b) Figure 28 Cylindrical lenses shown as sections of a solid and hollow cylindrical rotation of sugar c 1 0 d -i HWP, SA horizontal eip>4 c 1 0 0 d -i HWP, SA horizontal eip>2 c 1 0 d -i HWP, SA horizontal eip>2 c 1 0 d -i HWP, SA horizontal eip>4 c 1 0 0 d -i HWP, SA horizontal eip>4 c 1 0 d -i solutions is often used to determine concentration, via Eq. (4).6 The dependence of specific rotation on wavelength TABLE 2 SPECIFIC ROTATION OF QUARTZ 6 1 1nm2 r 1degrees>mm2 226.503 404.656 435.834 546.072 589.290 670.786 201.9 48.945 41.548 25.535 21.724 16.535 Ordinary corn syrup is often used in the optics lab to demonstrate optical activity. Pedrotti. The reflection of an intense laser beam of wavelength 694.3 nm from a ruby laser is easily seen. Gravitational wave detection would open a new window to the universe in much the same way that the development of infrared,
ultraviolet, and X-ray "telescopes" dramatically increased our store of knowledge regarding astronomical events. (b) Concave lens. Find the difference in frequency between two wavelength channels near 1550 nm that differ in wavelength by 0.8 nm. Vertical linearly polarized light is shown incident on a rotator in Figure 10. Determine the actual thickness of the layers. At what angle of diffraction does the beginning of overlap occur in each case for a grating of 1200 grooves/mm? Thus, neff for an axial ray depends only on the core index; for a ray at the critical angle, it depends only on the cladding index. That is, in the case of air, N. 20 Find the values of all the quantities listed in the first column of Table 2 for a mirror reflection coefficient of 0.999. Wavelengths present in the input radiation, which are smaller than a particular lmin, show up as longer wavelengths in the transformed spectrum. For example, refer to Figure 1a. An important difference between X-ray diffraction and light scattering occurs in a continuous manner from a thick, sinusoidal grating, rather than from discrete planes. The magnification, according to Eq. (22), is m = 1 -1.3321 +92 2 = + 1121 -302 5 The final image is, then, 2>5 the lateral size of its (virtual) object and apears with the same orientation. If the width of the second is 1/. In different modes of operation, one of these quantities is typically varied while the others are held constant. An evacuable cell with plane, parallel windows is interposed in the path of beam 3 (Figure 1a) and is filled with a gas at a pressure and temperature for which its index of refraction is desired. Solution Using Eq. (15), W = 2110 m 21546 * 10-9 m 2 Ll = 0.0218 m = 21.8 mm b 0.5 * 10-3 m Even highly collimated laser beams are subject to beam spreading as they propagate, due to diffraction.This general behavior is very similar to the behavior of a beam that passes through a circular aperture. The image is virtual, located behind the mirror surface. A right-handed object, however, appears left-handed in its image. of the laser beam at a given point in space. The ability to view a hologram with radiation of a wavelength different than that used in making the hologram offers other interesting possibilities. When the population inversion decreases to the level at which the gain per round-trip through the cavity, the nuous wave operation. Dispersion for a silica fiber is shown in Figure 11. Determine the normal reflectance for light of wavelength (a) 800 nm; (b) 600 nm; (c) 400 nm. The cladding around the fiber cores has another important function, which is to prevent what is called frustrated total internal reflection from occurring First-order diffraction u1 Incident light beam Zero order Modulated beam Piezoelectric crystal AM signal 24 Nonlinear Optics and the Modulation, reflection, reflection, reflection, reflection, and birefringence, fall in the category of what is called linear optics. Find the wavelengths of the light at P, deduced from the Fresnel zone scheme, is at variance by p>2 relative to the phase of the light reaching P directly along the axis. (1) and (2) requires knowledge of the form of the spectral energy density r1n2 and lineshape function g1n2. The density of the silver atoms, and thus the opacity of the film, is a measure of both the irradiance and the time of exposure, so that photographic film, unlike many other detectors, has the advantage of light-signal integration. The thicker, double-headed arrows indicate stimulated processes, and the lighter, single-headed arrows indicate decay processes. Optically active materials include both solids (for example, quartz and sugar) and liquids (turpentine and sugar) and liquids (turpentine and sugar). In this case, each fringe of one set can be followed down the film edge into the corresponding fringe of the second set, as in Figure 20. These boundary conditions require that the components of both the electric and magnetic fields parallel to the boundary plane be continuous as the boundary is crossed. In the visible and near ultraviolet, then N could not be less than about 67,000 without jeopardizing the correct analysis of wavelengths as small as 300 nm. Fraunhofer diffraction does, however, as in the case of the pattern formed by a point source and a lens. In contrast, we now turn our attention to what is referred to as spatial, or lateral, coherence, the correlation in phase between spatially distinct points of the radiation field. Optics for Clinicians, 2d ed. If the rods are each adjusted to a quarter wavelength for a TV channel that has a middle frequency of 90 MHz, how long are the rods? The composite diffraction pattern for the wire is shown in the photograph of Figure 17. Take l = 550 nm. (a) elliptically polarized with semi-axes E0x and E0y aligned with coordinate axes (b) elliptically polarized with principal axes at 45° to co-ordinate axes (c) circularly polarized, centered at origin, radius of E0 (d) linearly polarized with slope E0y /E0x Chapter 17 22. If N is small so that a1 aN, then for N odd the resultant amplitude is near zero. It is often a simple convex lens but may be a doublet or a triplet, thereby providing for higher-quality images. The small surface is oriented such that its normal makes an angle of 45° with the axis joining the centers of the two surfaces. If the optical-path difference at this time is d1, then from Eq. (4), 2d1 2d1 = + N (11) l i Let the optical-path difference at this time is d1, then from Eq. (4), 2d1 2d1 = + N (11) l i Let the optical-path difference at this time is d1, then from Eq. (4), 2d1 2d1 = + N (11) l i Let the optical-path difference at this time is d1, then from Eq. (4), 2d1 2d1 = + N (11) l i Let the optical-path difference at this time is d1, then from Eq. (4), 2d1 2d1 = + N (11) l i Let the optical-path difference at this time is d1, then from Eq. (4), 2d1 2d1 = + N (11) l i Let the optical-path difference at this time is d1, then from Eq. (4), 2d1 2d1 = + N (11) l i Let the optical-path difference at this time is d1, then from Eq. (4), 2d1 2d1 = + N (11) l i Let the optical-path difference at this time is d1, then from Eq. (4), 2d1 2d1 = + N (11) l i Let the optical-path difference at this time is d1, then from Eq. (4), 2d1 2d1 = + N (11) l i Let the optical-path difference at this time is d1, then from Eq. (4), 2d1 2d1 = + N (11) l i Let the optical-path difference at this time is d1, then from Eq. (4), 2d1 2d1 = + N (11) l i Let the optical-path difference at this time is d1, then from Eq. (4), 2d1 2d1 = + N (11) l i Let the optical-path difference at the optical-pat 1 1e0E2a e0 B b = EB = e0cEB 1m0 1e0m0 (38) Inserting this result into Eq. (37), S = e0c2EB (39) The power per unit area, S, when assigned the direction of propagation, is called the Poynting vector. Adjustment by a micrometer screw allows small changes in ¢w to be made. Consider first a one-dimensional wave pulse of arbitrary (but time independent) shape, described by y_i = f1x_i2, fixed to a (moving) coordinate system O_i1x_i, y_i2, as in Figure 1a. For example, notice that the N - 2 = 3 secondary maxima appear between the principal maxima for the case N = 5. The emission lacks both temporal and spatial coherence. A crystal having a center of symmetry is characterized by an inversion center, such that if the radial coordinate r is changed to - r, the crystal's atomic arrangement remains unchanged and so the crystal responds in the same way to a physical influence. In this section, we describe briefly the properties of the different types of atomic and molecular gain media and list a few examples of each. Notice that the ordinary ray is polarized perpendicular to the OA and so propagates with a refractive index of no = n = c>y . 18 A He-Ne laser has a beam waist (diameter) equal to about 1 mm. Finally we have noted [see problem 2] that for nearly monochromatic fields, 8u9 = I>c, where I is the irradiance of the electromagnetic fields, 8u9 = I>c, where I is the irradiance of the electromagnetic fields. together in the laser medium to produce amplification of light. Take the gain bandwidth of an argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the linewidth of an individual mode from the argon ion laser to be 2 GHz and the argon ion laser to be 2 GHz and the argon ion laser to be 2 GHz and the argon
ion laser to be 2 GHz and the argon ion laser to be 2 GHz and the argon ion laser to be 2 GHz and the argon ion laser when k g = a b D sin u = 3.832 2 or when D sin u = 1.22l (20) The irradiance pattern of Eq. (19) is plotted in Figure 8a. At this position the object subtends an angle a0 at the eye. (a) +1 in y-direction (b) -C/B in x-direction 9. The corresponding f-numbers, then, form a geometric series with ratio 22, as in Table 2. Formed plastic pieces such as a drawing triangle or safety glasses, often show such variations due to localized birefringent regions associated with strain. In this case, 22>11 A 2 = 2.93 mm. Figure 5 Construction to prove the law of reflection from Hero's principle. The Kerr Effect When the optical medium is isotropic, as in the case of liquids and glasses, the Pockels effect is absent and the polarization is modified by the thirdorder [in the expansion of the medium, see Eq. (3)] electro-optic effect. Using Eq. (21), w0 = 21c0>p = 21632.8 * 10-92 112>p m = 4.49 * 10-4 m = 0.449 mm. Then assuming that it is appropriate to use the smallsignal result given in Eq. (25), IL = 10e -1 = 10e -a0L L = 1>a0 = 0.33 cm Thus Nd atoms deeper than about 0.33 cm would not absorb much of the pump energy. What should their difference in thickness be such that they function together like a zeroth-order QWP? The spectral energy density r1n2 has a dimension of energy per volume per frequency interval. Appropriate refractive indices for mica are 1.599 and 1.594. This is also clear from Figure 4b, a phasor diagram in which each zone is subdivided into 15 subzones. 21. The eye positioned near the eyepiece—at the ExP— then sees a virtual image, inverted and magnified, as shown. Show that the number of bright fringes seen under the central diffraction peak in a Fraunhofer double-slit pattern is given by 21a>b2 - 1, where a/b is the ratio of slit separation to slit width. Thus the phase conjugate wave precisely retraces the path of the original beam and, at each position, reproduces the exact shape of the original wavefront. That is, gain saturation occurs. 610 References Welford, W. The imbalance in the circuit, due to the change in resistance, is indicated by a change of current in the bridge circuit. A good corrective lens forms, therefore, virtual images of real objects located anywhere from about 25 cm from the eye to very far from the eye to very far from the eye at positions where the unaided defective eye sees clearly. Light entering Input 1 of the fiber interferometer is split at a four-port fiber coupler, FC1. Determine the refractive index of a coating material and the thickness required to produce zero reflection for light of wavelength 550 nm. The condition for reinforcement must also be satisfied by a second point on the exit side of the hologram, a point I that is symmetrically placed with O_c relative to the plate. The chief ray in the cone of rays leaving object point O¿ is shown in all three systems of Figure 1. What reflectance is produced at 2 mm? This separation of colors is referred to as rotatory dispersion. In the superposition of incoherent beams, individual amplitudes add together, whereas in the superposition of incoherent beams, individual amplitudes add together. irradiances add together. Before continuing with applications of these equations, we must take into account the necessary modification of the theory that results when the incident electric field of Figure 1 has the other polarization, that is, in B the plane of inci B dence. u u Circularly polarized light 23 Incident light u Fresnel Equations INTRODUCTION The basic laws of reflection and refraction in geometrical optics were derived earlier on the basis of either Huygens' or Fermat's principles. L. Thus, the ratio MP¿>PM (magnification for the lower pencil). Notice that for ¢ 1 = l>2 or any even multiple of a quarter-wavelength, the reflectance is just that from the uncoated glass. 20 The lens on a 35-mm camera is marked "50 mm, 1:1.8." a. 490 Chapter 22 Theory of Multilayer Films a. Calculate the overall magnification of the telescope. The bandwidth of many gas gain media, like He-Ne and Ar+, for example, are primarily due to Doppler broadening. 53' 8. What is the coherence time and length of the light from the monochromator when set to give light of mean wavelength 500 nm? 14 Reproduce the curves shown in Figure 7 but extend the maximum length of the gain cell on the plot to 10 cm. When qx and qy are both zero, the functions coincide, yielding a product curve with the maximum area and correlation. Generally speaking, the radii of curvature of the corneal surface in two meridional planes (those containing the optical axis) are unequal. A typical normal dispersion curve and the nature of the resulting color separation are shown in Figure 12. (a) -i(1.24 m) (b) for each, approximately, 50 m -i(1.24 m) (c) 0.51 mm (c) 0.5 mm (d) 0.4 mrad (e) ≥ 64.6 m (f) 1.22 μ W/cm2 1 0 (b) [-0.53125 1] (a) 1.88 m (b) 1.88 m (c) (-0.952 m)i (d) ACq1 q2* + BD+ADq1* + BCq1 A2 q1 q1* + B 2 = R 1(l) + i 2 w22 (l) (e) l $\cong 6$ cm; w2 (l) $\cong 0.54$ mm 10. 447 Aberration Theory positive and negative lenses produce spherical aberration of opposite sign. It is possible, by employing an appropriate sign convention, to represent all cases by the single equation 2 1 1 = + s s? R (12) The sign convention to be used in conjunction with Eq. (12) is as follows. Polarized light can be produced by passing unpolarized light through one of a variety of optical systems that transmit only a particular polarization of light. In other words, 1 0 y0 2 6 3 4 5 a0 T y7 x0 x a7 7 x7 Figure 4 Steps in tracing a ray through an optical system. Upon each traversal, the TM mode is completely transmitted, whereas the TE mode is partially reflected (rejected). In his treatise Optics, Newton clearly regarded rays of light as streams of very small particles emitted from a source of light and traveling in straight lines. 5 A step-index fiber 0.0025 in. As a trivial but satisfying case, observe that when a = b, Eq. (30) requires that all orders (except p = 0) are missing. The pump field will induce a Stokes field at a frequency less than that of the pump field. In such a case, the "graininess" of the power in the signal is likely to go undetected. The irradiance at the peak of the central principal maximum (at a = 0) is I = N 210. Sternberg. Show that Malus' law follows in the ideal case. As a result, nearly all of the laser power is concentrated at the focal point of the laser power is concentrated at the focal power is concen the plate faster than the horizontal component. The luminous efficiency at the same wavelength: £ y112 = 685V112 for each watt of radiant power. Whereas sound waves propagate through a material medium, light waves propagate in vacuum The low Q of the cavity prevents growth of the intracavity irradiance and so spontaneous emission and incoherent decay processes are the only drains on the population of the upper lasing level. Browne, Introduction to the Theory of Determinants and Matrices (Chapel Hill: University of North Carolina, 1958). 0.2 mm 1 Two mutually coherent beams having parallel electric fields are described by 2d Problem 5. Note the difference in each ray P 2 3 2 1 P P 2 I 3 C O F 2 1 3 V 3 C F O V I P 1 1 (a) (b) 1 3 1 P 3 2 2 O P V I (c) F C Figure 17 Ray diagrams for spherical mirrors. Figure 15b shows the actual energy level diagram for a helium-neon laser, with the four steps described in Figure 15a clearly identified. It is interesting to note that this criterion is also used in the production of modern digital audio recordings, where an audio signal sampling rate of 50 kHz. Expressed in terms of our experimental parameters, the criterion states equivalently that, to avoid aliasing, the sampling interval must be less than half the smallest wavelength present in the source. In this way, spherical aberration and coma are eliminated. Thus, the Bessel function J1, which oscillates somewhat like the sine function, as shown in the plot of Figure 7. Assume the light propagates from left to right: F 1. Greater ease of observation is also achieved if the exit pupil is a little larger in diameter than the eye pupil, allowing for some relative motion between eye and b = f z f sin u, it is also possible to 'express z by ' z = f z f loss u + i sin u2. The expression in parentheses is, by Euler's formula, eiu = cos u + i sin u (13) ' ' z = f z f eiu (14) b u = tan-1 a b a (15) so that where ' The complex conjugate z ... is simply the complex conjugate z ... is half-angle ao is possible. (b) Tungsten lamp with pinhole. Figure 16 shows the same four-step process while focusing on the behavior of the atoms in the laser medium and the photon population in the
laser cavity. 21 How fast does one have to approach a red traffic light to see a green signal? Klein, Miles V. In this arrangement a region of intrinsic (undoped) material is layered between the p-type and n-type materials. Rare-gas atoms have filled outer shells and so tend not to bond to other atoms. The radiation pattern and size of the light source may also be ill-adapted to the fiber end, reducing input efficiency. What is a photon? Thus only those times during which the waves coincide—when w1t2 = w1t + t2—contribute to the integral, and we are left with g1t2 = a 1 - t ivt be t0 (29) The real part of g, required in Eq. (27), is given by Re [g1t2] = a 1 - t b cos vt t0 (30) and so takes on a maximum value of 1 when t = 0 (equal path lengths), a value of 0 when t = t0 (path difference equals coherence length), and values between 0 and 1 for t between t0 and 0. This is followed by a vacuum-evaporated overcoat of aluminum. In fact, rays emanating from an object point that are incident on an optical axis, after reflection, either intersect, or to the viewer appear to intersect, at different positions. Check your results using the ordinary lens equations. The internal ray continues, diminished in amplitude, to D, then to E, and so on. Other gases or vapors may be used to provide spectral lines of other colliding atoms, they act to interrupt the regular oscillation of the charge in the atom. S c r e e n 2 Call the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at some other point in the pattern I. Weisskopf, Richard F. Thus, we can say that only fields of frequencies given by n = 1En - Em2 ¢n ; K nO ; h 2h 2call the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the irradiance at the central Fraunhofer diffraction maximum of a single slit IO and the are likely to have a significant interaction with the pair of atomic levels with energies En and Em . The object is 14 cm in front of the lens. If the etalon is used in the vicinity of wavelength 546 nm, determine (a) the highestorder fringe in the interference pattern, (b) the ratio Tmax>Tmin , and (c) the resolving power When energy alone is recorded, the phase relationships of waves arriving from different directions and distances, and hence the visual lifelikeness of the scene, are lost. The far point with the corrective lens is therefore 53 cm from the eye. It is instructive to apply Babinet's principle at a point where Eu = 0. In PRK, the laser removes the corneal epithelium (topmost surface) and then recontours the underlying layers as needed. Thus, the same bundle of rays that fills the entrance window also fills the field stop and the exit window. The image of the aperture stop formed by the optical elements (if any) that precede it. Light traversing the cell thus encounters two refractive indices, ne and no , for polarizations parallel and perpendicular to the optic axis, and phase retardation results. Cavity mode frequencies are separated by nfsr = 0.15 GHz. For all three plots the gain coefficient at linecenter g01n02 is twice the threshold gain coefficient at line plots the gain bandwidth is 1 GHz. The small-signal gain coefficient at line plots the gain bandwidth is 1 GHz. quantity of radiant power reaching an element of area dA2 on surface S2 due to the source element dA1 on surface S1. Assume that the nominal arm length is L = 4 km and that the light makes an average of 50 round-trips in each arm of the interferometer. 6 INHOMOGENEOUS BROADENING The homogeneous gain bandwidth results from the broadening of the frequency response of each atom in the medium. 537 Optical Properties of Materials B When the applied E-field is static, there is no oscillation of the electron vanishes. d 2u l (c) 303 The Diffraction Grating Interference gratings produced by such optical techniques are also called holographic gratings, since a grating of uniformly spaced, parallel grooves can be considered as a hologram of a point source at infinity. Hg lamp Slit 1 mm Filter Figure 24 S c r e e n Mirror 1m 5th min. In a formal sense, the solution was achieved through the creation of quantum electrodynamics, one of the most successful theoretical structures in the solution was achieved through the creation of quantum electrodynamics, one of the most successful theoretical structures in the solution was achieved through the creation of quantum electrodynamics, one of the most successful theoretical structures in the solution was achieved through the creation of quantum electrodynamics, one of the most successful theoretical structures in the solution was achieved through the creation of quantum electrodynamics, one of the most successful theoretical structures in the solution was achieved through the creation of quantum electrodynamics, one of the most successful theoretical structures in the solution was achieved through the creation of quantum electrodynamics, one of the most successful theoretical structures in the solution was achieved through the creation of quantum electrodynamics, one of the most successful theoretical structures in the solution was achieved through the creation of quantum electrodynamics, one of the most successful theoretical structures in the solution was achieved through the creation of quantum electrodynamics, one of the most successful theoretical structures in the solution was achieved through the creation of quantum electrodynamics, one of the most successful theoretical structures in the solution was achieved through the creation of quantum electrodynamics, one of the most successful theoretical structures in the solution was achieved through the creation of the solution was achieved through the creation of quantum electrodynamics, one of the solution was achieved through the creation of quantum electrodynamics achieved through the creation of quantum electrodynamics achieved through the cr annals of physics. These dark pixels are used to form the patterns of numbers and letters used in the calculator and watch displays. The effective focal length f of two thin lenses, separated by a distance L, is given by 1 L 1 1 + = f f1 f2 f1f2 (35) where f1 and f2 represent the individual focal lengths of the pair. Excimer Lasers The gain medium in an excimer laser is a rare-gas halogen mixture. 2E0xE0y cos e The ellipse is situated in a rectangle of sides 2E0x and 2E0y. Aperture plane Spectrum plane waves in the continuous distribution intersect the xy-plane along the straight lines defined by Eq. (8). It scans a scene as expansive as the overhead sky or focuses on detail as small as the head of a pin Notice that points A and C lie on a common wavefront of such waves. When the fiber is thin enough so that only one mode (a ray in the axial direction) satisfies this condition, the fiber is said to be single-mode. As shown in Figure 9a, the input plane thus coincides with the first focal plane of the optical system. Prism Spectrometers An analytical instrument employing a prism as a dispersive element, together with the means of measuring the prism angle and the angles of deviation of various wavelength components in the incident light, is called a prism spectrometer. So, we must solve 11m + n2 0pi = 0zq1z2 pw21z2 (63) to obtain an expression for p(z). These are u = a + w and 2u = a + az which combine to give a - a_i = -2w (10) Using the small-angle approximation, the angles of Eq. (10) can be replaced by their tangents, yielding h h = -2 s s_i R 4 For example, for angles w around 1.5%. Two quartz plates are optically contacted so that they produce opposing retardations. Since the function is even in t, the coefficients bm are found to vanish, and only cosine terms (also even functions of t) remain. 25-27. An ink drawing of 20 zones is made with alternate zones shaded in, and a reduced photographic transparency is made of the drawing. For h = 1 mm, s' = 98.20 mm, $' = -0.567^\circ$; for h = 5 mm, s' = 102.45 mm, $' = -2.723^\circ n - n$ Chapter 19 1. New York: John Wiley and Sons, 1975. A concave primary reflector in (a) receives small bundles of parallel rays from various directions. How do the results differ when the two refractive indices are interchanged? Working in the field of electricity and magnetism, James Clerk Maxwell synthesized known principles in his set of four Maxwell equations. Observe that the corresponding sides of the two angles u are related such that
OX S1S2, and OP is almost exactly perpendicular to S1Q. The Fourier transform or spectrum of this composite transmission function is formed in the output plane, that is, the diffraction pattern there is described by q C[E11-x, - y2E21x, y2] = O -q E11 - x, - y2E21x, y2ei1xkx + yky2 dx dy (25) To concentrate only on the direct beam, or DC component, in the pattern, we set the spatial frequencies kx and ky equal to zero so that q C[E11- x, - y2E21x, y2]DC = O -q E11 - x, - y2E21x, optical, axis. (7) and (8) become +q f1x2 = L-q g1k2e-ikx dk (9) +q g1k2 = 1 f1x2eikx dx 2p L-q (10) 2 FOURIER ANALYSIS OF A FINITE HARMONIC WAVE TRAIN The spectral resolution of an infinitely long sinusoidal wave is extremely simple: It is one term of the Fourier series, the term corresponding to the actual frequency of the wave. If the crown glass prism has a prism angle of 15°, determine (a) the required prism angle for the flint glass and (b) the resulting "mean" deviation for the D line. In this case, even with anisotropy of electron-binding forces, there is little or no effect on optical absorption, and the material does not appear dichroic. If the path length difference is as found from part (a), find the ratio of the irradiances exiting through the two output ports if the inequality associated with the Heisenberg uncertainty relation is consistent with the inequality inherent in Eq. (15). (d) Porro prism. The absorption follows the usual expression for attenuation, I = I0e -ax where I0 is the incident irradiance at depth x of absorber. Note the change in transverse irradiance at depth x.) d. It should be emphasized that the indices of refraction involved in optical activity characterize circular birefringence ratherester. than ordinary birefringence. Directed distances separating their corresponding planes are defined in the drawing. For an inhomogeneous medium with a Gaussian lineshape function, as is appropriate for Doppler-broadened media, the gain saturation irradiance IS is that for the group of atoms with a center frequency at the cavity-mode frequency. TM linearly polarized light incident at Brewster's angle is fully transmitted at the first surface. Color CRT displays typically use three different phosphors packed closely together in strips or clusters in a repetitive pattern on the display screen. Suppose that source B is at the position of source or that the distance s in Figure 13 is zero. The order number m for a diffraction grating is, of course, much less. The same can be said of the magnetic field vector, which also maintains an orientation perpenb B dicular to the electric field vector such that the direction of E * B is everywhere the direction of wave propagation. The Ronchi ruling acts as a coarse grating, producing a series of bright spots that correspond to the various orders of diffraction. This ideal condition is not quite achieved in Polaroid H-sheet, which is less effective at the blue end of the spectrum. In this chapter, we introduce a convenient matrix description of polarization developed by R. 18 a. changes in its elevation and direction. As we shall see, such a relation is possible only to first-order approximation of the sines and cosines of the angles made by the object and image rays to the spherical surface. Calculate its focal length and refracting power in its actual environment, surrounded on both sides with fluid of effective index 1.33. This is shown schematically in step 3, where the incident resonant photon approaching from the "left" leaves the vicinity of an N2 atom in duplicate. Then kr cos u = k # Br - vt2 (22) In this form, Eq. (20) becomes B c = A sin1k # Br - vt2 (22) In this form, Eq. (20) becomes B c = A s Figure 6b. (Assume that the light beam is normal to the glass surface.) Solution Using Eq. (8), $l = 12210.0732 \ 2\cd = = 4.87 \ * 10-9 \ 2 \ APPLICATIONS \ * 10-9 \ APPLICATIO$ OF THE MICHELSON INTERFEROMETER The Michelson interferometer is easily adaptable to the measurement of thin films, a technique essentially the same as that described in the optical interferometer. Furthermore, it can be shown that if the reconstructing light of wavelength lr is longer than the wavelength ls used in "holographing" the subject from film) and q is the corresponding image distance (image from hologram). Estimate the "full width-at-half-depth" of each absorption dip. Up to this point we have been dealing with a cylindrical lens whose axis is either horizontal or vertical. Thus, the parabolic profile shown in Figure 10 is optimum. These four modes continue to grow while all others die out. Above is another quartz wedge, with relative motion possible along the inclined face. In general, several different cavity modes might have frequencies within the bandwidth of the gain medium and so see significant gain. 4 PARTIAL COHERENCE As pointed out previously, when the phase difference between two waves is constant, they are mutually coherent waves. The deformations of the water surface represent an acoustic hologram. This angle is the blaze angle of the grating. Ch. 4.1: "Radiometry and Photometry." McLaughlin, R. The net effect of the action of both components is to cause the unusual bending of the extraordinary ray shown in Figure 12. Constructive Interference Figure 2 aillustrates the case of constructive interference in which the individual waves being superposed are "in step" in the sense that the peaks of the waves occur at the same times. In the limit of very large irradiances, the spontaneous emission process becomes negligible, leading to a near equalization of population densities. Of course, ex and ey may be negative quantities. R1z2 = q at z = 0 and z = q. The same sign convention also applies to the angles um and ui: When um is on the opposite side of the grating normal relative to ui, as in Figure 3, it is considered negative. 35, 36. What is the angular separation between the secondorder principal maximum and the neighboring minimum on either side for the Fraunhofer pattern of a 24-groove 6 cm Lens Grating red Figure 13 blue 650 nm m3 Problem 2. The laser cavity is designed so that the beam emerges from a surface area ¢AS = 2.5 * 10-3 cm2 at the output mirror. The dips in the transmittance through the oxygen cell indicate that the oxygen cell indicate that the oxygen cell indicate that the oxygen molecule strongly absorbs
these frequencies. fiber is always available, regardless of the original nature of the signal. 14 527 528 Chapter 24 Nonlinear Optics and the Modulation of Light if the acoustic Bwave Bis reversed in direction, the corresponding vector triangle B is satisfied by k $\xi = k + kS$. This ensures that the beams are essentially coherent. Either deviation from normal length impairs the ability of the combined refracting elements, cornea and lens, to form a clear retinal image of objects located at both remote and nearby positions. This cosmic background radiation is important evidence supporting the Big Bang theory of the origin of the universe. The result is M = c cos2 u sin u cos u d sin2 u linear polarizer, TA at u (15) which includes Eqs. (28) and (29) are satisfied at the same point in the pattern (same u), dividing one equation by the other gives the condition for missing orders. The zeroth-order diffraction principal maximum, for which there is no dispersion, represents a waste of light energy, reducing grating efficiency. Obviously, other choices—an infinite number of themare possible, so that Jones matrices, like Jones vectors, are not unique. Exit pupil is the stop; entrance pupil is 4.29 cm behind the lens, inverted, and 3 cm long. If the image is 10.5 cm behind the lens, with an aperture of 3.43 cm; image is 10.5 cm behind the lens, inverted, and 3 cm long. analyzing this special case without having to do the explicit integration of Eq. (7). The prism rotation may be calibrated in terms of angle, or better, in terms of angle, or better, in terms of wavelengths, lc = 6563 A ° IF = 4861 A. For a normal beam. u = 0 and c p = 2d. The required focal length is 30 cm. 469 470 Chapter 21 Fourier Optics aberration-free system. G is just the function describing the Airy pattern. Principal planes in general do not coincide and may even be located outside the optical system itself. Operation in high orders further severely restricts available light because of the diffraction envelope constraint, unless means are taken to redirect the central diffraction peak into the desired order. We place a small object on axis at a distance of 16 cm from the left end of a long, plastic rod with a polished spherical end of radius 4 cm, as indicated in Figure 10. Light from the object is incident on the convex cylindrical surface of the lens. (46) and (47) considerably. For example, the host of the Nd:YAG laser is a crystal of yttrium aluminum garnet (commonly called YAG), whereas the laser atoms are the trivalent neodymium ions. Determine (a) the angle of refraction of the laser beam into the film; (c) the magnitudes of r; and tt2, using the Stokes relations and a reflected beams; (f) the independent amplitudes of the first two transmitted beams; (f) the minimum thickness of film that would lead to total cancellation of the reflected beams when they are brought together at a point by a lens. (b) As the irradiance in the cavity modes above threshold grows, the gain coefficient is reduced due to gain saturation. If crown glass optics is used in bringing the light to the entrance slit, what is the first wavelength in the spectrum that may contain secondorder lines? the hole in the narrow wavelength region 5500-5510 A 11 At a given temperature, lmax = 550 nm for a blackbody cavity. Both the negative (electrons) and positive (holes) charges increase the electrical conductivity of the sample. Even if the image were otherwise perfect, the effect of using a limited portion of the wavefront leads to diffraction and a blurred image, which is said to be diffraction limited. The inset illustrates the sign convention for ray angles. N1 N2 NP1 NP2 Figure 2 Illustration of the nodal planes (NP1 and NP2) of an optical system. 136 Chapter 6 Properties of Lasers Boltzmann distribution3 indicates that in thermal equilibrium, atoms are more likely to be in states with lower energies. If the radiance is determined at each angle u, it is found to be constant, because the intensity must be divided by the projected area A cos u A (14) Thus, when a radiating (or reflecting) surface has a radiance that is independent of the viewing angle, the surface is said to be perfectly diffuse, or a Lambertian surface. Solution We first need a matrix that represents the eighth-wave plate, that is, a phase retarder that introduces a relative phase of 2p>8 = p>4. Suppose we design a laser with a beam waist of 0.25-cm radius and a wavelength of 200 nm. Assume a 100% efficient polarizer. 344 Chapter 14 Matrix Treatment of Polarization direction that is perpendicular to the TA is represented by the Jones vector 1 c d. The center of the destructive interference. (b) TM mode. New York: Springer-Verlag, 1978. Using Eq. (22) with w0 = 4.49 * 10-4 m, z = -1 m, and z0 = 1, w21z2 = 14.49 * 10-422[1 + 1 - 1>122] m giving w1z2 = 6.35 * 10-4 m 0.64 mm. The hologram is then a grating hologram, formed by the intersection of two plane wavefronts of light arriving at the plate along different directions. These can be produced when high-energy electrons strike a metal target and are Nature of Light used as diagnostic tools in medicine to see bone structure and as treatments for certain cancers. General Superposition The general case of the superposition of two waves that are neither in step nor out of step is depicted in Figure 2c. 56 Chapter 3 Optical Instrumentation irradiance near the center. At what angle of incidence relative to the silver planes is a wavelength of 450 nm reinforced? Assume l = 589 nm. 2 cm Figure 18 a. Normal incidence is assumed. Here, m = 0, ;1, ; 2, Å . 453 Aberration for an off-axial object point and displays both longitudinal chromatic aberration (LCA) and lateral or transverse chromatic aberration (TCA). The thicker the emulsion and the greater the number of contributing reflecting planes, the more selective the hologram will be in reinforcing the correct wavelength. Courtesy of John Sohl. The reconstructed wavefront provides depth perception and parallax, allowing us to look around the edge of an object to see what is behind. These positions are most simply found by regarding the assembly including S, M1, and beams 1 and 3 of Figure 1a as rotated counterclockwise by 90° about the point of intersection of the beams with f = -100 cm and s = 25 cm, the virtual image distance s_i is found from $1 \ 1 \ 1 + = s \ s_i$ f or $1 \ 1 \ 1 + = 25 \ s_i - 100$ Solving gives s; = - 20 cm. Because the correcting plate is situated at the center of curvature of the mirror, it presents approximately the same optics to parallel beams arriving from different directions and so permits a wide field of view. The third ray usually drawn for thin-lens diagrams is one through the lens center, undeviated and negligibly displaced If the source radiates uniformly in all directions, determine its radiant intensity. Summarize the important differences in the behavior of the three-level gain medium considered in problem 3. However, the depth of this image will not be 3>4 the object depth, as for paraxial rays, and in general will vary with the angle of viewing. The conjugate image point P; marks the tip of the image—the entire image then lies between P; and the point on the optical axis directly above or below P;. The output of a variable-frequency diode laser is divided at a beam splitter so that part of the laser beam is incident on a Fabry-Perot cavity of fixed length and part of the laser beam passes through a sample cell containing atmospheric oxygen, as shown in Figure 21a. Similarly, along the other transverse direction, perpendicular to the y,z-axes in the plane of the page, bx = s;da n2 dx (3) The longitudinal ray aberration bz is related to the lateral ray aberration bz by bz = s;by by tan u = (4) y 2 THIRD-ORDER TREATMENT OF REFRACTION AT A SPHERICAL INTERFACE Let us solve now the case of refraction from a single effects. Noting that d = 2kd, we now express the finesse using the cavity length d as the independent variable: F = kdfsr dfsr 2d1 > 2 = dfsr 2kcd1 > 2 =2 di >2 Therefore, 2 di >2 = dfsr F = 1 2F Using the relation in Eq. (37) and imposing the resolution criterion illustrated in Figure 13, ¢dmin = = = 1 d d 2dF (38) 209 Optical Interferometry dmin 1.2 Scaled transmittance 1 0.8 ll 12 0.6 0.4 0.2 0 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 Change in cavity length (mm) The resolving power, R, of a Fabry-Perot interferometer is the inverse of this ratio: R K l 2dF = mF = ¢lmin l (39) Here, m = 2d>l is the mode number associated with the nominal wavelength l and nominal cavity length d. (a) The waves move in opposite directions along the xaxis, E1 to the left, with equal speeds of 43 m/s. The longitudinal chromatic aberration of a convex lens may easily be comparable to its spherical aberration for rays at widest aperture. The normal dispersion curve shown is typical but varies somewhat for different materials. d L x Polarizer Modulating voltage Nonlinear Optics and the Modulation of Light Eq. (7) becomes 1 = 2 + RE 2 2 n n0 or $f \notin n f = R 3$ 2 nE 2 0 (10) Experimentally, the difference between ne and no is found to obey a relation of the form ¢n = KE 2l (11) where K is the Kerr constant. Since the energy "graininess" is less for long-wavelength radiation. Kerr cells usually contain nitrobenzene or carbon disulfide in the space between two electrodes across which a voltage is applied, as indicated in Figure 8. Equation (42) can be used in Eq. (41) to give the desired expression for the steady-state irradiance at the output end of the gain cell. B The treatment is valid also for cases of unpolarized light, in which the E field can be represented by two (randomly phased) orthogonal components. The explanation of the interaction of electromagnetic radiation, n = A + B>12. System A clearly shows the best performance. It was Louis de Broglie who saw the other side of the picture. $a_1Q2 = a_21Q2 - a_21Q2 = cr_2 4 - b42$ (2) P \Leftrightarrow Q O B h
\Leftrightarrow C S u Q r r \Leftrightarrow O b B P Detail Figure 5 Imaging of off-axis point P. From Eq. (2), Snell's law can be approximated by (b) n1 tan u1 n2 tan u2 (3) and taking the appropriate tangents from Figure 9b, we have x x n1 a b = n2 a b s s? (c) n1 n2 u2 (3) O I1 n1 n2 (2) (1) x u2 n2 n2 I3 I2 n1 u1 s (d) Figure 8 mirror. The spacing of the interference fringes depends on the separation ls. L1: Since lens L1 is the first element, it acts as its own entrance pupil. An unobstructed wavefront is modeled by passage through an aperture with a vertical dimension 2 that ranges from - q to + q . 1 APPLICATIONS The simplest use of optical fibers, either singly or in bundles, is as light pipes. When it is required that one see sharp and detailed information—while removing a small splinter with a needle, for example— the eyes move continually so that light coming from the area of interest falls precisely on the fovea, a rod-free region about 200 mm in diameter. 16 Determine the difference in deflection angle for a He-Ne laser beam that is Bragg-scattered by an acoustic plane wave when the frequencies are 50 MHz and 80 MHz. The acoustic crystal is sapphire, with n = 1.76 and a sound speed of 11 km/s. The wave-particle controversy was resumed with vigor. The light spreads out in spherical waves from the source S according to Huygens' principle and is allowed to fall on a plane with two closely spaced holes, S1 and S2. (2) and (3), we find a0 = 1 an = a 2 np b b sin a np 2 so that the Fourier series that converges to the square wave of Figure 2 as more terms are included in the summation is 2 np 1 + a cabd cos mvt b sin a np 2 2 m=1 q f1t2 = Writing out the first few terms explicitly, f1t2 = 1 2 1 1 + a cos vt - cos 3vt + cos 3vt infer a similar law for Gaussian spherical waves by simply replacing R(z) with q(z). If yp 6 yg, their relative motion would, of course, be reversed. Approximately how large a spot would be produced on the surface of 376,000 km away from such a device, neglecting any scattering by the earth's atmosphere? In general, a minimum in spherical aberration is associated with the condition of equal refraction by each of the two surfaces, calling to mind the case of minimum deviation in a prism. When the field stop is located in an image plane, the entrance window lies in the conjugate object plane, where it outlines directly the lateral dimensions of the object field imaged by the optical system. Energy Quantization in Matter Atoms are composed of charged particles and so interact with electromagnetic fields. Q-switching refers to the periodic change of the loss rate of a cavity in Figure 13 Laser turn-on and approach to steady state. weak radiation can be detected by the cumulative effect of a long exposure. One of the LIGO instruments uses interferometer arms that are 4 km long. Light composed of two different (free-space) wavelength components 11 and 12 Output 2 r2 1 2 Output 1 M1 Figure 16 Standard and fiber Mach-Zehnder interferometers. We explore this relationship in Example 4. When the muscles are tensed, the shape of the lens becomes increasingly curved, providing increased refraction of light. Light from an object at the myopic near point (M.N.P.) closer in, thereby again ensuring clear vision for the myopic eye. This apparent contradiction results from our choice of B phase in the formulation of the E-field in Eqs. The basic molecular unit of calcite is CaCO3, which assumes a tetrahedral or pyramidal structure in the crystal. The lens specifications (all dimensions in mm) are as follows: R1 R2 R3 R4 = = = -120.8 - 34.6 - 96.2 - 51.2 t1 = 6 t2 = 2 t3 = 3 n1 = 1.521 n2 = 1.581 n3 = 1.514 Solution Since the rays are parallel to the axis, the second column of Table 3 is used to calculate the progress of the ray. The refractive index (and so the velocity) of the extraordinary (E) ray varies with direction through the crystal. However, there is no focusing of rays in a horizontal section, such as the pairs of rays 1 and 4, 2 and 5, or 3 and 6, along the line x = y, z = 0 c. New York: Academic Press, 1964. The interfering beams are collected at detector D. Then the reflection at A occurs with light going from a lower index nf, a condition usually called external reflection. This is achieved through blazing, to be discussed presently. One arm of the device is 2 cm longer than the other, and the wavelength of the light is 500 nm. Data: r1 r2 r3 r4 r5 r6 = = = = = = 19.4 mm - 128.3 mm - 57.8 mm 18.9 mm 311.3 mm - 66.4 mm t1 = 4.29 mm t2 = 0.93 mm t3 = 1.6110 d1 = 1.63 mm d2 = 12.90 mm t3 = 3.03 mm n1 = 1.6110 d1 = 1.63 mm d2 = 12.90 mm t3 = 3.03 mm n1 = 1.6110 d1 = 1.63 mm d2 = 12.90 mm t3 = 3.03 mm n1 = 1.6110 d1 = 1.63 mm d2 = 12.90 mm t3 = 3.03 mm n1 = 1.6110 d1 = 1.63 mm d2 = 12.90 mm t3 = 3.03 mm n1 = 1.6110 d1 = 1.63 mm d2 = 12.90 mm t3 = 3.03 mm n1 = 1.6110 d1 = 1.63 mm d2 = 12.90 mm t3 = 3.03 mm n1 = 1.6110 d1 = 1.63 mm d2 = 12.90 mm t3 = 3.03 mm n1 = 1.6110 d1 = 1.63 mm d2 = 12.90 mm t3 = 3.03 mm n1 = 1.6110 d1 = 1.63 mm d2 = 12.90 mm t3 = 3.03 mm t3 = 3. n_{c} and t = 0.208 Chapter 8 Optical Interferometry The wavelength difference is, then, $l_{2} - l_{1} = \psi l_{2} + 2 \psi d_{1} + 2 \psi d$ illustrated in Figure 8d. The lamp approximates a 3000-K gravbody source, providing a useful continuum from 0.3 to 2.5 mm. In other words, the effective aperture due to the AS is its image formed by the lens, the dashed line marked EnP. The TA of the Polaroids in a pair of sunglasses is therefore fixed in the vertical direction so as to reduce the partially polarized "glare" from reflection while still blocking only one-half of unpolarized light incident on the sunglasses. In accordance with this result, the minimum resolvable angular separation of two object points may be reduced (the resolving power P P dn l = b 1¢l2min dl (24) where we have incorporated Eq. (23). Pattern Recognition Another area in which holograms may be very useful is in pattern recognition. If the grid is rotated by 90°, the vertical B B E-vibrations are transmitted and the horizontal E-vibrations are canceled. This occurs because the departures from monochromaticity of each beam, while still present, will be correlated since both beams come from the system and through the glass of the beam splitters are identical. If this heat energy is not removed from the system and through the glass of the beam splitters are identical. If this heat energy is not removed from the system and through the glass of the beam splitters are identical. If this heat energy is not removed from the system and through the glass of the beam splitters are identical. If this heat energy is not removed from the system and through the glass of the beam splitters are identical. = 1 d 1 correct matrix is linear polarizer, TA at 45° (14) In the same way, a general matrix representing a linear polarizer with TA at angle u can be determined. The fraction of power P in the incident wave that is reflected or transmitted, called the reflectance and the transmittance, respectively, depends on the ratio of the amplitudes. (b) Lineshape function for the 2 to 1 transition of the atoms in (a). It is convenient to also define the normalized correlation function, g1t2 K e0cb 1 b 2 \neq 1t2 e0c interference term, is a function of t and therefore of the location of point P. New York: John Wiley and Sons, 1972. In Figure 31, the objects with a relaxed eye and objects as near as 25.5 cm from the eye with a fully accommodated eye. In this section we discuss the underlying broadening mechanisms that determine the width ¢n of the lineshape function and distinguish between homogeneous and inhomogeneous broadening mechanisms. At the remote end of the Signal Carrier FM modulated Figure 2 Three forms

of modulation in which a carrier wave is modified to carry a signal. It was first observed in 1971-1972 by researchers in the Soviet Union. Write a wave equation for this wave (a) that exhibits directly both wavelength and period; (b) that exhibits directly both models (b) that exhibits directly both models (b) that exhibits directly both wavelength and period; (c) in complex form. Use the results of your experiment to estimate the diameter range of your own pupils. In closing this section, we point out that both the saturation irradiance IS and the small-signal gain coefficient g0 are functions of the electromagnetic field frequency n_d, since they each depend on the cross section s, which in turn is proportional to the lineshape function g1n_d2. The light illuminates a double slit of spacing 0.1 mm. Calcite is birefringent in the visible spectrum, for example, and strongly dichroic in certain parts of the infrared spectrum. In Figure 15b, the pump energy (step 1) is supplied by an electrical discharge in the low-pressure gas mixture, thereby elevating ground state helium atoms to higher energy states, one of which is represented by the 21S level. Since the images S1; and S2; of the source plane in the mirrors must be separated by twice the mirror separation, the distance between Q1œ and Q2œ is 2d, and the optical-path difference ¢ p between the two beams relative to the optical axis. The design of an objective or an eyepiece is directly related to the performance of other optical elements in the instrument, often including a relay lens within the body tube of the microscope as well. Cosmic Background Radiation In 1965, Arno Penzias and Robert Wilson at the Bell Labs discovered that the earth is bathed in isotropic blackbody radiation with a spectral irradiance consistent with a color temperature of 2.7 K. The three rays leaving the tip of the object change direction due to refraction at the thin-lens interfaces. The notion that light interacts with matter by exchanging photons of definite energy, momentum, and polarization will serve us well several chapters hence when we consider laser operation. Measurement of both prism angle and minimum deviation of the sample determines n. A small fish in the tank is 20 cm from the lens. 18 Using the cardinal point locations (Table 2) in terms of the matrix elements for a general thick lens (problem 17), verify that f1 and f2 are given by Eqs. Example 1 Fringes are observed due to monochromatic light in a Michelson interferometer. A nonselective detector is one that depends only on the radiant flux, not on the wavelength. As a result, the energy of the electromagnetic wave passing by the atom is increased by one quantum hn; of energy. 15 A thin film of MgF2 1n = 1.382 is deposited on glass so that it is antireflecting at a wavelength of 580 nm under normal incidence. Chaps. Compare the coherence lengths of the light from each. 5 Consider an amplifying medium composed of homogeneously broadened four-level atoms like the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y x Figure 7 Polarized Light from each. 5 Consider an amplifying medium composed of homogeneously broadened four-level atoms like the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y x Figure 7 Polarized Light y at the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y at the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y at the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y at the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y at the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y at the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y at the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y at the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y at the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y at the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y at the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y at the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y at the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y at the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y at the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y at the one depicted in Figure 5. 355 356 Chapter 15 z O Production of Polarized Light y at the one depicted in Figure 5. 355 356 Chapter 15 z O Producting y at the one depicted in Figure 5. 355 356 Chapt mean that the medium, unlike a metal, contains no free charges. Refractive indices of quartz at this wavelength are n 7 = 1.555 and n = 1.546. Proceeding to the case of a phase retarder, we desire a matrix that will transform the elements E0xei/wx + ex2 E0yei/wy into E0yei/wy + ey2 and where ex and ey represent the advance in phase of the Ex- and Ey-components of the incident light. 10 cm 15 A slit illuminated with sodium light is placed 60 cm from a straight edge. In turn, the particulates reflect the radio wave back towards the source. h a Q s w I C Reflection at a spherical rays of light originating at O are drawn, one normal to the spherical surface at its vertex V and the other an arbitrary ray incident at P. If d>1 is small enough to make mmax 6 2, the fiber allows only the axial mode to propagate. A grating spectrograph is to be used in first order. of the entrance pupil formed by the eyepiece, we may write for the linear, transverse magnification, me = - f fe = x f0 (51) where x is the distance of the object (objective lens) from the focal point of the eyepiece, or f0. (b) Equal foci result in residual lateral chromatic aberration. The electromagnetic vacuum has 12 hn of energy at all frequencies, in all directions, and is randomly phased and so can induce the atom to emit photons in any direction and with any frequency that the atom to emit and so can induce the atom to emit and so can induce the atom can emit. light from Path 1 suffers no phase shift upon reflection into Output 1 while light from Path 2 suffers a p phase shift upon reflection into Output 2. The myopic correction, always measured in the meridian of least refractive power, is found in this instance to be - 2.00 D, along the horizontal meridian. 11 Refer to the externally focused TEM00 laser beam shown in Figure 10, with beam waist w01/2 = 0.54 mm, located at 0.06 m from the output element. The radiant power is d2 £ 12, a second-order differential because both the source and receptor are elemental areas. Mie scattering takes into account the size, shape, refractive index, and absorptivity of the scattering particles and includes Rayleigh scattering as a special case. 20 Two identical, thin, plano-convex lenses with radii of curvature of 15 cm are situated with their curved surface each second. Phase Matching The same nonlinear interaction that allows conversion of energy in the fundamental electromagnetic wave of frequency v into energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy conversion in the other direction. However, the outermost electromagnetic wave of frequency 2v also allows for energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy in the second harmonic electromagnetic wave of frequency 2v also allows for energy piece of paper, or over an illuminated pinhole, two images are seen while looking into the top surface. Thus, using Eq. (24) we can write I1r, z2 = I0 a w0 2 -2r2>w21z2 b e w1z2 (25) Here, I0 is the maximum irradiance, which occurs at the center of the beam waist. Is the image erect or inverted? If E is interpreted as the amplitude of a compressional wave, the result holds for sound intensities as well. Its essential components are shown in Figure 14. This permits us to write both waves with the same amplitude. Determine the Verdet constant for the line image formed by the lens. If the light source and slit, grating, and plate holder are placed in a dark room at three stable positions determined by the Rowland circle and the grating equation, the basic requirements of the Paschen-Runge spectrograph are met. (A spherical-mirror Fabry-Perot cavity was used in the experiment and so the transmittance includes peaks corresponding to both longitudinal and transverse modes.) 19 Plot the transmittance, T, as a function of cavity length, d, for a scanning
Fabry-Perot interferometer with a monochromatic input of wavelength 632.8 nm if the finesse, F, of the cavity is 15. Not surprisingly, the higher quantum efficiency associated with CCD detectors led to their early adoption by astronomers seeking to form and record images of faint astronomical sources. The remaining term on the right-hand side of Eq. (50) is due to pressure broadening, which contributes a term proportional to the rate of collisions, rcol, of the gain atoms with each other and with other species in the gain medium. Thrierr, Atlas of Optical Phenomenon, Plate 17, Berlin: Springer-Verlag, 1962.) the slit are comparable and small, each produces appreciable spreading, as illustrated in Figure 5b. 291 Fraunhofer Diffraction 18 Calculate by integration a is three times the slit width b. Calculate nR and nI for a dielectric, in terms of KI, at frequencies high enough such that KI = KR. Assume that the absorption cutoff is 350 nm for crown glass and 180 nm for quartz. 11 A concave reflection grating of 2-m radius is ruled with 1000 grooves/mm. The optical electric field can be small, since the DC field is itself large enough to produce nonlinear behavior. Thus it is generally not possible to interchange objectives and evepjeces between different model microscopes without loss or deterioration of the image. 37. 121 Superposition of the physically interesting case of the reflection of an electromagnetic field from a plane conducting mirror (and the analogous case of the reflection of a transverse wave in a string from a rigid boundary). This oscillation appears in a quantum-mechanical treatment of the atom as an alternating transition between the upper and lower laser states. distant object at the vertex of the primary mirror. 560 Chapter 26 Laser Operation change of the irradiance qI given in Eq. (36) becomes constant. When either is known as a function of frequency, MTF is the modulation transfer function. Discontinuities occur at uc = 41.8°, up = 56.3°, and upœ = 33.7° for refractive indices of n1 = 1 and n2 = 1.50. It will be shown in the following treatment that the spectral distribution, or spectrogram (irradiance versus wave number), of the light incident on a Michelson interferometer is just the Fourier transform of the irradiance versus wave number), of its two-beam interference as a function of mirror movement. To apply the equation to the silver layers in an emulsion I and u should be taken to be the wavelength and angle in the emulsion. The Design of Optical Spectrometers. In addition, the sine and cosine functions; that is, a linear combination of terms like those in Eq. (3) can be found to represent any periodic waveform. For a white light source the coherence length is about 1 mm; laser sources have coherence lengths that range formed is the result of an object point "at infinity," which produces parallel rays at the lens. On the other hand, for a point P¿ above P, we conclude that relative to its axis SO¿P¿, all of the 326 Chapter 13 Fresnel Diffraction P \diamond Q \Rightarrow Q P \diamond Q P (a) S(y) Ip Iu 1.5 2.5 E 0.5 1.0 2.0 \ge 0.5 P \diamond P P \diamond Vertical screen position (b) Figure 14 (a) Straight-edge diffraction. Find (a) the total number of grooves required; (b) the number of grooves required; (b) the number of S(y) Ip Iu 1.5 2.5 E 0.5 1.0 2.0 \ge 0.5 P \diamond P P \diamond Vertical screen position (b) Figure 14 (a) Straight-edge diffraction. Find (a) the total number of grooves required; (b) the number of grooves required; (b) the number of S(y) Ip Iu 1.5 2.5 E 0.5 1.0 2.0 \ge 0.5 P \diamond P \diamond P P \diamond Vertical screen position (b) Figure 14 (c) Straight-edge diffraction. Find (c) S(y) Ip Iu 1.5 2.5 E 0.5 1.0 2.0 \ge 0.5 P \diamond P \diamond grooves per millimeter on the grating with a blaze angle of 22°12¿; (c) the minimum width of the grating. Whereas the longer-than-normal myopic eye has too much convergence in its "optical system" and requires a converging lens to correct its over-refraction, the shorter-than-normal myopic eye has too little convergence and requires a converging lens to correct its over-refraction. to increase refraction. reflectance = R = Pr Er 2 = a b Pi E (31) transmittance = T = Pt cos ut 2 = na bt Pi cos ut 2 = na bt Note that y plays the role of a universal, dimensionless variable, allowing one Cornu spiral to serve for various combinations of p, q, and l. provides a nearly monochromatic beam of light. Solution From Eq. (23), $l = a cy > L = 10.0002 \text{ m} 213.29 \times 10^{-3} \text{ m} 2 > 11 \text{ m} 2 = 6.58 \times 10^{-7} \text{ m} = 658 \text{ m} \text{ According to Eq. (21)}$, $l = a cy > L = 10.0002 \text{ m} 213.29 \times 10^{-3} \text{ m} 2 > 11 \text{ m} 2 = 6.58 \times 10^{-7} \text{ m} = 658 \text{ m} \text{ According to Eq. (21)}$, $l = a cy > L = 10.0002 \text{ m} 213.29 \times 10^{-3} \text{ m} 2 > 11 \text{ m} 2 = 6.58 \times 10^{-7} \text{ m} = 658 \text{ m} \text{ According to Eq. (21)}$, $l = a cy > L = 10.0002 \text{ m} 213.29 \times 10^{-3} \text{ m} 2 > 11 \text{ m} 2 = 6.58 \times 10^{-7} \text{ m} = 658 \text{ m} \text{ According to Eq. (21)}$, $l = a cy > L = 10.0002 \text{ m} 213.29 \times 10^{-7} \text{ m} = 658 \text{ m} \text{ According to Eq. (21)}$, $l = a cy > L = 10.0002 \text{ m} 213.29 \times 10^{-7} \text{ m} = 658 \text{ m} \text{ According to Eq. (21)}$, $l = a cy > L = 10.0002 \text{ m} 213.29 \times 10^{-7} \text{ m} = 658 \text{ m} \text{ According to Eq. (21)}$, $l = a cy > L = 10.0002 \text{ m} 213.29 \times 10^{-7} \text{ m} = 658 \text{ m} \text{ According to Eq. (21)}$, $l = a cy > L = 10.0002 \text{ m} 213.29 \times 10^{-7} \text{ m} = 658 \text{ m} \text{ According to Eq. (21)}$, $l = a cy > L = 10.0002 \text{ m} 213.29 \times 10^{-7} \text{ m} = 658 \text{ m} \text{ According to Eq. (21)}$, $l = a cy > L = 10.0002 \text{ m} 213.29 \times 10^{-7} \text{ m} = 658 \text{ m} \text{ According to Eq. (21)}$, $l = a cy > L = 10.0002 \text{ m} 2 + 10.002 \text{$ therefore can reduce the response time of the photodiode. 5 WHITE-LIGHT (RAINBOW) HOLOGRAMS If the hologram of Figure 3 is viewed with a reference beam of color different than that used in its construction, it can be shown that the image of the fish will appear at a different angle. A combination of pinhole and lens is used to expand the beam from a laser. Since y is a function of two variables, x and t, we use the chain rule of partial differentiation and write $y = f1x_2^2$ where $x_2 = x$; yt so that $0x_2 > 0x = 1$ and $0x_2$ 2y 0x2 = 1 0 2y y2 0t2 (2) Any wave of the form of Eq. (1) must satisfy Eq. (2), regardless of the physical nature of the signal frequency, vs = vp - vi. Transmittance is then just the square of the transmission. The glass medium is bounded by two spherical refracting surfaces. What is the value of R1, the radius of the first Fresnel half-period zone, relative to the detector? Assume that the l1 component exits through Output 1. In these instances, the beam waist w01 may be of the order of a centimeter or more, thereby ensuring that the inequality pw 201>l 1z1 - f22 is satisfied. What is the plate factor in first order when the grating is used in a Czerny-Turner mounting with mirrors of 3.4-m radius of curvature? That is Thus, $\psi = 4$ R2 $\psi = 4$ R2 radius R1, we find that r0 = f1 > 3 and n = 3. The eye sees a point image at S₂ in exactly the same way it would see a real point object placed there. For lossless mirrors with $R1, 2 \equiv |r1, 2|2$, $(1-R1)(1-R2) = r1 + 4\sqrt{R1} R2$ in $/2 = r1 + 72 (1 + \sqrt{R1} R2) + 4\sqrt{R1} R2$ in $/2 = r1 + \sqrt{R1} R2$ (47) for zero reflectance of three-layer,
quarter-quar object point Q. If this lens is used for objects in water, with air on its opposite side, determine its effective focal length and sketch its focal and principal points. The generated difference wave is known as the idler wave. In this chapter we regard light as an electromagnetic wave and show that the laws of reflection and refraction can also be deduced from this point of view. The four-port fiber couplers FC1 and FC2 act as beam splitters. When a CCD is exposed to light, each of the discrete devices fabricated on a silicon chip, say, stores photo-induced charge in a potential well created by an applied gate voltage. With so many reflections occurring, the condition for total internal reflection must be accurately met over the entire length of the fiber. 78 Chapter 3 Optical Instrumentation which both the primary and intermediate images are located just in front of the field lens. 13°18′ (a) 0.0823°/nm; 0.464 nm/mm (b) 63,000 (a) 8.66′ (b) 612.5 nm (or 587.5 nm) (c) 48; 48 987; 494 (a) 700 nm, 360 nm (b) 57.1°, 25.6° (c) 350 nm and 175 nm for crown glass; 180 nm and 90 nm for quartz 120,000; 0.069 Å (a) third order (b) any width smaller than light beam (a) 21.8 cm, in each case (c) 21.8 cm, in each case ((b) 18.4 Å/mm (a) 11.5° (b) 11.8° 3550 grooves/mm; reduces it (a) 3647 (b) 1200 grooves/mm (c) 3.04 mm (a) 557 to 318 (b) 960 (c) 388,800; 0.014 Å (d) 0.41°/nm (e) 5.5 Å Chapter 13 1. After reflection, each is transmitted by the beam splitter into a microscope MS, where they are allowed to interfere. These mathematical steps are easily performed with a programmable calculator or a computer. Broadband Electromagnetic Energy Density function g1n2. Determine the four matrix elements of the system matrix where the system extends from the first refraction at the cornea to the final refraction at the second lens surface. The electric field incident on the interferometer from the left is EI, the reflected field is ET, and E1+ is the right-going intracavity field at Mirror 1. Further, when I W IS the gain coefficient gas a function of scaled irradiance I>IS. In this section we will consider the case of a nondispersive medium in which (by definition) waves of different frequency travel with the same speed. The interfering wavefronts are photographed on a grainless film of photoresist whose solubility to the etchant is proportional to the irradiance of exposure. This behavior is required in order that the total energy exiting the interferometer be the same as that entering the interferometer. What is the transmittance of five layers of film, each with an opacity of 1.25? In the case of sound, this is the usual beat frequencies. Notice that the amplitude of the light emerging from the analyzer is E0 cos u. Both pulsed and continuously operating (cw) lasers are represented. Gas Molecular Lasers Molecules have energy levels corresponding to different rotational and vibrational states of the molecule, in addition to the states associated with different electronic configurations. The primary disadvantage is that, since the pinhole admits so little of the available light, exposure times must be long. The most useful of these lamps, designed to operate from 50 W to 25 kW, are the high-pressure mercury arc lamp, with comparatively weak background radiation but strong spectral lines and a good source of ultraviolet; the xenon arc lamp, with practically continuous radiation from the near-ultraviolet through the visible and into the near-ultraviolet through the mercury spectrum but with xenon's contribution to the continuum and its own strong spectral emission in the 0.8- to 1-mm range. 11 An optic-fiber cable 3 km long is made up of three 1-km lengths, spliced together. As Table 1 indicates, the inequality may be reversed in other materials. Thus, when the spectrum is not a simple one, the overlap ambiguity is often resolved experimentally by using a filter that removes, say, the shorter wavelengths from the incident light. In gas lasers the most important inhomogeneous broadening mechanism is Doppler broadening, due to the Doppler effect. The thin lenses are best represented, for purposes of ray construction, by a vertical line with edges suggesting the general shape of the lens—ordinary arrowheads for converging lenses. Since L = 0.004 m is a very small dimension compared with f R2 f = 2 m or f R3 f = 0.64 m, repeat the ABCD calculation, replacing the translation matrix with the unit matrix c 1 0 6 A TEM00 He-Ne laser 11 = 0.6328 mm2 has a cavity that is 0.34 m long, a fully reflecting mirror of radius R = 10 m (concave inward). Practically speaking, if one knows the Fourier transform of simple aperture functions, one can more easily calculate the 2 If the light is coherent, the sum is a vector sum of complex electric field amplitudes. Reflection coefficients of the beam splitter surfaces are indicated. Photographic plate and entrance slit are separated along a direction transverse to the plane of the drawing. The nodal points of a thick lens or of any optical system, permit the correction to this ray, as shown in Figure 2. This relation, for different values of the constant, describes concentric spherical surfaces with different radii. Or, as in Figure 17b, it leaves point P as if it is coming from the point F to its left (dotted line), strikes the concave mirror, and reflects as a parallel ray. Thus, using Eq. (45), y 525 = 1 c 513 y = - 0.0234c = - 7020 km/s. The stimulated emission process (step 3) occurs between the neon levels 3s2 and 2p4, the transition with the highest probability4 from 3s2 to any of the ten 2p states. (In this regard, one may recall the use of symmetrical lenses or lens combinations, such as the achromatic double meniscus objective, where the aperture is placed midway between them.) Consider then the off-axis pencil of rays from object point P, as shown in Figure 5. The core radius is 20 mm. Linearly polarized light is incident on the B plate such that the E-field vibrations are at 45° to the optic axis. It must be remembered that if N is to be increased within a given width W of grating, the grooves must be proportionately closer together. c d 5 2 e. (Englewood Cliffs, N.J.: Prentice-Hall, 1989), Ch. 4.2. 357 Production of Polarized Light along the y- and the z-directions. If the direction of the incident ray is described by its unit vector, rN 1 = 1x, y, z2; then the reflection causes z Q r² 2 O r¹ 1 y P x (a) rN 1 = 1x, y, z2; rN 2 = 1 + x, -y, -z2 r² and the ray returns precisely parallel to the line of its original approach. One purpose of modulation is to render the wave capable of carrying information. I1 I2 Air Thin film n t Air Figure 29 Problem 22. Only with the availability of intense, coherent light have these higher-order terms become important. Notice also that a field stop with reticle can be employed at the location of the intermediate image in the astronomical telescope, whereas no such arrangement is possible in conjunction with the Galilean telescope. The radiating surface, shown in Figure 4. In the paraxial approximation, the angles may be represented by their tangents, giving h>s a M 25 = a 0 s h>25 If the image is viewed at infinity, s = f and M = 25 f (33) image at normal near point of the eye, then $s_{c} = -25 cm$, and from the thin-lens equation, s = 25f 25 + f giving a magnification of M = 25 + 1 image at normal near point f (34) a M h h a0 (a) (b) s 25 cm Figure 24 Operation of a simple magnifier. Introduction to Fiber Optics. A photographic negative, at points of ideal opacity, may produce an amplitude E = 0 but cannot provide negative, at points of ideal opacity, may produce an amplitude E = 0 but cannot provide negative, at points of ideal opacity, may produce an amplitude E = 0 but cannot provide negative values. 31. Inhomogeneities whose dimensions are much greater than the optical wavelength can result, for example, from inadequate mixing of the fiber material before solidification and from an
imperfect interface between core and cladding. The primary mirror collimates the light incident on the grating. The magnitude of z, symbolized by $\int z \int z = a^2 + b^2$ Figure 3 Graphical representation of a complex number along real (Re) and imaginary (Im) axes. In fact, g0 r g1n¿2 and IS r 1>g1n¿2 The import of these relations for the operation of a gain cell is explored in problem 13. Piezoelectric crystal AM signal 90 prism Output beam Laser cavity HR mirror (1) (2) AO beam deflector HR mirror a thin AO material in the Raman-Nath regime. Accordingly, if a particular film (whose speed is described by an ISO number) is perfectly exposed by light from a particular scene 1 s and a relative aperture of f/8, it will also be perfectly with a shutter speed of 50 exposed by any other combination that gives the same total exposure, for ex1 s and an aperture of f/8, it will also be perfectly exposed by any other combination that gives the same total exposure, for ex1 s and an aperture of f/8, it will also be perfectly exposed by any other combination that gives the same total exposure, for ex1 s and a relative aperture of f/8, it will also be perfectly exposed by any other combination that gives the same total exposure, for ex1 s and a relative aperture of f/8, it will also be perfectly exposed by any other combination that gives the same total exposure, for ex1 s and a relative aperture of f/8, it will also be perfectly exposed by any other combination that gives the same total exposure, for ex1 s and a relative aperture of f/8, it will also be perfectly exposed by any other combination that gives the same total exposure, for ex1 s and a relative aperture of f/8, it will also be perfectly exposed by any other combination that gives the same total exposure, for ex1 s and a relative aperture of f/8, it will also be perfectly exposed by any other combination that gives the same total exposure, for ex1 s and a relative aperture of f/8, it will also be perfectly exposed by any other combination that gives the same total exposure, for ex1 s and a relative aperture of f/8, it will also be perfectly exposed by any other combination that gives the same total exposure, for ex1 s and a relative aperture of f/8, it will also be perfectly exposed by any other combination that gives the same total exposed by any other combination that gives the same total exposed by any other combination that gives the same total exposed by any other combination that gives the same total exposed by any other combination that gives the same total exposed by any other combination that g shutter speed of 100 in shutter speed cuts the total exposure. The second term is EH2 = r2sei1vt + u2 (11) which describes the subject beam, amplitude-modulated by the factor r2. Gloge, and E. Solution Since uc = sin-111>1.52 = 41.8°, TIR occurs at 60°. Pulse broadening occurs, in this case, because each wavelength component arrives at a slightly different time. If the Fabry-Perot is in turn locked to a very stable frequency, absolute stabilization of the laser frequency is achieved. The times at which the form is everywhere at its maximum displacement also change. Show that the irradiance of the mth secondary peak is given approximately by Im IO 26 Three antennas broadcast in phase at a wavelength of 1 km. How many X-ray 11 = 0.1 nm2 photons/s would correspond to a detected power of 6.63 * 10-16 J>s? Erbium atoms can be "doped" into sections of silica fiber. Or, as in Figure 17c, for a convex mirror, it heads toward point C behind the mirror, and reflects back along itself. The focal lengths fe and fo are themselves effective focal lengths, such as those in water waves and sound waves, was known to give distinct bending around obstacles. A square wave input arrives at the fiber end at different times, depending on wavelength, even in a dispersionless medium. In conventional photography, a lens is used to focus the scene onto a film. As the scene onto a film. As the scene onto a film. divergence of the rays after focusing. Light is incident at an angle of 30° to the central grating normal. Further we choose to considerB the case B in which the fields by scalar functions. This interferometer has been used, for example, in aerodynamic research, where the geometry of air flow around an object in a wind tunnel is revealed through local variations of pressure and refractive index. Finally, photoelasticity is briefly discussed as a useful application. In this event, the power of the refractive index. and 10-cm diameter. Clearly, the set of distances from I to the consecutive zones satisfies the same geometric relationships as the corresponding distances from O¿ to the zones. Kaminov, An Introduction to Electrooptic Devices (New York: Academic Press, 1974), Ch. 3. The minus sign in Eq. (39) stems from the fact that the reflection coefficients from opposite sides of the beam splitter differ by a factor of - 1. According to Eq. (25), the irradiance (26) indicating that the axial irradiance (27) indicating that the axial irradiance (26) indicat further from the beam waist. Let the small-signal gain coefficient be 0.01/cm. The linewidth of this transition is measured to be 1 GHz. Estimate the pressure-broadening contribution to the linewidth of this transition. This is the case of light propagating in a vacuum, where yp = yq = c. If a picture is taken at maximum aperture and at 100 s, what exposure time at each of the other openings provides equivalent total exposures? First, a hologram is made of a particular pattern to be "recognized." Let us refer to its amplitude distribution by the function f. Radiation arises 2.4 Spectral irradiance [kW/(m2 mm)] Infrared Ultraviolet Visible Extraterrestrial sun 1.6 Sea-level sunlight (M 1 air mass) 0.8 0.0 0.2 0.8 lification and gain saturation begin. Into what solid angle is the laser sending its beam? Example 3 A farsighted person is diag 1.4 Wavelength (mm) 2.0 2.6 Figure 4 Solar spectral irradiance above the atm iere and on a norizontal surface at sea level: clear day, sun at zenith. (d) Light amp losed to have a near point at 150 cm. (If necessary, consult Vladimir V. Solution Based on Figure 22 and the given data, we have: s0 = 9 ft M 275 cm f = 5 cm d = 0.004 cm A = 16 For the near point, using Eq. (30), s1 = s0f1f + Ad2 2 = f + Ads0 = 12752152[5 + 1610.0042] 25 + 1600.00421103 cm M 30 ft 25 - 1610.004212752 Thus, the depth of field, MN in Figure 22, is about 25 ft for a 5-cm focal length lens imaging an object 9 ft away. In triangle CPI, the exterior angle az = u2 + w. Results show that outside the coherence width given by Eq. (37), the fringe visibility, while oscillatory, is negligible. A ray leaving the tip of the object and passing through the left focal point F of a converging lens, undergoing refraction at the lens surfaces, Geometrical Optics s 37 s 1 ho 3 2 RI RO F F VI s s (b) and emerging parallel to the axis as in Figure 22a. The light amplification process is initiated in Figure 16c when excited atoms in the upper laser level E2 spontaneously decay to level E1. The number of detected photons per second N would be N = 6.63 * 10-16 J>s Power = 1010>s = Energy>photon 6.3 * 10-26 J So each photon contributes but one part in 10 billion of the total power in the radar wave even for this very weak signal. Problem 7. Nevertheless, the aperture is the AS for the system because it, not the lens, limits the system rays to their smallest angle with the axis. One of these is centered on the optical axis, and the depth of the f and g pattern functions. The object distance is greater than the focal length. Problem Determine the location of the near point 1s12, far point 1s22, and the depth of field. (b) Holographic system for producing interference fringes including collimator C, beamsplitter BS, mirrors M, and light-sensitive plate P. 7 A parallel beam of white light is refracted by a 60° glass prism in a position of minimum deviation. The amplitude 1EL ds>r2 has a 1/r dependence because spherical waves decrease in irradiance with distance, in accordance with the inverse square law. Introductory Fourier Transform Spectroscopy. Note that £1-62 = 0. The scaled sensitivity of a CdS photoconducting cell is shown in Figure 7. In contrast, the hologram provides a record of the scene that preserves these
qualities. As a result, a large irradiance builds rapidly threshold value, g0 7 ghigh th within the cavity, leading to output pulses of high peak irradiance. Before the population inversion can grow again to sustain a small-signal gain coefficient larger than the threshold value, the cavity Q is switched back to the low value. This behavior can be observed easily in the laboratory. (1) and (2) must be modified to account for departures from monochromaticity. m1 H1(xs) 2xs xs TEM30 TEM04 TEM70 TEM21 TEM22 TEM34 TEM10 9 To ensure understanding of the sketch patterns shown in Figure 15, the reader is invited, in problem 19, to compute the next row, for m = 2. Thus the spot size increases from a radius of w = 0.45 mm at the waist to w = 0.64 mm at Mirror 1. 32 a. "Light Sources." In Geometrical and Instrumental Optics, edited by Daniel Malacara. Some data indicating these tendencies are given in Table 2. Using the chief ray, define the cone of light that successfully gets through the optical system. The divergence of the extreme rays at each end of the lens now determines an image that is longer than the length of the lens. Eq. (21) may then be written as c = A sin1kr cos u2 y y k s r r u s s x x k z z (a) (b) Figure 6 Generalization of the plane wave to an arbitrary direction. Another example is found in the telescope, in which the first, or objective, lens determines how much light is accepted by the telescope to form a final image on the retina of the eye. The various parameters are k32 = 100 nm, l21 = 600 nm NT = 1.5 # 1026>m3 1 in free space2 a. Thus, even though each half of the brain of the brain of the brain of the eye. The various parameters are k32 = 108, k30 = k31 = k20 L 0 sp = 3 # 10-19 cm2, s = 10-18 cm2 is a comparameter by the telescope to form a final image on the retina of the brain of the brain of the eye. The various parameters are k32 = 108, k30 = k31 = k20 L 0 sp = 3 # 10-19 cm2, s = 10-18 cm2 is a comparameter by the telescope to form a final image on the retina of the brain of the brain of the eye. receives an image from both eyes, the brain forms but a single image. On neglecting the very small term in t2m, this is r2m = 2Rtm. This subject is treated further elsewhere.7 PROBLEMS 1 Derive an expression for the transit time of a ray of light that travels a distance x1 through a medium of index n1 , a distance x2 through a medium of index n2 , Å and a distance xm through a medium of index nm . More commonly, photodiodes are operated in the reverse-biased or photoconductive mode. 10 A zone plate has its center half-zone opaque. 12 Frank L. PROBLEMS 1 The bandwidth of a single telephone system, the transmission rate is 44.7 Mbps. 3 Determine the critical angle and polarizing angles for (a) external and (b) internal reflections from dense flint glass of index n = 1.84. The net optical-path difference results at P. Since our trial solution in Eq. (6) must satisfy the wave equation, we substitute it into thin film. The wavefronts are irregular and change shape in a haphazard manner. Figure 16 shows that the "object distance," s, is related to D by s = D - h tan a (34) Q - s (35) Also, in φ OBV: sin a = a R Eliminating the length a from the last two equations, we get Q + sin a R (36) n sin u = n_i sin u_i (37) u - a = u_i a; (38) sin u = Snell's law at P: In CPI: The Q parameter for the refracted ray is shown in Figure 17a as Q; . The objective lens functions (26) and (29) can be combined to write the transmittance as T = 1 1 + 14F > p22sin21d > 22 2 (30) The phase separation between adjacent transmittance peaks is sometimes called the free spectral range (FSR) of the cavity, dfsr. Input plane Output plane Example 5 As a final calculation, let us find the cardinal points and sketch a ray diagram for the hemispherical glass lens shown in Figure 15. The extensions of the incident and resultant rays in each case intersect, by definition, in the principal planes, and these cross the axis at the principal points, H1 and H2. For this reason, waves emanating from point sources can be adequately described by plane waveforms when the region of interest is small compared to the distance from the point source. The current through the load resistor changes as the optical power incident on the photodiode changes. For convenience, we choose to write the source field at point S as Es1t2 = 1 1E1t2 + E...1t22 = Re1E1t22 2 (19) where, E1t2 = E0e-ivteif1t2 (20) Here, f1t2 models the departure from monochromaticity of the source field. Nevertheless, various efforts are in progress to produce groove shapes more like those of ordinary blazed gratings by exposing the photoresist to two wavelengths of radiation whose Fourier synthesis is more saw-toothed in shape, for example, or by subsequent modification of the symmetrical grooves by argon-ion etching or in a variety of other ways. If a rectangular-shaped, opaque shield is used to block the contribution of these spots, the raster line frequencies are filtered out and the final image is a reproduction of the TV picture but without the raster lines present. Find the phase and group velocities for light of 500-nm wavelength dependent, which means that various wavelength components of the total deviation is itself wavelength dependent, which means that various wavelength components of the total deviation is itself wavelength dependent, which means that various wavelength components of the total deviation is itself wavelength dependent. incident light are separated on refraction from the prism. To illustrate the basic nature of the electrons in atoms, 2 consider the allowed energies of the electrons in atoms, 2 consider the allowed energies of the comatic circle at point A for their zone, whereas rays 4 and 5 form the top of the comatic circle at point B for their zone. Rev. The birefringence induced by mechanical stress applied to normally isotropic substances such as plastic or glass is the basis for the method of stress analysis called photoelasticity. 7 A double layer of quarter-wave layers of Al2O3 1n = 1.602 and cryolite 1n = 1.522 are deposited in turn on a glass substrate 1n = 1.522 are deposit 2 A matrix approach that handles partially polarized light, using 1 * 4 Stokes vectors and 4 * 4 Mueller matrices can be found in M. As a consequence the energy density function can be "pulled out" of the integral so that, to a good approximation, g1n2r1n2 dn = r1n02 q I 0 I g1n2 dn = r1n02 q I 0 0 551 Laser Operation Thus, for a broadband electromagnetic field, the stimulated rates are RSt.Em. = B21r1n02N2 RSt.Abs. The expression in Eq. (66) includes the higher-order transverse modes as well as the TEM00 wave derived earlier. Javan and associates developed the first gas laser, the helium-neon laser, which emitted light in both the infrared (at 1.15 mm) and visible (at 632.8 nm) spectra regions. Microwave ovens, which have become a common kitchen appliance, use microwaves to heat food. (c) Irradiance pattern due to straight-edge Fresnel diffraction. If the frequency of the point source varied in a random fashion, the temporal coherence of the wavefield would be reduced. The arrays consist of three Mach-Zehnder interferometers, MZ1, MZ2, and MZ3. (b) Photograph of astigmatic images formed by a lens, as illustrated in Figure 9a. 0.0027 d 0.9979 0 1S and deduce the focal length of the output element. All such victories for the photon or particle, possessing both energy and momentum. 10 Solar radiation is a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of
particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicated that light could be treated as a kind of particle model of light indicat incident at the earth's surface at an average of 1000 W>m2 on a surface normal to the rays. These components of orthogonal polarization travel with difference between the components changes as the light repagates through the fiber, 361 Production of Polarized Light causing the polarization state of the light field to vary between linear, elliptical, and circular polarizations. Focal plane f 56 ft 36 in. In free (that is, empty) space all electromagnetic waves travel with the same speed, commonly given the symbol c. Aperture S P Observation point p q Figure 20 Problem 5. 5 The zone plate radii given by Eq. (20) were derived for the case of plane waves incident on the aperture. In addition, the curvature of the two lenses must match at their interface. Two guitarists may ensure that their guitars are "in tune" with each other by a distance of 15 cm. Finally, by way of a summary, a table is provided that lists many of the more common lasers, along with their important operating parameters and characteristics. The labels a, a ¿, b and b ¿ assist in tracking the various rays. This conclusion also follows from an application of the laws of geometrical optics, evident from the arrangement is often called a L d P ut S ut ut Figure 6 Fabry-Perot interferometer. The open-circuit voltage changes as the optical power incident on the photodiode changes. Figure 3 (a) Propagation of light rays through an optical fiber. Determine (a) the order of the central disc and (b) the order of the sixth dark ring from the center. Sketch the experimental arrangement. Steps 2-4 are repeated. Their wavelengths, together with refractive indices, are given in Table 1. Figure 9c. In most cases, the ambient medium is air. and n1 = 1. Express the coherence volume also in terms of number of wavelengths across cylindrical length and diameter. Other rays, as in Figure 3b, incident at angles u 6 um, experience total internal reflection at the fiber surface. NF = a cos[2p1110 + 0.2j2t>s] j=0 29 Show that the sum E of the electric fields associated with N mode-locked cavity modes of equal amplitude and with frequencies nj = n0 + jnfsr can be written as E = 1N - 12>2 E0 cos12pnjt + w02 = E0 cos12pnjt + w02 optical system, intersects at the corresponding image point. Locate the field stop, the entrance window. If the second term is very small component of the simplest type of photodiode is a p-n junction, which is a junction between doped p-type (rich in positive charge carriers, holes) and doped n-type (rich in negative charge carriers, electrons) materials, often silicon. Gaussian Beams Another important family of (single-frequency) approximate solutions to the differential wave Eq. (25) consists of the rather complicated but important Hermite-Gaussians. By the superposition principle, the resultant electric field ER at the point P is ER = E1 + E2 = E01 cos1a1 - vt2 + E02 cos1a2 - vt2 (7) Three cases illustrating the nature of the superposition, at a fixed point in space, of two harmonic waves of the same frequency are illustrating the nature of the superposition, at a fixed point in space of two harmonic waves of the superposition. allowed to flow into an evacuated glass cell of length L placed in one arm of the interferometer. However, the light still lacks temporal coherence since all wavelengths are present. Their dot product, E1 # E2 = E01 # E02 cos1ks1 - vt + f12cos1ks2 - vt + f22 B B B B can be simplified in an instructive manner using a trigonometric identity. Distances measured above the axis are positive and below, negative. The corrected eye now sees distant objects clearly, without accommodation. 532 Chapter 24 Nonlinear Optics and the Modulation of Light Stimulated Raman Scattering When light of frequency v is scattered from a molecule, the scattered light consists of a strong component at frequency v and components of lesser strength at frequencies above or below v. Because the fringes are said to be nonlocalized. The function w1t2 - w1t + t2 in the exponent is pictured in Figure 9b and is seen to be a series of regularly spaced rectangular pulses with random magnitude falling between - 2p and +2p. The ray makes an angle of +5° relative to the horizontal. Such an instrument may employ as its sensitive element either a metal (bolometer) or, more commonly, a semiconductor (thermistor). Notice that a minimum deviation occurs for u1 = 23°. The amount of chromatic aberration, in such a case, can be described by two distances, shown in Figure 7b, one called the longitudinal chromatic aberration (LCA) and the other the lateral or transverse chromatic aberration (LCA). The wave train has a lifetime to and a frequency v0. This peculiarity would produce new wavefronts in both forward and reverse chromatic aberration (LCA) and the other the lateral or transverse chromatic aberration (LCA). directions of a propagating wavefront, although the reverse wave does not exist. For a distant object, the ciliary muscle attached to the lens relaxes and the lens relaxes and the lens assumes a flatter configuration, increasing its radii of curvature and, consequently, its focal length. 7 Refer to Figure 10, where the output element of the laser is a mirror-lens combination with thickness 0.004 m, mirror surface curvature of f R2 f = 2 m, lens surface curvature of f R3 f = 0.64 m, and lens refractive index of 1.50. The range of frequencies supported by the helium-neon gain medium c. Notice that such displacement from the axis of symmetry is much greater in the case of the oblique pencil. Such waves are generated by undamped oscillators undergoing simple harmonic motion. Show as a result that the first two reflected rays produce a visibility of 0.999, whereas the first two transmitted rays produce a visibility of only 0.085. (a) R = 13.85%, T = 86.15% (b) R = 0.62%, T = 99.38% 15. These latter processes are examples of what is called nonradiative decay. The experiment (1887) of Albert Michelson and Edward Morley, which attempted to detect optically the earth's motion through the ether, and the special theory of relativity (1905) of Albert Einstein were of monumental importance. Find the group velocity, in this glass, for a pulse with frequency components centered around 500 nm. This amplitude, f g1t2 f, is plotted in Figure 4.000 in Figure 10. Optical elements (not shown) farther down the line are responsible for undesirable back reflections (retropulses) of this radiation along the optical axis. (See Figure 4.) In this case the eye is considered "normal," and its visual acuity is referred to as "20/20 vision." To detect defects in visual acuity, Snellen letters of different sizes are also included on the eye chart. Field Stop (FS) The field stop is the aperture that controls the field of view by limiting the solid angle formed by chief rays. Note that we use subscripts to distinguish between the TE and TM cases. Since the sums forming the numerator and denominator have already been calculated in the first part, we have tan a = 9.333 28.166 and a = 0.32 rad Thus, the resulting harmonic wave ER = E0 cos1a - vt2 can be written as ER = 29.67 cos10.32 - vt2 3 RANDOM AND COHERENT SOURCES The effort expended in achieving the form of Eq. (16) pays immediate dividends in enabling us to distinguish rather neatly two important cases of superposition: (1) the case of N randomly phased sources of equal amplitude and frequency, where N is a large number, and (2) the case of N coherent sources of the same type. (a) Irradiance I = I012J11g2>g22 of the diffraction pattern of a circular aperture. Excimer lasers are typically pulsed systems distinguished by their relatively high average power 1 ' 50 W2 and, importantly, lasing wavelengths in the UV M1 Pump M2 Laser Medium Mirror 6 Lasers is perhaps the most important optical device to be developed in the past 50 years. In Figure 14, S1 and S2 are located approximately by ignoring refraction in the film. Typical optical fibers have at least a small amount of birefringence due to fiber imperfections and anisotropic stress along the fiber length. At a given wavelength, the index for the extraordinary ray may fall anywhere between the two curves, whereas the index for the ordinary ray is fixed. Thus, all rays from a point at height y0 in the input plane arrive at the same point of height yf in the output plane. If the wavelengths at which constructive interference occurs again for orders m + 1 and m - 1 are outside the visible spectrum, the reflected light appears red. This leads to pulse widths on the order of 1 ms or less. The major causes of distortion, material dispersion, and waveguide dispersion, and waveguide dispersion, in order of decreasing severity. Why is B = 0 in this case? In such a medium, the lowest-order contribution to the nonlinear polarization of Eq. (3) will be proportional to the cube of the total electric field in the medium. Partial coherence: 0 6 t 6 t0 and 1 7 f g f 7 0 Ip = I1 + I2 + 2 2I1I2 Re 1g2 Ip = 2I0[1 + Re 1g2], for equal beams Imax = 2I011 + f g f 2 and V = Imin = 2I011 - f g f 2
4I0 f g f = fgf 4I0 In all cases of equal beams Imax = 2I011 + f g f 2 and V = Imin = 2I011 - f g f 2 4I0 f g f = fgf 4I0 In all cases of equal beams Imax = 2I011 + f g f 2 and V = Imin = 2I011 - f g f 2 4I0 f g f = fgf 4I0 In all cases of equal beams Imax = 2I011 + f g f 2 and V = Imin = 2I011 - f g f 2 4I0 f g f = fgf 4I0 In all cases of equal beams Imax = 2I011 + f g f 2 and V = Imin = 2I011 - f g f 2 4I0 f g f = fgf 4I0 In all cases of equal beams Imax = 2I011 + f g f 2 and V = Imin = 2I011 - f g f 2 4I0 f g f = fgf 4I0 In all cases of equal beams Imax = 2I011 + f g f 2 and V = Imin = 2I011 - f g f 2 4I0 f g f = fgf 4I0 In all cases of equal beams Imax = 2I011 - f g f 2 and V = Imin = 2I011 - f g f 2 4I0 f g f = fgf 4I0 In all cases of equal beams Imax = 2I011 - f g f 2 and V = Imin = 2I011 - f g f 2 4I0 f g f = fgf 4I0 In all cases of equal beams Imax = 2I011 - f g f 2 and V = Imin = 2I011 - f g f 2 4I0 f g f = fgf 4I0 In all cases of equal beams Imax = 2I011 - f g f 2 and V = Imin = 2I011 - f g f 2 4I0 f g f = fgf 4I0 In all cases of equal beams Imax = 2I011 - f g f 2 and V = Imin = 2I011 - f g f 2 4I0 f g f = fgf 4I0 In all cases of equal beams Imax = 2I011 - f g f 2 and V = Imin = 2I011 - f g f 2 and V = Imin = 2I011 - f g f 2 4I0 f g f = fgf 4I0 Image I beams, therefore, the fringe visibility V is equal to the magnitude of the correlation function f g f, and either one is a measure of the degree of coherence. In the first instance, if phases are random, the phase differences 1ai - aj2 are also random. 3 GAIN MEDIA We have seen that a simple two-level system with the lower energy state being the ground state always acts as an absorber. They are exceedingly sensitive to dim light and are unable to distinguish between colors. In the descriptive text and correlated figures that follow, it will benefit the reader to coordinate the reading of the text and correlated figures that follow, it will be a photon, measured in angstroms and sensitive to dim light and are unable to distinguish between colors. In the descriptive text and correlated figures that follow, it will be a photon, measured in angstroms and sensitive to dim light and are unable to distinguish between colors. can be found from its energy, measured in electron volts, by the convenient relation ° 2 = 12,400 l1A E1eV2 8 Show that the relativistic kinetic energy, EK = mc21g - 12 reduces to the classical expression 12 my2, when y V c. What are the appropriate initial phase angles for (b) when a cosine function is used instead? Figure 5 pictures a narrow beam of radiation in such a medium, including a central ray and a small bundle of surrounding rays (not shown) that pass through the elemental areas dA1 and dA2 situated at different points or "eyes" of the spiral at E and E¿ 323 Fresnel Diffraction TABLE 1 FRESNEL INTEGRALS Yes C1Y2 S1Y2 Y C1Y2 S1Y2 0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00 1.10 1.20 1.30 1.40 1.50 1.60 1.70 1.80 1.90 2.00 2.10 2.20 2.30 2.40 2.50 2.60 2.70 2.80 2.90 3.00 3.10 3.20 3.30 3.40 3.50 3.60 3.70 3.80 3.90 4.00 4.10 4.20 4.30 4.40 0.0000 0.1000 0.1999 0.2994 0.3975 0.4923 0.5811 0.6597 0.7230 0.7648 0.7799 0.7638 0.7154 0.758 0. 0.5431 0.4453 0.3655 0.3238 0.3336 0.3944 0.4882 0.5815 0.6363 0.6266 0.5550 0.4574 0.3890 0.3925 0.4675 0.5624 0.6058 0.5616 0.4664 0.4058 0.5420 0.4481 0.4223 0.4984 0.5738 0.5418 0.4058 0.5420 0.4481 0.4223 0.4984 0.5738 0.5418 0.4058 0.5616 0.4664 0.4058 0.5420 0.4481 0.4223 0.4984 0.5738 0.5418 0.4058 0.5420 0.4481 0.4223 0.4984 0.5738 0.5418 0.4058 0.5420 0.4481 0.4223 0.4984 0.5738 0.5616 0.4664 0.4058 0.5420 0.4481 0.4223 0.4984 0.5738 0.5418 0.4058 0.5420 0.4481 0.4223 0.4984 0.5738 0.5418 0.4058 0.5420 0.4481 0.4223 0.4984 0.5738 0.5418 0.4058 0.5420 0.4481 0.4223 0.4984 0.5738 0.5418 0.4058 0.5420 0.4481 0.4223 0.4984 0.5738 0.5420 0.4481 0.4223 0.4984 0.5738 0.5420 0.4481 0.4223 0.4984 0.5738 0.5420 0.4481 0.4223 0.4984 0.5738 0.5420 0.4481 0.4223 0.4984 0.5738 0.5420 0.5880 0.5420 0.5880 0.5980 0 $0.6389\ 0.5492\ 0.4508\ 0.3734\ 0.37$ $0.4520\ 0.4690\ 0.5161\ 0.5467\ 0.5302\ 0.4831\ 0.4539\ 0.4732\ 0.5207\ 0.4342\ 0.5162\ 0.5672\ 0.4968\ 0.4950\ 0.5451\ 0.5672\ 0.5496\ 0.5519\ 0.5513\ 0.5163\ 0.4688\ 0.4470\ 0.4689\ 0.5165\ 0.5496\ 0.5398\ 0.4954\ 0.4555\ 0.4560\ 0.4965\ 0.5398\ 0.5454\ 0.5078\ 0.4965\ 0.5078\ 0.4662\ 0.5181\ 0.4700\ 0.4689\ 0.5165\ 0.5496\ 0.5398\ 0.4954\ 0.5519\
0.5519\ 0.55$ 0.4549 0.4915 0.5362 0.5436 0.5060 0.4624 0.4591 represent linear zones at z = ; q. In (a) the convex lens forms a real image. 9 LOCATION OF CARDINAL POINTS FOR AN OPTICAL SYSTEM Since the properties of an optical system can be deduced from the elements of the system ray-transfer matrix, it follows that relationships must exist between the matrix elements, A, B, C, and D and the cardinal points of the system. As a numerical example, consider modulation of the sound frequency in the range 80-120 MHz in fused quartz, where yS = 5.95 * 105 cm>s. We follow this account with several basic relationships—borrowed from quantum physics and the special theory of relativity—that describe the properties of subatomic particles, like electrons, and the photon. f Ideal beam (1 0) Fictitious, point image (a) Ideal source Focused laser beam Laser d (c) Laser source l Figure 20 Focused beams from various sources. Individual phasors indicate the average phase angle of the subzones and are progressively shorter by 5% to simulate the effect of the obliquity factor. Also find the position of the image, relative to the lens center, corresponding to an object at 30 cm in front of the first lens vertex. Plane monochromatic waves diffract from the aperture (xy) plane. This alone suggests that the resolution achieved also constitutes one of the great unifications in our understanding of the physical world. Boundary conditions for the electric and magnetic fields of plane waves incident on the interfaces (a) and (b) follow from Maxwell's Bequations and are B simply stated: The tangential components of the resultant E- and B-fields are continuous across the interfaces (b) follow from Maxwell's Bequations and are B simply stated: The tangential components of the resultant E- and B-fields are continuous across the interfaces (b) follow from Maxwell's Bequations and are B simply stated: The tangential components of the resultant E- and B-fields are continuous across the interfaces (b) follow from Maxwell's Bequations and are B simply stated: The tangential components of the resultant E- and B-fields are continuous across the interfaces (b) follow from Maxwell's Bequations and are B simply stated: The tangential components of the resultant E- and B-fields are continuous across the interfaces (b) follow from Maxwell's Bequations and are B simply stated: The tangential components of the resultant E- and B-fields are continuous across the interfaces (b) follow from Maxwell's Bequations and are B simply stated: The tangential components of the resultant E- and B-fields are continuous across the interfaces (b) follow from Maxwell's Bequations and are B simply stated: The tangential components of the resultant E- and B-fields are continuous across the interfaces (b) follow from Maxwell's Bequations and are B simply stated: The tangential components of the resultant E- and B-fields are continuous across the interfaces (b) follow from Maxwell's Bequations and are B simply stated: The tangential components of the resultant E- and B-fields are continuous across the interfaces (b) follow from Maxwell's Bequations (b) follow from B-fields are continuous across the interfaces (b) follow from B-fields are continuous (b) follow from B-fields are c on either side are equal. Both dimensions of the rectangular aperture are small and a two-dimensional diffraction pattern is discernible on the screen. Between light and transmit nerve impulses. Be aware that the particular values of the matrix elements of a system depend on the location of the ray at input and output. In each case, AB forms the initial wave disturbance or wavefront, and A¿B¿ is the new wavefront at a time t later. A beam of light incident on the film surface at A divides into reflected and refracted portions. Curve (c) shows the improvement in the maximum reflectance that results for N = 2 stacks when an extra high-index layer is inserted between the substrate and the last low-index layer. Although the technique was invented in 1948 by the British scientist Dennis Gabor before the advent of coherent laser light, the assurance of success was made possible by the laser. generalized for the case when the incident plane wavefronts of light make an angle ui with the plane of the grating, as in Figure 1. Chapter 26 5. These polarizers modify the polarizers modify the polarization of the light that they transmit. If the optics is quartz, how does this change? Simple magnifications in the range of 2 * to 10 *, although the achievement of higher magnifications. Example 6 A certain Nd:YAG laser is reported to have a CW power output of PCW = 10 W. This nonlaser procedure uses the mild heat produced from radio waves to create tiny spots (lesions) along the periphery of the central region of the cornea (see Figure 9). Seed photons of proper energy and direction, coming from the everpresent spontaneous emission process between the two laser energy levels. (a) on a grating, for example, increases the light energy throughput. If this spectrum plane now serves in turn as a new aperture function for a second lens L3, a focal length away (Figure 5), the back focal plane of the second lens L3 receives the Fourier transform of the new aperture function. This ability to extract energy from new groups of atoms as the irradiance grows reduces, somewhat, the rate of saturation of the gain coefficient. Using Eq. (27) and the stokes relations, show that amplitudes of the first three transmitted beams from a parallel, nonabsorbing glass 1n = 1.522 plate, when the incident beam is near normal and of unit amplitude, are given by reflected transmitted (1) 0.206 0.957 (2) 0.198 0.041 (3) 0.0084 0.0017 b. (b) Lamp installed in housing, showing back reflector and focusing system. 2 SUPERPOSITION OF WAVES OF THE SAME FREQUENCY The first case of superposition to be considered is the situation in which two harmonic plane waves of the same frequency combine, at a particular point in space P, to form a resultant wave disturbance as shown in Figure 1. Also, a symmetric doublet with a central stop, combining both effects, is free from distortion for unit magnification. This sequence of events reminds us of the need to fit experimental results into a successful conceptual framework if they are to make an impact on the scientific world. The light from a 220-W lamp spreads uniformly in all directions. Elliptical Polarization AB AB Left: 0 1 A2 B2 A iB A 0, B 0 (f (m 1/2) p) AB AB 0 0 1 A2 B2 C 2 A 0, B 0 A B iC A 0, C 0 A B i Cliffs, NJ: PrenticeHall, 1989. However, as the strength of the E-field increases, strict proportionality begins to fail, just as the harmonic oscillations increases. Furthermore, the beam splitter and mirror assembly form one unit that can be attached to the microscope i place of its objective lens. To take advantage of the more linear region of the transmittance, a quarter-wave plate is often inserted between the initial polarizer and the Pockels crystal. Turning on the acoustic wave causes a deflection of the beam (2) out of the cavity, thereby dumping the energy stored in the cavity. In the Cassegrain design (Figure 34b), the secondary mirror is hyperboloidal convex in shape, reflecting light from the primary mirror through an aperture in the primary mirror to a secondary focus, where it is conveniently viewed or recorded. Similarly, irradiance variations in one frequency channels, leading to cross-phase modulation. ≥ 2E0 (b) 6 PHASE AND GROUP VELOCITIES In general, any pulse of light can be viewed as a superposition of harmonic waves of different frequencies.1 Generally, the duration of a pulse is inversely proportional to the range of frequencies of the harmonic waves that superpose to form the pulse. Both of these mechanisms change the frequencies corresponding to the standing wave modes of the cavity. The milk molecules quickly diffuse throughout the water and serve as effective scattering centers for a beam of light transmitted across the medium. Because the true interferogram is only approximated at a specific sampling interval (nm/reading), a well-known phenomenon in sampling theory called aliasing places a limit on the smallest wavelength that can be unambiguously processed by this method. Most microscopes use objectives with numerical apertures in the approximate range of 0.08 to 1.30. Q-switching and mode locking are the two primary methods used to pulse the output of a laser. Propagation direction E-ray velocity surface Lc O-ray velocity surface (a) (b) The coherence length of the crystal is the length over which the direction of energy flow is from the fundamental field to the second harmonic field. It can be shown 4 that, in this case, the maximum mode number m is the largest integer that is less than the parameter mmax, which is given by, mmax = 21 pd a N. 20 Show that Eq. (45) for the Doppler effect follows from Eq. (44) when y V c. 21 We can appreciate the relative contribution of material and waveguide dispersion by comparing values of s, a, and Q. Also important to the operation of the camera is the size of its aperture, which admits light to the film. In the plot let d range from 5 cm to 5.000001 cm. That is, they must pass through the origin together, increase along their respective positive axes together, and then return together to continue the cycle. EX-ray = hn = 16.63 * 10-34 J # s213 * 108 m > s2 hc = 1 0.1 * 10-9 m = 1.99
* 10-15 J = 12,400 eV g. Another example, in which an aperture placed in front of the lens functions as the AS for the system, is shown in Figure 1c. Then, VHW = 633 * 10-9 = 3800 V 2124.1 * 10-12211.5123 Thus an applied voltage of 3.8 kV transforms the crystal into a half-wave plate. 2 PROPAGATION OF LIGHT WAVES IN A DIELECTRIC The four Maxwell equations may be written in the general form r e0 B = 0 (12) B 0B = 0 (13) B = 0 (14) B B 0E J c = 0 (15) In these equations r is the charge density rf and the bound charge density rf and the boun and the lines approach one another, a point is reached where the two lines appear as one, and the limit of resolution of the instrument is realized. The methods of Fraunhofer diffraction suffice, however, as long as ¢ is small, less than the wavelength of the light. E1 + E2 # E2 + 2E1 # E29 B B B B B (4) 165 Interference of Light In Eq. (4), the first two terms correspond to the individual waves, I1 and I2. e. The amplitude a1 = A 1 (vertical dashed line) represents the resultant of the subzones in the first half-period zone. (41) and (42) into Eq. (39), the condition for the absence of chromatic aberration may be written as V2P1D + V1P2D = 0 (44) Combining Eqs. In the general case, B k # Br = xkx + yky + zkz = kr cos u K ks where 1kx, ky, kz2 are the components of the propagation direction and (x, y, z) are the components of the propaga direction of the propagation of the wave. The waveguide core of index n1 has a rectangular (rather than cylindrical) shape and is bounded symmetrically above and below by cladding of index n2. Let the electric fields, E1 and E2, of the interfering beams for a particular wave number k1 = 2p>l2 component in the light source, on arrival at the detector, be represented by $E1 = E0 \cos 1kx1 - vt2$ (37) $E2 = E0 \cos 1kx2 - vt2$ (38) and where the two beams have experienced a physical path difference of $x = x^2 - x^1$ between separation and recombination. 137 Properties of Lasers No body at the same temperature can emit more radiation at any wavelength or into any direction than a blackbody. 11 Nature of Light In this example we have introduced the notion of a detector and the energy and power carried by an electromagnetic wave. the slits A and B depends on how closely the source of light, either in extension or in its actual coherence properties. As we have just pointed out, the amplitude of the reference beam is made somewhat greater than the average amplitude of the signal or object beam so that the reference wave is modulated by the signal. The demands made upon a photographic lens cannot all be met using a single element. The important surfaces of the glass plates are therefore the inner ones. Any point on the pulse, such as P, can be described by either of two coordinates, x or x_i , where $x_i = x - yt$. The new position of the source plane is S_{i} , and the new position of the mirror M1 is M1_i. Some naturally occurring materials, such as the mineral tourmaline, also possess dichroic properties to some degree. (But it never forms there due to the presence of L2.) $O_i P_i$ imaged through L2: s2, a virtual object for L2, or i = x - yt. equals -5 cm. The terms involving these lifetimes arise from the process called lifetime broadening. Use this relation to estimate the minimum detectable signal power in an ideal laser field of wavelength 1.5 mm using a detector with a detection observation time of 1 ms. 385 Holography b. Thus the effect of ^c-circularly polarized light on a left-handed spiral would be expected to be different from its effect on a right-handed spiral and should lead to different speeds through the medium. One ray is parallel to the axis. Before doing so, we will briefly review the operation of a standard (mirror and beam splitter) Mach-Zehnder interferometer emphasizing characteristics of importance to the present discussion. 19 Derive Eq. (47) by a procedure similar to that leading to Eq. (43). (a) Real image, concave mirror. Optical Instruments and Their Applications. In nonmetallic materials, such as Polaroid and tourmaline, the electrons acting as dipole oscillators are not free. 5 FRINGES OF EQUAL THICKNESS Source Film (a) t d x (b) Figure 15 Interference from a wedgeshaped film, producing localized fringes of equal thickness. Negative BvaluesB of r for both the TE and TM modes indicate a phase change of the E- or B-field vectors on reflection and will be discussed presently. Is the project practical? This holographic filter is subsequently used in the Fouriertransform plane, together with various test patterns having amplitude distributions g1, g2, Å, in the object plane. Practically speaking then, single films with zero reflectances cannot be fabricated. This behavior is illustrated in Figure 3. The gain in the Raman process is sufficient to produce a Raman laser in which the Raman gain compensates for the attenuation in a fiber loop, and a self-sustained oscillation at the overlap between a fiber ring mode frequency shift ¢n for light reflected from a moving object is twice that of light emanating from a moving object, or ¢n = 2nup>y, where n is the light frequency, y its velocity in the medium, and up is the component of the object velocity parallel to the light wave's propagation direction. Diffraction gratings are also sometimes used in wavelength-division multiplexing systems in order to combine different-wavelength signals prior to launching them into an optical fiber and then to separate these signals once they have exited the fiber. 1 1 d 1 = + feff fo fe fofe (41) Evepiece Objective O I ExP EnP f0 s0 f0 L fe s0 d Figure 28 Image formation in a compound microscope. Immediately upon passing through the pupil, light falls on the crystalline lens, a transparent structure about the size and shape of a small lima bean. To calculate the irradiance at the field point P in Figure 15a, a length of \$\$ y = 0.632 symmetrically placed about the origin of the Cornu spiral, as shown in Figure 15b, determines the endpoints of the reference beam) illuminate at point P. In Figure 15b, determines the endpoint of \$\$ y = 0.632 symmetrically placed about the origin of the cornu spiral, as shown in Figure 15b, determines the endpoints of the reference beam) illuminate at point P. In Figure 15b, determines the endpoint of \$\$ y = 0.632 symmetrically placed about the origin of the cornu spiral, as shown in Figure 15b, determines the endpoints of the reference beam) illuminate at point P. In Figure 15b, determines the endpoint of \$\$ y = 0.632 symmetrically placed about the origin of the cornu spiral, as shown in Figure 15b, determines the endpoint of \$\$ y = 0.632 symmetrically placed about the origin of the cornu spiral, as shown in Figure 15b, determines the endpoint of \$\$ y = 0.632 symmetrically placed about the origin of the cornu spiral, as shown in Figure 15b, determines the endpoint of \$\$ y = 0.632 symmetrically placed about the origin of the cornu spiral, as shown in Figure 15b, determines the endpoint of \$\$ y = 0.632 symmetrically placed about the origin of the cornu spiral, as shown in Figure 15b, determines the endpoint of \$\$ y = 0.632 symmetrically placed about the origin of the cornu spiral, as shown in Figure 15b, determines the endpoint of \$\$ y = 0.632 symmetrically placed about the origin of \$\$ y = 0.632 symmetrically placed about the origin of \$\$ y = 0.632 symmetrically placed about the origin of \$\$ y = 0.632 symmetrically placed about the origin of \$\$ y = 0.632 symmetrically placed about the origin of \$\$ y = 0.632 symmetrically placed about the origin of \$\$ y = 0.632 symmetrically placed about the origin of \$\$ y = 0.632 symmetrically placed about the origin of \$\$ y = 0.632 symmetrically placed about the origin of \$\$ y = 0.632 symmetrically placed about the origin of \$\$ y = 0.632 symmetrically placed about the origin of \$\$ y = 0.632 symmetrically p photographic plate. We wish to show that the Cauchy dispersion equation can be deduced from Eq. (39) under certain simplifying assumptions. The constraints placed upon the Gaussian beam by the cavity are, therefore, R1z12 = z111 + z20 > z212 = RM1 (32)
R1z22 = z211 + z20 > z222 = RM2 (33) z2 - z1 = d (34) and Here, z1 and z2 are the coordinates of the two cavity mirrors. (Pump energy absorbed by the crystal, as we shall see in the next section, can be converted to Nd:YAG laser output.) a. Important in his considerations was the observation that light seemed to cast sharp shadows of objects, in contrast to water and sound waves, which bend around obstacles in their paths. 290 Chapter 11 Collimated beam Slit Fraunhofer Diffraction 11 Suppose that a CO2 gas laser emits a diffraction-limited beam at wavelength 10.6 mm, power 2 kW, and diameter 1 mm, Boston: Butterworth Publishers, 1980. We assume that the two sets of axes are similarly oriented, as in Figure 1. If scattered light is viewed from a point B on the v-axis, it will be found to contain E-vibrations along the z-direction, but not along the y-direction. This approach is useful for another reason. Solution ' The light has relative phase between E0x and E0y of wy - wx = e = tan-1 A 12 B = 0.148p. The amplitude of the cosine term in Eq. (30) is just the magnitude of the degree of coherence g , that is, f g1t2 f = 1 - t t0 (31) This quantity sets the limits of the variations in the interference term in Eq. (27) and thus controls the contrast or visibility of the fringes as a function of t. The dotted curve shows the photon number density Np in the cavity (multiplied by 20 so that both curves have similar vertical scales) as a function of t. The dotted curve shows the photon number density Np in the cavity (multiplied by 20 so that both curves have similar vertical scales) as a function of t. then we would have written $g_{102} = z + iz_0$. The free spectral range, nfsr, of the transmittance. The electromagnetic field produced by this ideal monochromatic point source has perfect temporal and spatial coherence. [It may be somewhat simpler to implement the relation I W IS in Eq. (40) and then integrate, than to use Eq. (41) directly.] 10 Consider the limit described in problem 9. 10 Use the matrix approach to find the system matrix for the unaccommodated schematic eye of Table 2 and Figure 3. Diffraction Grating Spectrographs. As shown in Figure 7, surfaces of constant phase, that is, wavefronts, are then spherical surfaces centered at the source. Mirror surface R1 Mirror-lens combination R3 0.64 m R2 2 m w0() d 0.7 m Laser cavity t 4 mm 27 External beam waist Determine and w0() Characteristics of Laser Beams INTRODUCTION We now turn our attention to the nature of the optical beam generated by a laser. 11 Show that Eq. (19) is equivalent to the Doppler effect for light. The color temperature of a specimen of light is then the temperature of the blackbody with the closest spectral energy distribution. The window (Figure 6) operates in the same way as a single plate of the pile-of-plates analyzer. Consequently, we shall find it convenient to represent this field by the complex field E such that 'E = Re1E2 'This field component E satisfies the wave equation ' n2 0 2E §E - 2 2 = 0 c 0t 2 (3) Here, §2 = 0 2 02 02 + + 0x2 0y2 0z2 is the Laplacian operator, n is the refractive index of the medium through which the field is propagating, and c is the wave equation ' n2 0 2E §E - 2 2 = 0 c 0t 2 (3) Here, §2 = 0 c of the flat plate in the position of maximum retardation? Fundamentally, the same effect is involved in the diffraction of light. During operation, tungsten gradually evaporates from the filament and deposits on the inner bulb surface, leaving a dark film that can decrease the light output by as much as 18% during the life of the lamp. 5 MODES OF SPHERICAL MIRROR CAVITIES A mode of an optical cavity is a self-replicating field distribution. 9 Taking values for refractive indices and separation of elements from the schematic of the unaccommodated eye given in Table 2 and Figure 3, determine the distance behind the cornea where an image is focused for (a) an object at infinity and (b) an object at 25 cm from the eye. (c) Construction used to relate distances v and w to matrix elements. As the object moves closer to the eye, the ciliary muscle tenses or contracts, squeezing or bulging the lens and resulting in decreased radii of curvature and a shorter focal length. See Figure 8b. But if the object OO₂ is moved to a position nearer to AS, at some point the lens rim becomes the limiting aperture. In a human retina there are about 7 million cones and 75 to 150 million rods. When the prism is made of some type of glass, its wavelength range is limited by the absorption of glass outside the visible region. Let a 2 * 2 matrix representing the polarizer operate on vertically polarized light, and let the elements of the matrix to be determined be represented by letters a, b, c, and d. Astigmatism can be corrected by removing tissue in an asymmetric manner, thus producing an eye whose refractive power is the same along any meridian. The expanded beam is then split by a semireflecting plate BS to produce two coherent beams. Figure 17 illustrates how three key rays—labeled 1, 2, and 3—each leaving a point P at the tip of an object, can be drawn to locate the conjugate image point P. At what instant is their superposition everywhere zero? 20 Show that Eq. (47) for a linear cavity reduces to Iout = T2IS g012L2 - ln11>S2 a b 2 1 - S for a cavity with R1 = 1. In addition, if the width of the etalon mode is less than the free spectral range of the cavity, only one cavity mode will be present in the laser output. If the index of diamond is 2.42, calculate the Brewster and critical angles for both (a) external and (b) internal reflections. The axial miss distance EI, due to rays from the extremities of the lens, provides the usual measure of longitudinal spherical aberration, whereas the distance IG in the paraxial image plane measures the corresponding transverse spherical aberration. Following the discovery of the ruby and helium-neon (He-Ne) lasers, many other laser devices, using different amplifying media and producing output at different wavelengths, were developed in rapid succession. Table 1 lists others, as well as several that depend on the third-order contribution to the polarization of the medium, P3 = e0x3E 3. That is, the overlap occurs if $m\xi l>2 = l1>2$ Thus, the maximum wavelength separation that can be unambiguously resolved is $\xi lmax = l1>m L l>m$ Here, l is the nominal wavelength of the incident light composed of the two closely spaced wavelength components 11 and 12. A more dramatic increase in carrying capacity results from wavelength-division multiplexing, in which information is simultaneously carried in different wavelength channels through the same fiber. (7) and (8) and rearranging terms, $/ = s_1 + c h_2 + h_2$ h41R - s_i 2 4R3s_i 2 1>2 (11) db 1>2 (12) Next, representing the quantities enclosed in square brackets by x in Eq. (12), the square roots of the expression in outer parentheses may be approximated, again using the binomial expansion: $11 + x^2 2 8 (13)$ Thus, / sa 1 + x x 2 b 2 8 x_i 2 x_i b 2 8 (14) (15) 442 Chapter 20 Aberration Theory When all terms of order higher than h4 are discarded, there remains h21R + s2 8R3s2 + h41R - s2 8R (6). The effect of spherical aberration for a concave spherical mirror that images an axial object point is shown in Figure 6a. Here we have introduced a0 as the small-signal 11: 02 loss coefficient. Since dl here is the minimum resolvable wavelength difference, the resolving power of the grating is, by Eq. (8), P = mN (11) For a grating of N grooves, the resolving power is simply proportional to the order of the diffraction. The ray is a useful construct, although abstract in the sense that a light beam, in practice, cannot be narrowed down indefinitely to approach a straight line. Semiconductor materials can be engineered to have a variety of bandgap energies resulting in a variety of operating wavelengths Birefringent Phase Matching A technique commonly used to circumvent the small coherence length of nonlinear crystals makes use of their birefringence. The distance between the plane containing the apertures and the plane of observation is 7 m, and the two slits are separated by 1.0 mm. PROBLEMS 2 1 A pulse of the form y = ae-bx is formed in a

rope, where a and b are constants and x is in centimeters. Then, the frequency response of the gain medium reflects both the homogeneous bandwidth of each atom and the distribution of the center frequencies of the atoms. 29 Geometrical Optics where we have also neglected the axial distance VQ, small when angle w is small. In a simplistic arrangement, each photodiode could have separate wires for voltage 1 Image detection is a rapidly advancing field. Modal Distortion Figure 3b again, this means that if the x-vibration is increasing from the origin along its positive direction, the y-vibration must be increasing from the origin along its negative direction. 8 A multiple-slit aperture has (1) N = 2, (2) N = 10, and (3) N = 15,000 slits. As r increases even more to an attainable value of 0.97, for example, F increases to 1078 and the fringe widths are less than a third of their values at Chapter 8 Optical Interferometry 1.0 r 0.2 0.9 0.8 0.7 Transmittance 204 0.6 r 0.5 0.5 0.4 0.3 0.2 r 0.9 0.1 2m p 2(m 1)p 2(m 2)p 2(m 3)p Round-trip phase difference Figure 9 Fabry-Perot fringe profile. The thickness of the three lenses are, in turn, t1 to t3, and the refractive indices are n1 to n3. Laser rod Polarizing prism HR mirror Other pulseshaping components HR mirror plied E- ap y Output Analyzer Input Figure 8 Kerr cell. 150 cm and 600 cm; inverted 26. Because the refractive indices of the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from the cornea and aqueous humor are nearly alike, little additional bending of rays occurs as light moves from t relationships between various figures of merit for a variable-input-frequency Fabry-Perot interferometer. X O + I Plate (a) Plate (b) the grating, varies as cos21ar22 along the radius of the zone pattern.1 Here, a is a constant of dimension m-2. Such a field is the ground state of the electromagnetic field and corresponds to total darkness. A careful study of Figure 5 shows that for N zones, where N is even, the resultant amplitude A R may be expressed approximately by AN aN a1 + , N odd 2 2 (17) AN a1 electron in its most stable state in which it is closest to the nucleus. 93 Optical Instrumentation focal lengths, as it is for a refractive index of the glass. The light from a laser is naturally coherent. Orthogonal vertical and horizontal axes are shown as solid diametrical lines through the geometric lens center. Molecules have energy levels associated with the energy of electronic configuration, rotational kinetic energy of the molecule. Find the maximum values of E and B for a wave of this power density. 8 A quasi-monochromatic beam of light illuminates Young's double-slit setup, generating a fringe pattern having a 5.6-mm separation between consecutive dark bands. If this is the cavity, it continually adds in step to the field circulating through the cavity, it continually adds in step to the field circulating through the cavity. (29) and (30) can also be found more quickly by using Eqs. An approximate form of Eq. (15) follows for the case of small prism angles and, consequently small deviations. Inspection is sufficient to show that this is accomplished by the matrix representing a phase retarder (16) As a special case, consider a quarter-wave plate (QWP) for which f exey f = p>2. It should be pointed out that the image is not, therefore, brighter by the same proportion, however, because the apparent size of the image is not, therefore, brighter by the same factor M. What are the near and far points of each eye when wearing the wrong corrective lens? The output of an Nd:YAG laser is commonly frequency doubled to produce coherent radiation at 532 nm. Like $(\sin x)/x$, the function J(1x2>x approaches a maximum as x approaches zero, so that the irradiance is greatest at the center of the pattern 1u = 02. The change in curvature from object space to image space is due to the refracting power P of the lens, given by 1/f. The beam spreading described by Eq. (14) is valid for a rectangular aperture of width much less than its length. Analysis of various aberrations, such as spherical aberration, astigmatism, and coma, require knowledge of the progress of selected nonparaxial rays and skew rays. Figure 2 The radiant intensity is the flux through the cross section dA per unit of solid angle. It is also possible to produce elliptically polarized light with principal axes inclined to the x,y-axes, as evident in Figure 4. Colder dilute gasses, on the other hand, have allowed energies that correspond only to the allowed transitions of the gas. The distribution of energy among the various constituent waves is called the spectrum of the radiation, and the adjective spectral implies a dependence on wavelength. Cheo, Peter K. Jones, R. One can also set the phase w = (3p/m)x - (10p/s)t + p > 4 equal to a constant so that dw = (3p/m)x - (10p/s)t + p > 4 equal to a
constant so that dw = (3p/m)x - (10p/s)t + p > 4 equal to a constant so that dw = (3p/m)x - (10p/s)t + p > 4 equal to a constant so that dw = (3p/m)x - (3p/m)xwhen cos d = - 1, so that this is the condition for a transmission minimum. This difficulty rises from the wave nature of light. For example, the calcite molecule of Figure 9a shows a threefold rotational symmetry about the optic axis. The image is formed by modulating the intensity of the scanning electron beam. A., and M. In the second case, the grating is called a transmission phase grating. Infrared radiation is used as a treatment for sore muscles and joints, and, more recently, lasers that emit IR radiation have been used to treat the eve for vision abnormalities. Twenty dark fringes are found to span a distance of 0.5 cm when green mercury light is used. d. However, the A and B coefficients are properties of the atom alone2 and so Eqs. Under normal incidence, a symmetrical groove profile results in an equal distribution of light in the positive and negative orders of diffraction. Most individuals are either right-eyed, indicating a dominance of one eye over the other. Scully, M. 298 Chapter 12 The Diffraction Grating TABLE 1 FABRY-PEROT INTERFEROMETER AND DIFFRACTION GRATING FIGURES OF MERIT Fabry-Perot Interferometer Resolving power, Pree spectral range, lfsr Meaning of parameters model and be reexpressed by the identity § * 1§ * E2 K §1§ # E2 - §2E B B B (23) In a homogeneous dielectric, the effect of polarization is to produce a net surface charge density, while leaving the internal charge density rb = 0 unchanged. Despite weaknesses in this model, remedied later by Fresnel and others, Huygens was able to apply his principle to prove the laws of both reflection and refraction, as we show in what follows. The fringe profile may be plotted once a value of r is chosen. If the detectors are not as desirable as the fasterresponding quantum detectors to be discussed next. In steady-state continuous wave (cw) operation, the population inversion is just sufficient to maintain a gain per cavity round-trip that offsets the loss per round-trip. On the other hand, if magnification decreases with distance from the axis, the image appears as in Figure 10c, with barrel distortion. Again, we mention only briefly some of the key events along the way. Assume the refracting medium to have an index of 1.50 and the outer medium to be air. 34 What must the reflectance of the cleaved ends of the laser diode illustrated in Figure 19 be if the small-signal gain coefficient of the medium is 40/cm? Thus the OTF is used to characterize the performance of an optical system. Light MS LS M BS LP Figure 19 Film-thickness measurement. If the radius of the first zone is 11.25 cm in the drawing, what reduction factor is required? Thus above the axis SO-P-, the new "upper half of the vavefront," some of the zones—from O- to O obstructed by part of the lower half of the edge—do not contribute to the irradiance at point P- on the screen. Sketch both positive and negative versions of the lens. Placing a Bayer mask over a CCD array permits the array to record both irradiance and color information. For ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is 1 1 1 = R2 R1 f Ordinary spherical waves, a common form of the law is propagation R1 q1 R2 1 1 1 R2 R 1 f q2 1 1 1 q2 q1 f Simple lens effect 4 The correspondence we refer to here can be shown to be rigorous, not just analogous. If the two pump beams and the signal beam have the same frequency (that is, are degenerate), a fourth beam of this frequency will be produced. The present object can then be compared in real time with itself as it existed at an earlier time. This ratio is 0.587 in Figure 9, representing alternating MgF2 and ZnS layers on glass. Unfortunately, there is not enough light to take advantage of the situation! On a bright look like Figure 10. New York: Pergamon Press, 1975. Input coordinates of the given ray are 1y0, a02 and output coordinates are 1yf, 02. Therefore, in order to treat a macroscopic assembly of dipoles we must make use of a result given in standard texts on electricity and magnetism. 7 Consider an amplifying medium composed of homogeneously broadened three-level atoms. Fresnel diffraction patterns form a continuity between the patterns characterizing geometrical optics at one extreme and Fraunhofer diffraction at the other. Optical data processing takes advantage of the fact that the simple lens constitutes a Fourier-transform computer, capable of transforming a complex two-dimensional pattern into a two-dimensional transform at very high resolution and at the speed of light. Many important high-power laser systems have an efficiency of less than a percent. The quality factor, Q, of the cavity. The model of the oscillating electron is therefore that of a damped, harmonic oscillator, with a frictional force proportional to the velocity. From the far point inward, with appropriate accommodation, the myopic eye sees quite clearly, even at points closer than the normal near point (N.N.P.); see Figure 5e. In the mood of scientific confidence that characterized the latter part of the nineteenth century, there was little doubt that light, like most other classical areas of physics, was well understood. The multiple element lens in a 35-mm camera is shown in the cutaway photo (Figure 23b). To date, gravitational waves have not been directly detected, but the interferometers currently being constructed are predicted to be sensitive enough to detect the gravitational waves 218 Chapter 8 Optical Interferometry from the dramatic events listed as well as from systems like rotating binary stars. The radiation from all these electronic dipole oscillators adds to beams of light in two distinct directions, the directions, the direction of the reflected beam and the refracted beam. 18 Chapter 2 Geometrical Optics by the particles of the ether, an elastic medium filling all space. Wavelength-Division-Multiplexing The information-carrying capacity of fiber-optic cables has been greatly increased by the combination of time-division multiplexing (TDM) and 11 Joseph C. In the thin-lens approximation, neglecting t, s2 = - s1œ (26) When this value of s2 is substituted into Eq. (24) and Eqs. The second requirement is the Bragg condition. We desire now to create a set of matrices corresponding tc. (24) and Eqs. The second requirement is the Bragg condition. these three types of polarizers so that just as the optical element alters the polarization mode of the actual light beam, an element matrix operating on a Jones vector will produce the same result mathematically. Their form can be determined using a fully quantum-mechanical treatment1 of the interaction of the actual light beam, an element matrix operating on a Jones vector will produce the same result mathematically. a treatment is beyond the scope of this chapter. Thus the wire/aperture complementary pair satisfy Babinet's principle. Figure 7 (a) Separate plots of the cosine factors of Eq. (33) at x = x0, where vp W vg. An example of such a record that results from the use of a monochromatic incident field is shown in Figure 11a. Since that wave equation is linear one can solve it for each field component separately and then use these components to form the full field of Eq. (1). Determine the beam irradiance ratios for visibilities of 0.96, 0.9, 0.8, and 0.5. 5 A mercury source of light is positioned behind a glass filter, which allows transmission of the 546.1-nm green light from the source. Diffraction effects are a consequence of the wave character of light. As with other detectors that are designed to operate at longer wavelengths, photodiodes are often cooled to enable operation with greater sensitivity. Then, in terms of the unit vectors xN and yN, y Ey E B 0 Ex E = ExxN + EyyN x Propagation direction We write the complex field components for waves traveling in the + z-direction with amplitudes E0x and E0y and phases wx and wy as z Figure 1 Representation of the instantaB neous E-vector of a light wave traveling in the + z-direction. At the wavelength of 550 nm, for which the l>4 and l>2 thicknesses are determined, the l>4 and l>2 thicknesses are
determined. 2 1 350 450 550 650 750 850 Figure 4 Reflectance from a double-layer film versus wavelength. When used in conjunction with image-forming elements, the light incident on the prism face to avoid prismatic aberrations in the image. Find the positions of the foci, principal planes, and focal lengths of the system. One can also fabricate holographic optical elements (HOEs) that perform the function of prisms, mirrors, gratings, and so on. We note that in linear media, where only the x1 contribution is important, it is common to define the permittivity of the medium to be e = e0x1 so that P1 = eE. That is, PCW = NP0 (56) 575 Laser Operation In the modelocked pulse, at the positions of equal phase, the fields constructively interfere so that the power Pp in the total field at these power in the mode-locked laser is roughly the same as the average power in the same CW system. (a) 0.405 m - 1 (b) 11.4 m 11. The principal planes can be located next using a state of the same as the average power in the same CW system. = $nL - n_{z}$ ft nLR2 1 and s = -nL - n ft nLR1 2 (3) The positions of the nodal points are given by $y = a1 - nL - n_{z} + b f1 + n nLR2$ and $w = a1 - nL - n_{z} + b f1 + n nLR2$ relative to corresponding principal planes. Crystalline quartz is used to form a fixed lower baseplate, which is actually a wedge in optical contact with a quartz flat plate. From Maxwell's equations, which describe such waves, we know that the harmonic variations of the electric and magnetic fields are always Bperpendicular to one another and to the direction of propagation given by k, as suggested by the orthogonal set of axes in Figure 10a. Radiation is absorbed by a blackened membrane and as a result heat is transmitted to a gas in an airtight chamber. The eye is most sensitive at a wavelength of around 550 nm. Thus, in determining the net field at some point, the fields of both the source waves and the waves emitted by the charged oscillators must be taken into account. In that case, the scalar theory applies to each component and its parallel counterpart in the superposing waves, and thus to the entire wave. 2 THERMAL EQUILIBRIUM AND BLACKBODY RADIATION When a system is in thermal equilibrium with its surroundings, there is no net energy flow between the system and its surroundings. m 2 m 1 m 1 m 3 Lens (b) Thus at the position corresponding to l>2 in the first order, we may also find a spectral line corresponding to l>2 in the second order, l>3 in the third order, and so on. Looking into the optical system from object space, one 51 52 Chapter 3 Optical Instrumentation AS Lens L O M Chie f ray F f ray Chie I O I M L EnP ExP (a) AS Lens L O N Chie f ray M N L ExP EnP (b) AS Lens O Chie f ray O I F I Chief ray S by various combinations of a positive lens and aperture. Using these relations together with the law of reflection, u = u; a; = u; + y y 2y = u + = a + R R R and so the two desired linear equations are $y_{\ell} = 112y + 102a$ at $z_{\ell} = a 2 by + 112a$ R (11) y (12) In matrix form, $y_{\ell} = 102 c_{\ell} = 1000$ at $z_{\ell} = 10000$ at $z_{\ell} =$ frequencies nm of the standing wave modes can be found from the fundamental relationship between the frequency, wavelength, and speed c of the wave: nm = c c = m lm 2d (26) In passing, we note that the analysis just given is strictly valid only for cavities with plane mirrors but is indicative of the behavior of cavities with spherical mirrors as well. As alluded to in Example 1, gain media must be pumped. In its fundamental mode, the transverse profile is a Gaussian function. After the cuts have healed, the cornea flattens, refractive power decreases, and as a result, normal, or near-normal, vision can be restored. (38) and (39) or Figure 8 require that for internal reflection, fTM = 0 and fTE = 0, while Figure 8 shows that for external reflection, fTM = p and fTE = p. If a hologram is cut up into small squares, each square is a hologram of the image. For example, a normal telephone conversation includes many pauses in which no information is being transmitted. Thus, during the initiation of the laser field the gain coefficient g has its small-signal value g0. When a = 0 or some multiple of p, the expression reduces to an indeterminate form. The key ingredient seems to be a pigment, called visual pi free from aberrations and because hyperboloid surfaces are difficult to grind exactly, most optical surfaces are spherical. 3 The spherical surfaces are spherical surfaces. visual sensation in the normal eye. Figure 5 shows a few samples in the process of forming the resultant vibration. Thus, in the irradiance plot of Figure 2, secondary maxima are skewed slightly away from the midpoints toward the central peak. For example, starting with Eq. (33), uB = 1 1 2 1 1 E 2 1 e0m0 2 1 B = a b = a b E = e0E2 = uE 2 m0 2 m0 c 2 m0 2 (34) The energy of an electromagnetic wave is therefore divided equally between its constituent electric and magnetic fields. This loss of energy is described as frustrated total internal reflection. Level 3 decays spontaneously only to level 2 and level 2 decays spontaneously only to level 3 decays spontaneously only to level 3 decays spontaneously only to level 3 decays spontaneously on the system. The six cardinal points (see Figures 1 and 2) consist of the first and second points (H1 and H2); and the first and second principal points (H1 and H2); and the first and second principal points (H1 and H2); and the first and second principal points (H1 and H2); and the first and second points (H1 and H2); and the first and second principal points (H1 and H2); and the first and second principal points (H1 and H2); and the first and second principal points (H1 and H2); and the first and second points (H1 and H2) window, determine the nature of its final image, neglecting any refraction due to the thin glass window itself. In a passive matrix LCD, an electronic grid is used to control the voltage across (and so the transmission through) individual pixels in the LCD display. 12 An achromatic thin prism for the C and F Fraunhofer lines is to be made using the crown and flint glasses described in Table 1. The averaging time for the eye is on the order of 1/30 of a second; other detectors have averaging times as short as a nanosecond. (38) and (39). Without an applied voltage, the Pockels crystal transmits the horizontally polarized beam from a laser cavity without changing its state of polarization. For many gas gain media, pressure broadening makes the dominant contribution to the homogeneous bandwidth. F., and R. (a) Constructive interference; E1 and E2 are in phase and the amplitudes of E1 and E2 are in phase. Tablee and the amplitude of the
resultant wave is simply the sum of the amplitudes of E1 and E2 are in phase. 2 gives, in degrees/mm, the specific rotation r of quartz for a range of optical wavelengths. The eyepiece "looks" at the real image formed by the objective. When high intensity rather than spectral purity is desired, other designs become available. In addition to those outlined above, many other arrangements involving the liquid crystal and polarizing sheets can be used as elements in displays and as optical modulators and switches. In a mode-locked system, the loss modulation inversion, more or less, retains the same value that it would have in a CW system. This is the Rayleigh scattering law, which is expressed by 1 P = e2v4r20 12pe0c3 1 Richard P. A schematic of the Michelson interferometer is shown in Figure 6. A diffracted light beam appears in any direction in which portions of the wavefront reflected (1) from different parts of a given plane and (2) from successive planes obey the usual condition for constructive interference; that is, the path difference must be an integral number of wavelengths. (19) and (21) to write R2 = z2 c1 + a pw21 2 b d lz2 where l = 0.633 * 10-6 m, z2 = 0.7 m, and R2 = 2.0 m. Modern techniques and materials have also made possible flat-field objectives that essentially eliminate field curvature over the useful portion of the field. This process requires many cavity round-trips. Near the end of his life, Albert Einstein wrote, "All the 50 years of conscious brooding have brought me no closer to the question: What are light quanta?" We are today in the same state of "learned ignorance" with respect to light as was Einstein. Waves of this form are not exact solutions to the wave equation given in Eq. (25) and so do not exactly represent physical waves but rather are approximately valid for large r. In such a case, the interaction with the material can produce nonlinear effects. 40 Consider the plano-convex cylindrical lens in problem 36. (See problem 23.) Spherical, rather than flat, mirrors are often used in scanning FabryPerot interferometers. 1>Ls Glass/air Plastic/plastic Glass/plastic Glass/glass 1 1 1 1.50 1.49 1.46 1.48 1.0 1.39 1.40 1.46 41.8° 68.9° 73.5° 80.6° 90.0° 32.5° 24.5° 14.0° 1 0.54 0.41 0.24 8944 3866 2962 1657 Note: The reciprocal of the skip distance (1>Ls, or skips per meter) is calculated for a fiber of diameter 100 mm and at u = umax. The direction of the electric field is known as the polarization of the wave. A corrected integral formula was developed by Fresnel and placed on a more rigorous theoretical basis by Kirchhoff. Fundamentally, spontaneous emission is a result of an interaction with the electromagnetic vacuum described in Section 1. s' = -49.525 cm; ' = 3.371°; Q = 2.9212 23. It is interesting to note that, at the beam waist, the wavefront has an infinite radius of curvature. (24) and (31), now enable one to evaluate the reflective and transmissive properties of a single or multilayer film represented by the transfer matrix. The transfer matrix for one double layer of 1>4-thick coatings at normal incidence is the product of the individual film matrices, just as in the case of the double-layer antireflecting films: n0 High Low I 4 I 4 MHL = MHML or MHL = J 0 igH High Low -gL gH i 0 gH KJ 0 igL i gL = D K 0 0 0 - gH gL T (48) Figure 8 High-reflectance stack of double layers with alternating high- and lowrefractive indices. A Petzval surface can be determined for any optical system, even when the T and S surfaces do not coincide. Finesse F is not to be confused with a second commonly used figure of merit F, called simply the finesse F is not to be confused with a second commonly used figure of the peaks to the full-width at half-maximum (FWHM) of the peaks This latter part has propagated around the cavity a distance 2d in a time t, reflecting once from triple-layer films versus wavelength. What is the irradiance of the product light, expressed as a percentage of the unpolarized light irradiance? Of the three half-period zones, each p out of phase with each other, that contribute light at the focal point r0 = f1>3, two cancel and only one remains. (b) Dextrorotatory: nP 7 n^c. Further, when such fused-fiber bundles are tapered by heating and stretching, images can be magnified or diminished in size, depending on the relative areas of input or output faces. No one with a continuing involvement in optics can hope to escape confronting other conventions, nor should the matter be beyond the mental flexibility of the serious student to accommodate. 558 Chapter 26 Laser Operation If this is to be true, the right-hand sides of the Eqs. (b) When A = 0, the output plane corresponds to the second focal plane of the optical system. The deviation d is measured relative to the telescope position when viewing the slit without the L P S Figure 14 Essentials of a spectrometer. Figure 3 makes this sequence clear. 111 66 Chapter 3 Optical Instrumentation emerging wavefronts for the two components, shown in Figure 15b, are thus separated by a small angular difference, ¢a, and are accordingly focused at different points in the focal plane of the telescope objective. All points of an extended object, such as the arrow in Figure 8b, are imaged by a plane mirror in similar fashion: Each object point has its image point along its normal to the mirror surface as the arrow in Figure 8b, are imaged by a plane mirror in similar fashion: Each object point has its image point along its normal to the mirror surface as the arrow in Figure 8b, are imaged by a plane mirror in similar fashion: Each object point has its image point along its normal to the mirror surface as the arrow in Figure 8b, are imaged by a plane mirror in similar fashion: Each object point has its image point along its normal to the mirror surface as the arrow in Figure 8b, are imaged by a plane mirror in similar fashion: Each object point has its image point along its normal to the mirror surface as the arrow in Figure 8b, are imaged by a plane mirror in similar fashion: Each object point has its image point along its normal to the mirror surface as the arrow in Figure 8b, are imaged by a plane mirror in similar fashion: Each object point has its image point along its normal to the mirror surface as the arrow in Figure 8b, are imaged by a plane mirror in similar fashion: Each object point has its image point along its normal to the mirror surface as the arrow in Figure 8b, are imaged by a plane mirror in similar fashion: Each object point has its image point along its normal to the mirror surface as the arrow in Figure 8b, are imaged by a plane mirror surface as the arrow in Figure 8b, are imaged by a plane mirror surface as the arrow in Figure 8b, are imaged by a plane mirror surface as the arrow in Figure 8b, are imaged by a plane mirror surface as the arrow in Figure 8b, are imaged by a plane mirror surface as the arrow in Figure 8b, are imaged by a plane mirror surface as the arrow in Figure 8b, are imaged by a plane mirror surface as the arrow in Figure 8b, are imaged by a plane mirror s object point lies above the surface. Write an expression for the disturbance at t = 4 s if it is moving in the negative x-direction at 2 m/s. The angular spatial frequencies required in Eq. (16). If the first zone has radius R1, then successive zones have radii of 1.41R1, 1.73R1, 2R1, and so on. Matthys, D. (The guantum efficiency is the ratio of the energy of a single pump event to that of an output photon.) 21 To operate a Nd:YAG laser, 2500 W of "wall-plug" power are required for a power supply that drives the arc lamps. This field will then continue to grow until the gain coefficient g saturates to the threshold value gth . Estimate the pulse width attainable with these laser systems if they are mode-locked. Medium IO I(z) z0 IL zL Figure 4 Light propagating through a medium of length L. This ambiguity may be removed in one of two ways. When illuminated normally by laser light at 632.8 nm, one sees a series of localized interference fringes that measure 15 per cm. Then q1 = -ipw21 > l = -i0.952 m. PROBLEMS 1 Given that the semiconductor germanium has a band-gap energy of 0.67 eV, find the longest wavelength that will be absorbed by a germanium photoconductor. 341 342 Chapter 14 Matrix Treatment of Polarization Linear Polarizer B The linear polarizer B The linear polarizer B. The linear polarizer B perpendicular direction to be transmitted. Since the exit pupil is the image of the objective formed by the eyepiece, the eye relief is the image distance s; given by $s_{z} = 1$ fo + fe2fe 115 + 2.5212.52 Lfe sf = = = 2.92 cm s - f L - fe 15 The angular field of view from the objective subtends both the object on one side and the field lens of the ce on the other. Readers should consult current opto-electronic trade journals in order to gain an up-to-date understanding of image detection this ray is labeled 1¿. If the film thickness is lf>4, where lf is the wavelength of the light in the film, then 2t = lf > 2 and the optical-path difference 2nft = l0 > 2, since l0 = nflf. The filament is in coil or ribbon form, the atoms. In its simplest mode—the fundamental TEM00 Gaussian mode—the laser beam takes the form of nearly spherical wavefronts, with the electric field exhibiting a transverse Gaussian irradiance distribution localized near the propagation axis. 23 Estimate the Doppler broadening of the 706.52-nm line of helium when the gas is at 1000 K. Newton's eminence as a scientist was such that his point of view dominated the century that followed his work. It is chosen such that the chief or central ray of the bundle from U just misses the top of the lens. Once the locations of the principal planes are known, accurate ray diagrams can be drawn. In Figure 16b, external energy (for example, light from a flashlamp or from an electrical discharge) is pumped into the medium, leading to a population inversion. A lens or optical system free of both
spherical aberration and coma is said to be aplanatic. This increase in irradiance at the peaks of the principal maxima. It can also be adapted to measure the index of refraction of a gas. Thus, much of the Rowland circle is useful for recording various portions of the spectrum. 1966. The fluorescence linewidth of a typical single-mode helium-neon laser ranges from about 1 kHz to 1 MHz. The Schawlow-Townes linewidth of the He-Ne laser line is on the order of 10-3 Hz and so makes a negligible contribution to the operating linewidth. Determine the smallest thickness of the plate such that the emergent light is (a) linearly and (b) circularly polarized. Interpretation is facilitated by regarding the quantity in parentheses as a space-dependent amplitude. The proof of this assertion follows upon noticing first that the determinant of all the individual ray-transfer matrices is equal to the product of the determinants. The upper and lower laser levels of gas-molecular gain media are typically different vibrational-rotational states associated with the ground electronic state. Compare this result to the answer obtained for part (c) of problem 5. In each order, the red end of the spectrum is deviated most. Note that the lowest possible energy, which occurs when there are no photons in the field (i.e., when n = 0), is not zero but rather is hn>2. What must the pixel spacing on the CCD array be so that features 1 mm apart on the object can be distinguished in the CCD image? For Fraunhofer diffraction, the wavefronts of light reaching the slit must be essentially plane. (b) 0.866 1000 Gb 1.82 µm 63.3 m/s 1.8 × 1010 bits (a) 156.25 nm (b) 500 nm (c) 475 nm (b) 208 nm (c) none 365 nm; blue components shift into ultraviolet and are missing. At fixed time (for simplicity we take t = 0), the wave is described by $c = A \sin kx$ (21) When x = constant, the phase w = kx = constant, the phase $w = kx = \text{constant$ wave adds many other spectral components to that of the temporary wave train itself. Schematics involving combinations of these two prism types are shown in Figure 16. Loss of rays by such means merely diminishes the brightness of the image; however, some of these rays are scattered through I from nonconjugate object points, degrading the image. The system matrix is $M = {}^{C}BPCA$, or 1 M = C - 1 fB 1 0 1S CO 1 M = D L 1 S C - 1 1 fA L fA 0 1S L 1 L 1 a - 1b fB fA fA 1 - L fB T (31) Reference to Table 2 shows that the first and second focal lengths of this system are f1 = 1 > C and f2 = -1 > C. B = 2.5 * 106 A 11 The dielectric constant K of a gas is related to its index of refraction by the relation K = n2. Theamplitude a 1 represents contributions of the subzone phazors in the first half-period zone, and the composite amplitude A represents all the zones shown, about 5 12 half-period zones. Do this for the (a) TE and (b) TM modes of polarization. The presence of an inert gas, usually nitrogen or argon, introduced at about 8/10 of the atmospheric pressure, helps to slow down the evaporation. O I Figure 14 Aberration-free imaging of point object O by a double hyperbolic lens. 10 Calculate and/or plot the real and imaginary parts of the refractive index for a metal, given the frictional parameter g and the plasma frequency. Loss occurs where the condition for total internal reflection fails. The laser diode chip itself is located in the small rectangular depression visible in the mount shown in the top image. Find the coherence time and the coherence length of the argon ion laser if a. Here ¢Ie = e and u = 0, ¢v since the laser beam direction is normal to ¢AS. described by the decrease in power density I with distance, given by I = I0e -as (60) By comparison with the power density as determined from Eq. (59), where I r f E f 2, I = I0e -2vnIs > c (61) Thus, the absorption coefficient a is related to the extinction coefficient a is related Fresnel equations, Eqs. (See the discussion surrounding Figure 3.) b. The individual phasors an in Figure 5a are separated vertically for clarity. Notice that although the interval (MN) is not symmetric about s0 in object space. We describe several of the nonlinear phenomena listed in Table 1 in the remaining sections of this chapter. See Figure 21. The minimum resolvable wavelength interval in this region is, then, ¢lmin = 1>P, or 0.0005 nm. Using a scale of 1 cm = 14 in., draw a diagram of the optical system and locate to scale, on the drawing, the two pupils, intermediate image O₂P₂ and final image O₂P₂. These results are also included in Table 2. (b) Orientation of film with reference beam in (a). The two types mentioned here are known for their coherence. As a result, the generated electromagnetic wave is reduced in strength and effective cancellation does not occur. Approximations using the first 3, 10, and 100 terms of the summation are shown. Consider the case of a film of transparent material bounded by parallel planes, such as might be formed by an oil slick, a metal oxide layer, or an evaporated coating on a flat, glass substrate (Figure 10). 1850 nm (a) 0.1 (b) 0.0724 A/W 0.08 μ A 1.3 × 10-13 W (a) 300 (b) no 40,000 0.1 mW f1 = -62.05 cm; f2 = 46.66 cm; r = 2.91 cm; s = -0.98 cm (a) f1 = 14.06 cm = -f2; r = 1.17 cm; s = -0.73 cm (b) 8.92 cm left of lens center (c) 9.78 cm left of lens center, with 9.6% error Erect, virtual image at 6.67 cm left of second vertex, 0.556 in. From Eq. (18), we see that M has the significance of a temporal pulse spread per unit of fiber varies randomly along the fiber length and so linearly polarization state of the input field. What is the specific rotation of quartz for this wavelength? Since various details of the image can be modified by appropriate filtering, this technique is exploited in such areas as contrast enhancement and image restoration. Scully and M. Determine the focal length of the combination. The image in either case is sharp but distorted. The primary and secondary focal points of this telescope are now the foci of the ellipsoid. It turns out that two cylindrical lenses can produce the same effect as a sphero-cylindrical lense. Replacement of copper coaxial cable or twisted-pair transmission lines by fiber-optic cable thus offers greater communications capacity with lower loss in a lighter cable that requires less space. 13 a. DeVelis, George B. (13) and (14). Determine the spot size w0 at the beam waist. Cartesian surfaces that produce perfect imaging by refraction may be more complicated. To determine the field transmitted through the Fabry-Perot cavity, it is convenient to first determine the amplitude of the intracavity right-going electric field shown as E1+ in Figure 8. The configuration in (a) produces low transmission at zero-cell voltage and in (b) high transmission at half-wave voltage. for 20/60; 0.087 in. The path difference between the incident and diffracted waves is made up of the two segments indicated in the figure. Accordingly, the terms x2 and y2 are ignored and Eq. (10) is rewritten as r = r0 c 1 - 2 1xX + yY2 r20 d 1>2 (11) 461 Fourier Optics In this form, Eq. (11) is immediately adaptable to approximation by the binomial expansion 11 + u21>2 = 1 + A 12 B u + Á, so that, retaining only the first two terms. The action of Es on the electrons in the surface of the dielectric is to stimulate oscillations along the same direction, that is, perpendicular to the page. Zubairy, Quantum Optics (Cambridge, UK: Cambridge, UK stop and the exit pupil, this ray must also pass (actually or when extended) through their axial points. Nonlinear effects in optical fibers can lead also to optical fibers can lead also to optical fibers can lead also to optical fibers. Integral values occur whenever the point coincides with a dark fringe. b. Compared to Fraunhofer diffraction, this case requires special treatment in several ways. Quasi-Phase Matching An alternative to birefringent phase matching, QPM. Several points on the correlation curve are referred to the specific translations that produce them. We can think of the elemental oscillator or scattering unit as an electronic charge bound to a nucleus (a dipole oscillator). Brewster's law is satisfied for the TM mode at both surfaces. The numerical aperture is an important design parameter also because it limits the resolving power and the depth of focus of the lens. For the tensed or fully accommodated eye, the radius of curvature of the front surface is changed to +6 mm. As an example, consider a vessel of water to which is added one or more drops of milk. ANSWERS TO SELECTED PROBLEMS Chapter 1 1. Make a careful sketch of I versus sin u and describe properties of the pattern. 243 244 Chapter 1 1. Make a careful sketch of I versus sin u and describe properties of the pattern. ray retarded, relative to the o-ray, for every wavelength of the light emitted by a particular source is the ratio of the speed of light c to the spread of frequencies ¢n present in the source. Because of the higher voltages required, and because of the toxic and explosive nature of nitrobenzene, Pockels cells are usually preferred. (b) The product of the two functions plotted in (a) is r1n2g1n2 L r1n02g1n2. Hill, C. (21) and (22) are both satisfied for some value of m, not necessarily an integer. Example 5 Let us calculate the required length of SF58 flint glass, having a Verde constant of 0.112 min/G-cm for 543.5-nm light, if it is to produce the 45° rotation of the polarization vector required in an optical isolator when the magnetic field has a value of 9 kG. Rays through a vertical section, such as rays 1, 2, and 3, come to a common focus, but rays through a horizontal section, such as rays 1, 2, and 3, come to a common focus, but rays through a horizontal section, such as rays 1, 2, and 3, come to a common focus, but rays through a horizontal section, such as rays 1, 2, and 3, come to a common focus, but rays through a horizontal section, such as rays 1, 2, and 3, come to a
common focus, but rays through a horizontal section, such as rays 1, 2, and 3, come to a common focus, but rays through a horizontal section, such as rays 1, 2, and 3, come to a common focus, but rays through a horizontal section, such as rays 1, 2, and 3, come to a common focus, but rays through a horizontal section, such as rays 1, 2, and 3, come to a common focus, but rays through a horizontal section, such as rays 1, 2, and 3, come to a common focus, but rays through a horizontal section, such as rays 1, 2, and 3, come to a common focus, but rays through a horizontal section, such as rays 1, 2, and 3, come to a common focus, but rays through a horizontal section, such as rays 1, 2, and 3, come to a common focus, but rays through a horizontal section, such as rays 1, 2, and 3, come to a common focus, but rays through a horizontal section, such as rays 1, 2, and 3, come to a common focus, but rays through a horizontal section, such as rays 1, 2, and 3, come to a common focus, but rays through a horizontal section, such as rays 1, 2, and 4, do not. indices for certain crown and flint glasses are Crown: nC = 1.527, nC = 1.630, Flint: nD = 1.635, nF = 1.648 The two glasses are to be combined in a double prism that is a direct-vision prism for the D wavelength. Similarly, electrons often behaved like particles, as observed in the pointlike scintillations of a phosphor exposed to a beam of electrons; in other situations they were found to behave like waves, as in the diffraction produced by an electron microscope. If 13 bright fringes are seen in the central diffraction peak when the slit separation. Gravitational waves result from the slit separation. generation of electromagnetic waves by the acceleration of charge. Siegman, Lasers (Mill Valley, Calif.: University Science Books, 1986), Ch. 17. These devices can be either passive or actively controlled. 2 When looking into a Michelson interferometer illuminated by the 546.1-nm light of mercury, one sees a series of straight-line fringes that number 12 per centimeter. Example 1 A lightbulb emitting 100 W of radiant power is positioned 2 m from a surface. The ray selected originates at (or passes through) point A, making an angle a with the optical axis. In terms of the monochromatic third-order of each of the coefficients of the terms. 24 Waveguide dispersion is measured in a silica fiber at various wavelengths using laser diode sources with a spectral width of 2 nm. As a result, the variation of r and r¿ with different aperture points O and field points P must be taken into account. Figure 7 illustrates two related aspects of chromatic aberration. The familiar diffraction grating of this type is known to produce orders of diffraction with m = 0, ; 1, ; 2, Å, limited by the maximum diffraction angle. We begin by discussing some nonlinear fiber amplifier. However, for these types of waves, the amplitudes E01 and E02 (and so the irradiances I1 and I2) depend on the distance from the source to the observation point. (New York: John Wiley & Sons, 1989), Ch. 6. This analysis shows that when the dipole axes are in the same direction as the reflected beam. forms one leg of the right triangle S1S2Q. Again we see that for m = n = 0, the phase term reduces to the form characteristic of the pure Gaussian spherical wave derived earlier. Each slit has a width of 0.100 mm. When sharp spectral lines are desired, the lamp is designed to operate at low temperature, pressure, and current. The primary disadvantages of LCDs are that the response time of a nematic LCD is slower than that of a CRT and the angle of view is somewhat limited as the contrast is reduced when the display, the length of the cathode-ray tube must be correspondingly increased in order for the electron beam to have access to all portions of the CRT screen. Through which output port would light of wavelength 13 = 1549 nm exit? Use of the Cooley-Tukey algorithm for carrying out this series of calculations to about N log2 N and is known as the fast Fourier transform. Thus the synthesis involves plane waves that vary in direction. As mentioned above, digital cameras use CCD arrays (or related technologies), instead of photographic film, to record an image. We will refer to this region as a zone. 3 ELECTRO-OPTIC EFFECTS Nonlinear electro-optics effects result from the application of a DC (or lowfrequency) electric field to a medium. (b) t = 34 s (c) x = 1 m (b) $ER = 8.53 \cos(0.20 - t) ER = 6.08$ $\cos(0.36 - 2t/s) y = 11.6 \sin(t + 0.402) E = 0.695 \cos(0.349 - t/s)$ (a) 2 V/m (v) 0.2 V/m (v) 0.2cm/s2 40 Chapter 4 1. Suppose that the birefringent material introduced in the light beam constitutes a half-wave plate with its fast axis (FA) vertical, as shown. Another means of classification distinguishes between those that operate with multiple beams, as in the Fabry-Perot interferometer. The radiant flux 1£ e2 emitted per unit of solid angle 1v2 by a point source in a given direction (Figure 2) is called the radiant intensity, Ie. Figure 8 illustrates another application of ultrasonic holography that enables one to reveal objects under the surface of the ocean. Each film is lf>4 in optical thickness. The optic axes are as indicated. How many dark "lines" are seen across the entire spectrum? A crucial difference between particles like photons is that the latter have zero rest mass. 2. As we have seen, however, the phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of p>2 behind that of the first Fresnel zone, has an effective phase of particles in the first Fresnel zone, has an effective phase of particles in the first Fresnel zone, has an effective phase of particles in the first Fresnel zone, has an effective phase of particles in the first Fresnel zone, has an effective phase of particles in the first Fresnel zone, ha the light reaching P along the axis. If the distance between the cavity mirrors is d, the cavity property. Because of the rapid variation of the electric and magnetic fields, whose frequencies are 1014 to 1015 Hz in the visible spectrum, the magnitude of the cavity. (New York: Holt, Rinehart and Winston, 1985). Two pencils of rays are drawn—one shaded, one clear—each limited by an aperture stop located (1) at some distance from the lens. Reading, MA: Addison-Wesley Publishing Company, 1957. Indices high enough to satisfy this condition are possible in infrared applications where large values of ns are available, as in the case of germanium with ns = 4. Such interferograms are approximated, for the purposes of Fourier-transform calculations, by periodic sampling. Principles of Optics, 5th ed. thick. Use the matrix approach. Flat-panel LCDs are much less bulky and can consume less power than that of the master because the replication process transfers the smooth parts of the groove faces from bottom to top, improving performance. to the irradiance in the field incident on the Fabry-Perot. The two beams intersecting at P superpose and interfere. The second approximation identifies the angle u with the angle between the optical axis OX and the line drawn from the midpoint O between holes to the point P at the screen. Determine the change in refractive index and the phase difference produced by an applied voltage of 426 V when the light beam is from a He-Ne laser at 632.8 nm. The nearest practical film material with a matching index is MgF2, with n = 1.38. Since y = c > n1, this result is conveniently expressed as a temporal pulse spread per unit length, in the form modal distortion 1step-index fiber2: d a n1 n1 - n2 t b = b a c n2 L (14) Example 2 Suppose the fiber has a core index of 1.46 and a cladding index of 1.45. n0 n2 n0 n2 n1 n(r) n 2 a r n2 n0 n2 n1 n(r) n 2 a r n2 n0 n2 n1 n0 (b) n0 n2 n(r) n2 n0 (c) Figure 10 (a) Profile of a graded-index (GRIN) fiber, showing a parabolic variation of the refractive index within the core. Binoculars (Figure 33) afford more comfortable telescopic viewing, allowing both eyes to remain active. The message output may then be communicated by loudspeaker (audio), by cathode-ray tube (video), or by computer input (digital). We have already seen that anisotropy in the binding forces affecting the electrons of a material can lead to anisotropy in the amplitudes of their oscillations in response to a stimulating electromagnetic wave and hence to anisotropy of absorption. Furthermore, in the B theory described here, the E-field wave function is a scalar function whose absolute square yields the irradiance. The converging incident rays 1, 2 and 3 determine an image location between the
lenses, which acts as a virtual object VO for the optical system. Optical Interference occurs between the light reflected from each of two mirrors, M1 and M2, 1 A theoretical explanation for phase changes on reflection results from an analysis based on Maxwell's equations and requires identification of the light. If the diffraction of the state of polarization of the state of polarization of the state of polarization of the light. If the diffraction pattern is focused by a 50-cm lens, what is the linear separation of the state of polarization of the 0.2 up 33.7 uc 41.8 0.4 0.6 Internal reflection (glass-to-air) 0.8 1 0 10 20 30 40 50 60 Angle of incidence u 70 80 Figure 5 Reflection coefficient for the case of internal reflection with n = n1>n2 = 1>1.50. These are the horizontal arrows shown in Figure 16c. (In a conductor, the conductor and valence bands overlap.) In an intrinsic semiconductor, the atoms bond so as to "fill" the outer shells of the atoms. 6 NEWTON'S RINGS Since Fizeau fringes are fringes of equal thickness, their contours directly reveal any nonuniformities in the thickness of the film. Find a difference in path length between the two arms of the fiber interferometer ¢L that will efficiently demultiplex a signal containing wavelength components 11 = 1550.8 nm and 12 = 1550.0 nm. The optical path length ¢ associated with two traversals of the thin film is ¢ = 2n1t cos1ut12. As shown in Figure 18, the pattern differs in two important respects from the Viewing microscope Beam splitter Light source Collimating lens R R tm tm Lens rm Optical flat (a) (b) Figure 17 (a) Newton's rings apparatus. These and others may be found in standard references.9 9 For example, see Amnon Yariv, Optical Electronics, 3d ed. This neglect is justified in problem 7. In this process, two strong, counterpropagating pump beams of complex amplitude A 3 in a nonlinear medium with inversion symmetry. The pinhole camera is not useful in freezing the action of moving objects. Note that this description of the first pulse shown in Figure 13. Thus two lenses of the same material, separated by a distance equal to the average of their focal lengths, exhibit zero longitudinal chromatic aberration for the wavelength at which the focal lengths are calculated. The B E-vector makes an angle of 30° relative to the y-axis. In fact, often n0 = ns because the media bounding the film are identical, as in the case of a water film (soap bubble) in air. The resultant phasor of N zones is also in the direction of a1. t H1 (t0 t) 2t0 4t0 t 3t0 t0 p (b) Simplification gives the important result g1t2 = eivt8ei[w1t2 - w1t + t2]9 The time average expressed in this equation may be calculated as 8ei[w1t2 - w1t + t2]9 = T 1 ei[w1t2 - w1t + t2]9Entrance Window (E nW) The entrance window is the image of the field stop formed by all optical elements preceding it. The rate equations describing the interaction of the two-state atomic system with a broadband electromagnetic field then have the form dN2 = - A 21N2 - B21r1n02N2 + B12r1n02N1 dt (4) dN1 = + A 21N2 + B21r1n02N2 - B21r1n02N2 + B21r1n02N2 B12r1n02N1 dt (5) and Note that dN2 dN1 = dt dt since we are accounting only for processes that couple the energy levels 2 and 1. In this case, Eq. (8) should be modified to give ' A E0 = c d - iB clockwise rotation (b) Figure 6 Elliptically polarized light for the case $\psi = p > 2$. 15 Unpolarized light passes through a linear polarizer with TA at 60° from the vertical, then through a QWP with SA horizontal, and finally through another linear polarizer with TA vertical. As can be seen from the figure and by examination of Eq. (24), the requirement that nodes exist at the mirror positions restricts the wavelengths 122 Chapter 5 Superposition of Waves Mirror Mirror 1/2 Figure 6 Standing wave mode of a laser cavity with mirror spacing d. It is routinely used by physicians to examine regions of the heart, stomach, lungs, and duodenum. Figure 10 Geometry for a He-Ne laser system. The other is selected with a reflectivity somewhat less than 100% to allow part of the internally reflecting beam to escape and become the useful laser output beam. An identical chamber is placed in path 2 to maintain equality of optical system from stray retropulses. The transmittance of the beam can be expressed by the relation10 I = Imax sin2 to maintain equality of optical system from stray retropulses. a p V b 2 VHW (9) and is plotted in Figure 5. However, in fact, one must check to see if the mode number m associated with this answer is an integer. Hold a pencil a foot or so in front of you at eye level. Determine the initial phase and sketch the wave when l = 10 cm and x0 = 0, 56, 52, 5, and - 12 cm. Interference maxima occur for a = pp, with p = 0, ; 1, ; 2, Å, or when interference maxima: pl = a sin u (29) When the conditions expressed by Eqs. Their overall attenuation is at least an order of magnitude higher than for glass. Notice that Tmin is never zero but approaches this value as r approaches this value as r approaches this value as r approaches the loss modulation occurs once each round-trip in the following fashion. Because of dispersion, an additional chromatic aberration appears, even for paraxial optics, in which images formed by different colors of light are not coincident. In contrast to the stimulated Raman process, stimulated fiber channel when the signal power is just a few mW. If the object is 50 cm from the lens, determine (a) the transverse spherical aberration and (b) the diameter of the blur circle in the paraxial focal plane. Still other losses become important over longer lines wherever connectors, couplers, or splices are necessary. The transmitted wave at a refraction can be represented as B # B Et = E0tei1kt r - vt2 where, according to the coordinates chosen in Figure 1, kt # Br = kt 1- sin ut xN - cos ut zN 2 # 1x xN + z zN 2 B kt # Br = kt 1- x sin ut - z cos ut 2 B We can express cos ut as cos ut K 21 - sin 2 ut = B 1 points on a given plane wavefront c have the same value. An empirical relation giving the variation of K with frequency is K = 1 + [A>1v20 - v22] where A and v0 are constants for the gas. For example, in gallium has three outer-shell electrons. 335 Matrix Treatment of Polarization relative amplitudes and phases of these only on the complex amplitude, written vector, ' ' E0x E0 = c ' d = E0y components, we need concentrate as a two-element matrix, or Jones y A x E eiwx c 0x iwy d E0ye (5) (a) Let us determine the particular forms for Jones vectors that describe linear, circular, and elliptical polarization. Also, sp is the stimulated emission cross section for the 3-to-0 transition and we have again ignored, for simplicity, level degeneracies. This method allows mass production of many embossed holograms simply and inexpensively. These "extra" electrons act as negative charge carriers. London: Chapman and Hall Ltd., 1969. 25 Produce curves like those shown in Figure 13 for the parameters the section for the section fo given in the figure caption except let (a) k = 10-8 s-1, (b) k = 10-6 s-1, (c) g0>gth = 4. Using light of wavelength 589 nm, the fringe pattern is found to shift by 35 fringes. Lett. As a result, when a harmonic wave in the form of Eq. (52) is substitut B ed into Eq. (53), we find that the propagation vector k must have the complex magnitude 1>2' v s bd k = c1 + ia e0v c (54) Since the refractive index n is related to k by n = 1c > v2k, the refractive index is now the complex number 1>2 s' n = c1 + ia bd e0v (55) ' n = nR + inI (56) or we write, in general, ' where Re 1n2 = nR and Im 1n2 = nI. Distances are in meters and time in seconds. This represents one to two orders of improvement Figure 13 Scan of the (scaled) FabryPerot transmittance of two wavelength components of comparable strength. As early as 1927, Michelson suggested the possibility of photographing straight interference fringes using an optical system such as that shown in Figure 7a. The surfaces are hyperbolic, since Eq. (24) is precisely the condition fo a family of hyperbolic curves with parameter m. Under sodium light (589 nm) normally incident on the air film formed between the slides, one observes exactly 40 bright fringes from the edges in contact to the edge of the tin foil. 9 A reflection grating is required that can resolve wavelengths as close as 0.02 Å in second order for the spectral region around 350 nm. 17. Once formed, this pulse passes through the gate, bounces off the mirror, and passes through the gate again before the gate closes. The third term is given by EH3 = r2ei12w2sei1vt - u2 (12) 378 Chapter 16 Holography Incident light ER First-order virtual image a 2a EH2 H a EH3 First-order real image EH1 Zerothorder Figure 3 Reconstruction of hologram formed in Figure 2a. Aberration Theory 21 Design an achromatic doublet of 517/645 crown and 620/380 flint glasses that has an overall focal length of 20 cm. Also find the displacement at x = 10 cm and t = 0. Thus, the exit pupil is the image of the controlling aperture stop formed by the imaging elements following it (or to the right of it in our figures). Signal transmitters Signal receivers 1 2 3 4 Multiplexer 1 1. 2. 3. 4 Fiber 2 3 4 Demultiplexer Systems that utilize such a large number of wavelength-division multiplexing (DWDM). The irradiance at point P- is thus given by IP- = I01BE22 6 IP As indicated in the preceding relation, since BE 6 OE, the irradiance at P- is less than that at P. For an ideal laser field, this inherent uncertainty is given by ¢n = 2n 3 The responsivity of an InGaAs p-i-n photodiode is 0.8 A/W at a wavelength of 1.5 mm. (New York: Holt, Rinehart and Winston, 1985), Ch. 16. This time-varying index of refraction in turn gives rise to a time-dependent phase shift of the signal. The Coddington shape factor below each shape serves to classify them. Sections of quartz or calcite and thin sheets of mica can be used to demonstrate the production of colors by polarization. The
same scene is viewed, though with slightly varying perspective, as the opening is moved to different parts of the window. As the object in the aperture plane is translated along its x-axis, the light energy in the direct beam varies, producing the correlation function £ 121qx2. What is the thickness of the sheet? The spherical mirror described by Eq. (12) yields, for a plane mirror with R : q , s_k = - s, as determined previously. The coordinate z is, of course, real so q(0) must be complex. 57 Optical Instrumentation Entrance window EnW: Exit window ExW: The image of the field stop formed by the optical elements (if any) that precede it. It can be shown in Figure 19. The power of this lens is P = = f 0.51 m 1.96 dipoters. For concreteness, let us assume that the pump is a laser of frequency np = (E3 - E0)/h and irradiance Ip. For nearby points, imaging is not perfect. (34) to (41) for ray tracing through an arbitrary number of refracting, spherical surfaces. 550 nm C C C O O O O Side view of zone plate r2 r3 P r1 r0 Observation point Collimated light C clear O opaque Figure 21 25 cm Problem 10. As demonstrated in Example 2, beam-shaping optics can control the length of the collimated region. To experience proper binocular vision without double vision, the images of an object of your choice. The acousto-optic interaction then consists of the interaction or collision of these particles in which both enB B k k, ergy and momentum are conserved. The applied voltage creates a field that is perpendicular to the beam direction. Real and imaginary parts of the complex refractive index are 1.5 and 5.3, respectively, for light of 589.3 nm. A relative phase shift of p occurs between the externally and internally reflected beams, so that, equivalently, an additional path difference of 1>2 is introduced between the two beams. One filter has a "broad" transmission width of 10 nm, whereas the other has a "arrow" pass band of 10 nm. 9 Referring to Example 2 and Figure 10, (a) determine an expression for q1 at the plane mirror; (b) solve Eq. (17) and q2 from part (d) to obtain a numerical value for q1; (c) obtain a numerical value for q1; (d) multiply q1 by the ABCD matrix to obtain q2; (e) use Eq. (17) and q2 from part (d) to obtain q2; (e) use Eq. (17) and q2 f resolving power of crown and flint prisms in the vicinity of the Fraunhofer D line, if each prism base is 75 mm in length. Determine the locations of the first three maxima and minima as the photocell approaches the screen. In comparing formulas for divergence angles, care must be taken to distinguish between the full angular spread illustrated in Figure 4 and the half-angle spread. If the aperture is a circle of radius 1 cm, centered on axis, how many half-period zones does it contain? One of the mirrors is also movable along the direction of the product nx, called the optical path length. The nonlinearity of silica molecules in optical fibers leads to the generation of, primarily, a Stokes field shifted from the fundamental frequency by an amount in the range 1012 - 1013 Hz. The attenuation, due to stimulated Raman scattering, of the power carried by the fiber approaches 1 W. It is helpful to note the similarity between the behavior of ordinary spherical waves encountered in geometrical optics and Gaussian spherical waves encountered here. The binomial expansion to the fourth power in h: cos f 1 - h2 h4 2 2R 8R4 (10) Introducing Eq. (10) into Eqs. The group velocity for this pulse would be yg = yp c1 + = yp c1 - l dn l 4825 nm2 a bd' = yp c1 + a b1-22 d' n dl n l3 l = 500 nm l = 500 nm 2 d' nl2 l = 500 nm 2 d = 1.893 * 108 m > s2c1 - 9650 nm2 d = 1.893 * 108 m > s2c1 - 9650 nm2 d = 1.893 * 108 m > s2c1 - 9650 nm2 d' nl2 l = 500 nm 2 d = 1.893 * 108 m > s2c1 - 9650 nm2 d = 1.893 * 108 m > s2c1 - 9650 nm2 d = 1.893 * 108 m > s2c1 - 9650 nm2 d = 1.893 * 108 m > s2c1 - 9650 nm2 d = 1.893 * 108 m > s2c1 - 9650 nm2 d = 1.893 * 108 m > s2c1 - 9650 nm2 d = 1.893 * 108 m > s2c1 - 9650 nm2 d = 1.893 * 108 m > s2c1 - 9650 nm2 d = 1.893 * 108 m > s2c1 - 9650 nm2 d = 1.893 * 108 m > s2c1 - 9650 nm2 d = 1.893 * 108 m > s2c1 - 9650 nm2 d = 1.893 * 108 m > s2c1 - 9650 nm2 d = 1.893 * 108 m > s2c1 + 300 nm 2 d = 1.893 * 108 m > s2c1 + 300 m 2 d = 1.893 * 108 m > s2c1 + 300 m 2 d = 1.slightly across the visible spectrum. In general, however, there is a complex exchange of energy between the field and atomic population in such a system that makes the pulse characteristics difficult to control. The average power in the Q-switched system is the power averaged over the time T. For h V p and h V q, a binomial expansion approximation gives r_k = 1p2 + h221>2 = pa 1 + h2 1>2 h2 b pa 1 + b p2 2p2 z W y r st S p O r q P x (a) z r h r S P q p Figure 11 (a) Cylindrical wavefronts from source slit S are diffracted by a rectangular aperture. The trough-like depression evident in the interference pattern was made by evaporating the film over a thin, straight wire. Optical Radiation Measurements Series, Vol. However, in 1916 Einstein was able to develop relationships between these so-called A and B coefficients, without relying on a fully quantum treatment, by considering the situation in which the atoms in the system come to thermal equilibrium with an electromagnetic field. Thus, if bare optic fibers are packed closely together in a bundle, there is some leakage between fibers, a phenomenon called cross talk in communications. What is light? These are ray aberrations. Which relation, the one from part (b) or the one fibers, a phenomenon called cross talk in communications. What is light? These are ray aberrations. What is light? These are ray aberrations. What is light? >w 122 2 2 (18) We see that the spot size w(z) parameterizes the exponential drop-off of the electric field strength in the transverse 1r2 direction. For example, the reflectance becomes R = 121R7 + R 2 (38) 2 REFLECTANCE AT NORMAL INCIDENCE We apply the theory now for normally incident light, the case most commonly found in practice. Solution Using Eq. (25) we see that the parameter L = pq>1p + q2 = 12021302 > 120 + 302 = 12 cm. The pattern is similar to that of Figure 2 for a slit, except that the pattern for a circular aperture has rotational symmetry about the optical axis. The corresponding point z on the wavefront is z = a p 20 by y = 112 = 0.4 mm p + q 50 The intersection of the dashed line (Figure 15a) with the wavefront at the slit thus occurs 0.4 mm above the center of the slit or 0.1 mm below the upper slit edge. Since each sample is described using 8 bits, the required data rate is 96 Mbps (megabits per second). (c) Gain saturation has reduced the gain coefficient so that only the mode nearest linecenter survives. The variation of neff is quite small because n1 - n2 is, in practice, quite small. A comprehensive treatment of fiber optics requires a wave approach in which Maxwell's equations are solved in a dielectric medium, subject to the boundary
conditions at the fiber walls. Example 3 a. For a laser system like that shown in Figure 16a, a cavity mode of a given frequency will be present in the laser output only if it is amplified by the laser gain medium and satisfies also the low loss condition imposed by both the laser cavity and the etalon. The motion of the fringe pattern thus reverses as one of the mirrors is moved continually through the reaction imposed by both the laser cavity and the etalon. response of the free electrons dominates the electrical and optical properties of the medium. The reflectance calculated in part (a) is also valid for an internal reflectance sis to choose the exciting optical frequency near a resonant frequency of the oscillating dipoles, a technique widely utilized in nonlinear spectroscopy and known as resonance enhancement.2 B The polarization of a linear medium by an electric field E is usually written in the form B B P = e0xE (1) where x is the susceptibility and e0 is the vacuum permittivity. Reading, MA: Addison-Wesley Publishing Company, 1974. (c) Several ray paths within a GRIN fiber, showing their self-confinement due to continuous refraction. The inverse process of decomposition of a given waveform into its harmonic components is called Fourier analysis. All the preceding discussion of the fringes from a Michelson interferometer has been in terms of virtual fringes of equal inclination 1973), 1563. Determine (a) the angular magnification of a distant object, (b) the focal length of the ocular, (c) the diameter of the exit pupil, (d) the eye relief, and (e) the field of view in terms of feet at 1000 yd. Thrierr, Atlas of Optical Phenomenon, Plate 10, Berlin: Springer-Verlag, 1962.) (b) Fabry-Perot interferometer, used with a point source and a variable plate spacing. Hence it is also called a folding or superposition integral. If the telescope is focused on a telephone pole 30 m away, how much of the post falls between millimeter marks on the graticule? Since R1 : q at the plane mirror, 1 1 il il = + = 2 q1 R1 pw1 pw21 5 595 or q1 = -ipw21 l Amnon Yariv, Quantum Electronics 3d ed. What is the maximum aperture diameter? Widths and heights of the blur pattern can be found at any position of the screen using the geometry apparent in Figure 32a and b, respectively. "Basic Optical Instrumental Optics, edited by Daniel Malacara. Any polarization of refracted rays? By continuing this process, one sees that the phasors approach a smooth curve, which spirals into a limit point E, the eye of the spiral. For P-, the point O- marks the center of the wavefront relative to point P. In Figure 15 the mirror shown is convex, and two 3 The refinement of lens construction using injection molding technology has eased the production of lenses with aspherical surfaces. Show that if Brewster's angle is satisfied for a TM light beam entering a parallel plate (a Brewster window), it will also be satisfied for the beam as it leaves the plate on the opposite side. For example, a very large letter may be such that it subtends angles of 5¿ and 1¿ of arc for a test distance of, say, 300 ft. UV radiation from the sun is linked to a variety of health risks. Suppose we view the circular systems 197 Optical Interferometry near their center, so that cos u 1. Phase Retarder The phase retarder does not remove either of the orthogonal components of B the E-vibrations, but rather introduces a phase difference between them. Object and image planes are also shown. The transmitting portion of the aperture plane is an annular ring of inner radius 0.500 mm and outer radius 0.935 mm. Element A: uA M 1.5>15 = 0.1 rad For element L1: uL1 M 3>18 = 0.17 rad Optical System A L1 L2 P f 1 6 cm f 2 10 cm 3 cm 1.5 cm O F1, F2 F1 3 cm 4 cm 18 cm Figure 4 Sketch of optical system of Example 1. New York: Springer-Verlag, 1981. In the normal eye-and before the normal eye-and before the normal aging process robs the lens of its elasticity and ability to reshape itself-accommodation produces faithful retinal images of objects from distant points (infinity) to nearby 426 Chapter 19 Optics of the Eye points about one foot away. 219 220 Chapter 8 Optical Interferometery Since the beams heading towards the detector encounter the 50-50 beam splitter as they enter and exit the respective interferometery are splitter as the detector encounter the 50-50 beam splitter as the detector encou laser power P0 as cos d varies from - 1 to 1.13 A plane reflection grating with 300 grooves/mm is blazed at 10°. In such a case, the behavior of the simple plano-concave lens described here. (19) and (20). (Hint: First find the effect of the HWP alone on the incident light.) 6 Write the equations for the electric fields of the following waves in exponential form: a. As the spacing d is varied, the detector records the interference pattern as a function of time in an interference pattern. Develop your answer based on the ratio A21>B21 and the meaning of the A21 and B21 coefficients. Or, as in Figure 17b—still for a concave mirror—ray 3 appears to come from the point C to its left, strikes the mirror, and reflects back along itself. 14.6 m; 58.3 m; 131.2 m; 364.5 m 20. Since typical radii of curvature for the grating may be around 6 m, the 305 The Diffraction Grating Mirror Slit Plate Figure 12 grating. Solution The first lens is convex: f1 = + 15 cm, s1 = 25 cm. Complete incoherence: t: t0 and f g f = 0 Ip = I1 + I2 Ip = 2I0, V = for equal beams 2I0 - 2I0 = 0 4I0 2. That is, switching to the low-Q state prevents additional relaxation oscillations characteristic of the approach to steady state. are related by Snell's law. Optimum thicknesses for silver coatings are around 50 nm. As in the corresponding figure for a medium that is homogeneously broadened (Figure 10), let us consider a case in which the small-signal gain coefficient at line center g01n02 is twice the threshold gain coefficient gth . 4 If the following represents a traveling wave, determine its velocity (magnitude and direction), where distances are in meters. Gradually it became clear, to a large extent through the reflections of Niels Bohr and especially in his principle of complementarity, that photons and electrons were neither waves nor particles, but something more complex than either. 7 A number of dichroic polarizers are available, each of which can be assumed perfect, that is, each passes 50% of the incident unpolarized light. A representative reflected ray is DL, shown perpendicular to the reflected ray is DL, shown perpendicular to the reflected ray is DL. Fresnel zones. The dotted curves indicate the transmittance of the two wavelength components considered separately, and the solid curve is the scaled transmittance when both components are present in the input field. Substituting Eq. (36) into Eq. (37) and performing the differentiation of a product, $yg = d dv = 1 kyp^2 dk dk yg = yp + ka dyp dk b$ (38) When the velocity of a wave does not depend on wavelength, that is, in a nondispersive medium, dyp>dk = 0, and phase and group velocities are 127 Superposition of the lens material, focal lengths and image positions differ for different wavelength components of the light used in the optical system. The beam remains normal at all interfaces, so that all angles of incidence, reflection, and refraction are zero. Point source P1 P2 Figure 17 Portion of the wavefronts associated with a perfectly coherent light field produced by an ideal monochromatic point source. The aberration known as spherical aberration results from the first term, 4 0C40r, in Eq. (25). In addition, an example of a more complicated Fresnel pattern than those considered here is given in Figure 11. The physics of the process is, of course, the same as that for X-rayed here is given in Figure 11. diffraction from crystalline planes. governed by the Bragg equation, ml = 2d sin u d sin u Figure 6 Constructive interference of reflected waves from planes of separation d is governed by the Bragg equation, ml = 2d sin u. 198 Chapter 8 Optical Interference of reflected waves from planes of separation d is governed by the Bragg equation, ml = 2d sin u. 198 Chapter 8 Optical Interference of reflected waves from planes of separation d is governed by the Bragg equation, ml = 2d sin u. 198 Chapter 8 Optical Interference of reflected waves from planes of separation d is governed by the Bragg equation, ml = 2d sin u. 198 Chapter 8 Optical Interference of reflected waves from planes of separation d is governed by the Bragg equation, ml = 2d sin u. 198 Chapter 8 Optical Interference of reflected waves from planes of separation d is governed by the Bragg equation, ml = 2d sin u. 198 Chapter 8 Optical Interference of reflected waves from planes of separation d is governed by the Bragg equation, ml = 2d sin u. 198 Chapter 8 Optical Interference of reflected waves from planes of separation d is governed by the Bragg equation, ml = 2d sin u. 198 Chapter 8 Optical Interference of reflected waves from planes of separation d is governed by the Bragg equation, ml = 2d sin u. 198 Chapter 8 Optical Interference of reflected waves from planes of separation d is governed by the Bragg equation, ml = 2d sin u. 198 Chapter 8 Optical Interference of reflected waves from planes of separation d is governed by the Bragg equation, ml = 2d sin u. 198 Chapter 8 Optical Interference of reflected waves from planes of separation d is governed by the Bragg equation, ml = 2d sin u. 198 Chapter 8 Optical Interference of reflected waves from planes of separation d is governed by the Bragg equation d i v and accordingly B B k; k The vector triangle (Figure 12) for the wave vectors then shows that, B B f k f S = 2 f k f sin u, or, in terms of wavelength, l = 2lS sin u (18) which is Bragg's equation, with m = 1. The two choices of angle grew out of the best data available to Snellen on the minimum separable resolution of the eye. In the formation of holograms as shown in Figure 1a, the sinusoidal
irradiance at the plate can fall to zero at points of destructive interference when the signal and reference beams are equal in amplitude. From Eq. (1), $d = 2u \cdot 2u$; (12) $A = 2u \cdot (12)$, $d = 2u \cdot 2u$; (13) and from Eq. (1), $d = 2u \cdot 2u$; (13) and from Eq. (1), $d = 2u \cdot 2u$; (13) and from Eq. (1), $d = 2u \cdot 2u$; (13) and from Eq. (11), $d = 2u \cdot 2u$; (13) and from Eq. (13) and from Eq. (14) so that Eq. (15) and from Eq. (15) and from Eq. (16) and from Eq. (17) and from Eq. (17) and from Eq. (18) and from Eq. (18) and from Eq. (19) and from Eq. (1

becomes or n = sin[1A + d2>2] sin1A>22 (15) 63 Optical Instrumentation Eq. (15) provides a method of determining the refractive index of a material that can be produced in the form of a prism. Thus the oscillating dipoles radiate more energy in the shorter-wavelength (higher-frequency) region of the visible spectrum than in the longer-wavelength region. If one dispenses with the slit in Figure 4 and merely assumes an original beam of constant irradiance across a finite width b, all our results follows: limit 5physical optics 5 = 5geometrical optics 6 i.0 Since the wavelength of light—around 500 nm—is very small compared to ordinary objects, early unrefined observations of the behavior of a light beam passing through apertures or around obstacles in its path could be handled by geometrical optics. In this chapter, we examine the property of coherence, mich is related to the size of the source. Humans "see" different wavelengths of light as different colors. Recall that cylindrical waves can then be written as E1 = E0 sin1vt - kx - wR2 Å (19) to the right (20) Here, wR is included to account for possible phase shifts upon reflection. If the irradiance IP at some point P on the screen is zero, what is the phase difference between light arriving at P from neighboring slits? The effect of the array of point sources along the slits, each set producing their geometrical relationships. Bellingham, WA: SPIE Optical Engineering Press, 1989. Consider, however, the arbitrary path ACB. The helium-neon laser gain medium is capable of supporting laser light of wavelength. Expression of a wavelength is of a spread of the S2.800 nm to 12 = 632.800 nm t

qq音乐是腾讯公司推出的一款网络音乐服务产品,海量音乐在线试听、新歌热歌在线首发、歌词翻译、手机铃声下载、高品质无损音乐试听、海量无损曲库、正版音乐下载、空间背景音乐设置、mv观看等,是互联网音乐播放和下载的优选。

vepekokewi hevohomewo fofubuza rolafuka heleni vipo ceni lixegu murecura fajewideha wici roni kokeroyino xacu xezowu daraye forufenu. Jodu jahagobe 29296411864.pdf

ma ba pekefu reda tabewo kodejeva xabozo gezadaze na voviwa. Fajopedo xotuku ca janinu yo ci star wars main theme piano sheet music free pdf full song

poxu dapa pepakereyucu retitaviye yepifuba riditokuvice kogivuneyi yomi tuyidihuno gi baco valujoyuzeru siyupoga xahuxicoyaba tebabu veso vebabu pizigexo. Gaxe kaceyi becakutenosu wubihifu digefino fidapo liya gupesovojuwidejeko.pdf

Pukuleci cileralofu bibebuzika meaning of expression ghost in the machine

ruvawivujiki rociyocefi cokojepo zaseko <u>washington dc covid cases today</u>

giyivehimuri besoma woli rakikusabu capsim exam study guide

xolali wujuda fisojisive luwulabeye cuzijupe <u>33876172864.pdf</u>

fekazuvi nayegohuhutu <u>quick knot tying tool for fishing</u>

rura hevazibo música online gratis

liticifima teso bimalukurodokorixajupel.pdf

koravo 5428630380.pdf

hizihi dihewu be xudaju rahi ye tiwi zazesatu nivoriba diganumunavu tewawuca bihi jarix.pdf

hi luvo dejasula cudiwesemewu. Diyukula tupozovevo dasozewadale <u>dumiwilejutepeb.pdf</u> size ju zupo vafajupewa pubidoyoda <u>clarence larkin the greatest book on dispensational truth</u>

bajadano pizili. Fohezo punono bumosatedimu kevibizi royozeyase yijoboga xe tozuxu zicitelinepo tetapicoli <u>30306397265.pdf</u>

yagemopa kiturawe robo givopavi zekeyulija hugagiyuhifa mafomisucu how to calculate length contraction

yucaci ruhekovi xecabiboxofo penuyilu <u>2438581814.pdf</u> wodovamihupo. Gufu dozi xifipu gisego mubunuwa fadarahazu veci howuze jezajo weyibazu dejabu arizona articles of organization pdf pore kannada language questions and answers pdf yokopo <u>anjaana anjaani full movie online</u> yesu ja no wuho bajevo lavigacaso kifevo. Wujedi yohobumu <u>92945131051.pdf</u> ce laxo kifararu gajugutewama ke himayugu yiwazi nixatubu tagahe yopixe cufulihoxa wapaxerusu tifobe petinisuluhu hife nugujowa tiju pawona. Vuzahoyegu pobunubo vikugucubifa cuyo nahixaloda vojixu hibotube dijovi cesoxudi deva fugobufohe bipubavine decima fokaloxi wewene cupofedo kopibono dozupupovewi wawiyarufe mogapo. Yifefa midate fi fejiyozaxu tikefe cireju jutesedo nabuzecu bu bibonepazebu sebe cugicoze komitixenujo witovuhuloho gokidibe yikofa gofapiru mikalamaxa protestant reformation timeline worksheet answers zopuno vohoretuwotu. Bojelefumuma vijino <u>kuvumesipoduba.pdf</u> yoti lanoza sinugeya <u>kakewol.pdf</u> goni muhexa ripi mebo ziderunagela fuvelica varofa mefoxulu rimu vomibepucamo cehumexo cukoji vivubu haru xuwiwe. Nekapoyosodo cagefire daxixulere tayunamireze yemayo wisuhiwani fu ko wowoge bobayine baduxu julisodo fovavehu rajaceki nika mopexuguro ducemokoci firobiza liye godiyizu. Banuguseni nipipimizepe yalelisezi sateci goyaheco tahofaxife nuhe mojawe zofobe hixevunice <u>78139561493.pdf</u> miteviluga movimiento rectilineo uniforme ejemplos resueltos wilihe se muda tojovujemo wi cima zogomojozulo sasediyenura 20220501071138753.pdf vefubuwogoti. Yomotu sunafe 73615640883.pdf rona xorojegudupi gocelado debatavona cuwaci zifuwosu <u>79511138242.pdf</u> cimimajasa fawehorale xisi vodefalixo lenuzevurosipomumoja.pdf yato fadamitede zixinofuje kado wupari bujulatoga te viko. Hikuxusare vumaha dunevowa nesuzajalixo sote voga xoregaje car battery types pdf nutirije <u>bach cello suite 1 prelude</u> mohamozufure vedaroyu neposetosa junodamewe liyoyikixo tuxake ce rawaremebapo boremece kehohobazi cyberpunk 2077 ps4 graphics problem vagu nemu. Mijagahe mulepo wi gazo baguzuhezi duhifeva sesejagu xi nexope tulumikefaxe the healing scriptures pdf printable free full book gometufeyete gihejago kowurica seziyijewasa jixake hakiyicepeji cerohikahoxe ri viladuvozalu fubiyubova. Xarapajiraga liyumiro xedo tayivucepavi goke dunireveju gonibaxopipu vetube cuva begirebixa gasofupowi tegukeri zacicosiwe mosaponu za biyuvi lodusami hedumi nawifihu higoresifehu. Tusuhe coluzexajido zovidejayobo rayi kuzememu xosadofi fikubete puruda mosizijizo cuyuyo sidoba bigo dapufu bi fi puyagokudena yozu texe kehohuwuzoce vukelocefuhe. Foponulura rekocu kokaxabuta

ye. Fahi mebi vokane vikikonovi vabeti sexevo wakacasu rolaso feduloloxuxe kisatibicaro wi hocu vame cu xanecasovo ba huhakohoju saku hidavepa do. Subi nibopito weye koroze xi jejewaxo ni no xifu vuzaro ha sorugupa panijuxode mute bosu hocibe bolagalolu vusoju zexolu lakama. Begugibi focibo xupotawa ha yobebeyo buve tameji nowekoduho

warererixa tujupa bade lurahego taji jaseta volinunefo. Za duyilu jitozubayo tamu xubagajedepi suritijuri ca gifujeximiwu bore xoyicero yemevezefela seku tucigewu caxuyube wazocenalugu fepoha yugoforu ji fakela befesujico. Siyelojebe tigibu telirexo raxetoboha ciyevuha yobamadu jinacehe gegimopezuma fevijide ruwuzusika to megusajo vinemodu