Contents

PREFACE

1. LIGHT AS WAVES, RAYS AND PHOTONS

1

The nature of light. Waves and rays. Total internal reflection. The light wave. Electromagnetic waves. The electromagnetic spectrum. Stimulated emission: the laser. Photons and material particles.

2. GEOMETRIC OPTICS

19

The thin prism: the ray approach and the wavefront approach. The lens as an assembly of prisms. Refraction at a spherical surface. Two surfaces; the simple lens. Imaging in spherical mirrors. General properties of imaging systems. Separated thin lenses in air. Ray tracing by matrices. Locating the cardinal points: position of a nodal point, focal point, principal point, focal length, the other cardinal points. Perfect imaging. Perfect imaging of surfaces. Ray and wave aberrations. Wave aberration on-axis – spherical aberration. Off-axis aberrations. The influence of aperture stops. The correction of chromatic aberration. Achromatism in separated lens systems. Adaptive optics.

3. OPTICAL INSTRUMENTS

57

The human eye. The simple lens magnifier. The compound microscope. The confocal scanning microscope. Resolving power; conventional and near-field microscopes. The telescope. Advantages of the various types of telescope. Binoculars. The camera. Illumination in optical instruments.

4. PERIODIC AND NON-PERIODIC WAVES

83

Simple harmonic waves. Positive and negative frequencies. Standing waves. Beats between oscillators. Similarities between beats and standing wave patterns. Standing waves at a reflector. The Doppler effect. Doppler radar. Astronomical aberration. Fourier series. Modulated waves: Fourier transforms. Modulation by a non-periodic function. Convolution. Delta and grating functions. Autocorrelation and the power spectrum. Wave groups. An angular spread of plane waves.

Contents

5. ELECTROMAGNETIC WAVES

vi

115

Maxwell's equations. Transverse waves. Reflection and transmission: Fresnel's equations. Total internal reflection: evanescent waves. Energy flow. Photon momentum and radiation pressure. Blackbody radiation.

6. FIBRE AND WAVEGUIDE OPTICS

135

The light pipe. Guided waves. The slab dielectric guide. Evanescent fields in fibre optics. Cylindrical fibres and waveguides. Numerical aperture. Materials for optical fibres. Dispersion in optical fibres. Dispersion compensation. Modulation and communications. Fibre optical components. Hole-array light guide; photonic crystal fibres. Optical fibre sensors. Fabrication of optical fibres.

7. POLARIZATION OF LIGHT

163

Polarization of transverse waves. Analysis of elliptically polarized waves. Polarizers. Liquid crystal displays. Birefringence in anisotropic media. Birefringent polarizers. Generalizing Snell's law for anisotropic materials. Quarter- and half-wave plates. Optical activity. Formal descriptions of polarization. Induced birefringence.

8. INTERFERENCE

185

Interference. Young's experiment. Newton's rings. Interference effects with a plane-parallel plate. Thin films. Michelson's spectral interferometer. Multiple beam interference. The Fabry-Pérot interferometer. Interference filters.

9. INTERFEROMETRY: LENGTH, ANGLE AND ROTATION

205

The Rayleigh interferometer. Wedge fringes and end gauges. The Twyman and Green interferometer. The standard of length. The Michelson-Morley experiment. Detecting gravitational waves by interferometry. The Sagnac ring interferometer. Optical fibres in interferometers. The ring laser gyroscope. Measuring angular width. The effect of slit width. Source size and coherence. Michelson's stellar interferometer. Very long baseline interferometry. The intensity interferometer.

10. DIFFRACTION

231

Diffraction at a single slit. The general aperture. Rectangular and circular apertures: uniformly illuminated single slit: two infinitesimally narrow slits: two slits with finite width: uniformly illuminated rectangular aperture: uniformly illuminated circular aperture. Fraunhofer and Fresnel diffraction. Shadow edges – Fresnel diffraction at a straight edge. Diffraction of cylindrical wavefronts. Fresnel diffraction by slits and strip obstacles. Spherical waves and circular apertures: half-period zones. Fresnel-Kirchhoff diffraction theory. Babinet's principle. The field at the edge of an aperture.

11. THE DIFFRACTION GRATING AND ITS APPLICATIONS

259

The diffraction grating. Diffraction pattern of the grating. The effect of slit width and shape. Fourier transforms in grating theory. Missing orders and blazed gratings. Making gratings.

Contents

Concave gratings. Blazed, echellette, echelle and echelon gratings. Radio antenna arrays: end-fire array shooting equally in both directions: end-fire array shooting in only one direction: the broadside array: two-dimensional broadside arrays. X-ray diffraction with a ruled grating. Diffraction by a crystal lattice. The Talbot effect.

12. SPECTRA AND SPECTROMETRY

281

Spectral lines. Linewidth and lineshape. The prism spectrometer. The grating spectrometer. Resolution and resolving power. Resolving power: the prism spectrometer. Resolving power: grating spectrometers. The Fabry-Pérot spectrometer. Twin beam spectrometry; Fourier transform spectrometry. Irradiance fluctuation, or photon-counting spectrometry. Scattered laser light.

13. COHERENCE AND CORRELATION

307

Temporal and spatial coherence. Correlation as a measure of coherence. Temporal coherence of a wavetrain. Fluctuations in irradiance. The van Cittert–Zernike theorem. Autocorrelation and coherence. Two-dimensional angular resolution. Irradiance fluctuations: the intensity interferometer. Spatial filtering.

14. HOLOGRAPHY

329

Reconstructing a plane wave. Gabor's original method. Basic holography analysis. Holographic recording: off-axis holography. Aspect effects. Types of hologram. Holography in colour. The rainbow hologram. Holography of moving objects. Holographic interferometry. Holographic optical elements. Holographic data storage.

15. LASERS

349

Stimulated emission. Pumping: the energy source. Absorption and emission of radiation. Laser gain. Population inversion. Threshold gain coefficient. Laser resonators. Beam irradiance and divergence. Examples of important laser systems: gas lasers, solid state lasers, liquid lasers.

16. LASER LIGHT

371

Laser linewidth. Spatial coherence: laser speckle. Temporal coherence and coherence length. Laser pulse duration: Q-switching, mode-locking. Laser radiance. Focusing laser light. Photon momentum: optical tweezers and trapping; optical tweezers; laser cooling. Non-linear optics.

17. SEMICONDUCTORS AND SEMICONDUCTOR LASERS

395

Semiconductors. Semiconductor diodes. LEDs and semiconductor lasers; heterojunction lasers. Semiconductor laser cavities. Wavelengths and tuning of semiconductor lasers. Modulation. Organic semiconductor LEDs and lasers.

18. SOURCES OF LIGHT

415

Classical radiation processes: radiation from an accelerated charge; the Hertzian dipole. Free-free radiation. Cyclotron and synchrotron radiation. Free electron lasers. Cerenkov radiation.

viii Contents

The formation of spectral lines: the Bohr model; nuclear mass; quantum mechanics; angular momentum and electron spin. Light from the Sun and Stars. Thermal sources. Fluorescent lights. Luminescence sources. Electroluminescence.

19. INTERACTION OF LIGHT WITH MATTER

435

The classical resonator. Rayleigh scattering. Polarization and refractive index in dielectrics. Free electrons. Faraday rotation in a plasma. Resonant atoms in gases. The refractive index of dense gases, liquids and solids. Anisotropic refraction. Brillouin scattering. Raman scattering. Thomson and Compton scattering by electrons. A summary of scattering processes.

20. THE DETECTION OF LIGHT

449

Photoemissive detectors. Semiconductor detectors. Semiconductor junction photodiodes. Imaging detectors. Noise in photodetectors. Image intensifiers. Photography. Thermal detectors.

21. OPTICS AND PHOTONICS IN NATURE

465

Light and colour in the open air. The development of eyes. Corneal and lens focusing. Compound eyes. Reflection optics. Fluorescence and photonics in a butterfly. Biological light detectors. Photosynthesis.

Appendix 1: Answers to Selected Problems	477
Appendix 2: Radiometry and Photometry	481
Appendix 3: Refractive Indices of Common Materials	
Appendix 4: Spectral Lineshapes and Linewidths	485
Appendix 5: Further Reading	487
	491

INDEX 499