CONTENTS

Starred sections may be omitted without loss of continuity.

CHAPTER 1. HUYGENS' PRINCIPLE AND THE APPROXIMATION OF GEOMETRICAL OPTICS 1

1–1 The three laws of geometrical optics 1
1–2 The corpuscular model and the wave model of light 5
1–3 A digression on mechanical waves in one dimension 6
1–4 A digression on mechanical waves in space 14
1–5 The optical disturbance. The superposition principle 16
1–6 Huygens' principle 18
1–7 Rectilinear propagation of light 31
1–8 The Huygens construction 38
1–9 Light rays. The laws of reflection and refraction derived from Huygens' principle 41
Problems 45

CHAPTER 2. SOME APPLICATIONS OF GEOMETRICAL OPTICS 50

2–1 Reflection and refraction of a wave at a surface of arbitrary shape 50
2–2 Propagation of light in nonhomogeneous media 52
*2–3 General equations for the propagation of light in nonhomogeneous media 57
2–4 Fermat's principle 60
2–5 Real and virtual images 63
2–6 Formation of images by plane, parabolic, elliptical, and hyperbolic mirrors 65
2–7 Spherical mirrors 67
2–8 Construction of the images produced by spherical mirrors . . 69
2–9 Aberrations of spherical mirrors 73
2–10 Image formation by refraction at plane and spherical surfaces . 75
2–11 Some general properties of optical systems 79
2–12 Lenses 83
2–13 The prism 86
2–14 Dispersion 87
2–15 Optical instruments and the eye 90
Problems 98

CHAPTER 3. INTERFERENCE 103

3–1 General considerations 103
3–2 Sinusoidal waves 106
3–3 Propagation of sinusoidal waves 108
3–4 Amplitude and phase relations in reflection and refraction . . 109
3–5 Addition of sinusoidal functions 112

3–6 Interference of two spherical waves 115
3–7 Fresnel double mirror, Fresnel biprism, Lloyd's mirror . . . 118
3–8 Interference in thin films 123
3–9 Interference fringes observed with plane-parallel plates. Interference by many waves 130
*3–10 Mathematical treatment of multiple-wave interference . . . 135
3–11 The Fabry-Perot interferometer and the Lummer-Gehrke plate . 140
3–12 The Michelson interferometer 144
3–13 The Mach-Zender interferometer 145
3–14 Length of wave trains and monochromaticity 146
3–15 Physical implications of Fourier's theorem 148
3–16 Superposition of waves from incoherent sources 154
Problems 156

CHAPTER 4. DIFFRACTION 161

4–1 The principle of Huygens-Fresnel 161
4–2 Free propagation of a spherical wave. The vibration curve. . 162
4–3 Fresnel zones 167
*4–4 Further discussion of the principle of Huygens-Fresnel . . . 169
4–5 The approximation of geometrical optics 171
4–6 Diffraction by a circular aperture 175
4–7 Diffraction by a circular opaque screen 180
4–8 Zone plates 182
4–9 The Cornu spiral 184
*4–10 The Fresnel integrals 189
4–11 Fresnel diffraction by a straight edge 194
4–12 Fresnel diffraction by a slit 196
4–13 Shadow of a wire 197
4–14 Fraunhofer diffraction by a slit: elementary treatment . . . 198
4–15 Fraunhofer diffraction by a rectangular aperture: rigorous treatment 202
4–16 Fraunhofer diffraction by a circular aperture. Limit of resolution of optical instruments 208
4–17 Fraunhofer diffraction by a double slit 211
4–18 The diffraction grating 214
4–19 Two-dimensional gratings 222
4–20 Three-dimensional gratings. X-ray diffraction by crystals . . 224
4–21 Abbe's theory of image formation and phase-contrast microscopy 230
Problems 239

CHAPTER 5. THE VELOCITY OF LIGHT 246

5–1 Astronomical methods for the measurement of the velocity of light 246
5–2 Terrestrial methods for the measurement of the velocity of light 249
5–3 The Michelson-Morley experiment 252
5–4 The Doppler effect 255

5–5 Phase and group velocity 259
5–6 The velocity of light in matter 263
Problems 265

CHAPTER 6. POLARIZATION AND CRYSTAL OPTICS 266

6–1 Polarization of light waves 266
6–2 Superposition of polarized waves. Elliptical and circular polarization 269
6–3 Interference of polarized waves. Experimental determination of the plane of vibration 274
6–4 Reflection and refraction of polarized light 277
6–5 A fundamental optical property of anisotropic media . . . 280
6–6 Production of elliptically and circularly polarized light . . . 282
6–7 Analysis of elliptically and circularly polarized light 284
6–8 Birefringent plate in white polarized light 285
6–9 Dichroism 287
6–10 The Fresnel ellipsoid 288
6–11 Wave surfaces in birefringent media 291
6–12 Waves and rays in uniaxial crystals 294
6–13 Refraction of waves and rays 296
6–14 The Nicol prism 299
6–15 Rotation of the plane of vibration 300
6–16 Temporary birefringence and optical activity 304
Problems 307

CHAPTER 7. ELECTROMAGNETIC THEORY OF LIGHT 312

7–1 The physical nature of light waves 312
7–2 The fundamental laws of electromagnetism 313
7–3 Plane electromagnetic waves in isotropic and homogeneous dielectrics 317
7–4 The Poynting vector 326
7–5 Light as electromagnetic waves 327
7–6 Radiation from an accelerated charge 334
Problems 344

CHAPTER 8. LIGHT AND MATTER 348

8–1 The process of light emission 348
8–2 Damping of the oscillating dipoles 354
8–3 Forced oscillations of atomic electrons 358
8–4 The propagation of light waves in homogeneous dielectrics. Dispersion 362
8–5 Reflection and refraction at the boundary between two transparent media 366
8–6 Some consequences of Fresnel's formulas. Identification of the optical vector 376

*8–7 Total reflection 379
8–8 Scattering 387
*8–9 The function of the secondary waves in the phenomena of reflection and refraction 392
8–10 Absorption, resonance, anomalous dispersion 402
*8–11 Optical properties of metals 404
8–12 Momentum and angular momentum of electromagnetic waves . 411
*8–13 Electromagnetic waves in anisotropic dielectrics 417
8–14 The Zeeman effect and the Stark effect 424
8–15 The Faraday effect 427
Problems 431

CHAPTER 9. LIGHT QUANTA 437

9–1 The photoelectric effect 437
9–2 Photons. The Compton effect 439
9–3 The uncertainty principle 443
9–4 Complementarity 447
9–5 The "state" of a photon 448
9–6 Wave mechanics 450
Problems 453

APPENDIX 1. MATHEMATICAL FORMULAS 455

(a) Vectors 455
(b) Complex numbers 456
(c) Sum of the geometric series 458
(d) The sagitta theorem 458

APPENDIX 2. MECHANICAL WAVES 459

(a) Waves on a string 459
(b) Sound waves in a pipe 463
(c) Energy of waves 466
(d) A model of waves with frequency-dependent velocity 469
(e) A model of transverse waves with velocity dependent on the plane of vibration 470
(f) Reflection and transmission of waves at points of discontinuity . 472
(g) Spherical waves in a fluid 475
(h) The general differential equation of sound waves in a fluid . . 479

APPENDIX 3. THE ELECTROMAGNETIC FIELD OF A POINT CHARGE MOVING WITH CONSTANT VELOCITY ON A STRAIGHT LINE . 481

APPENDIX 4. NUMERICAL DATA 484

ANSWERS TO PROBLEMS 489

INDEX 503