

<b>Preface to the Fourth Edition</b>	<b>xvii</b>
<b>Preface to the Third Edition</b>	<b>xix</b>
<b>Part One Geometrical Optics</b>	
<b>1 Properties of Light</b>	<b>3</b>
<i>1.1</i> The Rectilinear Propagation of Light	5
<i>1.2</i> The Speed of Light	6
<i>1.3</i> The Speed of Light in Stationary Matter	8
<i>1.4</i> The Refractive Index	9
<i>1.5</i> Optical Path	10
<i>1.6</i> Laws of Reflection and Refraction	11
<i>1.7</i> Graphical Construction for Refraction	13
<i>1.8</i> The Principle of Reversibility	14
<i>1.9</i> Fermat's Principle	14
<i>1.10</i> Color Dispersion	18

<b>2 Plane Surfaces and Prisms</b>	<b>24</b>	<b>5. Thick Lenses</b>	<b>78</b>
2.1 Parallel Beam	24	5.1 Two Spherical Surfaces	78
2.2 The Critical Angle and Total Reflection	25	5.2 The Parallel-Ray Method	79
2.3 Plane-Parallel Plate	28	5.3 Focal Points and Principal Points	81
2.4 Refraction by a Prism	29	5.4 Conjugate Relations	82
2.5 Minimum Deviation	30	5.5 The Oblique-Ray Method	82
2.6 Thin Prisms	32	5.6 General Thick-Lens Formulas	84
2.7 Combinations of Thin Prisms	32	5.7 Special Thick Lenses	88
2.8 Graphical Method of Ray Tracing	33	5.8 Nodal Points and Optical Center	88
2.9 Direct-Vision Prisms	34	5.9 Other Cardinal Points	90
2.10 Reflection of Divergent Rays	36	5.10 Thin-Lens Combination as a Thick Lens	91
2.11 Refraction of Divergent Rays	36	5.11 Thick-Lens Combinations	93
2.12 Images Formed by Paraxial Rays	38	5.12 Nodal Slide	93
2.13 Fiber Optics	40		
<b>3 Spherical Surfaces</b>	<b>44</b>	<b>6 Spherical Mirrors</b>	<b>98</b>
3.1 Focal Points and Focal Lengths	45	6.1 Focal Point and Focal Length	98
3.2 Image Formation	46	6.2 Graphical Constructions	99
3.3 Virtual Images	47	6.3 Mirror Formulas	102
3.4 Conjugate Points and Planes	47	6.4 Power of Mirrors	104
3.5 Convention of Signs	50	6.5 Thick Mirrors	105
3.6 Graphical Constructions. The Parallel-Ray Method	50	6.6 Thick-Mirror Formulas	107
3.7 Oblique-Ray Methods	52	6.7 Other Thick Mirrors	109
3.8 Magnification	54	6.8 Spherical Aberration	109
3.9 Reduced Vergence	54	6.9 Astigmatism	111
3.10 Derivation of the Gaussian Formula	56		
3.11 Nomography	57	<b>7 The Effects of Stops</b>	<b>115</b>
<b>4 Thin Lenses</b>	<b>60</b>	7.1 Field Stop and Aperture Stop	115
4.1 Focal Points and Focal Lengths	60	7.2 Entrance and Exit Pupils	116
4.2 Image Formation	62	7.3 Chief Ray	117
4.3 Conjugate Points and Planes	62	7.4 Front Stop	117
4.4 The Parallel-Ray Method	62	7.5 Stop between Two Lenses	118
4.5 The Oblique-Ray Method	63	7.6 Two Lenses with No Stop	120
4.6 Use of the Lens Formula	64	7.7 Determination of the Aperture Stop	121
4.7 Lateral Magnification	64	7.8 Field of View	122
4.8 Virtual Images	65	7.9 Field of a Plane Mirror	122
4.9 Lens Makers' Formula	67	7.10 Field of a Convex Mirror	124
4.10 Thin-Lens Combinations	68	7.11 Field of a Positive Lens	124
4.11 Object Space and Image Space	70		
4.12 The Power of a Thin Lens	70	<b>8 Ray Tracing</b>	<b>130</b>
4.13 Thin Lenses in Contact	71	8.1 Oblique Rays	130
4.14 Derivation of the Lens Formula	72	8.2 Graphical Method for Ray Tracing	131
4.15 Derivation of the Lens Makers' Formula	73	8.3 Ray-tracing Formulas	134
		8.4 Sample Ray-tracing Calculations	135

<b>9</b>	<b>Lens Aberrations</b>	<b>149</b>			
9.1	Expansion of the Sine. First-Order Theory	150		11.5	Transverse Waves
9.2	Third-Order Theory of Aberrations	151		11.6	Sine Waves
9.3	Spherical Aberration of a Single Surface	152		11.7	Phase Angles
9.4	Spherical Aberration of a Thin Lens	153		11.8	Phase Velocity and Wave Velocity
9.5	Results of Third-Order Theory	157		11.9	Amplitude and Intensity
9.6	Fifth-Order Spherical Aberration	160		11.10	Frequency and Wavelength
9.7	Coma	162		11.11	Wave Packets
9.8	Aplanatic Points of a Spherical Surface	166		<b>12</b>	<b>The Superposition of Waves</b>
9.9	Astigmatism	167		12.1	Addition of Simple Harmonic Motions along the Same Line
9.10	Curvature of Field	170		12.2	Vector Addition of Amplitudes
9.11	Distortion	171		12.3	Superposition of Two Wave Trains of the Same Frequency
9.12	The Sine Theorem and Abbe's Sine Condition	173		12.4	Superposition of Many Waves with Random Phases
9.13	Chromatic Aberration	176		12.5	Complex Waves
9.14	Separated Doublet	182		12.6	Fourier Analysis
<b>10</b>	<b>Optical Instruments</b>	<b>188</b>		12.7	Group Velocity
10.1	The Human Eye	188		12.8	Graphical Relation between Wave and Group Velocity
10.2	Cameras and Photographic Objectives	191		12.9	Addition of Simple Harmonic Motions at Right Angles
10.3	Speed of Lenses	191		<b>13</b>	<b>Interference of Two Beams of Light</b>
10.4	Meniscus Lenses	193		13.1	Huygens' Principle
10.5	Symmetrical Lenses	193		13.2	Young's Experiment
10.6	Triplet Anastigmats	194		13.3	Interference Fringes from a Double Source
10.7	Telephoto Lenses	195		13.4	Intensity Distribution in the Fringe System
10.8	Magnifiers	195		13.5	Fresnel's Biprism
10.9	Types of Magnifiers	198		13.6	Other Apparatus Depending on Division of the Wave Front
10.10	Spectacle Lenses	198		13.7	Coherent Sources
10.11	Microscopes	200		13.8	Division of Amplitude. Michelson Interferometer
10.12	Microscope Objectives	201		13.9	Circular Fringes
10.13	Astronomical Telescopes	202		13.10	Localized Fringes
10.14	Oculars and Eyepieces	205		13.11	White-Light Fringes
10.15	Huygens Eyepiece	205		13.12	Visibility of the Fringes
10.16	Ramsden Eyepiece	206		13.13	Interferometric Measurements of Length
10.17	Kellner or Achromatized Ramsden Eyepiece	206		13.14	Twyman and Green Interferometer
10.18	Special Eyepieces	206		13.15	Index of Refraction by Interference Methods
10.19	Prism Binoculars	207		<b>14</b>	<b>Interference Involving Multiple Reflections</b>
10.20	The Kellner-Schmidt Optical System	208		14.1	Reflection from a Plane-Parallel Film
10.21	Concentric Optical Systems	209		14.2	Fringes of Equal Inclination
<b>Part Two</b>	<b>Wave Optics</b>			14.3	Interference in the Transmitted Light
<b>11</b>	<b>Vibrations and Waves</b>	<b>215</b>		14.4	Fringes of Equal Thickness
11.1	Simple Harmonic Motion	216		14.5	Newton's Rings
11.2	The Theory of Simple Harmonic Motion	217		14.6	Nonreflecting Films
11.3	Stretching of a Coiled Spring	218		14.7	Sharpness of the Fringes
11.4	Vibrating Spring	221		14.8	Method of Complex Amplitudes
				14.9	Derivation of the Intensity Function

14.10	Fabry-Perot Interferometer	301
14.11	Brewster's Fringes	302
14.12	Chromatic Resolving Power	303
14.13	Comparison of Wavelengths with the Interferometer	305
14.14	Study of Hyperfine Structure and of Line Shape	308
14.15	Other Interference Spectroscopes	310
14.16	Channeled Spectra. Interference Filter	311
<b>15</b>	<b>Fraunhofer Diffraction by a Single Opening</b>	<b>315</b>
15.1	Fresnel and Fraunhofer Diffraction	315
15.2	Diffraction by a Single Slit	316
15.3	Further Investigation of the Single-Slit Diffraction Pattern	319
15.4	Graphical Treatment of Amplitudes. The Vibration Curve	322
15.5	Rectangular Aperture	324
15.6	Resolving Power with a Rectangular Aperture	325
15.7	Chromatic Resolving Power of a Prism	327
15.8	Circular Aperture	329
15.9	Resolving Power of a Telescope	330
15.10	Resolving Power of a Microscope	332
15.11	Diffraction Patterns with Sound and Microwaves	334
<b>16</b>	<b>The Double Slit</b>	<b>338</b>
16.1	Qualitative Aspects of the Pattern	338
16.2	Derivation of the Equation for the Intensity	339
16.3	Comparison of the Single-Slit and Double-Slit Patterns	341
16.4	Distinction between Interference and Diffraction	341
16.5	Position of the Maxima and Minima. Missing Orders	342
16.6	Vibration Curve	346
16.7	Effect of Finite Width of Source Slit	347
16.8	Michelson's Stellar Interferometer	349
16.9	Correlation Interferometer	351
16.10	Wide-Angle Interference	352
<b>17</b>	<b>The Diffraction Grating</b>	<b>355</b>
17.1	Effect of Increasing the Number of Slits	355
17.2	Intensity Distribution from an Ideal Grating	357
17.3	Principal Maxima	358
17.4	Minima and Secondary Maxima	358
17.5	Formation of Spectra by a Grating	359
17.6	Dispersion	362
17.7	Overlapping of Orders	362
17.8	Width of the Principal Maxima	363
17.9	Resolving Power	364
17.10	Vibration Curve	365
17.11	Production of Ruled Gratings	368
17.12	Ghosts	370

17.13	Control of the Intensity Distribution among Orders	370
17.14	Measurement of Wavelength with the Grating	373
17.15	Concave Grating	373
17.16	Grating Spectrographs	374
<b>18</b>	<b>Fresnel Diffraction</b>	<b>378</b>
18.1	Shadows	378
18.2	Fresnel's Half-Period Zones	380
18.3	Diffraction by a Circular Aperture	383
18.4	Diffraction by a Circular Obstacle	384
18.5	Zone Plate	385
18.6	Vibration Curve for Circular Division of the Wave Front	386
18.7	Apertures and Obstacles with Straight Edges	388
18.8	Strip Division of the Wave Front	389
18.9	Vibration Curve for Strip Division. Cornu's Spiral	389
18.10	Fresnel's Integrals	390
18.11	The Straight Edge	393
18.12	Rectilinear Propagation of Light	395
18.13	Single Slit	397
18.14	Use of Fresnel's Integrals in Solving Diffraction Problems	399
18.15	Diffraction by an Opaque Strip	400
<b>19</b>	<b>The Speed of Light</b>	<b>403</b>
19.1	Römer's Method	403
19.2	Bradley's Method. The Aberration of Light	405
19.3	Michelson's Experiments	406
19.4	Measurements in a Vacuum	408
19.5	Kerr-Cell Method	408
19.6	Speed of Radio Waves	410
19.7	Ratio of the Electrical Units	411
19.8	The Speed of Light in Stationary Matter	411
19.9	Speed of Light in Moving Matter	412
19.10	Fresnel's Dragging Coefficient	413
19.11	Airy's Experiment	414
19.12	Effect of Motion of the Observer	414
19.13	The Michelson-Morley Experiment	416
19.14	Principle of Relativity	418
19.15	The Three First-Order Relativity Effects	419
<b>20</b>	<b>The Electromagnetic Character of Light</b>	<b>423</b>
20.1	Transverse Nature of Light Vibrations	424
20.2	Maxwell's Equations for a Vacuum	424
20.3	Displacement Current	425
20.4	The Equations for Plane Electromagnetic Waves	427
20.5	Pictorial Representation of an Electromagnetic Wave	428
20.6	Light Vector in an Electromagnetic Wave	429

20.7	Energy and Intensity of the Electromagnetic Wave	429	23.10	Theory of Dispersion	491
20.8	Radiation from an Accelerated Charge	430	23.11	Nature of the Vibrating Particles and Frictional Forces	494
20.9	Radiation From a Charge in Periodic Motion	432	<b>24</b>	<b>The Polarization of Light</b>	<b>497</b>
20.10	Hertz's Verification of the Existence of Electromagnetic Waves	432	24.1	Polarization by Reflection	498
20.11	Speed of Electromagnetic Waves in Free Space	434	24.2	Representation of the Vibrations in Light	499
20.12	Čerenkov Radiation	434	24.3	Polarizing Angle and Brewster's Law	500
<b>21</b>	<b>Sources of Light and Their Spectra</b>	<b>438</b>	24.4	Polarization by a Pile of Plates	501
21.1	Classification of Sources	438	24.5	Law of Malus	503
21.2	Solids at High Temperature	439	24.6	Polarization by Dichroic Crystals	504
21.3	Metallic Arcs	439	24.7	Double Refraction	505
21.4	Bunsen Flame	442	24.8	Optic Axis	507
21.5	Spark	442	24.9	Principal Sections and Principal Planes	507
21.6	Vacuum Tube	443	24.10	Polarization by Double Refraction	508
21.7	Classification of Spectra	445	24.11	Nicol Prism	510
21.8	Emittance and Absorptance	445	24.12	Parallel and Crossed Polarizers	511
21.9	Continuous Spectra	447	24.13	Refraction by Calcite Prisms	511
21.10	Line Spectra	450	24.14	Rochon and Wollaston Prisms	513
21.11	Series of Spectral Lines	452	24.15	Scattering of Light and the Blue Sky	514
21.12	Band Spectra	453	24.16	The Red Sunset	515
<b>22</b>	<b>Absorption and Scattering</b>	<b>457</b>	24.17	Polarization by Scattering	516
22.1	General and Selective Absorption	457	24.18	The Optical Properties of Gemstones	518
22.2	Distinction between Absorption and Scattering	458	<b>25</b>	<b>Reflection</b>	<b>523</b>
22.3	Absorption by Solids and Liquids	459	25.1	Reflection from Dielectrics	523
22.4	Absorption by Gases	461	25.2	Intensities of the Transmitted Light	526
22.5	Resonance and Fluorescence of Gases	461	25.3	Internal Reflection	527
22.6	Fluorescence of Solids and Liquids	464	25.4	Phase Changes on Reflection	527
22.7	Selective Reflection. Residual Rays	464	25.5	Reflection of Plane-polarized Light from Dielectrics	529
22.8	Theory of the Connection between Absorption and Reflection	465	25.6	Elliptically Polarized Light by Internal Reflection	531
22.9	Scattering by Small Particles	466	25.7	Penetration into the Rare Medium	533
22.10	Molecular Scattering	468	25.8	Metallic Reflection	534
22.11	Raman Effect	469	25.9	Optical Constants of Metals	536
22.12	Theory of Scattering	470	25.10	Description of the Light Reflected from Metals	538
22.13	Scattering and Refractive Index	471	25.11	Measurement of the Principal Angle of Incidence and Principal Azimuth	540
<b>23</b>	<b>Dispersion</b>	<b>474</b>	25.12	Wiener's Experiments	541
23.1	Dispersion of a Prism	474	<b>26</b>	<b>Double Refraction</b>	<b>544</b>
23.2	Normal Dispersion	475	26.1	Wave Surfaces for Uniaxial Crystals	544
23.3	Cauchy's Equation	479	26.2	Propagation of Plane Waves in Uniaxial Crystals	546
23.4	Anomalous Dispersion	479	26.3	Plane Waves at Oblique Incidence	549
23.5	Sellmeier's Equation	482	26.4	Direction of the Vibrations	550
23.6	Effect of Absorption on Dispersion	485	26.5	Indices of Refraction for Uniaxial Crystals	551
23.7	Wave and Group Velocity in the Medium	487	26.6	Wave Surfaces in Biaxial Crystals	553
23.8	The Complete Dispersion Curve of a Substance	488	26.7	Internal Conical Refraction	556
23.9	The Electromagnetic Equations for Transparent Media	489			

26.8	External Conical Refraction	557	30.3	The Ruby Laser	635
26.9	Theory of Double Refraction	559	30.4	The Helium-Neon Gas Laser	636
<b>27</b>	<b>Interference of Polarized Light</b>	<b>564</b>	30.5	Concave Mirrors and Brewster's Windows	642
27.1	Elliptically and Circularly Polarized Light	564	30.6	The Carbon Dioxide Laser	643
27.2	Quarter- and Half-Wave Plates	567	30.7	Resonant Cavities	646
27.3	Crystal Plates between Crossed Polarizers	568	30.8	Coherence Length	650
27.4	Babinet Compensator	569	30.9	Frequency Doubling	652
27.5	Analysis of Polarized Light	571	30.10	Other Lasers	653
27.6	Interference with White Light	572	30.11	Laser Safety	653
27.7	Polarizing Monochromatic Filter	575	30.12	The Speckle Effect	653
27.8	Applications of Interference in Parallel Light	576	30.13	Laser Applications	654
27.9	Interference in Highly Convergent Light	576	<b>31</b>	<b>Holography</b>	<b>658</b>
<b>28</b>	<b>Optical Activity and Modern Wave Optics</b>	<b>581</b>	31.1	The Basic Principles of Holography	659
28.1	Rotation of the Plane of Polarization	581	31.2	Viewing a Hologram	664
28.2	Rotary Dispersion	582	31.3	The Thick, or Volume, Hologram	665
28.3	Fresnel's Explanation of Rotation	584	31.4	Multiplex Holograms	669
28.4	Double Refraction in Optically Active Crystals	586	31.5	White-Light-Reflection Holograms	670
28.5	Shape of the Wave Surfaces in Quartz	588	31.6	Other Holograms	672
28.6	Fresnel's Multiple Prism	589	31.7	Student Laboratory Holography	675
28.7	Cornu Prism	590	<b>32</b>	<b>Magneto-Optics and Electro-Optics</b>	<b>678</b>
28.8	Vibration Forms and Intensities in Active Crystals	591	32.1	Zeeman Effect	679
28.9	Theory of Optical Activity	593	32.2	Inverse Zeeman Effect	685
28.10	Rotation in Liquids	594	32.3	Faraday Effect	686
28.11	Modern Wave Optics	596	32.4	Voigt Effect, or Magnetic Double Refraction	688
28.12	Spatial Filtering	597	32.5	Cotton-Mouton Effect	
28.13	Phase-Contrast Microscope	602	32.6	Kerr Magneto-optic Effect	691
28.14	Schlieren Optics	604	32.7	Stark Effect	691
<b>Part Three</b>	<b>Quantum Optics</b>		32.8	Inverse Stark Effect	692
<b>29</b>	<b>Light Quanta and Their Origin</b>	<b>611</b>	32.9	Electric Double Refraction	693
29.1	The Bohr Atom	612	32.10	Kerr Electro-optic Effect	693
29.2	Energy Levels	616	32.11	Pockels Electro-optic Effect	695
29.3	Bohr-Stoner Scheme for Building Up Atoms	617	<b>33</b>	<b>The Dual Nature of Light</b>	<b>698</b>
29.4	Elliptical Orbits, or Penetrating Orbitals	619	33.1	Shortcomings of the Wave Theory	699
29.5	Wave Mechanics	622	33.2	Evidence for Light Quanta	700
29.6	The Spectrum of Sodium	625	33.3	Energy, Momentum, and Velocity of Photons	703
29.7	Resonance Radiation	626	33.4	Development of Quantum Mechanics	704
29.8	Metastable States	629	33.5	Principle of Indeterminacy	705
29.9	Optical Pumping	630	33.6	Diffraction by a Slit	705
<b>30</b>	<b>Lasers</b>	<b>632</b>	33.7	Complementarity	707
30.1	Stimulated Emission	633	33.8	Double Slit	707
30.2	Laser Design	634	33.9	Determination of Position with a Microscope	709
			33.10	Use of a Shutter	710

33.11	Interpretation of the Dual Character of Light	711
33.12	Realms of Applicability of Waves and Photons	712
	<b>Appendixes</b>	<b>715</b>
I	The Physical Constants	716
II	Electron Subshells	717
III	Refractive Indices and Dispersions for Optical Glasses	720
IV	Refractive Indices and Dispersions of Optical Crystals	721
V	The Most Intense Fraunhofer Lines	722
VI	Abbreviated Number System	723
VII	Significant Figures	724
	<b>Index</b>	<b>727</b>