
Contents

Preface	vii
1 Geometrical Optics	1
1.1 Introduction	1
1.2 Fermat's Principle and the Law of Refraction	2
1.3 Prisms	7
1.3.1 Angle of Deviation	7
1.4 Convex Spherical Surfaces	9
1.4.1 Image Formation and Conjugate Points	9
1.4.2 Sign Convention	11
1.4.3 Object and Image Distance, Object and Image Focus, Real and Virtual Objects, and Singularities	11
1.4.4 Real Objects, Geometrical Constructions, and Magnification	15
1.4.5 Virtual Objects, Geometrical Constructions, and Magnification	17
1.5 Concave Spherical Surfaces	19
1.6 Thin Lens Equation	23
1.6.1 Thin Lens Equation	23
1.6.2 Object Focus and Image Focus	24
1.6.3 Magnification	25
1.6.4 Positive Lens, Graph, Calculations of Image Positions, and Graphical Constructions of Images	25
1.6.5 Negative Lens, Graph, Calculations of Image Positions, and Graphical Constructions of Images	30
1.6.6 Thin Lens and Two Different Media on the Outside	33
1.7 Optical Instruments	35

1.7.1	Two Lens System	36
1.7.2	Magnifier and Object Positions	37
1.7.3	Microscope	42
1.7.4	Telescope	44
1.8	Matrix Formulation for Thick Lenses	48
1.8.1	Refraction and Translation Matrices	48
1.8.2	Two Spherical Surfaces at Distance d and Principal Planes	51
1.8.3	System of Lenses	59
1.9	Plane and Spherical Mirrors	67
1.9.1	Plane Mirrors and Virtual Images	67
1.9.2	Spherical Mirrors and Mirror Equation	67
1.9.3	Sign Convention	69
1.9.4	Magnification	69
1.9.5	Graphical Method and Graphs of x_i Depending on x_o	70
1.10	Matrices for a Reflecting Cavity and the Eigenvalue Problem	73
2	Interference	79
2.1	Introduction	79
2.2	Harmonic Waves	80
2.3	Superposition of Harmonic Waves	82
2.3.1	Superposition of Two Waves Depending on Space and Time Coordinates	82
2.3.2	Intensities	86
2.3.3	Normalization	88
2.4	Two-Beam Wavefront Dividing Interferometry	89
2.4.1	Model Description for Wavefront Division	89
2.4.2	Young's Experiment	90
2.5	Two-Beam Amplitude Dividing Interferometry	96
2.5.1	Model Description for Amplitude Division	96
2.5.2	Plane Parallel Plate	97
2.5.3	Michelson Interferometer and Heidingen and Fizeau Fringes	103
2.6	Multiple Beam Interferometry	110
2.6.1	Plane Parallel Plate	110
2.6.2	Fabry-Perot Etalon	115
2.6.3	Fabry-Perot Spectrometer and Resolution	118
2.6.4	Array of Source Points	121
2.7	Random Arrangement of Source Points	125
3	Diffraction	129
3.1	Introduction	129
3.2	Kirchhoff-Fresnel Integral	131
3.2.1	The Integral	131
3.2.2	On Axis Observation for the Circular Opening	133

3.2.3	On Axis Observation for Circular Stop	135
3.3	Fresnel Diffraction, Far Field Approximation, and Fraunhofer Observation	136
3.3.1	Small Angle Approximation in Cartesian Coordinates	137
3.3.2	Fresnel, Far Field, and Fraunhofer Diffraction	138
3.4	Far Field and Fraunhofer Diffraction	139
3.4.1	Diffraction on a Slit	140
3.4.2	Diffraction on a Slit and Fourier Transformation	144
3.4.3	Rectangular Aperture	145
3.4.4	Circular Aperture	148
3.4.5	Gratings	152
3.4.6	Resolution	162
3.5	Babinet's Theorem	166
3.6	Apertures in Random Arrangement	169
3.7	Fresnel Diffraction	172
3.7.1	Coordinates for Diffraction on a Slit and Fresnel's Integrals	172
3.7.2	Fresnel Diffraction on a Slit	173
3.7.3	Fresnel Diffraction on an Edge	175
A3.1.1	Step Grating	178
A3.2.1	Cornu's Spiral	181
A3.2.2	Babinet's Principle and Cornu's Spiral	182
4	Coherence	185
4.1	Spatial Coherence	185
4.1.1	Introduction	185
4.1.2	Two Source Points	185
4.1.3	Coherence Condition	189
4.1.4	Extended Source	190
4.1.5	Visibility	194
4.1.6	Michelson Stellar Interferometer	197
4.2	Temporal Coherence	200
4.2.1	Wavetrains and Quasimonochromatic Light	200
4.2.2	Superposition of Wavetrains	201
4.2.3	Length of Wavetrains	202
A4.1.1	Fourier Transform Spectrometer and Blackbody Radiation	203
5	Maxwell's Theory	205
5.1	Introduction	205
5.2	Harmonic Plane Waves and the Superposition Principle	206
5.2.1	Plane Waves	206
5.2.2	The Superposition Principle	208
5.3	Differentiation Operation	208

5.3.1	Differentiation “Time” $\partial/\partial t$	208
5.3.2	Differentiation “Space” $\nabla = \mathbf{i}\partial/\partial x + \mathbf{j}\partial/\partial y + \mathbf{k}\partial/\partial z$	208
5.4	Poynting Vector in Vacuum	209
5.5	Electromagnetic Waves in an Isotropic Nonconducting Medium	210
5.6	Fresnel’s Formulas	211
5.6.1	Electrical Field Vectors in the Plane of Incidence (Parallel Case)	211
5.6.2	Electrical Field Vector Perpendicular to the Plane of Incidence (Perpendicular Case)	214
5.6.3	Fresnel’s Formulas Depending on the Angle of Incidence	215
5.6.4	Light Incident on a Denser Medium, $n_1 < n_2$, and the Brewster Angle	216
5.6.5	Light Incident on a Less Dense Medium, $n_1 > n_2$, Brewster and Critical Angle	219
5.6.6	Reflected and Transmitted Intensities	222
5.6.7	Total Reflection and Evanescent Wave	228
5.7	Polarized Light	230
5.7.1	Introduction	230
5.7.2	Ordinary and Extraordinary Indices of Refraction	231
5.7.3	Phase Difference Between Waves Moving in the Direction of or Perpendicular to the Optical Axis	232
5.7.4	Half-Wave Plate, Phase Shift of π	233
5.7.5	Quarter Wave Plate, Phase Shift $\pi/2$	235
5.7.6	Crossed Polarizers	238
5.7.7	General Phase Shift	240
A5.1.1	Wave Equation Obtained from Maxwell’s Equation	242
A5.1.2	The Operations ∇ and ∇^2	243
A5.2.1	Rotation of the Coordinate System as a Principal Axis Transformation and Equivalence to the Solution of the Eigenvalue Problem	243
A5.3.1	Phase Difference Between Internally Reflected Components	244
A5.4.1	Jones Vectors and Jones Matrices	244
A5.4.2	Jones Matrices	245
A5.4.3	Applications	245
6	Maxwell II. Modes and Mode Propagation	249
6.1	Introduction	249
6.2	Stratified Media	252
6.2.1	Two Interfaces at Distance d	253
6.2.2	Plate of Thickness $d = (\lambda/2n_2)$	255
6.2.3	Plate of Thickness d and Index n_2	256
6.2.4	Antireflection Coating	256

6.2.5	Multiple Layer Filters with Alternating High and Low Refractive Index	258
6.3	Guided Waves by Total Internal Reflection Through a Planar Waveguide	259
6.3.1	Traveling Waves	259
6.3.2	Restrictive Conditions for Mode Propagation	261
6.3.3	Phase Condition for Mode Formation	262
6.3.4	(TE) Modes or s -Polarization	262
6.3.5	(TM) Modes or p -Polarization	265
6.4	Fiber Optics Waveguides	266
6.4.1	Modes in a Dielectric Waveguide	266
A6.1.1	Boundary Value Method Applied to TE Modes of Plane Plate Waveguide	270
7	Blackbody Radiation, Atomic Emission, and Lasers	273
7.1	Introduction	273
7.2	Blackbody Radiation	274
7.2.1	The Rayleigh–Jeans Law	274
7.2.2	Planck’s Law	275
7.2.3	Stefan–Boltzmann Law	277
7.2.4	Wien’s Law	278
7.2.5	Files of Planck’s, Stefan–Boltzmann’s, and Wien’s Laws. Radiance, Area, and Solid Angle	279
7.3	Atomic Emission	281
7.3.1	Introduction	281
7.3.2	Bohr’s Model and the One Electron Atom	282
7.3.3	Many Electron Atoms	282
7.4	Bandwidth	285
7.4.1	Introduction	285
7.4.2	Classical Model, Lorentzian Line Shape, and Homogeneous Broadening	286
7.4.3	Natural Emission Line Width, Quantum Mechanical Model	289
7.4.4	Doppler Broadening (Inhomogeneous)	289
7.5	Lasers	291
7.5.1	Introduction	291
7.5.2	Population Inversion	292
7.5.3	Stimulated Emission, Spontaneous Emission, and the Amplification Factor	293
7.5.4	The Fabry–Perot Cavity, Losses, and Threshold Condition	294
7.5.5	Simplified Example of a Three-Level Laser	296
7.6	Confocal Cavity, Gaussian Beam, and Modes	297
7.6.1	Paraxial Wave Equation and Beam Parameters	297
7.6.2	Fundamental Mode in Confocal Cavity	299

7.6.3	Diffraction Losses and Fresnel Number	302	A9.1.1	Asymmetric Fourier Transform Spectroscopy	370
7.6.4	Higher Modes in the Confocal Cavity	303			
8	Optical Constants	315	10	Imaging Using Wave Theory	375
8.1	Introduction	315	10.1	Introduction	375
8.2	Optical Constants of Dielectrics	316	10.2	Spatial Waves and Blackening Curves, Spatial Frequencies, and Fourier Transformation	376
8.2.1	The Wave Equation, Electrical Polarizability, and Refractive Index	316	10.3	Object, Image, and the Two Fourier Transformations	382
8.2.2	Oscillator Model and the Wave Equation	317	10.3.1	Waves from Object and Aperture Plane and Lens	382
8.3	Determination of Optical Constants	320	10.3.2	Summation Processes	383
8.3.1	Fresnel's Formulas and Reflection Coefficients	320	10.3.3	The Pair of Fourier Transformations	385
8.3.2	Ratios of the Amplitude Reflection Coefficients	321	10.4	Image Formation Using Incoherent Light	386
8.3.3	Oscillator Expressions	322	10.4.1	Spread Function	386
8.3.4	Sellmeier Formula	324	10.4.2	The Convolution Integral	387
8.4	Optical Constants of Metals	326	10.4.3	Impulse Response and the Intensity Pattern	387
8.4.1	Drude Model	326	10.4.4	Examples of Convolution with Spread Function	388
8.4.2	Low Frequency Region	327	10.4.5	Transfer Function	392
8.4.3	High Frequency Region	328	10.4.6	Resolution	395
8.4.4	Skin Depth	331	10.5	Image Formation with Coherent Light	398
8.4.5	Reflectance at Normal Incidence and Reflection Coefficients with Absorption	333	10.5.1	Spread Function	398
8.4.6	Elliptically Polarized Light	334	10.5.2	Resolution	399
A8.1.1	Analytical Expressions and Approximations for the Determination of n and K	335	10.5.3	Transfer Function	401
9	Fourier Transformation and FT-Spectroscopy	339	10.6	Holography	403
9.1	Fourier Transformation	339	10.6.1	Introduction	403
9.1.1	Introduction	339	10.6.2	Recording of the Interferogram	403
9.1.2	The Fourier Integrals	339	10.6.3	Recovery of Image with Same Plane Wave Used for Recording	404
9.1.3	Examples of Fourier Transformations Using Analytical Functions	340	10.6.4	Recovery Using a Different Plane Wave	405
9.1.4	Numerical Fourier Transformation	341	10.6.5	Production of Real and Virtual Image Under an Angle	405
9.1.5	Fourier Transformation of a Product of Two Functions and the Convolution Integral	350	10.6.6	Size of Hologram	406
9.2	Fourier Transform Spectroscopy	352	11	Aberration	415
9.2.1	Interferogram and Fourier Transformation. Superposition of Cosine Waves	352	11.1	Introduction	415
9.2.2	Michelson Interferometer and Interferograms	353	11.2	Spherical Aberration of a Single Refracting Surface	415
9.2.3	The Fourier Transform Integral	355	11.3	Longitudinal and Lateral Spherical Aberration of a Thin Lens	418
9.2.4	Discrete Length and Frequency Coordinates	356	11.4	The π - σ Equation and Spherical Aberration	421
9.2.5	Folding of the Fourier Transform Spectrum	359	11.5	Coma	423
9.2.6	High Resolution Spectroscopy	363	11.6	Aplanatic Lens	425
9.2.7	Apodization	366	11.7	Astigmatism	427
			11.7.1	Astigmatism of a Single Spherical Surface	427
			11.7.2	Astigmatism of a Thin Lens	428
			11.8	Chromatic Aberration and the Achromatic Doublet	430
			11.9	Chromatic Aberration and the Achromatic Doublet with Separated Lenses	432

Appendix A	About Graphs and Matrices in Mathcad	435
Appendix B	Formulas	439
References		443
Index		445