

Contents

Preface	xiv
Acknowledgements	xv
Author biography	xvi
1 Introduction	1-1
1.1 What is the purpose of this book, and for whom it is intended	1-1
1.2 Basic equipment: hardware, light sources, lenses, mirrors, windows, filters, cameras etc	1-2
1.2.1 Standard equipment	1-2
1.2.2 Common procedures: alignment of components, cleaning optics, spatial filtering a laser beam, calibrating a camera or detector	1-4
1.2.3 Laser safety	1-8
2 Geometrical optics	2-1
2.1 Prism spectrometer and glass dispersion	2-1
2.1.1 Calibration	2-3
2.1.2 Spectral resolution	2-3
2.2 Critical angle of reflection and Abbe refractometer: measurement of refractive index of a fluid	2-3
2.2.1 A classroom demonstration of critical reflection at the air–glass interface	2-3
2.2.2 The Abbe refractometer	2-3
2.2.3 Using the refractometer to measure the refractive index of a glass plate	2-5
2.2.4 A lab experiment	2-5
2.3 Paraxial imaging by singlet lenses: thin lens imaging, Newton’s law, depth of field, Scheimpflug construction	2-6
2.3.1 Determination of the focal length of a single converging lens	2-7
2.3.2 The focal length of a thin diverging lens	2-9
2.3.3 The Scheimpflug construction	2-9
2.3.4 Commonly encountered problems	2-10
2.4 Compound and thick lenses: focal, principal and nodal planes, zoom lenses	2-11
2.4.1 Cardinal points and planes of a compound or thick lens	2-11
2.4.2 Telephoto combination	2-11
2.4.3 Determining the focal planes and effective focal length	2-11

2.4.4	Nodal points	2-12
2.4.5	Telecentric lens combination	2-13
2.5	Telescopes: refractor telescopes, Newton reflector telescope and periscope	2-14
2.5.1	The concepts of stops and pupils	2-14
2.5.2	Refractor telescope	2-15
2.5.3	Field of view	2-17
2.5.4	Terrestrial telescope	2-17
2.5.5	Galilean telescope	2-18
2.5.6	Newtonian reflector telescope	2-18
2.5.7	Periscope	2-18
2.5.8	Compound eyepiece	2-20
2.6	Microscopes: transmission, reflection, dark field	2-20
2.6.1	Construction	2-21
2.6.2	Magnification	2-22
2.6.3	Numerical aperture	2-22
2.6.4	Depth of focus	2-22
2.6.5	Dark-ground imaging	2-23
2.6.6	Reflection microscope	2-23
2.6.7	Polarization and phase microscopy	2-24
2.7	Autocollimator: measuring focal planes of a lens and angle of rotation	2-25
2.8	Aberrations and their reduction: some basic concepts, use of stops	2-26
2.8.1	Chromatic aberration	2-26
2.8.2	Spherical aberration	2-27
2.8.3	Off-axis aberrations	2-27
2.8.4	Distortion	2-28
2.9	Gravitational lens analogy: an example of an aspherical lens	2-30
2.9.1	Gravitational lensing	2-30
2.9.2	Properties of an analogue gravitational lens	2-32
2.9.3	A laboratory gravitational lens	2-33
	References	2-35
3	Polarization and scattering	3-1
3.1	Polarized light	3-1
3.1.1	Ordinary and extraordinary light rays in crystals	3-1
3.1.2	Types of polarized light	3-2

3.1.3	Creation of polarized light	3-3
3.1.4	Characterizing the polarizers	3-4
3.2	Fresnel coefficients for reflection at an interface	3-5
3.2.1	Fresnel coefficients	3-5
3.2.2	Measuring the Fresnel coefficients	3-6
3.2.3	Incidence within the medium	3-7
3.2.4	Using total internal reflection to create circularly-polarized polychromatic light: Fresnel Rhomb	3-8
3.3	Ellipsometry: using polarized light to measure properties of thin films	3-9
3.3.1	The basic ellipsometer layout	3-9
3.3.2	Samples	3-10
3.3.3	Measurement method	3-10
3.3.4	Appendix 1: Derivation of the multiple reflection amplitude	3-12
3.3.5	Appendix 2: Derivation of the null angles	3-13
3.4	Rayleigh scattering	3-14
3.4.1	Scattering of polarized light, photographic applications	3-14
3.4.2	Wavelength dependence of Rayleigh scattering	3-15
3.5	Coherent back-scattering	3-15
3.5.1	Localization of light by non-absorbing random materials	3-15
3.5.2	Experiments	3-16
	References	3-18
4	Physical optics I: diffraction and imaging	4-1
4.1	Fraunhofer (far-field) diffraction and Fourier transforms	4-1
4.1.1	Optical setup	4-2
4.1.2	Construction of diffraction objects	4-3
4.1.3	15 ideas for significant diffraction objects	4-6
4.1.4	Comparison with calculated Fourier transforms	4-9
4.2	Fresnel (near-field) diffraction	4-9
4.2.1	Objects with axial symmetry	4-11
4.2.2	Linear objects: knife edge and slits	4-13
4.2.3	Fresnel diffraction by a one-dimensional periodic object: Talbot re-imaging effect	4-13
4.2.4	Radial star target	4-15
4.3	Diffraction gratings: transmission and reflection gratings and spectroscopy	4-16
4.3.1	Square wave grating	4-17

4.3.2	Blazed gratings	4-18
4.3.3	Spectroscopy	4-18
4.3.4	Monochromator	4-22
4.4	Imaging with coherent illumination	4-22
4.4.1	Coherent imaging experimental setups	4-23
4.4.2	Resolution limit	4-24
4.4.3	Passive resolution improvement	4-25
4.4.4	Spatial Filtering in the Fourier plane	4-25
4.4.5	Demonstrating spatial filtering	4-29
4.5	Optical transfer function: incoherent resolution measurement	4-31
4.5.1	Measuring the OTF using a resolution target	4-31
4.5.2	Random target method	4-32
4.5.3	Using the line and point spread functions	4-33
4.5.4	An OTF lab bench experiment	4-34
4.6	Diffraction by three-dimensional objects: analogues of crystallography	4-35
4.6.1	Diffraction by a pair of parallel diffraction gratings: banded spectrum	4-36
4.6.2	Carrying out the experiment	4-37
4.6.3	Interpretation in terms of crystal diffraction theory: the Ewald sphere	4-38
4.6.4	Interpretation using the Talbot effect	4-39
4.7	High resolution, wide field Fourier ptychographic microscopy	4-40
	References	4-41
5	Physical optics II: interference	5-1
5.1	Newton's rings and flat plate interference	5-1
5.1.1	Experimental setup	5-1
5.1.2	Newton's rings	5-2
5.1.3	Wedge interference	5-3
5.2	Michelson and Twyman–Green interferometer: absolute measurement of wavelength, Fourier spectroscopy and optical testing	5-3
5.2.1	Michelson's interferometer	5-4
5.2.2	Fringe types in interferometers	5-8
5.2.3	Measuring the wavelength	5-9
5.2.4	White-light fringes and spectroscopy	5-10

5.2.5	Fourier spectroscopy	5-11
5.2.6	Optical testing—the Twyman–Green interferometer	5-11
5.2.7	Interpreting interferograms quantitatively	5-12
5.3	Sagnac common-path interferometer	5-12
5.3.1	Aligning the interferometer	5-14
5.3.2	Sagnac interferometer in a stationary frame of reference	5-14
5.3.3	Fourier spectroscopy with a Sagnac interferometer	5-15
5.3.4	Optical testing using the Sagnac interferometer	5-16
5.4	Fabry–Perot étalon	5-16
5.4.1	Laboratory model	5-17
5.4.2	Interference pattern	5-18
5.4.3	Measuring the thickness of the étalon	5-19
5.4.4	Applications	5-20
5.5	Holography with a digital camera	5-21
5.5.1	Experiments	5-23
5.5.2	Off-line (or side-band) holography	5-23
5.5.3	Reconstruction algorithm	5-24
5.5.4	Experimental aims	5-25
5.5.5	In-line holography	5-27
5.5.6	Appendix. Derivation of the reconstruction procedure in the Fresnel (small angle) approximation	5-27
5.6	Interferometric holography	5-29
5.6.1	Double exposure holographic interferometry	5-29
5.6.2	Time exposure holography	5-30
5.6.3	A comment on holographic interferometry from the point of view of wave–particle duality	5-31
5.7	Computer-generated holography	5-31
5.7.1	Reconstruction	5-32
5.7.2	Three-dimensional object	5-32
	References	5-33
6	Physical optics III: topics in wave propagation	6-1
6.1	Optical tunnelling: frustrated total internal reflection	6-1
6.1.1	Theory of optical tunnelling	6-2
6.1.2	Visualizing tunnelling in a Newton’s rings configuration	6-3
6.1.3	Interpreting the results	6-4
6.1.4	Direct measurement of the tunnelling probability	6-5

6.2	The acousto-optic effect	6-6
6.2.1	Experiments in the Raman–Nath regime	6-6
6.2.2	Experimental suggestions	6-9
6.3	Berry’s geometric phase	6-9
6.3.1	Berry’s phase in an optical fibre	6-9
6.4	Spatial coherence function: measurement and interpretation	6-11
6.4.1	Measuring the spatial coherence function using Young’s fringes	6-11
6.4.2	Measuring the spatial coherence function using a shearing interferometer	6-12
6.5	Aperture synthesis	6-14
6.5.1	A laboratory aperture synthesis experiment	6-15
6.6	Gouy phase shift through a focus	6-17
6.6.1	Experimental setup	6-17
6.6.2	Two questions for investigation	6-18
6.7	Optical vortices	6-18
6.7.1	Interference patterns	6-20
6.7.2	Creating vortex waves	6-20
	References	6-22
7	Optics of materials	7-1
7.1	Interferometric measurement of the refractive index of a gas	7-1
7.2	Anisotropic materials: interference figures of uniaxial and biaxial crystals	7-2
7.2.1	Basic description of birefringent crystals in terms of the refractive index surface	7-2
7.2.2	Uniaxial and biaxial crystals	7-3
7.3	Chiral materials: optical activity	7-5
7.4	Non-linear optics: second harmonic generation	7-6
7.4.1	Phase matching	7-6
7.4.2	The experiment	7-8
7.5	Surface plasmon resonance	7-10
7.5.1	Observing the plasmons	7-11
7.5.2	Experiments using the Kretschmann configuration	7-12
7.5.3	Experiments using the Otto configuration	7-13
7.6	Induced optical anisotropy: photo-elastic, electro-optic and magneto-optic effects	7-14
7.6.1	Photoelastic effect	7-14

7.6.2	Electro-optic effect	7-15
7.6.3	Magneto-optic effect	7-17
	References	7-18
8	Atmospheric optics	8-1
8.1	Rainbow: geometrical and physical optical effects, high-order rainbows	8-1
8.1.1	The geometrical optical theory of the rainbow	8-1
8.1.2	Experiments	8-3
8.2	Mirages and gradient-index optics	8-5
8.2.1	Basic theory of ray paths	8-6
8.2.2	Laboratory experiments	8-7
8.2.3	Appendix	8-8
8.3	Green flash	8-9
8.3.1	Physical origin of the green flash	8-10
8.3.2	A laboratory experiment	8-10
8.4	Sky polarization, the sunstone and Viking navigation	8-12
8.4.1	How the Vikings used a birefringent crystal for navigation	8-12
8.4.2	A Sunstone in the laboratory and the open air	8-13
	References	8-14
9	Relativistic optics	9-1
9.1	Fizeau's experiment: velocity of light in moving water	9-1
9.2	Optical fibre gyroscope: measurement of rate of rotation	9-3
9.2.1	Sagnac interferometer in a rotating frame of reference: optical gyroscope	9-3
9.2.2	Fibre-optical gyroscope	9-4
	References	9-5
10	Basic experiments in quantum optics	10-1
10.1	Coincidence experiments	10-1
10.2	Measuring the Planck constant	10-4
10.3	Laser modes	10-6
10.4	The spectrum of black-body radiation	10-7
	References	10-9