

---

# CONTENTS

---

<b>Contributors</b>	xvi
<b>Preface</b>	xix
<b>Glossary and Fundamental Constants</b>	xxi

## **Part 1. Optical Elements** **1.1**

### **Chapter 1. Lenses** *R. Barry Johnson* **1.3**

---

1.1.	Glossary /	1.3
1.2.	Introduction /	1.5
1.3.	Basics /	1.5
1.4.	Stops and Pupils /	1.8
1.5.	F-Number and Numerical Aperture /	1.9
1.6.	Magnifier or Eye Loupe /	1.9
1.7.	Compound Microscopes /	1.9
1.8.	Field and Relay Lenses /	1.10
1.9.	Aplanatic Surfaces and Immersion Lenses /	1.10
1.10.	Single Element Lens /	1.11
1.11.	Landscape Lenses and the Influence of Stop Position /	1.17
1.12.	Two-Lens Systems /	1.19
1.13.	Achromatic Doublets /	1.23
1.14.	Triplet Lenses /	1.26
1.15.	Symmetrical Lenses /	1.27
1.16.	Double-Gauss Lenses /	1.28
1.17.	Petzval Lenses /	1.29
1.18.	Telephoto Lenses /	1.29
1.19.	Inverted or Reverse Telephoto Lenses /	1.30
1.20.	Performance of Representative Lenses	1.30
1.21.	Rapid Estimation of Lens Performance /	1.36
1.22.	Bibliography /	1.41

### **Chapter 2. Afocal Systems** *William B. Wetherell* **2.1**

---

2.1.	Glossary /	2.1
2.2.	Introduction /	2.1
2.3.	Gaussian Analysis of Afocal Lenses /	2.2
2.4.	Keplerian Afocal Lenses /	2.7
2.5.	Galilean and Inverse Galilean Afocal Lenses /	2.14
2.6.	Relay Trains and Periscopes /	2.16
2.7.	Reflecting and Catadioptric Afocal Lenses /	2.19
2.8.	References /	2.22

---

**Chapter 3. Polarizers** *Jean M. Bennett* **3.1**

---

- 3.1. Glossary / 3.1
- 3.2. Prism Polarizers / 3.2
- 3.3. Glan-Type Prisms / 3.9
- 3.4. Nicol-Type Prism / 3.17
- 3.5. Polarizing Beam-Splitter Prisms / 3.19
- 3.6. Dichroic and Diffraction-Type Polarizers / 3.26
- 3.7. Non-Normal-Incidence Reflection and Transmission Polarizers / 3.36
- 3.8. Retardation Plates / 3.46
- 3.9. Variable Retardation Plates and Compensators / 3.57
- 3.10. Half-Shade Devices / 3.60
- 3.11. Minature Polarization Devices / 3.61
- 3.12. References / 3.62

---

**Chapter 4. Nondispersive Prisms** *William L. Wolfe* **4.1**

---

- 4.1. Glossary / 4.1
- 4.2. Introduction / 4.1
- 4.3. Inversion, Reversion / 4.2
- 4.4. Deviation, Displacement / 4.2
- 4.5. Summary of Prism Properties / 4.3
- 4.6. Prism Descriptions / 4.3
- 4.7. References / 4.29

---

**Chapter 5. Dispersive Prisms and Gratings** *George J. Zissis* **5.1**

---

- 5.1. Glossary / 5.1
- 5.2. Introduction / 5.1
- 5.3. Prisms / 5.1
- 5.4. Gratings / 5.3
- 5.5. Prism and Grating Configurations and Instruments / 5.4
- 5.6. References / 5.15

---

**Chapter 6. Integrated Optics** *Thomas L. Koch, Frederick, J. Leonberger, and Paul G Suchoski* **6.1**

---

- 6.1. Glossary / 6.1
- 6.2. Introduction / 6.2
- 6.3. Device Physics / 6.3
- 6.4. Integrated Optics Materials and Fabrication Technology / 6.12
- 6.5. Circuit Elements / 6.20
- 6.6. Applications of Integrated Optics / 6.28
- 6.7. Future Trends / 6.37
- 6.8. References / 6.38

---

**Chapter 7. Miniature and Micro-Optics** *Tom D. Milster* **7.1**

---

- 7.1. Glossary / 7.1
- 7.2. Introduction / 7.2
- 7.3. Uses of Micro-Optics / 7.2
- 7.4. Micro-Optics Design Considerations / 7.2
- 7.5. Molded Microlenses / 7.4

- 7.6. Monolithic Lenslet Modules / 7.12
- 7.7. Distributed-Index Planer Microlenses / 7.13
- 7.8. Smile Microlenses / 7.16
- 7.9. Micro-Fresnel Lenses / 7.18
- 7.10. Other Technologies / 7.27
- 7.11. References / 7.31

---

## **Chapter 8. Binary Optics** *Michael W. Farn and Wilfrid B. Veldkamp* **8.1**

---

- 8.1. Glossary / 8.1
- 8.2. Introduction / 8.2
- 8.3. Design—Geometrical Optics / 8.2
- 8.4. Design—Scalar Diffraction Theory / 8.10
- 8.5. Design—Vector Diffraction Theory / 8.14
- 8.6. Fabrication / 8.14
- 8.7. References / 8.18

---

## **Chapter 9. Gradient Index Optics** *Duncan T. Moore* **9.1**

---

- 9.1. Glossary / 9.1
- 9.2. Introduction / 9.1
- 9.3. Analytic Solutions / 9.2
- 9.4. Mathematical Representation / 9.2
- 9.5. Axial Gradient Lenses / 9.2
- 9.6. Radial Gradients / 9.5
- 9.7. Radial Gradients with Curved Surfaces / 9.7
- 9.8. Shallow Radial Gradients / 9.7
- 9.9. Materials / 9.8
- 9.10. References / 9.9

---

## **Chapter 10. Optical Fibers and Fiber-Optic Communications** *Tom G. Brown* **10.1**

---

- 10.1. Glossary / 10.1
- 10.2. Introduction / 10.3
- 10.3. Principles of Operation / 10.4
- 10.4. Fiber Dispersion and Attenuation / 10.8
- 10.5. Polarization Characteristics of Fibers / 10.11
- 10.6. Optical and Mechanical Properties of Fibers / 10.12
- 10.7. Optical Fiber Communications / 10.19
- 10.8. Nonlinear Optical Properties of Fibers / 10.37
- 10.9. Optical Fiber Materials: Chemistry and Fabrication / 10.42
- 10.10. References / 10.46
- 10.11. Further Reading / 10.49

---

## **Chapter 11. X-Ray Optics** *James E. Harvey* **11.1**

---

- 11.1. Glossary / 11.1
- 11.2. Introduction / 11.2
- 11.3. Historical Background / 11.3
- 11.4. Optical Performance of X-Ray/EUV Imaging Systems / 11.6
- 11.5. Diffraction Effects of Grazing Incidence X-Ray Optics / 11.8
- 11.6. Ghost Images in Grazing Incidence X-Ray Telescopes / 11.14
- 11.7. Scattering Effects from Optical Fabrication Errors / 11.16

- 11.8. Image Quality Predictions for Various Applications / 11.25
- 11.9. Summary and Conclusion / 11.29
- 11.10. References / 11.30

---

## **Chapter 12. Acousto-Optic Devices and Applications** *I. C. Chang* **12.1**

---

- 12.1. Glossary / 12.1
- 12.2. Introduction / 12.2
- 12.3. Theory of Acousto-Optic Interaction / 12.3
- 12.4. Acoustic-Optic Materials / 12.14
- 12.5. Basic Acousto-Optic Devices / 12.16
- 12.6. Applications / 12.34
- 12.7. References / 12.49

---

## **Chapter 13. Electro-Optic Modulators** *Theresa A. Maldonado* **13.1**

---

- 13.1. Glossary / 13.1
- 13.2. Introduction / 13.3
- 13.3. Crystal Optics and the Index Ellipsoid / 13.4
- 13.4. The Electro-Optic Effect / 13.6
- 13.5. Modulator Devices / 13.15
- 13.6. Appendix: Euler Angles / 13.33
- 13.7. References / 13.33

---

## **Chapter 14. Liquid Crystals** *Shin-Tson Wu* **14.1**

---

- 14.1. Glossary / 14.1
- 14.2. Introduction / 14.2
- 14.3. Physical Properties of Thermotropic Liquid Crystals / 14.2
- 14.4. Physical Mechanisms for Modulating Light / 14.10
- 14.5. Electro-Optics of Nematic Liquid Crystals / 14.12
- 14.6. Electro-Optics of Polymer-Dispersed Liquid Crystals / 14.17
- 14.7. Electro-Optics of Ferroelectric Liquid Crystals / 14.19
- 14.8. Conclusion / 14.23
- 14.9. References / 14.24

---

## **Part 2. Optical Instruments** **15.1**

---

### **Chapter 15. Cameras** *Norman Goldberg* **15.3**

---

- 15.1. Introduction / 15.3
- 15.2. Background / 15.3
- 15.3. Properties of the Final Image / 15.4
- 15.4. Film Choice / 15.5
- 15.5. Resolving Fine Detail / 15.5
- 15.6. Film Sizes / 15.6
- 15.7. Display / 15.6
- 15.8. Distributing the Image / 15.7
- 15.9. Video Cameras / 15.7
- 15.10. Instant Pictures / 15.8
- 15.11. Critical Features / 15.8
- 15.12. Time Lag / 15.9
- 15.13. Automation / 15.10

- 15.14. Flash / 15.16
- 15.15. Flexibility through Features and Accessories / 15.17
- 15.16. Advantage of Various Formats / 15.18
- 15.17. Large Format: A Different World / 15.19
- 15.18. Special Cameras / 15.21
- 15.19. Further Reading / 15.28

---

**Chapter 16. Camera Lenses** *Ellis Betensky, M. Kreitzer, and J. Moskovich* **16.1**

---

- 16.1. Introduction / 16.1
- 16.2. Imposed Design Limitations / 16.1
- 16.3. Modern Lens Types / 16.2
- 16.4. Classification System / 16.20
- 16.5. Lens Performance Data / 16.25
- 16.6. Acknowledgments / 16.26
- 16.7. References / 16.26

---

**Chapter 17. Microscopes** *Shinya Inoué and Rudolf Oldenboug* **17.1**

---

- 17.1. Glossary / 17.1
- 17.2. Introduction / 17.1
- 17.3. General Optical Considerations / 17.4
- 17.4. Microscope Lenses, Aberrations / 17.12
- 17.5. Contrast Generation / 17.22
- 17.6. Illumination and Imaging Modes / 17.37
- 17.7. Optical Manipulation of Specimen with the Light Microscope / 17.47
- 17.8. Mechanical Standards / 17.48
- 17.9. Acknowledgments / 17.49
- 17.10. References / 17.49

---

**Chapter 18. Reflective and Catadioptric Objectives** *Lloyd Jones* **18.1**

---

- 18.1. Glossary / 18.1
- 18.2. Introduction / 18.1
- 18.3. Glass Varieties / 18.2
- 18.4. Introduction to Catadioptric and Reflective Objectives / 18.2
- 18.5. Field-of-View Plots / 18.38
- 18.6. Definitions / 18.40
- 18.7. References / 18.42

---

**Chapter 19. Scanners** *Leo Beiser and R. Barry Johnson* **19.1**

---

- 19.1. Glossary / 19.1
- 19.2. Introduction / 19.2
- 19.3. Scanned Resolution / 19.7
- 19.4. Scanners for Remote Sensing / 19.15
- 19.5. Scanning for Input/Output Imaging / 19.26
- 19.6. Scanner Devices and Techniques / 19.34
- 19.7. Scan-Error Reduction / 19.51
- 19.8. References / 19.54
- 19.9. Further Reading / 19.56

**Chapter 20. Optical Spectrometers** *Brian Henderson*

20.1

- 
- 20.1. Glossary / 20.1
  - 20.2. Introduction / 20.2
  - 20.3. Optical Absorption Spectrometers / 20.2
  - 20.4. Luminescence Spectrometers / 20.5
  - 20.5. Photoluminescence Decay Time / 20.12
  - 20.6. Polarization Spectrometers / 20.15
  - 20.7. High-Resolution Techniques / 20.23
  - 20.8. Light Scattering / 20.30
  - 20.9. References / 20.32

**Chapter 21. Interferometers** *P. Hariharan*

21.1

- 
- 21.1. Glossary / 21.1
  - 21.2. Introduction / 21.1
  - 21.3. Basic Types of Interferometers / 21.2
  - 21.4. Three-Beam and Double-Passed Two-Beam Interferometers / 21.7
  - 21.5. Fringe-Counting Interferometers / 21.10
  - 21.6. Two-Wavelength Interferometry / 21.11
  - 21.7. Frequency-Modulation Interferometers / 21.11
  - 21.8. Heterodyne Interferometers / 21.12
  - 21.9. Phase-Shifting Interferometers / 21.13
  - 21.10. Phase-Locked Interferometers / 21.14
  - 21.11. Laser-Doppler Interferometers / 21.15
  - 21.12. Laser-Feedback Interferometers / 21.16
  - 21.13. Fiber Interferometers / 21.17
  - 21.14. Interferometric Wave Meters / 21.19
  - 21.15. Second-Harmonic and Phase-Conjugate Interferometers / 21.21
  - 21.16. Stellar Interferometers / 21.22
  - 21.17. Michelson's Stellar Interferometers / 21.22
  - 21.18. Gravitational-Wave Interferometers / 21.23
  - 21.19. References / 21.25

**Chapter 22. Polarimetry** *Russell A. Chipman*

22.1

- 
- 22.1. Glossary / 22.1
  - 22.2. Objectives / 22.3
  - 22.3. Polarimeters / 22.3
  - 22.4. Light-Measuring and Sampling-Measuring Polarimeters / 22.3
  - 22.5. Sample-Measuring Polarimeters / 22.4
  - 22.6. Complete and Incomplete Polarimeters / 22.4
  - 22.7. Polarization Generators and Analyzers / 22.4
  - 22.8. Classes of Light-Measuring Polarimeters / 22.5
  - 22.9. Time-Sequential Measurements / 22.5
  - 22.10. Polarization Modulation / 22.5
  - 22.11. Division of Aperture / 22.5
  - 22.12. Division of Amplitude / 22.6
  - 22.13. Definitions / 22.6
  - 22.14. Stokes Vectors and Mueller Matrices / 22.8
  - 22.15. Phenomenological Definition of the Stokes Vector / 22.8
  - 22.16. Polarization Properties of Light Beams / 22.9
  - 22.17. Mueller Matrices / 22.10
  - 22.18. Coordinate System for the Mueller Matrix / 22.12
  - 22.19. Elliptical and Circular Polarizers and Analyzers / 22.13
  - 22.20. Light-Measuring Polarimeters / 22.14

- 22.21. Sample-Measuring Polarimeters for Measuring Mueller Matrix Elements / 22.16
- 22.22. Polarimetric Measurement Equation and Polarimetric Data Reduction Equation / 22.17
- 22.23. Dual Rotating Retarder Polarimeter / 22.19
- 22.24. Incomplete Sample-Measuring Polarimeter / 22.20
- 22.25. Dual Rotating Polarizer Polarimeter / 22.20
- 22.26. Nonideal Polarization Elements / 22.22
- 22.27. Polarization Properties of Polarization Elements / 22.23
- 22.28. Common Defects of Polarization Elements / 22.23
- 22.29. The Muller Matrix for Polarization Component Characterization / 22.25
- 22.30. Application of Polarimetry / 22.26
- 22.31. Interpretation of Mueller Matrices / 22.28
- 22.32. Diattenuation and Polarization Sensitivity / 22.28
- 22.33. Polarizance / 22.29
- 22.34. Physically Realizable Mueller Matrices / 22.30
- 22.35. Depolarization / 22.30
- 22.36. Nondepolarizing Mueller Matrices and Jones Matrices / 22.31
- 22.37. Homogeneous and Inhomogeneous Polarization Elements / 22.32
- 22.38. References / 22.33

---

### **Chapter 23. Holography and Holographic Instruments** *Lloyd Huff* **23.1**

- 23.1. Glossary / 23.1
- 23.2. Introduction / 23.2
- 23.3. Background and Basic Principles / 23.2
- 23.4. Holographic Interferometry / 23.5
- 23.5. Holographic Optical Elements / 23.12
- 23.6. Holographic Inspection / 23.17
- 23.7. Holographic Lithography / 23.16
- 23.8. Holographic Memory / 23.25
- 23.9. Conclusion / 23.26
- 23.10. References / 23.26

## **Part 3. Optical Measurements** **24.1**

---

### **Chapter 24. Radiometry and Photometry** *Edward F. Zalewski* **24.3**

- 24.1. Glossary / 24.3
- 24.2. Introduction / 24.6
- 24.3. Radiometric Definitions and Basic Concepts / 24.8
- 24.4. Radiant Transfer Approximations / 24.15
- 24.5. Absolute Measurements / 24.12
- 24.6. Photometry / 24.40
- 24.7. References / 24.48

---

### **Chapter 25. The Measurement of Transmission, Absorption, Emission, and Reflection** *James M. Palmer* **25.1**

- 25.1. Glossary / 25.1
- 25.2. Introduction and Terminology / 25.2
- 25.3. Transmittance / 25.3
- 25.4. Absorption / 25.4
- 25.5. Reflectance / 25.4
- 25.6. Emittance / 25.7

- 25.7. Kirchhoff's Law / 25.8
- 25.8. Relationship Between Transmittance, Reflectance, and Absorption / 25.8
- 25.9. Measurement of Transmittance / 25.8
- 25.10. Measurement of Absorption / 25.11
- 25.11. Measurement of Reflectance / 25.11
- 25.12. Measurement of Emittance / 25.16
- 25.13. References / 25.18
- 25.14. Further Reading / 25.25

---

**Chapter 26. Scatterometers** *John C. Stover* **26.1**

- 26.1. Glossary / 26.1
- 26.2. Introduction / 26.1
- 26.3. Definitions and Specifications / 26.2
- 26.4. Instrument Configurations and Component Descriptions / 26.5
- 26.5. Instrumentation Issues / 26.9
- 26.6. Measurement Issues / 26.11
- 26.7. Incident Power Measurement, System Calibration, and Error Analysis / 26.13
- 26.8. Summary / 26.14
- 26.9. References / 26.15

---

**Chapter 27. Ellipsometry** *Rasheed M. A. Azzam* **27.1**

- 27.1. Glossary / 27.1
- 27.2. Introduction / 27.2
- 27.3. Conventions / 27.3
- 27.4. Modeling and Inversion / 27.4
- 27.5. Transmission Ellipsometry / 27.10
- 27.6. Instrumentation / 27.10
- 27.7. Jones-Matrix Generalized Ellipsometry / 27.19
- 27.8. Mueller-Matrix Generalized Ellipsometry / 27.20
- 27.9. Applications / 27.22
- 27.10. References / 27.22

---

**Chapter 28. Spectroscopic Measurements** *Brian Henderson* **25.1**

- 28.1. Glossary / 28.1
- 28.2. Introductory Comments / 28.2
- 28.3. Optical Absorption Measurements of Energy Levels / 28.2
- 28.4. The Homogeneous Lineshape of Spectra / 28.14
- 28.5. Absorption, Photoluminescence, and Radiative Decay Measurements / 28.20
- 28.6. References / 28.26

---

**Chapter 29. Optical Metrology** *Daniel Malacara and Zacarias Malacara* **29.1**

- 29.1. Glossary / 29.1
- 29.2. Introduction and Definitions / 29.1
- 29.3. Lengths and Straightness Measurements / 29.3
- 29.4. Angle Measurements / 29.12
- 29.5. Curvature and Focal Length Measurements / 29.20
- 29.6. Velocity Measurements / 29.27
- 29.7. References / 29.29



**Chapter 30. Optical Testing** *Daniel Malacara* **30.1**

- 
- 30.1. Glossary / 30.1
  - 30.2. Introduction / 30.1
  - 30.3. Classical Noninterferometric Tests / 30.1
  - 30.4. Interferometric Tests / 30.6
  - 30.5. Increasing and Sensitivity of Interferometers / 30.8
  - 30.6. Interferogram Evaluation / 30.12
  - 30.7. Phase-Shifting Interferometry / 30.16
  - 30.8. Measuring Aspherical Wavefronts / 30.22
  - 30.9. References / 30.25

**Chapter 31. Use of Computer-Generated Holograms in Optical Testing** *Katherine Creath and James C. Wyant* **31.1**

- 
- 31.1. Glossary / 31.1
  - 31.2. Introduction / 31.2
  - 31.3. Types of CGHs / 31.2
  - 31.4. Plotting CGHs / 31.3
  - 31.5. Interferometers Using Computer-Generated Holograms / 31.6
  - 31.6. Accuracy Limitations / 31.7
  - 31.7. Experimental Results / 31.8
  - 31.8. References / 31.10

**Chapter 32. Transfer Function Techniques** *Glenn D. Boreman* **32.1**

- 
- 32.1. Glossary / 32.1
  - 32.2. Introduction / 32.1
  - 32.3. Definitions / 32.2
  - 32.4. MTF Calculations / 32.4
  - 32.5. MTF Measurements / 32.7
  - 32.6. References / 32.9

**Part 4. Optical and Physical Properties of Materials** **33.1****Chapter 33. Properties of Crystals and Glasses** *William J. Tropf, Michael Thomas, and Terry J. Harris* **33.3**

- 
- 33.1. Glossary / 33.3
  - 33.2. Introduction / 33.5
  - 33.3. Optical Materials / 33.6
  - 33.4. Properties of Materials / 33.7
  - 33.5. Properties Tables / 33.38
  - 33.6. References / 33.84

**Chapter 34. Polymetric Optics** *John D. Lytle* **34.1**

- 
- 34.1. Glossary / 34.1
  - 34.2. Introduction / 34.1
  - 34.3. Forms / 34.2
  - 34.4. Physical Properties / 34.2

- 34.5. Optical Properties / 34.6
- 34.6. Optical Design / 34.8
- 34.7. Processing / 34.12
- 34.8. Coatings / 34.19
- 34.9. References / 34.20

---

**Chapter 35. Properties of Metals** *Roger A. Paquin* **35.1**

---

- 35.1. Glossary / 35.1
- 35.2. Introduction / 35.3
- 35.3. Summary Data / 35.12
- 35.4. References / 35.74

---

**Chapter 36. Optical Properties of Semiconductors** *Paul M. Amirtharaj and David G. Seiler* **36.1**

---

- 36.1. Glossary / 36.1
- 36.2. Introduction / 36.3
- 36.3. Optical Properties / 36.8
- 36.4. Measurement Techniques / 36.59
- 36.5. Acknowledgments / 36.82
- 36.6. Summary and Conclusions / 36.82
- 36.7. References / 36.92

---

**Chapter 37. Black Surfaces for Optical Systems** *Stephen M. Pompea and Robert P. Breault* **37.1**

---

- 37.1. Introduction / 37.1
- 37.2. Selection Process for Black Baffle Surfaces in Optical Systems / 37.12
- 37.3. The Creation of Black Surfaces for Specific Applications / 37.15
- 37.4. Environmental Degradation of Black Surfaces / 37.18
- 37.5. Optical Characterization of Black Surfaces / 37.21
- 37.6. Surfaces for Ultraviolet and Far-Infrared Applications / 37.23
- 37.7. Survey of Surfaces with Optical Data / 37.29
- 37.8. Paints / 37.30
- 37.9. Conclusions / 37.63
- 37.10. Acknowledgments / 37.63
- 37.11. References / 37.63

---

**Part 5. Nonlinear and Photorefractive Optics** **38.1**

---

**Chapter 38. Nonlinear Optics** *Chung L. Tang* **38.3**

---

- 38.1. Glossary / 38.3
- 38.2. Introduction / 38.4
- 38.3. Basic Concepts / 38.6
- 38.4. Material Considerations / 38.20
- 38.5. Appendix / 38.23
- 38.6. References / 38.25

**Chapter 39. Photorefractive Materials and Devices Mark Cronin-Golomb and Marvin Klein**

**39.1**

- 39.1. Introduction / 39.1
- 39.2. Materials / 39.11
- 39.3. Devices / 39.25
- 39.4. References / 39.35
- 39.5. Further Reading / 39.42

**Index follows Chapter 39 1.1**

*[Faint, mostly illegible text listing authors and affiliations, including names like M. A. Azzam, Lee Rubin, Jeff M. Benoit, Ellis Betsworth, Glenn D. Boreman, Robert P. Breiby, Tom J. Brown, J. C. Chiao, Russell A. Chipman, Katherine Cochran, Mark Cronin-Golomb, Malcolm W. Fein, Jonathan Goldberg, P. Machorin, Tony J. Marks, James E. Harvey, Bruce Manderson, David Huff, Ronald Inge, R. Barry Johnson, Lloyd Jones, and Phyllis Klein.]*