

CONTENTS

Preface	xiii
1. Introduction	1
1.1. Motivation for Optical Imaging	1
1.2. General Behavior of Light in Biological Tissue	2
1.3. Basic Physics of Light–Matter Interaction	3
1.4. Absorption and its Biological Origins	5
1.5. Scattering and its Biological Origins	7
1.6. Polarization and its Biological Origins	9
1.7. Fluorescence and its Biological Origins	9
1.8. Image Characterization	10
Problems	14
Reading	15
Further Reading	15
2. Rayleigh Theory and Mie Theory for a Single Scatterer	17
2.1. Introduction	17
2.2. Summary of Rayleigh Theory	17
2.3. Numerical Example of Rayleigh Theory	19
2.4. Summary of Mie Theory	20
2.5. Numerical Example of Mie Theory	21
Appendix 2A. Derivation of Rayleigh Theory	23
Appendix 2B. Derivation of Mie Theory	26
Problems	34
Reading	35
Further Reading	35
	vii

3. Monte Carlo Modeling of Photon Transport in Biological Tissue	37
3.1. Introduction	37
3.2. Monte Carlo Method	37
3.3. Definition of Problem	38
3.4. Propagation of Photons	39
3.5. Physical Quantities	50
3.6. Computational Examples	55
Appendix 3A. Summary of MCML	58
Appendix 3B. Probability Density Function	60
Problems	60
Reading	62
Further Reading	62
4. Convolution for Broadbeam Responses	67
4.1. Introduction	67
4.2. General Formulation of Convolution	67
4.3. Convolution over a Gaussian Beam	69
4.4. Convolution over a Top-Hat Beam	71
4.5. Numerical Solution to Convolution	72
4.6. Computational Examples	77
Appendix 4A. Summary of CONV	77
Problems	80
Reading	81
Further Reading	81
5. Radiative Transfer Equation and Diffusion Theory	83
5.1. Introduction	83
5.2. Definitions of Physical Quantities	83
5.3. Derivation of Radiative Transport Equation	85
5.4. Diffusion Theory	88
5.5. Boundary Conditions	101
5.6. Diffuse Reflectance	106

5.7. Photon Propagation Regimes	114
Problems	116
Reading	117
Further Reading	118
6. Hybrid Model of Monte Carlo Method and Diffusion Theory	119
6.1. Introduction	119
6.2. Definition of Problem	119
6.3. Diffusion Theory	119
6.4. Hybrid Model	122
6.5. Numerical Computation	124
6.6. Computational Examples	125
Problems	132
Reading	133
Further Reading	133
7. Sensing of Optical Properties and Spectroscopy	135
7.1. Introduction	135
7.2. Collimated Transmission Method	135
7.3. Spectrophotometry	139
7.4. Oblique-Incidence Reflectometry	140
7.5. White-Light Spectroscopy	144
7.6. Time-Resolved Measurement	145
7.7. Fluorescence Spectroscopy	146
7.8. Fluorescence Modeling	147
Problems	148
Reading	149
Further Reading	149
8. Ballistic Imaging and Microscopy	153
8.1. Introduction	153
8.2. Characteristics of Ballistic Light	153

x CONTENTS

8.3.	Time-Gated Imaging	154
8.4.	Spatiofrequency-Filtered Imaging	156
8.5.	Polarization-Difference Imaging	157
8.6.	Coherence-Gated Holographic Imaging	158
8.7.	Optical Heterodyne Imaging	160
8.8.	Radon Transformation and Computed Tomography	163
8.9.	Confocal Microscopy	164
8.10.	Two-Photon Microscopy	169
	Appendix 8A. Holography	171
	Problems	175
	Reading	177
	Further Reading	177
9.	Optical Coherence Tomography	181
9.1.	Introduction	181
9.2.	Michelson Interferometry	181
9.3.	Coherence Length and Coherence Time	184
9.4.	Time-Domain OCT	185
9.5.	Fourier-Domain Rapid-Scanning Optical Delay Line	195
9.6.	Fourier-Domain OCT	198
9.7.	Doppler OCT	206
9.8.	Group Velocity Dispersion	207
9.9.	Monte Carlo Modeling of OCT	210
	Problems	213
	Reading	215
	Further Reading	215
10.	Mueller Optical Coherence Tomography	219
10.1.	Introduction	219
10.2.	Mueller Calculus versus Jones Calculus	219
10.3.	Polarization State	219
10.4.	Stokes Vector	222

10.5. Mueller Matrix	224
10.6. Mueller Matrices for a Rotator, a Polarizer, and a Retarder	225
10.7. Measurement of Mueller Matrix	227
10.8. Jones Vector	229
10.9. Jones Matrix	230
10.10. Jones Matrices for a Rotator, a Polarizer, and a Retarder	230
10.11. Eigenvectors and Eigenvalues of Jones Matrix	231
10.12. Conversion from Jones Calculus to Mueller Calculus	235
10.13. Degree of Polarization in OCT	236
10.14. Serial Mueller OCT	237
10.15. Parallel Mueller OCT	237
Problems	243
Reading	244
Further Reading	245
11. Diffuse Optical Tomography	249
11.1. Introduction	249
11.2. Modes of Diffuse Optical Tomography	249
11.3. Time-Domain System	251
11.4. Direct-Current System	252
11.5. Frequency-Domain System	253
11.6. Frequency-Domain Theory: Basics	256
11.7. Frequency-Domain Theory: Linear Image Reconstruction	261
11.8. Frequency-Domain Theory: General Image Reconstruction	267
Appendix 11A. ART and SIRT	275
Problems	276
Reading	279
Further Reading	279
12. Photoacoustic Tomography	283
12.1. Introduction	283
12.2. Motivation for Photoacoustic Tomography	283

12.3. Initial Photoacoustic Pressure	284
12.4. General Photoacoustic Equation	287
12.5. General Forward Solution	288
12.6. Delta-Pulse Excitation of a Slab	293
12.7. Delta-Pulse Excitation of a Sphere	297
12.8. Finite-Duration Pulse Excitation of a Thin Slab	302
12.9. Finite-Duration Pulse Excitation of a Small Sphere	303
12.10. Dark-Field Confocal Photoacoustic Microscopy	303
12.11. Synthetic Aperture Image Reconstruction	307
12.12. General Image Reconstruction	309
Appendix 12A. Derivation of Acoustic Wave Equation	313
Appendix 12B. Green Function Approach	316
Problems	317
Reading	319
Further Reading	319
13. Ultrasound-Modulated Optical Tomography	323
13.1. Introduction	323
13.2. Mechanisms of Ultrasonic Modulation of Coherent Light	323
13.3. Time-Resolved Frequency-Swept UOT	326
13.4. Frequency-Swept UOT with Parallel-Speckle Detection	329
13.5. Ultrasonically Modulated Virtual Optical Source	331
13.6. Reconstruction-Based UOT	332
13.7. UOT with Fabry–Perot Interferometry	335
Problems	338
Reading	339
Further Reading	339
Appendix A. Definitions of Optical Properties	343
Appendix B. List of Acronyms	345
Index	347