

Contents

<i>Preface to the Second Edition</i>	<i>v</i>
<i>Preface to the First Edition</i>	<i>vii</i>
<i>Acknowledgements</i>	<i>ix</i>
<i>Milestones in the Development of Lasers and Their Applications</i>	<i>xix</i>

PART I **Fundamentals of Lasers**

1 INTRODUCTION	3—7
2 BASIC OPTICS	8—30
2.1 Introduction	8
2.2 The Wave Equation	8
2.3 Linearly Polarized Waves	12
2.4 Circularly and Elliptically Polarized Waves	14
2.5 The Diffraction Integral	16
2.6 Diffraction of a Gaussian Beam	18
2.7 Intensity Distribution at the Back Focal Plane of a Lens	21
2.8 Two Beam Interference	22
2.9 Multiple Reflections from a Plane Parallel Film	23
2.10 Modes of the Fabry-Perot Cavity	27
<i>Problems</i>	28
<i>Solution</i>	29
3 ELEMENTS OF QUANTUM MECHANICS	31—59
3.1 Introduction	31
3.2 The One-Dimensional Schrödinger Equation	31
3.3 The Three-dimensional Schrödinger Equation	41
3.4 Physical Interpretation of ψ and its Normalization	42
3.4.1 Density of States	45

3.5	Expectation Values of Dynamical Quantities	46
3.6	The Commutator	47
3.7	Orthogonality of Wave Functions	48
3.8	Spherically Symmetric Potentials	49
3.9	The Two-body Problem	51
3.9.1	The Hydrogen-like Atom Problem	52
	<i>Problems</i>	57
4.	EINSTEIN COEFFICIENTS AND LIGHT AMPLIFICATION	60-93
4.1	Introduction	60
4.2	The Einstein Coefficients	60
4.2.1	Absorption and Emission Cross Sections	65
4.3	Light Amplification	66
4.4	The Threshold Condition	69
4.5	Line Broadening Mechanisms	72
4.5.1	Natural Broadening	72
4.5.2	Collision Broadening	74
4.5.3	Doppler Broadening	77
4.6	Saturation Behaviour of Homogeneously and Inhomogeneously Broadened Transitions	79
4.7	Quantum Theory for the Evaluation of Transition Rates and Einstein Coefficients	81
4.7.1	Interaction with Radiation having a Broad Spectrum	84
4.7.2	Interaction of a Near Monochromatic Wave with an Atom Having a Broad Frequency Response	88
4.8	More Accurate Solution for the Two-level System	88
	<i>Additional Problems</i>	92
5.	LASER RATE EQUATIONS	94-117
5.1	Introduction	94
5.2	The Two-level System	95
5.3	The Three-level Laser System	97
5.4	The Four-level Laser System	102
5.5	Variation of Laser Power Around Threshold	107
5.6	Optimum Output Coupling	114
	<i>Problems</i>	116
6.	SEMICLASSICAL THEORY OF LASER	118-138
6.1	Introduction	118
6.2	Cavity Modes	119
6.3	Polarization of the Cavity Medium	124
6.3.1	First-order Theory	128
6.3.2	Higher-order Theory	133

7. OPTICAL RESONATORS**139–193**

- 7.1 Introduction 139
- 7.2 Modes of a Rectangular Cavity and the Open Planar Resonator 140
- 7.3 Spherical Mirror Resonators 147
- 7.4 The Quality Factor 149
- 7.5 The Ultimate Linewidth of a Laser 151
- 7.6 Mode Selection 154
 - 7.6.1 Transverse Mode Selection 154
 - 7.6.2 Longitudinal Mode Selection 155
- 7.7 Pulsed Operation of Lasers 160
 - 7.7.1 Q-switching 160
 - 7.7.2 Techniques for Q-switching 166
 - 7.7.3 Mode Locking 168
- 7.8 Modes of Confocal Resonator System 177
- 7.9 Modes of a General Spherical Resonator 184

*Problems***8. VECTOR SPACES AND LINEAR OPERATIONS: DIRAC NOTATION****194–215**

- 8.1 Introduction 194
- 8.2 The BRA and KET Notation 194
- 8.3 Linear Operators 195
- 8.4 The Eigenvalue Equation 197
- 8.5 Observables 198
- 8.6 The Harmonic Oscillator Problem 199
 - 8.6.1 The Number Operator 203
 - 8.6.2 The Uncertainty Product 204
 - 8.6.3 Coherent States 205
- 8.7 Time Development of States 207
- 8.8 The Density Operator 209
- 8.9 The Schrödinger and Heisenberg Pictures 212

*Problems***9. QUANTUM THEORY OF INTERACTION OF RADIATION FIELD WITH MATTER****216–250**

- 9.1 Introduction 216
- 9.2 Quantization of the Electromagnetic Field 217
- 9.3 The Eigenkets of the Hamiltonian 224
- 9.4 The Coherent States 229
- 9.5 Squeezed States of Light 232
- 9.6 Transition Rates 235
- 9.7 The Phase Operator 240
- 9.8 Photons Incident on a Beam Splitter 243

Problems

248

10. PROPERTIES OF LASERS	251-262
10.1 Introduction	251
10.2 Laser Beam Characteristics	251
10.3 Coherence Properties of Laser Light	257
10.3.1 Temporal Coherence	257
10.3.2 Spatial Coherence	259
<i>Problems</i>	261
11. SOME LASER SYSTEMS	263-274
11.1 Introduction	263
11.2 Ruby Laser	263
11.3 Neodymium-based Lasers	266
11.3.1 Nd:YAG Laser	266
11.3.2 Nd:glass Laser	267
11.4 Titanium Sapphire Laser	268
11.5 The He-Ne Laser	269
11.6 The Argon Ion Laser	270
11.7 The CO ₂ Laser	271
11.8 Dye Lasers	273
<i>Problems</i>	274
12. DOPED FIBER AMPLIFIERS AND LASERS	275-303
12.1 Introduction	275
12.2 The Fiber Laser	276
12.3 Basic Equations for Amplification in Erbium Doped Fiber	278
12.4 Fiber Lasers	287
12.5 Erbium Doped Fiber Amplifier	294
12.6 Mode Locking in Fiber Lasers	297
<i>Problems</i>	302
13. SEMICONDUCTOR LASERS	304-343
13.1 Introduction	304
13.2 Some Basics of Semiconductors	304
13.2.1 E vs. k	305
13.3 Optical Gain in Semiconductors	308
13.3.1 Density of States	308
13.3.2 Probability of Occupancy of States	309
13.3.3 Interaction with Light	310
13.3.4 Joint Density of States	312
13.3.5 Absorption and Emission Rates	314
13.3.6 Light Amplification	315
13.4 Gain Coefficient	317
13.4.1 Electron Hole Population and Quasi Fermi Levels	321
13.4.2 Gain in a Forward Biased $p-n$ Junction	323

13.4.3	Laser Oscillation	326
13.4.4	Heterostructure Lasers	326
13.5	Quantum-well Lasers	330
13.5.1	Joint Density of States	334
13.6	Materials	337
13.7	Laser Diode Characteristics	337
13.8	Vertical Cavity Surface Emitting Lasers (VCSELs)	341
<i>Problems</i>		342

14. OPTICAL PARAMETRIC OSCILLATORS **344–366**

14.1	Introduction	344
14.2	Nonlinearity	345
14.3	Parametric Amplification	350
14.4	Singly Resonant Oscillator	354
14.5	Doubly Resonant Oscillator	356
14.6	Frequency Tuning	359
14.7	Phase Matching	361
14.7.1	Birefringence Phase Matching	361
14.7.2	Quasi Phase Matching	361
<i>Problems</i>		364

PART II

Some Important Applications of Lasers

15. SPATIAL FREQUENCY FILTERING AND HOLOGRAPHY **367–381**

15.1	Introduction	369
15.2	Spatial Frequency Filtering	369
15.3	Holography	374
<i>Problems</i>		380

16. LASER-INDUCED FUSION **382–393**

16.1	Introduction	382
16.2	The Fusion Process	382
16.3	The Laser Energy Requirements	384
16.4	The Laser-induced Fusion Reactor	387

17. LIGHTWAVE COMMUNICATIONS **394–371**

17.1	Introduction	394
17.2	Carrier Wave Communication	394
17.2.1	Analog Modulation	395
17.2.2	Digital Modulation	398
17.3	Optical Fibers in Communication	403
17.4	The Optical Fiber	403

17.5	Why Glass Fibers?	405
17.6	Attenuation in Optical Fibers	405
17.7	Numerical Aperture in the Fiber	407
17.8	Multimode and Single Mode Fibers	408
17.9	Single Mode Fiber	410
17.10	Pulse Dispersion in Optical Fibers	411
	<i>Problems</i>	416
18.	LASERS IN SCIENCE	418-440
18.1	Introduction	418
18.2	Second Harmonic Generation	418
18.3	Stimulated Raman Emission	423
18.4	Intensity Dependent Refractive Index	428
18.5	Lasers in Chemistry	430
18.6	Lasers and Ether Drift	431
18.7	Lasers and Gravitational Waves	432
18.8	Rotation of the Earth	432
18.8	Photon Statistics	434
18.9	Lasers in Isotope Separation	436
18.9.1	Separation Using Radiation Pressure	437
18.9.2	Separation by Selective Photoionization or Photodissociation	438
18.9.3	Photochemical Separation	439
	<i>Problems</i>	440
19.	LASERS IN INDUSTRY	441-472
19.1	Introduction	441
19.2	Applications in Material Processing	443
19.2.1	Laser Welding	443
19.2.2	Hole Drilling	445
19.2.3	Laser Cutting	446
19.2.4	Other Applications	448
19.3	Laser Tracking	448
19.4	Lidar	452
19.5	Lasers in Medicine	453
19.6	Precision Length Measurement	454
19.7	Laser Interferometry and Speckle Metrology	455
19.7.1	Homodyne and Heterodyne Interferometry	456
19.7.2	Holographic Interferometry	459
19.7.3	Laser Interferometry Lithography	461
19.7.4	Speckle Metrology	462
19.8	Velocity Measurement	467
19.8.1	Lasers in Information System Storage	470
19.8.2	Bar Code Scanner	471
	<i>Problems</i>	472

PART III

Nobel Lectures

1.	PRODUCTION OF COHERENT RADIATION BY ATOMS AND MOLECULES	473-495
2.	SEMICONDUCTOR LASERS	496-507
3.	QUANTUM ELECTRONICS	508-512
4.	PASSION FOR PRECISION	513-532

APPENDIX		533-565
-----------------	--	----------------

A.	Solution for the Harmonic Oscillator Equation	533
B.	The Solution of the Radial Part of the Schrödinger Equation	536
C.	The Fourier Transform	540
D.	Planck's Law	549
E.	The Density of States	552
F.	Fourier Transforming Property of a Lens	555
G.	The Natural Lineshape Function	559
H.	Nonlinear Polarization in Optical Fibers	563

REFERENCES AND SUGGESTED READING		567-572
---	--	----------------

INDEX		573-577
--------------	--	----------------