

# Contents

1. Introduction . . . . .	1
PART I: BASIC LASER THEORY	
2. Elements of Quantum Mechanics . . . . .	9
2.1. Introduction . . . . .	9
2.2. Wave Packet . . . . .	9
2.3. The Schrödinger Equation . . . . .	13
2.4. Physical Interpretation of $\Psi$ and Its Normalization . . . . .	16
2.5. Expectation Values of Dynamical Quantities . . . . .	17
2.6. The Commutator . . . . .	19
2.7. The Uncertainty Principle . . . . .	19
2.8. The Linear Harmonic Oscillator . . . . .	22
2.9. Orthogonality of Wave Functions . . . . .	25
2.10. The Hydrogenlike Atom Problem . . . . .	27
2.11. Some Simple Solutions of the Schrödinger Equation . . . . .	29
3. The Einstein Coefficients and Light Amplification . . . . .	33
3.1. Introduction . . . . .	33
3.2. The Einstein Coefficients . . . . .	33
3.3. Quantum Theory for the Evaluation of the Transition Rates and Einstein Coefficients . . . . .	43
3.3.1. Interaction with Radiation Having a Broad Spectrum . . . . .	46
3.3.2. Interaction of a Near-Monochromatic Wave with an Atom Having a Broad Frequency Response . . . . .	50
3.4. More Accurate Solution for the Two-Level System . . . . .	51
3.5. Line-Broadening Mechanisms . . . . .	54
3.6. Saturation Behavior of Homogeneously and Inhomogeneously Broadened Transitions . . . . .	59
4. Laser Rate Equations . . . . .	63
4.1. Introduction . . . . .	63
4.2. The Three-Level System . . . . .	64

4.3. The Four-Level System . . . . .	69
4.4. Variation of Laser Power around Threshold . . . . .	75
4.5. Optimum Output Coupling . . . . .	81
4.6. Laser Spiking . . . . .	82
<b>5. Semiclassical Theory of the Laser . . . . .</b>	<b>85</b>
5.1. Introduction . . . . .	85
5.2. Cavity Modes . . . . .	86
5.3. Polarization of the Cavity Medium . . . . .	92
5.3.1. First-Order Theory . . . . .	96
5.3.2. Higher-Order Theory . . . . .	101
<b>6. Optical Resonators . . . . .</b>	<b>107</b>
6.1. Introduction . . . . .	107
6.2. Modes of a Rectangular Cavity and the Open Planar Resonator . . . . .	108
6.3. The Quality Factor . . . . .	115
6.4. The Ultimate Linewidth of the Laser . . . . .	119
6.5. Transverse and Longitudinal Mode Selection . . . . .	121
6.5.1. Transverse Mode Selection . . . . .	121
6.5.2. Longitudinal Mode Selection . . . . .	122
6.6. Q Switching . . . . .	123
6.7. Mode Locking in Lasers . . . . .	125
6.8. Confocal Resonator System . . . . .	129
6.9. Planar Resonators . . . . .	138
6.10. General Spherical Resonator . . . . .	141
6.11. Geometrical Optics Analysis of Optical Resonators . . . . .	144
<b>7. Vector Spaces and Linear Operators: Dirac Notation . . . . .</b>	<b>155</b>
7.1. Introduction . . . . .	155
7.2. The Bra and Ket Notation . . . . .	155
7.3. Linear Operators . . . . .	156
7.4. The Eigenvalue Equation . . . . .	158
7.5. Observables . . . . .	159
7.6. The Harmonic Oscillator Problem . . . . .	160
7.6.1. The Number Operator . . . . .	163
7.6.2. The Uncertainty Product . . . . .	164
7.6.3. The Coherent States . . . . .	165
7.7. Time Development of States . . . . .	167
7.8. The Density Operator . . . . .	169
7.9. The Schrödinger and Heisenberg Pictures . . . . .	172
<b>8. Quantum Theory of Interaction of Radiation Field with Matter . . . . .</b>	<b>177</b>
8.1. Introduction . . . . .	177
8.2. Quantization of the Electromagnetic Field . . . . .	178

8.3. The Eigenkets of the Hamiltonian . . . . .	184
8.4. The Coherent States . . . . .	186
8.5. Transition Rates . . . . .	189
8.6. The Phase Operator . . . . .	194
<b>9. Properties of Laser Beams and Types of Lasers . . . . .</b>	<b>199</b>
9.1. Introduction . . . . .	199
9.2. Coherence Properties of Laser Light . . . . .	199
9.2.1. Temporal Coherence . . . . .	199
9.2.2. Spatial Coherence . . . . .	202
9.2.3. Directionality . . . . .	205
9.3. The Ruby Laser . . . . .	209
9.4. The Helium-Neon Laser . . . . .	211
9.5. Four-Level Solid State Lasers . . . . .	214
9.6. The Carbon Dioxide Laser . . . . .	215
9.7. Dye Lasers . . . . .	217
9.8. Semiconductor Lasers . . . . .	219
 <b>PART II: SOME IMPORTANT APPLICATIONS OF LASERS</b> 	
<b>10. Spatial Frequency Filtering and Holography . . . . .</b>	<b>227</b>
10.1. Introduction . . . . .	227
10.2. Spatial Frequency Filtering . . . . .	227
10.3. Holography . . . . .	233
<b>11. Laser-Induced Fusion . . . . .</b>	<b>239</b>
11.1. Introduction . . . . .	239
11.2. The Fusion Process . . . . .	239
11.3. The Laser Energy Requirements . . . . .	241
11.4. The Laser-Induced Fusion Reactor . . . . .	245
<b>12. Lightwave Communications . . . . .</b>	<b>253</b>
12.1. Introduction . . . . .	253
12.2. Large Information-Carrying Capacity of Lightwaves . . . . .	255
12.3. Components of a Lightwave Communication System . . . . .	264
12.3.1. The Optical Fiber . . . . .	264
12.3.2. Modulators and Detectors . . . . .	270
<b>13. Lasers in Science . . . . .</b>	<b>273</b>
13.1. Introduction . . . . .	273
13.2. Harmonic Generation . . . . .	273
13.3. Stimulated Raman Emission . . . . .	277
13.4. Self-Focusing . . . . .	278
13.5. Lasers in Chemistry . . . . .	279

13.6. Lasers and Ether Drift . . . . .	280
13.7. Rotation of the Earth . . . . .	281
13.8. Photon Statistics . . . . .	283
13.9. Lasers in Isotope Separation . . . . .	286
13.9.1. Separation Using Radiation Pressure . . . . .	288
13.9.2. Separation by Selective Photoionization or Photodissociation . . . . .	289
13.9.3. Photochemical Separation . . . . .	290
<b>14. Lasers in Industry . . . . .</b>	<b>291</b>
14.1. Introduction . . . . .	291
14.2. Applications in Material Processing . . . . .	294
14.2.1. Laser Welding . . . . .	294
14.2.2. Hole Drilling . . . . .	295
14.2.3. Laser Cutting . . . . .	297
14.2.4. Other Applications . . . . .	299
14.3. Laser Tracking . . . . .	300
14.4. Lidar . . . . .	304
14.5. Lasers in Medicine . . . . .	306
14.6. Precision Length Measurement . . . . .	307
14.7. Velocity Measurement . . . . .	308

### PART III: THE NOBEL LECTURES

<i>Production of Coherent Radiation by Atoms and Molecules</i> . . . . .	313
Charles H. Townes	
<i>Quantum Electronics</i> . . . . .	341
A. M. Prochorov	
<i>Semiconductor Lasers</i> . . . . .	349
Nicolai G. Basov	
<i>Holography, 1948-1971</i> . . . . .	365
Dennis Gabor	
<b>Appendix</b>	
A. The Fourier Transform . . . . .	403
B. Propagation of a Gaussian Wave Packet . . . . .	412
C. Planck's Law . . . . .	413
D. The Density of States . . . . .	416
E. The Fourier Transforming Property of a Lens . . . . .	418
F. The Natural Lineshape Function . . . . .	421
<i>References</i> . . . . .	425
<i>Index</i> . . . . .	429