Contents

1. PLANCK'S RADIATION LAW AND THE EINSTEIN COEFFICIENTS 1

Maxwell's equations 1
Density of field modes in a cavity 4
Quantization of the field energy 6
Planck's law 9
Einstein's A and B coefficients 12
The case of thermal equilibrium 14
Fluctuations in photon number 16
Restriction to high frequencies 19

2. THEORY OF SIMPLE OPTICAL PROCESSES 22

Macroscopic theory of absorption 22
Properties of the microscopic processes 24
Optical excitation of atoms 27
Microscopic theory of absorption 29
Population inversion: the laser 33
Radiation pressure 37

3. QUANTUM THEORY OF THE EINSTEIN B COEFFICIENT 39

Time-dependent quantum mechanics 39
Form of the interaction Hamiltonian 42
The transition rate 44
Expression for the B coefficient 51
The Dirac delta-function 53

4. THE FREQUENCY-DEPENDENT SUSCEPTIBILITY 56

Definition of the susceptibility 56
Classical theory of the susceptibility 58

The flow of energy 61
Kramers–Kronig relations 64
Sum rules 68
Quantum theory of the susceptibility 70
Inclusion of damping in the quantum theory 73
Oscillator strengths 77

5. THEORY OF CHAOTIC LIGHT AND COHERENCE 81
Doppler broadening 82
Collision broadening 84
Composite emission lineshape 88
Time dependence of a chaotic light beam 90
Intensity fluctuations of chaotic light 95
Young's interference fringes 100
Evaluation of the first-order correlation function 102
Fringe intensity and first-order coherence 107
Intensity interference and higher-order coherence 111

6. QUANTIZATION OF THE RADIATION FIELD 120
Potential theory for the classical electromagnetic field 121
The Coulomb gauge 123
The free classical field 126
The quantum-mechanical harmonic oscillator 128
Quantization of the field 133
The zero-point energy 137

7. STATES OF THE QUANTIZED RADIATION FIELD 139
The photon phase operator 140
States of well-defined photon phase 143
Physical properties of the single-mode number states 145
Physical properties of the single-mode phase states 146
The coherent photon states 148
Physical properties of the single-mode coherent states 150
The density operator 154
Density operators for pure states 157
Statistical mixture states of the radiation field 159

8. INTERACTION OF THE RADIATION FIELD WITH AN ATOM 164
Classical Hamiltonian for coupled fields and charges 164
Multipole expansion of the Hamiltonian 168
The electric-dipole approximation 171
Second quantization of the atomic Hamiltonian 174
Calculation of photon absorption and emission rates 177
Transformation to the Schrödinger representation 181
Diagonalization of the atom–radiation Hamiltonian 184
Radiative linewidth and frequency shift 191
Frequency-dependent susceptibility for multilevel atoms 195

9. PHOTON OPTICS 199
The photoelectric effect 199
Measurement of the photon intensity 203
Photon coherence properties 207
Higher-order photon coherence 210
Photon counting 214
Photon distributions for coherent and chaotic light 217
Quantum-mechanical photon-count distribution 221
Photon experiments 225

10. THEORY OF THE LASER 232
Photon rate-equations 232
Time dependence of the photon coherence 236
Laser threshold condition 241
Rate equations for the atoms 244
Rate equations for the laser photons 248
The laser photon distribution 251
Fluctuations in laser light 258
Laser phase-diffusion rate 261
Appendix to Chapter 10 264

11. THE SCATTERING OF LIGHT BY ATOMS 267
The scattering cross-section 267
Classical theory of elastic scattering 271

General expression for radiative transition rates 275
Time-dependent perturbation theory 278
The Kramers–Heisenberg formula 281
Elastic scattering 285
Inelastic scattering: the Raman effect 290

12. NON-LINEAR OPTICS 297
Two-photon absorption (two beams) 298
Two-photon absorption (single beam) 304
The non-linear susceptibility 307
The stimulated Raman effect 312
Third-harmonic generation 318
Photon statistical properties and non-linear optics 323

INDEX 331