

CONTENTS

CHAPTER 1 FUNDAMENTALS OF RADIATIVE TRANSFER 1

- 1.1 The Electromagnetic Spectrum; Elementary Properties of Radiation 1
- 1.2 Radiative Flux 2
 - Macroscopic Description of the Propagation of Radiation* 2
 - Flux from an Isotropic Source—The Inverse Square Law* 2
- 1.3 The Specific Intensity and Its Moments 3
 - Definition of Specific Intensity or Brightness* 3
 - Net Flux and Momentum Flux* 4
 - Radiative Energy Density* 5
 - Radiation Pressure in an Enclosure Containing an Isotropic Radiation Field* 6
 - Constancy of Specific Intensity Along Rays in Free Space* 7
 - Proof of the Inverse Square Law for a Uniformly Bright Sphere* 7

X Contents

1.4	Radiative Transfer	8
	<i>Emission</i>	9
	<i>Absorption</i>	9
	<i>The Radiative Transfer Equation</i>	11
	<i>Optical Depth and Source Function</i>	12
	<i>Mean Free Path</i>	14
	<i>Radiation Force</i>	15
1.5	Thermal Radiation	15
	<i>Blackbody Radiation</i>	15
	<i>Kirchhoff's Law for Thermal Emission</i>	16
	<i>Thermodynamics of Blackbody Radiation</i>	17
	<i>The Planck Spectrum</i>	20
	<i>Properties of the Planck Law</i>	23
	<i>Characteristic Temperatures Related to Planck Spectrum</i>	25
1.6	The Einstein Coefficients	27
	<i>Definition of Coefficients</i>	27
	<i>Relations between Einstein Coefficients</i>	29
	<i>Absorption and Emission Coefficients in Terms of Einstein Coefficients</i>	30
1.7	Scattering Effects; Random Walks	33
	<i>Pure Scattering</i>	33
	<i>Combined Scattering and Absorption</i>	36
1.8	Radiative Diffusion	39
	<i>The Rosseland Approximation</i>	39
	<i>The Eddington Approximation; Two-Stream Approximation</i>	42
	<i>PROBLEMS</i>	45
	<i>REFERENCES</i>	50

CHAPTER 2	
BASIC THEORY OF RADIATION FIELDS	51

2.1	Review of Maxwell's Equations	51
2.2	Plane Electromagnetic Waves	55
2.3	The Radiation Spectrum	58
2.4	Polarization and Stokes Parameters	62
	<i>Monochromatic Waves</i>	62
	<i>Quasi-monochromatic Waves</i>	65

2.5	Electromagnetic Potentials	69
2.6	Applicability of Transfer Theory and the Geometrical Optics Limit	72
	<i>PROBLEMS</i>	74
	<i>REFERENCES</i>	76

CHAPTER 3

RADIATION FROM MOVING CHARGES 77

3.1	Retarded Potentials of Single Moving Charges: The Liénard-Wiechart Potentials	77
3.2	The Velocity and Radiation Fields	80
3.3	Radiation from Nonrelativistic Systems of Particles	83
	<i>Larmor's Formula</i>	83
	<i>The Dipole Approximation</i>	85
	<i>The General Multipole Expansion</i>	88
3.4	Thomson Scattering (Electron Scattering)	90
3.5	Radiation Reaction	93
3.6	Radiation from Harmonically Bound Particles	96
	<i>Undriven Harmonically Bound Particles</i>	96
	<i>Driven Harmonically Bound Particles</i>	99
	<i>PROBLEMS</i>	102
	<i>REFERENCE</i>	105

CHAPTER 4

RELATIVISTIC COVARIANCE AND KINEMATICS 106

4.1	Review of Lorentz Transformations	106
4.2	Four-Vectors	113
4.3	Tensor Analysis	122
4.4	Covariance of Electromagnetic Phenomena	125
4.5	A Physical Understanding of Field Transformations	129
4.6	Fields of a Uniformly Moving Charge	130
4.7	Relativistic Mechanics and the Lorentz Four-Force	136

xii Contents

4.8 Emission from Relativistic Particles	138
<i>Total Emission</i>	138
<i>Angular Distribution of Emitted and Received Power</i>	140
4.9 Invariant Phase Volumes and Specific Intensity	145
<i>PROBLEMS</i>	148
<i>REFERENCES</i>	154

CHAPTER 5	
BREMSSTRAHLUNG	155

5.1 Emission from Single-Speed Electrons	156
5.2 Thermal Bremsstrahlung Emission	159
5.3 Thermal Bremsstrahlung (Free-Free) Absorption	162
5.4 Relativistic Bremsstrahlung	163
<i>PROBLEMS</i>	165
<i>REFERENCES</i>	166

CHAPTER 6	
SYNCHROTRON RADIATION	167

6.1 Total Emitted Power	167
6.2 Spectrum of Synchrotron Radiation: A Qualitative Discussion	169
6.3 Spectral Index for Power-Law Electron Distribution	173
6.4 Spectrum and Polarization of Synchrotron Radiation: A Detailed Discussion	175
6.5 Polarization of Synchrotron Radiation	180
6.6 Transition from Cyclotron to Synchrotron Emission	181
6.7 Distinction between Received and Emitted Power	184
6.8 Synchrotron Self-Absorption	186
6.9 The Impossibility of a Synchrotron Maser in Vacuum	191
<i>PROBLEMS</i>	192
<i>REFERENCES</i>	194

CHAPTER 7 COMPTON SCATTERING 195

- 7.1 Cross Section and Energy Transfer for the Fundamental Process 195
 - Scattering from Electrons at Rest* 195
 - Scattering from Electrons in Motion: Energy Transfer* 197
- 7.2 Inverse Compton Power for Single Scattering 199
- 7.3 Inverse Compton Spectra for Single Scattering 202
- 7.4 Energy Transfer for Repeated Scatterings in a Finite, Thermal Medium: The Compton Y Parameter 208
- 7.5 Inverse Compton Spectra and Power for Repeated Scatterings by Relativistic Electrons of Small Optical Depth 211
- 7.6 Repeated Scatterings by Nonrelativistic Electrons: The Kompaneets Equation 213
- 7.7 Spectral Regimes for Repeated Scattering by Nonrelativistic Electrons 216
 - Modified Blackbody Spectra; $y \ll 1$* 218
 - Wien Spectra; $y \gg 1$* 219
 - Unsaturated Comptonization with Soft Photon Input* 221
- PROBLEMS 223
- REFERENCES 223

CHAPTER 8 PLASMA EFFECTS 224

- 8.1 Dispersion in Cold, Isotropic Plasma 224
 - The Plasma Frequency* 224
 - Group and Phase Velocity and the Index of Refraction* 227
- 8.2 Propagation Along a Magnetic Field; Faraday Rotation 229
- 8.3 Plasma Effects in High-Energy Emission Processes 232
 - Cherenkov Radiation* 233
 - Razin Effect* 234
- PROBLEMS 236
- REFERENCES 237

CHAPTER 9
ATOMIC STRUCTURE **238**

- 9.1 A Review of the Schrödinger Equation 238
- 9.2 One Electron in a Central Field 240
 - Wave Functions* 240
 - Spin* 243
- 9.3 Many-Electron Systems 243
 - Statistics: The Pauli Principle* 243
 - Hartree–Fock Approximation: Configurations* 245
 - The Electrostatic Interaction; LS Coupling and Terms* 247
- 9.4 Perturbations, Level Splittings, and Term Diagrams 248
 - Equivalent and Nonequivalent Electrons and Their Spectroscopic Terms* 248
 - Parity* 251
 - Spin-Orbit Coupling* 252
 - Zeeman Effect* 256
 - Role of the Nucleus; Hyperfine Structure* 257
- 9.5 Thermal Distribution of Energy Levels and Ionization 259
 - Thermal Equilibrium: Boltzmann Population of Levels* 259
 - The Saha Equation* 260
- PROBLEMS** 263
- REFERENCES** 266

CHAPTER 10
RADIATIVE TRANSITIONS **267**

- 10.1 Semi-Classical Theory of Radiative Transitions 267
 - The Electromagnetic Hamiltonian* 268
 - The Transition Probability* 269
- 10.2 The Dipole Approximation 271
- 10.3 Einstein Coefficients and Oscillator Strengths 274
- 10.4 Selection Rules 278
- 10.5 Transition Rates 280
 - Bound-Bound Transitions for Hydrogen* 280

	<i>Bound-Free Transitions (Continuous Absorption) for Hydrogen</i>	282
	<i>Radiative Recombination—Milne Relations</i>	284
	<i>The Role of Coupling Schemes in the Determination of f Values</i>	286
10.6	Line Broadening Mechanisms	287
	<i>Doppler Broadening</i>	287
	<i>Natural Broadening</i>	289
	<i>Collisional Broadening</i>	290
	<i>Combined Doppler and Lorentz Profiles</i>	291
	PROBLEMS	291
	REFERENCES	292

CHAPTER 11

MOLECULAR STRUCTURE 294

11.1	The Born–Oppenheimer Approximation: An Order of Magnitude Estimate of Energy Levels	294
11.2	Electronic Binding of Nuclei	296
	<i>The H_2^+ Ion</i>	297
	<i>The H_2 Molecule</i>	300
11.3	Pure Rotation Spectra	302
	<i>Energy Levels</i>	302
	<i>Selection Rules and Emission Frequencies</i>	304
11.4	Rotation-Vibration Spectra	305
	<i>Energy Levels and the Morse Potential</i>	305
	<i>Selection Rules and Emission Frequencies</i>	306
11.5	Electronic-Rotational-Vibrational Spectra	308
	<i>Energy Levels</i>	308
	<i>Selection Rules and Emission Frequencies</i>	308
	PROBLEMS	311
	REFERENCES	312

SOLUTIONS 313

INDEX 375