

Table of Contents

Part One: The Birth of a New Physics	1
1.1 The Electron	3
1.2 Electromagnetic Waves	9
1.2.1 The Production and Properties of Electromagnetic Waves	15
1.2.2 The Limits of Electromagnetic Theory	16
1.3 The Special Theory of Relativity	19
1.3.1 The Principle of Covariance	21
1.3.2 The Newtonian Conception of Motion	26
<i>Example 1.1</i> The Galilean Transformation	
<i>Example 1.2</i> The Velocity of Sound Relative to a Moving Observer	
1.3.3 The Michelson-Morley Experiment	34
1.3.4 The Postulates of the Special Theory of Relativity	38
1.3.5 Simultaneity and the Relativity of Time	39
1.3.6 The Lorentz Transformation	45
<i>Example 1.3</i> The Lorentz Transformation and Special Relativity	
1.3.7 Relativistic Mechanics - Kinematics	47
<i>Example 1.4</i> The Mystery of the Muons	
<i>Example 1.5</i> Stationary Clocks and Moving Clocks	
<i>Example 1.6</i> The Minkowski Diagrams of Different Observers - The Twins Paradox	
1.3.8 Relativistic Mechanics - Dynamics	57
<i>Example 1.7</i> Calculations in Relativistic Mechanics	
<i>Example 1.8</i> The Transformation of Energy and Momentum	
1.3.9 Magnetism - A Relativistic Effect	65
1.4 The General Theory of Relativity	71
1.4.1 The Postulates of the General Theory of Relativity	72
1.4.2 Gravitation and the General Theory of Relativity	76
1.4.3 Gravity and Geometry	78
1.5 Appendices to Part One	84
1.5.1 Velocity Addition in Special Relativity	84
1.5.2 The Kinetic Energy of a Particle in Special Relativity	86
1.5.3 The Total Energy of a Particle	87
1.5.4 The Transformation of Force	88
Questions, Exercises and Problems	89

Part Two: Quantum Theory	93
2.1 The Quantum Hypothesis	95
2.1.1 Radiators and Radiation	95
2.1.2 Thermal Radiation	96
2.1.3 Black-body Radiation	97
<i>Example 2.1</i> Wien's Law	
<i>Example 2.2</i> Blackbody Radiation and Astronomy	
2.1.4 Difficulties in the Classical Theory of Radiation	103
<i>Example 2.3</i> The Frequencies in Cavity Radiation	
2.1.5 Planck's Quantum Hypothesis	105
2.1.6 Atomic Spectra	107
2.1.7 The Franck-Hertz Experiment	112
2.2 The Photoelectric Effect	115
2.2.1 The Photoelectric Effect - The Problem	115
2.2.2 Einstein's Equation	116
<i>Example 2.4</i> Photons and Wavelengths	
<i>Example 2.5</i> Counting Photons	
2.2.3 Planck's Constant	119
<i>Example 2.6</i> Photoelectrons	
2.2.4 X-rays	122
<i>Example 2.7</i> Minimum X-ray Wavelength	
2.2.5 X-rays and Crystallography	124
<i>Example 2.8</i> X-ray Crystallography	
2.3 Photons	129
2.3.1 Photon Mass	129
<i>Example 2.9</i> Radiation Pressure	
2.3.2 The Compton Effect	132
<i>Example 2.10</i> The Compton Wavelength	
2.3.3 Photons - Light Particles	137
2.3.4 The Locality Paradox	144
<i>Example 2.11</i> Photons and Interference Patterns	
2.4 The Mechanics of Minute Particles	147
2.4.1 De Broglie's Hypothesis	147
<i>Example 2.12</i> Electron Diffraction - Thomson's Experiment	
2.4.2 Heisenberg's Uncertainty Principle	154
<i>Example 2.13</i> Heisenberg's Uncertainty Principle	
2.4.3 Matter Waves	159
2.4.4 Wave Functions and Probability Amplitudes	161
2.4.5 The Wave Function of a Free Particle	164
2.4.6 Quantum Mechanics - Schrödinger's Equation	165
2.4.7 Quantum Mechanics - Potential Wells	167
2.4.8 The Tunnel Effect	171

Table of Contents

ix

2.5 Appendices to Part Two	174
2.5.1 The Kinetic Energy and Linear Momentum of a Particle	174
2.5.2 The Wave Function of a Trapped Particle	174
Questions, Exercises and Problems	177
Part Three: The Nuclear Atom	183
3.1 The Structure of the Atom	185
3.1.1 The Thomson Model of the Atom	185
3.1.2 The Nuclear Atom	187
<i>Example 3.1</i> The Atomic Nucleus	
3.2 The Bohr Model of the Atom	193
3.2.1 The Hydrogen Atom	195
<i>Example 3.2</i> Spectral Transitions	
<i>Example 3.3</i> The Correspondence Principle	
<i>Example 3.4</i> The Bohr Atom and De Broglie's Principle	
3.2.2 The Zeeman Effect - Space Quantisation	204
3.2.3 Moseley's Experiment	207
<i>Example 3.5</i> The Characteristic X-ray Spectrum of Copper	
3.3 The Quantum Mechanical Model of the Atom	215
3.3.1 The Hydrogen Atom	215
<i>Example 3.6</i> The Average Distance of the Electron from the Hydrogen Nucleus	
<i>Example 3.7</i> The Probability of Finding an Electron	
3.3.2 Atomic Spectra and Quantum Mechanics	226
3.4 Electron Spin	231
3.4.1 Electron Spin	231
3.4.2 The Stern-Gerlach Experiment	233
<i>Example 3.8</i> Electron Spin Resonance	
3.4.3 Spin-Orbit Coupling	236
3.4.4 The Pauli Exclusion Principle and the Periodic Table	238
3.4.5 Spin, Identical Particles and the Pauli Principle	243
3.4.6 Total Spin	247
3.4.7 The Energy Levels in Multi-electron Atoms	249
3.4.8 Total Spin and the Energy Levels in Molecules	254
3.5 Appendices to Part Three	262
3.5.1 The Energy of an Orbiting Charged Particle	262
3.5.2 The Schrödinger Equation for the Hydrogen Atom	263
3.5.3 The Angular Momentum of an Orbiting Particle	270
Questions, Exercises and Problems	272

Part Four: Interactions of Electromagnetic Radiation and Matter	277
4.1 The Passage of Radiation through Matter	279
4.1.1 The Attenuation of Radiation by Matter	281
<i>Example 4.1</i> The Attenuation of Ultra-violet Radiation	
4.1.2 Mechanisms of the Absorption of Radiation	282
4.1.3 Quantum Electrodynamics	287
4.2 Molecular Spectra	295
4.2.1 Molecular Energies	295
4.2.2 Rotational Spectra	296
<i>Example 4.2</i> The Interatomic Distance in the HCl Molecule	
4.2.3 Vibrational Spectra	300
<i>Example 4.3</i> Vibrational Spectrum of CO	
4.2.4 Electronic Spectra	304
<i>Example 4.4</i> The Excitation of π Electrons	
4.2.5 Raman Spectra	307
4.3 Fluorescence and Phosphorescence	309
4.3.1 Fluorescence in Biological Systems	311
4.4 Appendices to Part Four	318
4.4.1 Raleigh Scattering	318
4.4.2 Moment of Inertia of a Diatomic Molecule	318
Questions, Exercises and Problems	320
Part Five: Nuclear Physics	323
5.1 The Structure of the Nucleus	325
5.1.1 Nucleons	325
5.1.2 Nuclear Nomenclature	326
5.1.3 Nuclear Masses; Isotopes	328
<i>Example 5.1</i> The Density of Nuclear Material	
5.1.4 Nuclear Binding Energy	330
<i>Example 5.2</i> Binding Energy per Nucleon	
<i>Example 5.3</i> Nuclear Magic Numbers	
5.1.5 The Nuclear ('Strong') Force	333
5.1.6 Nuclear Models	336
5.1.7 The Elementary Particles of Matter	337
5.2 Nuclear Radiations	345
5.2.1 The Nature of the Nuclear Radiations	345
5.2.2 Mechanisms of Nuclear Radiation Attenuation	347

Table of Contents

xi

5.2.3	Detectors of Ionising Radiation	350
5.2.4	The Biological Effects of Nuclear Radiation	353
5.3	Radioactivity	359
5.3.1	The Disintegration of Unstable Nuclei	359
	<i>Example 5.4</i> Disintegration Energy	
5.3.2	The Kinetics of Radioactive Disintegration	362
	<i>Example 5.5</i> Radioactive Disintegration	
5.3.3	Age Determination with Radio-isotopes	364
	<i>Example 5.6</i> Carbon 14 Dating	
5.3.4	Uses of Radio-isotopes	366
	<i>Example 5.7</i> Dosimetry	
5.3.5	The Factors Affecting Nuclear Stability	368
	<i>Example 5.8</i> Disintegration Modes of Heavy Nuclei	
5.3.6	The Mechanism of α Decay	371
5.3.7	The Mechanism of β Decay - Weak Charge	373
5.4	Nuclear Reactions and Nuclear Energy	385
5.4.1	Nuclear Reactions	386
5.4.2	The Discovery of the Neutron	388
5.4.3	Nuclear Cross-sections	390
	<i>Example 5.9</i> Nuclear Cross-sections	
5.4.4	Nuclear Energy - Fusion and Fission	393
	<i>Example 5.10</i> Endoergic Nuclear Reactions	
5.4.5	Nuclear Fusion	396
5.4.6	Nuclear Fission	399
5.4.7	Nuclear Chain Reactions	403
5.4.8	Fission by Fast Neutrons - Bombs	407
5.4.9	Fission by Slow Neutrons - Nuclear Reactors	413
	<i>Example 5.11</i> The Slow Neutron Chain Reaction of Natural Uranium	
5.4.10	Nuclear Engineering: The Chernobyl Catastrophe	419
5.5	Appendices to Part Five	424
5.5.1	The Mean Lifetime of a Radioactive Nucleus	424
5.5.2	Radioactive Decays of the Type $A \rightarrow B \rightarrow C$	424
	Questions, Exercises and Problems	426
	Part Six: Selected Applications	429
6.1	The Laser	431
6.1.1	The Spontaneous and Stimulated Emission of Radiation	431
6.1.2	Laser Action	433
6.1.3	The Ruby Laser	435
6.1.4	The Helium-Neon Laser	437
6.1.5	Laser Applications	438

6.2	The Mössbauer Effect	443
6.2.1	The Width of Spectral Lines	443
	<i>Example 6.1</i> The Width of Spectral Lines	
6.2.2	The Mechanics of Photon Emission and Absorption	446
6.2.3	Recoilless Emission and Absorption	448
6.2.4	The Gravitational Shift - Black Holes	450
6.3	Nuclear Magnetic Resonance	455
6.3.1	Magnetism and Angular Momentum	455
6.3.2	Nuclear Magnetic Moments	456
6.3.3	Nuclear Magnetic Resonance	459
6.3.4	Observing Nuclear Magnetic Resonance	461
6.3.5	Chemical Shift	465
6.3.6	Applications of Nuclear Magnetic Resonance	468
6.4	The Conduction of Electricity Through Solids	471
6.4.1	The Electrical Conductivity of Solids	471
6.4.2	The Electron Gas	473
	<i>Example 6.2</i> The Relaxation Time of Conduction Electrons	
6.4.3	Energy Levels in Solids - Band Theory	475
6.4.4	Insulators	477
6.4.5	Metallic Conductors	478
	<i>Example 6.3</i> The Velocity of Conduction Electrons	
	<i>Example 6.4</i> The Mean Path-length of the Conduction Electrons	
6.4.6	Superconductivity	483
6.4.7	Semiconductors	485
6.4.8	The p-n Junction	489
6.4.9	Semiconductor Devices	493
6.5	Invariance, Symmetry and Conservation Laws	501
6.5.1	The Symmetry of the Laws of Physics	502
6.5.2	Group Theory	503
6.5.3	Noether's Theorem	506
6.5.4	The Conservation Laws of Particle Physics	508
6.6	Appendices to Part Six	514
6.6.1	The Probabilities of Stimulated and Spontaneous Emission	514
	Questions, Exercises and Problems	517
	Supplementary Topics	519
A	The Mathematical Description of Wave Motion	519
B	List of Physical Constants and Conversion Factors	527
C	The Greek Alphabet	527
	Answers to the Numerical Exercises and Problems	528
	Index	531