

Contents

How to Use This Book xiii
Student Resources xvii
Resources for Instructors xviii
Acknowledgments xix
New to the Second Edition xxiii

The Big Picture 1

PART 1: MECHANICS OF POINT PARTICLES

1 Overview 7

- 1.1 Why Study Physics? 8
- 1.2 Working with Numbers 9
- 1.3 SI Unit System 10
- 1.4 The Scales of Our World 14
- 1.5 General Problem-Solving Strategy 16
- 1.6 Vectors 23
- What We Have Learned/Exam Study Guide 32
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 33



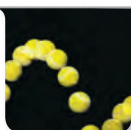
2 Motion in a Straight Line 38

- 2.1 Introduction to Kinematics 39
- 2.2 Position Vector, Displacement Vector, and Distance 39
- 2.3 Velocity Vector, Average Velocity, and Speed 42
- 2.4 Acceleration Vector 45
- 2.5 Computer Solutions and Difference Formulas 47
- 2.6 Finding Displacement and Velocity from Acceleration 48
- 2.7 Motion with Constant Acceleration 49
- 2.8 Free Fall 56
- 2.9 Reducing Motion in More Than One Dimension to One Dimension 61
- What We Have Learned/Exam Study Guide 64
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 65



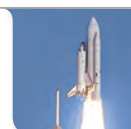
3 Motion in Two and Three Dimensions 72

- 3.1 Three-Dimensional Coordinate Systems 73
- 3.2 Velocity and Acceleration in Two or Three Dimensions 74
- 3.3 Ideal Projectile Motion 74
- 3.4 Maximum Height and Range of a Projectile 78
- 3.5 Realistic Projectile Motion 85
- 3.6 Relative Motion 86



4 Force 97

- 4.1 Types of Forces 98
- 4.2 Gravitational Force Vector, Weight, and Mass 100
- 4.3 Net Force 102
- 4.4 Newton's Laws 103
- 4.5 Ropes and Pulleys 105
- 4.6 Applying Newton's Laws 109
- 4.7 Friction Force 114
- 4.8 Applications of the Friction Force 119
- What We Have Learned/Exam Study Guide 125
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 126



5 Kinetic Energy, Work, and Power 134

- 5.1 Energy in Our Daily Lives 135
- 5.2 Kinetic Energy 137
- 5.3 Work 138
- 5.4 Work Done by a Constant Force 139
- 5.5 Work Done by a Variable Force 145
- 5.6 Spring Force 146
- 5.7 Power 150
- What We Have Learned/Exam Study Guide 154
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 156



6 Potential Energy and Energy Conservation 160

- 6.1 Potential Energy 161
- 6.2 Conservative and Nonconservative Forces 163
- 6.3 Work and Potential Energy 166
- 6.4 Potential Energy and Force 167
- 6.5 Conservation of Mechanical Energy 170
- 6.6 Work and Energy for the Spring Force 174
- 6.7 Nonconservative Forces and the Work-Energy Theorem 179
- 6.8 Potential Energy and Stability 184
- What We Have Learned/Exam Study Guide 187
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 188



7 Momentum and Collisions 194



- 7.1 Linear Momentum 195
- 7.2 Impulse 197
- 7.3 Conservation of Linear Momentum 200
- 7.4 Elastic Collisions in One Dimension 202
- 7.5 Elastic Collisions in Two or Three Dimensions 205
- 7.6 Totally Inelastic Collisions 209
- 7.7 Partially Inelastic Collisions 217
- 7.8 Billiards and Chaos 218
- What We Have Learned/Exam Study Guide 220
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 221

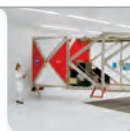
PART 2: EXTENDED OBJECTS, MATTER, AND CIRCULAR MOTION

8 Systems of Particles and Extended Objects 231



- 8.1 Center of Mass and Center of Gravity 232
- 8.2 Center-of-Mass Momentum 235
- 8.3 Rocket Motion 239
- 8.4 Calculating the Center of Mass 243
- What We Have Learned/Exam Study Guide 252
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 253

9 Circular Motion 260



- 9.1 Polar Coordinates 261
- 9.2 Angular Coordinates and Angular Displacement 262
- 9.3 Angular Velocity, Angular Frequency, and Period 264
- 9.4 Angular and Centripetal Acceleration 267
- 9.5 Centripetal Force 270
- 9.6 Circular and Linear Motion 275
- 9.7 More Examples for Circular Motion 279
- What We Have Learned/Exam Study Guide 282
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 284

10 Rotation 290



- 10.1 Kinetic Energy of Rotation 291
- 10.2 Calculation of Moment of Inertia 292
- 10.3 Rolling without Slipping 299
- 10.4 Torque 303
- 10.5 Newton's Second Law for Rotation 304
- 10.6 Work Done by a Torque 309
- 10.7 Angular Momentum 312
- 10.8 Precession 319
- 10.9 Quantized Angular Momentum 320
- What We Have Learned/Exam Study Guide 320
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 322

11 Static Equilibrium 329



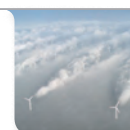
- 11.1 Equilibrium Conditions 330
- 11.2 Examples Involving Static Equilibrium 332
- 11.3 Stability of Structures 342
- What We Have Learned/Exam Study Guide 347
- Multiple-Choice Questions/Conceptual Questions/
Exercises/Multi-Version Exercises 348

12 Gravitation 356



- 12.1 Newton's Law of Gravity 357
- 12.2 Gravitation near the Surface of the Earth 362
- 12.3 Gravitation inside the Earth 364
- 12.4 Gravitational Potential Energy 366
- 12.5 Kepler's Laws and Planetary Motion 371
- 12.6 Satellite Orbits 376
- 12.7 Dark Matter 380
- What We Have Learned/Exam Study Guide 382
- Multiple-Choice Questions/Conceptual Questions/
Exercises/Multi-Version Exercises 383

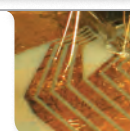
13 Solids and Fluids 389



- 13.1 Atoms and the Composition of Matter 390
- 13.2 States of Matter 392
- 13.3 Tension, Compression, and Shear 393
- 13.4 Pressure 396
- 13.5 Archimedes' Principle 403
- 13.6 Ideal Fluid Motion 408
- 13.7 Viscosity 416
- 13.8 Turbulence and Research Frontiers in Fluid Flow 418
- What We Have Learned/Exam Study Guide 419
- Multiple-Choice Questions/Conceptual Questions/
Exercises/Multi-Version Exercises 420

PART 3: OSCILLATIONS AND WAVES

14 Oscillations 426



- 14.1 Simple Harmonic Motion 427
- 14.2 Pendulum Motion 435
- 14.3 Work and Energy in Harmonic Oscillations 438
- 14.4 Damped Harmonic Motion 441
- 14.5 Forced Harmonic Motion and Resonance 451
- 14.6 Phase Space 453
- 14.7 Chaos 454
- What We Have Learned/Exam Study Guide 455
- Multiple-Choice Questions/Conceptual Questions/
Exercises/Multi-Version Exercises 456

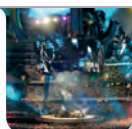
15 Waves 462

- 15.1 Wave Motion 463
- 15.2 Coupled Oscillators 464
- 15.3 Mathematical Description of Waves 465
- 15.4 Derivation of the Wave Equation 469
- 15.5 Waves in Two- and Three-Dimensional Spaces 473
- 15.6 Energy, Power, and Intensity of Waves 476
- 15.7 Superposition Principle and Interference 479
- 15.8 Standing Waves and Resonance 480
- 15.9 Research on Waves 485
- What We Have Learned/Exam Study Guide 487
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 488



16 Sound 493

- 16.1 Longitudinal Pressure Waves 494
- 16.2 Sound Intensity 497
- 16.3 Sound Interference 500
- 16.4 Doppler Effect 506
- 16.5 Resonance and Music 513
- What We Have Learned/Exam Study Guide 516
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 517



PART 4: THERMAL PHYSICS

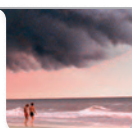
17 Temperature 523

- 17.1 Definition of Temperature 524
- 17.2 Temperature Ranges 526
- 17.3 Measuring Temperature 530
- 17.4 Thermal Expansion 531
- 17.5 Surface Temperature of the Earth 538
- 17.6 Temperature of the Universe 540
- What We Have Learned/Exam Study Guide 541
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 542



18 Heat and the First Law of Thermodynamics 547

- 18.1 Definition of Heat 548
- 18.2 Mechanical Equivalent of Heat 549
- 18.3 Heat and Work 550
- 18.4 First Law of Thermodynamics 552
- 18.5 First Law for Special Processes 553
- 18.6 Specific Heats of Solids and Fluids 555
- 18.7 Latent Heat and Phase Transitions 557
- 18.8 Modes of Thermal Energy Transfer 561
- What We Have Learned/Exam Study Guide 574
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 575



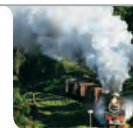
19 Ideal Gases 581

- 19.1 Empirical Gas Laws 582
- 19.2 Ideal Gas Law 584
- 19.3 Equipartition Theorem 593
- 19.4 Specific Heat of an Ideal Gas 596
- 19.5 Adiabatic Processes for an Ideal Gas 600
- 19.6 Kinetic Theory of Gases 604
- 19.7 Real Gases 609
- What We Have Learned/Exam Study Guide 610
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 612



20 The Second Law of Thermodynamics 617

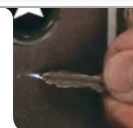
- 20.1 Reversible and Irreversible Processes 618
- 20.2 Engines and Refrigerators 620
- 20.3 Ideal Engines 622
- 20.4 Real Engines and Efficiency 628
- 20.5 The Second Law of Thermodynamics 635
- 20.6 Entropy 637
- 20.7 Microscopic Interpretation of Entropy 640
- What We Have Learned/Exam Study Guide 643
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 645



PART 5: ELECTRICITY

21 Electrostatics 651

- 21.1 Electromagnetism 652
- 21.2 Electric Charge 653
- 21.3 Insulators, Conductors, Semiconductors, and Superconductors 656
- 21.4 Electrostatic Charging 657
- 21.5 Electrostatic Force—Coulomb's Law 660
- 21.6 Coulomb's Law and Newton's Law of Gravitation 669
- What We Have Learned/Exam Study Guide 670
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 671



22 Electric Fields and Gauss's Law 676

- 22.1 Definition of an Electric Field 677
- 22.2 Field Lines 677
- 22.3 Electric Field due to Point Charges 680
- 22.4 Electric Field due to a Dipole 682
- 22.5 General Charge Distributions 684
- 22.6 Force due to an Electric Field 687
- 22.7 Electric Flux 692
- 22.8 Gauss's Law 693
- 22.9 Special Symmetries 696
- What We Have Learned/Exam Study Guide 702
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 703



23 Electric Potential 709

- 23.1 Electric Potential Energy 710
- 23.2 Definition of Electric Potential 712
- 23.3 Equipotential Surfaces and Lines 717
- 23.4 Electric Potential of Various Charge Distributions 719
- 23.5 Finding the Electric Field from the Electric Potential 727
- 23.6 Electric Potential Energy of a System of Point Charges 729

What We Have Learned/Exam Study Guide 730

Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 731

**24 Capacitors 737**

- 24.1 Capacitance 738
- 24.2 Circuits 740
- 24.3 Parallel Plate Capacitor and Other Types of Capacitors 740
- 24.4 Capacitors in Circuits 744
- 24.5 Energy Stored in Capacitors 747
- 24.6 Capacitors with Dielectrics 751
- 24.7 Microscopic Perspective on Dielectrics 755

What We Have Learned/Exam Study Guide 758

Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 759

**25 Current and Resistance 765**

- 25.1 Electric Current 766
- 25.2 Current Density 769
- 25.3 Resistivity and Resistance 771
- 25.4 Electromotive Force and Ohm's Law 775
- 25.5 Resistors in Series 777
- 25.6 Resistors in Parallel 780
- 25.7 Energy and Power in Electric Circuits 784
- 25.8 Diodes: One-Way Streets in Circuits 787

What We Have Learned/Exam Study Guide 788

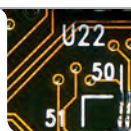
Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 789

**26 Direct Current Circuits 795**

- 26.1 Kirchhoff's Rules 796
- 26.2 Single-Loop Circuits 798
- 26.3 Multiloop Circuits 800
- 26.4 Ammeters and Voltmeters 803
- 26.5 RC Circuits 805

What We Have Learned/Exam Study Guide 812

Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 813

**PART 6: MAGNETISM****27 Magnetism 819**

- 27.1 Permanent Magnets 820
- 27.2 Magnetic Force 823
- 27.3 Motion of Charged Particles in a Magnetic Field 825
- 27.4 Magnetic Force on a Current-Carrying Wire 832
- 27.5 Torque on a Current-Carrying Loop 834
- 27.6 Magnetic Dipole Moment 835
- 27.7 Hall Effect 837

What We Have Learned/Exam Study Guide 838

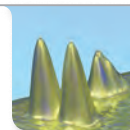
Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 839

**28 Magnetic Fields of Moving Charges 845**

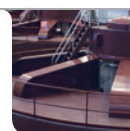
- 28.1 Biot-Savart Law 846
- 28.2 Magnetic Fields due to Current Distributions 847
- 28.3 Ampere's Law 856
- 28.4 Magnetic Fields of Solenoids and Toroids 858
- 28.5 Atoms as Magnets 862
- 28.6 Magnetic Properties of Matter 864
- 28.7 Magnetism and Superconductivity 867

What We Have Learned/Exam Study Guide 868

Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 869

**29 Electromagnetic Induction 875**

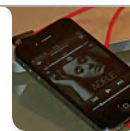
- 29.1 Faraday's Experiments 876
 - 29.2 Faraday's Law of Induction 877
 - 29.3 Lenz's Law 882
 - 29.4 Generators and Motors 889
 - 29.5 Induced Electric Field 890
 - 29.6 Inductance of a Solenoid 891
 - 29.7 Self-Induction and Mutual Induction 892
 - 29.8 RL Circuits 894
 - 29.9 Energy and Energy Density of a Magnetic Field 897
 - 29.10 Applications to Information Technology 898
- What We Have Learned/Exam Study Guide 900
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 901

**30 Alternating Current Circuits 907**

- 30.1 LC Circuits 908
- 30.2 Analysis of LC Oscillations 910
- 30.3 Damped Oscillations in an RLC Circuit 912
- 30.4 Driven AC Circuits 914
- 30.5 Series RLC Circuit 917
- 30.6 Energy and Power in AC Circuits 923
- 30.7 Transformers 929
- 30.8 Rectifiers 931

What We Have Learned/Exam Study Guide 933

Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 934



31 Electromagnetic Waves 939

- 31.1 Maxwell's Law of Induction for Induced Magnetic Fields 940
- 31.2 Wave Solutions to Maxwell's Equations 943
- 31.3 The Electromagnetic Spectrum 947
- 31.4 Poynting Vector and Energy Transport 951
- 31.5 Radiation Pressure 953
- 31.6 Polarization 958
- 31.7 Derivation of the Wave Equation 964
- What We Have Learned/Exam Study Guide 965
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 966



PART 7: OPTICS

32 Geometric Optics 971

- 32.1 Light Rays and Shadows 972
- 32.2 Reflection and Plane Mirrors 974
- 32.3 Curved Mirrors 978
- 32.4 Refraction and Snell's Law 987
- What We Have Learned/Exam Study Guide 997
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 998



33 Lenses and Optical Instruments 1003

- 33.1 Lenses 1004
- 33.2 Magnifier 1012
- 33.3 Systems of Two or More Optical Elements 1013
- 33.4 Human Eye 1018
- 33.5 Camera 1021
- 33.6 Microscope 1024
- 33.7 Telescope 1026
- 33.8 Laser Tweezers 1030
- What We Have Learned/Exam Study Guide 1031
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 1032



34 Wave Optics 1038

- 34.1 Light Waves 1039
- 34.2 Interference 1041
- 34.3 Diffraction 1051
- 34.4 Gratings 1058
- What We Have Learned/Exam Study Guide 1066
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 1067



PART 8: RELATIVITY AND QUANTUM PHYSICS

35 Relativity 1072

- 35.1 Space, Time, and the Speed of Light 1073



- 35.2 Time Dilation and Length Contraction 1077
- 35.3 Lorentz Transformation 1084
- 35.4 Relativistic Momentum and Energy 1090
- 35.5 General Relativity 1097
- 35.6 Relativity in Our Daily Lives: GPS 1099
- What We Have Learned/Exam Study Guide 1100
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 1101

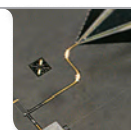
36 Quantum Physics 1107

- 36.1 The Nature of Matter, Space, and Time 1108
- 36.2 Blackbody Radiation 1109
- 36.3 Photoelectric Effect 1113
- 36.4 Compton Scattering 1117
- 36.5 Matter Waves 1121
- 36.6 Uncertainty Relation 1124
- 36.7 Spin 1127
- 36.8 Spin and Statistics 1128
- What We Have Learned/Exam Study Guide 1135
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 1136



37 Quantum Mechanics 1141

- 37.1 Wave Function 1142
- 37.2 Time-Independent Schrödinger Equation 1145
- 37.3 Infinite Potential Well 1146
- 37.4 Finite Potential Wells 1152
- 37.5 Harmonic Oscillator 1160
- 37.6 Wave Functions and Measurements 1164
- 37.7 Correspondence Principle 1167
- 37.8 Time-Dependent Schrödinger Equation 1168
- 37.9 Many-Particle Wave Function 1170
- 37.10 Antimatter 1174
- What We Have Learned/Exam Study Guide 1178
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 1180



38 Atomic Physics 1185

- 38.1 Spectral Lines 1186
- 38.2 Bohr's Model of the Atom 1188
- 38.3 Hydrogen Electron Wave Function 1193
- 38.4 Other Atoms 1205
- 38.5 Lasers 1210
- What We Have Learned/Exam Study Guide 1214
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 1216



39 Elementary Particle Physics 1219

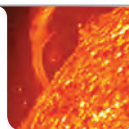
- 39.1 Reductionism 1220
- 39.2 Probing Substructure 1223
- 39.3 Elementary Particles 1229
- 39.4 Extensions of the Standard Model 1238



- 39.5 Composite Particles 1241
- 39.6 Big Bang Cosmology 1247
- What We Have Learned/Exam Study Guide 1252
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 1253

40 Nuclear Physics 1256

- 40.1 Nuclear Properties 1257
- 40.2 Nuclear Decay 1266
- 40.3 Nuclear Models 1278
- 40.4 Nuclear Energy: Fission and Fusion 1283
- 40.5 Nuclear Astrophysics 1290



- 40.6 Nuclear Medicine 1292
- What We Have Learned/Exam Study Guide 1294
- Multiple-Choice Questions/Conceptual Questions/Exercises/
Multi-Version Exercises 1295

Appendix A Mathematical Primer A-1

Appendix B Element Properties A-9

Answers to Selected Questions and Problems AP-1

Credits C-1

Index I-1