# Contents

#### Preface xiii

Additional Resources for Instructors and Students xxv 360° Development xxvii

#### The Big Picture 1

# **PART 1: MECHANICS OF POINT PARTICLES**

#### 1 **Overview** 7

2.1



- Why Study Physics? 8 1.1 Working with Numbers 9
- 1.2 1.3 SI Unit System 11
- 1.4 The Scales of Our World 14
- 1.5 General Problem-Solving Strategy 16
- Vectors 23 1.6

What We Have Learned/Exam Study Guide 28 Multiple-Choice Questions/Questions/Problems 30

#### 2 Motion in a Straight Line 35

- Introduction to Kinematics 36
- Position Vector, Displacement Vector, 2.2 and Distance 36
- 2.3 Velocity Vector, Average Velocity, and Speed 40
- 2.4 Acceleration Vector 43
- 2.5 Computer Solutions and Difference Formulas 44
- Finding Displacement and Velocity from 2.6 Acceleration 46
- Motion with Constant Acceleration 47 2.7
- 2.8 Reducing Motion in More Than One Dimension to One Dimension 56

What We Have Learned/Exam Study Guide 59 Multiple-Choice Questions/Questions/Problems 64

#### 3 Motion in Two and Three **Dimensions 71**



- Three-Dimensional Coordinate 3.1 Systems 72
- 3.2 Velocity and Acceleration in a Plane 73
- Ideal Projectile Motion 74 3.3
- Maximum Height and Range of a Projectile 78 3.4
- Realistic Projectile Motion 83 3.5
- 3.6 Relative Motion 84

What We Have Learned/Exam Study Guide 87

Multiple-Choice Questions/Questions/Problems 92

#### Force 100

- 4.1 Types of Forces 101
- Gravitational Force Vector, Weight, and 4.2 Mass 103
- 4.3 Net Force 105
- **4.4** Newton's Laws 106
- 4.5 Ropes and Pulleys 109
- Applying Newton's Laws 112 4.6
- Friction Force 118 4.7
- Applications of the Friction Force 123 **4.8**

What We Have Learned/Exam Study Guide 126 Multiple-Choice Questions/Questions/Problems 132

#### 5 Kinetic Energy, Work, and Power 140

- Energy in Our Daily Lives 141
- 5.2 Kinetic Energy 143
- 5.3 Work 145

5.1

- 5.4 Work Done by a Constant Force 145
- Work Done by a Variable Force 152 5.5
- 5.6 Spring Force 153
- Power 157 5.7

What We Have Learned/Exam Study Guide 159 Multiple-Choice Questions/Questions/Problems 164

#### 6 **Potential Energy and Energy Conservation 168**



- 6.1 Potential Energy 169 6.2 Conservative and Nonconservative
- Forces 171
- 6.3 Work and Potential Energy 173 6.4
- Potential Energy and Force 174 6.5 Conservation of Mechanical Energy 177
- Work and Energy for the Spring Force 181
- 6.6 Nonconservative Forces and the Work-Energy 6.7 Theorem 186
- 6.8 Potential Energy and Stability 190
- What We Have Learned/Exam Study Guide 192

Multiple-Choice Questions/Questions/Problems 198



#### 7 Momentum and Collisions 205



- 7.1 Linear Momentum 206
- Impulse 208 7.2
- 7.3 Conservation of Linear Momentum 210
- 7.4 Elastic Collisions in One Dimension 212
- 7.5 Elastic Collisions in Two or Three Dimensions 216
- Totally Inelastic Collisions 220 7.6
- 7.7 Partially Inelastic Collisions 227
- 7.8 Billiards and Chaos 228

What We Have Learned/Exam Study Guide 229 Multiple-Choice Questions/Questions/Problems 235

#### PART 2: EXTENDED OBJECTS, MATTER, AND CIRCULAR MOTION

#### Systems of Particles and Extended **Objects 246**



- 8.1 Center of Mass and Center of Gravity 247
- 8.2 Center-of-Mass Momentum 251
- 8.3 Rocket Motion 256
- Calculating the Center of Mass 259 8.4

What We Have Learned/Exam Study Guide 266 Multiple-Choice Questions/Questions/Problems 272

#### **Circular Motion 279**



- 9.1 Polar Coordinates 280
- Angular Coordinates and Angular 9.2 Displacement 281
- 9.3 Angular Velocity, Angular Frequency, and Period 283
- Angular and Centripetal Acceleration 286 9.4
- 9.5 Centripetal Force 289
- Circular and Linear Motion 293 9.6
- 9.7 More Examples for Circular Motion 296
- What We Have Learned/Exam Study Guide 300

Multiple-Choice Questions/Questions/Problems 305

## **10** Rotation 312



- 10.1 Kinetic Energy of Rotation 313 Calculation of Moment of Inertia 314 10.2
- Rolling without Slipping 322 10.3
- Torque 326 10.4
- 10.5 Newton's Second Law for Rotation 328
- 10.6 Work Done by a Torque 332
- 10.7 Angular Momentum 335
- 10.8 Precession 341
- Quantized Angular Momentum 343 10.9
- What We Have Learned/Exam Study Guide 343
- Multiple-Choice Questions/Questions/Problems 346

#### **11** Static Equilibrium 354

- 11.1 Equilibrium Conditions 355
- 11.2 Examples Involving Static Equilibrium 357



11.3 Stability of Structures 366

What We Have Learned/Exam Study Guide 370 Multiple-Choice Questions/Questions/Problems 373

# **12** Gravitation 381

- 12.1 Newton's Law of Gravity 382
- Gravitation near the Surface of the 12.2 Earth 387
- 12.3 Gravitation inside the Earth 389
- 12.4 Gravitational Potential Energy 391
- Kepler's Laws and Planetary Motion 395 12.5
- 12.6 Satellite Orbits 400
- 12.7 Dark Matter 405

What We Have Learned/Exam Study Guide 407 Multiple-Choice Questions/Questions/Problems 410

## **13** Solids and Fluids 417

- 13.1 Atoms and the Composition of Matter 418
- States of Matter 420 13.2
- Tension, Compression, and Shear 421 13.3
- 13.4 Pressure 425
- 13.5 Archimedes' Principle 430
- 13.6 Ideal Fluid Motion 434
- 13.7 Viscosity 442
- Turbulence and Research Frontiers in Fluid Flow 444 13.8 What We Have Learned/Exam Study Guide 445

Multiple-Choice Questions/Questions/Problems 449

# PART 3: OSCILLATIONS AND WAVES

#### 14 Oscillations 455

- 14.1 Simple Harmonic Motion 456
- 14.2 Pendulum Motion 464
- Work and Energy in Harmonic Oscillations 466 14.3
- Damped Harmonic Motion 470 14.4
- 14.5 Forced Harmonic Motion and Resonance 477
- 14.6 Phase Space 479
- Chaos 480 14.7

What We Have Learned/Exam Study Guide 481 Multiple-Choice Questions/Questions/Problems 485

#### 15 Waves 492

- 15.1 Wave Motion 493
- Coupled Oscillators 494 15.2
- 15.3 Mathematical Description of Waves 495
- Derivation of the Wave Equation 498 15.4
- Waves in Two- and Three-Dimensional Spaces 502 15.5
- Energy, Power, and Intensity of Waves 505 15.6
- 15.7 Superposition Principle and Interference 508
- 15.8 Standing Waves and Resonance 510
- Research on Waves 513 15.9
- What We Have Learned/Exam Study Guide 515

Multiple-Choice Questions/Questions/Problems 519





#### 16 Sound 524

- 16.1 Longitudinal Pressure Waves 525
- Sound Intensity 529 16.2
- Sound Interference 533 16.3
- 16.4 Doppler Effect 536
- 16.5 Resonance and Music 542

What We Have Learned/Exam Study Guide 545 Multiple-Choice Questions/Questions/Problems 550

# **PART 4: THERMAL PHYSICS**

#### **17** Temperature 556



- Definition of Temperature 557 17.1 17.2 Temperature Ranges 559
- 17.3 Measuring Temperature 563
- Thermal Expansion 563 17.4
- Surface Temperature of the Earth 571 17.5
- 17.6 Temperature of the Universe 573
- What We Have Learned/Exam Study Guide 574

Multiple-Choice Questions/Questions/Problems 576

# **18** Heat and the First Law of **Thermodynamics 581**



- 18.1 Definition of Heat 582
- Mechanical Equivalent of Heat 583 18.2
- Heat and Work 584 18.3
- First Law of Thermodynamics 586 18.4
- 18.5 First Law for Special Processes 588
- Specific Heats of Solids and Fluids 589 18.6
- Latent Heat and Phase Transitions 592 18.7
- 18.8 Modes of Thermal Energy Transfer 596
- What We Have Learned/Exam Study Guide 605 Multiple-Choice Questions/Questions/Problems 608

**19** Ideal Gases 614

- 19.1 Empirical Gas Laws 615
- 19.2 Ideal Gas Law 617
- Equipartition Theorem 623 19.3
- 19.4 Specific Heat of an Ideal Gas 626
- Adiabatic Processes for an Ideal Gas 630 19.5
- 19.6 Kinetic Theory of Gases 634
- What We Have Learned/Exam Study Guide 640
- Multiple-Choice Questions/Questions/Problems 644

### 20 The Second Law of **Thermodynamics 649**

- Reversible and Irreversible 20.1 Processes 650
- Engines and Refrigerators 652 20.2
- 20.3 Ideal Engines 654
- Real Engines and Efficiency 658 20.4
- The Second Law of Thermodynamics 664 20.5
- 20.6 Entropy 666

20.7 Microscopic Interpretation of Entropy 669 What We Have Learned/Exam Study Guide 672 Multiple-Choice Questions/Questions/Problems 677

### PART 5: ELECTRICITY

# 21 Electrostatics 683

- 21.1 Electromagnetism 684
- Electric Charge 685 21.2
- 21.3 Insulators, Conductors, Semiconductors, and Superconductors 688
- Electrostatic Charging 690 21.4
- Electrostatic Force—Coulomb's Law 692 21.5
- 21.6 Coulomb's Law and Newton's Law of Gravitation 699
- What We Have Learned/Exam Study Guide 699

Multiple-Choice Questions/Questions/Problems 704

# 22 Electric Fields and Gauss's Law 710

- Definition of an Electric Field 711 22.1
- 22.2 Field Lines 712
- 22.3 Electric Field due to Point Charges 714
- Electric Field due to a Dipole 716 22.4
- General Charge Distributions 717 22.5
- Force due to an Electric Field 721 22.6
- 22.7 Electric Flux 725
- 22.8 Gauss's Law 726
- 22.9 Special Symmetries 729

What We Have Learned/Exam Study Guide 735 Multiple-Choice Questions/Questions/Problems 738

#### 23 Electric Potential 745

- 23.1 Electric Potential Energy 746
- 23.2 Definition of Electric Potential 747
- 23.4 Distributions 755
- 23.5 Finding the Electric Field from the Electric Potential 759
- 23.6 Electric Potential Energy of a System of Point Charges 761

What We Have Learned/Exam Study Guide 763 Multiple-Choice Questions/Questions/Problems 766

## 24 Capacitors 773

- 24.1 Capacitance 774
- 24.2 Circuits 776
- Parallel Plate Capacitor 777 24.3
- Cylindrical Capacitor 779 24.4
- Spherical Capacitor 779 24.5
- 24.6 Capacitors in Circuits 780
- Energy Stored in Capacitors 784 24.7
- 24.8 Capacitors with Dielectrics 788
- Microscopic Perspective on Dielectrics 791 24.9

What We Have Learned/Exam Study Guide 793 Multiple-Choice Questions/Questions/Problems 797







- Electric Potential of Various Charge



- Equipotential Surfaces and Lines 752

#### 25 Current and Resistance 804

- 25.1 Electric Current 805
- Current Density 808 25.2
- Resistivity and Resistance 811 25.3
- 25.4 Electromotive Force and Ohm's Law 816
- Resistors in Series 818 25.5
- 25.6 Resistors in Parallel 821
- 25.7 Energy and Power in Electric Circuits 825
- 25.8 Diodes: One-Way Streets in Circuits 827

What We Have Learned/Exam Study Guide 828 Multiple-Choice Questions/Questions/Problems 831

# **26** Direct Current Circuits 838

26.1 Kirchhoff's Rules 839



- 26.2 Single-Loop Circuits 842
- 26.3 Multiloop Circuits 843
- 26.4 Ammeters and Voltmeters 847
- 26.5 RC Circuits 849

What We Have Learned/Exam Study Guide 855 Multiple-Choice Questions/Questions/Problems 857

#### **PART 6: MAGNETISM**

#### 27 Magnetism 864

27.1



27.2 Magnetic Force 868

Permanent Magnets 865

- Motion of Charged Particles in a 27.3 Magnetic Field 871
- Magnetic Force on a Current-Carrying Wire 878 27.4
- 27.5 Torque on a Current-Carrying Loop 880
- 27.6 Magnetic Dipole Moment 881
- 27.7 Hall Effect 881

What We Have Learned/Exam Study Guide 883 Multiple-Choice Questions/Questions/Problems 885

#### 28 Magnetic Fields of Moving Charges 892



Biot-Savart Law 893 28.1 28.2 Magnetic Fields due to Current

- Distributions 894
- 28.3 Ampere's Law 903
- 28.4 Magnetic Fields of Solenoids and Toroids 904
- 28.5 Atoms as Magnets 909
- 28.6 Magnetic Properties of Matter 910
- 28.7 Magnetism and Superconductivity 913

What We Have Learned/Exam Study Guide 914 Multiple-Choice Questions/Questions/Problems 918

# **29** Electromagnetic Induction 925

- Faraday's Experiments 926 29.1
- Faraday's Law of Induction 928 29.2
- 29.3 Lenz's Law 932
- 29.4 Generators and Motors 937

- Induced Electric Field 939 29.5
- 29.6 Inductance of a Solenoid 939
- Self-Inductance and Mutual Induction 940 29.7
- 29.8 RL Circuits 943

Energy and Energy Density of a Magnetic Field 946 29.9

29.10 Applications to Information Technology 947

What We Have Learned/Exam Study Guide 948 Multiple-Choice Questions/Questions/Problems 951

#### **30** Electromagnetic Oscillations and **Currents 958**



- LC Circuits 959 30.1
- 30.2 Analysis of LC Oscillations 961
- 30.3 Damped Oscillations in an RLC Circuit 964
- 30.4 Driven AC Circuits 965
- Series RLC Circuit 968 30.5
- 30.6 Energy and Power in AC Circuits 975
- Transformers 979 30.7
- Rectifiers 981 30.8

What We Have Learned/Exam Study Guide 982 Multiple-Choice Questions/Questions/Problems 986

#### 31 Electromagnetic Waves 992

- 31.1 Induced Magnetic Fields 993
- 31.2 Displacement Current 994
- 31.3 Maxwell's Equations 996
- Wave Solutions to Maxwell's Equations 996 31.4
- 31.5 The Speed of Light 1000
- The Electromagnetic Spectrum 1000 31.6
- 31.7 Traveling Electromagnetic Waves 1003
- 31.8 Poynting Vector and Energy Transport 1004
- Radiation Pressure 1006 31.9
- 31.10 Polarization 1010
- 31.11 Derivation of the Wave Equation 1014 What We Have Learned/Exam Study Guide 1015

Multiple-Choice Questions/Questions/Problems 1019

# PART 7: OPTICS

### 32 Geometric Optics 1025

- Light Rays and Shadows 1026 32.1
- Reflection and Plane Mirrors 1029 32.2
- 32.3 Curved Mirrors 1033
- 32.4 Refraction and Snell's Law 1041

What We Have Learned/Exam Study Guide 1052

Multiple-Choice Questions/Questions/Problems 1053

#### **33** Lenses and Optical **Instruments 1058**

- Lenses 1059 33.1
- Magnifier 1067 33.2
- 33.3 Systems of Two or More Optical Elements 1068
- 33.4 Human Eye 1071
- 33.5 Camera 1074



- Microscope 1077 33.6
- Telescope 1078 33.7
- 33.8 Laser Tweezers 1083

What We Have Learned/Exam Study Guide 1084 Multiple-Choice Questions/Questions/Problems 1089

#### **34** Wave Optics 1096

- 34.1 Light Waves 1097
- Interference 1100 34.2



- Double-Slit Interference 1101 34.3
- Thin-Film Interference and Newton's Rings 1104 34.4
- 34.5 Interferometer 1107
- 34.6 Diffraction 1109
- 34.7 Single-Slit Diffraction 1110
- 34.8 Diffraction by a Circular Opening 1113
- 34.9 Double-Slit Diffraction 1114
- 34.10 Gratings 1115

34.11 X-Ray Diffraction and Crystal Structure 1121 What We Have Learned/Exam Study Guide 1122 Multiple-Choice Questions/Questions/Problems 1126

#### **PART 8: RELATIVITY AND QUANTUM** PHYSICS

#### 35 Relativity 1132

35.1

- Search for the Aether 1133 35.2 Einstein's Postulates and Reference Frames 1134
- Time Dilation and Length Contraction 1138 35.3
- 35.4 Relativistic Frequency Shift 1144
- 35.5 Lorentz Transformation 1145
- 35.6 Relativistic Velocity Transformation 1148
- 35.7 Relativistic Momentum and Energy 1151
- 35.8 General Relativity 1158
- 35.9 Relativity in Our Daily Lives: GPS 1160
- What We Have Learned/Exam Study Guide 1161 Multiple-Choice Questions/Questions/Problems 1164

#### 36 Quantum Physics 1170

- 36.1 The Nature of Matter, Space, and Time 1171
- Blackbody Radiation 1172 36.2
- 36.3 Photoelectric Effect 1177
- 36.4 Compton Scattering 1181
- Matter Waves 1185 36.5
- 36.6 Uncertainty Relation 1188
- Spin 1192 36.7
- Spin and Statistics 1193 36.8
- What We Have Learned/Exam Study Guide 1198 Multiple-Choice Questions/Questions/Problems 1201

### **37** Quantum Mechanics 1206

- Wave Function 1207 37.1
- Schrödinger Equation 1210 37.2



- Infinite Potential Well 1211 37.3
- Finite Potential Wells 1217 37.4
- 37.5 Harmonic Oscillator 1225
- 37.6 Wave Functions and Measurements 1228
- 37.7 Correspondence Principle 1232
- Time-Dependent Schrödinger Equation 1233 37.8
- 37.9 Many-Particle Wave Function 1234
- 37.10 Antimatter 1238

What We Have Learned/Exam Study Guide 1242 Multiple-Choice Questions/Questions/Problems 1246

# **38** Atomic Physics 1251

- 38.1 Spectral Lines 1252
- 38.2 Bohr's Model of the Atom 1255
- 38.3 Hydrogen Electron Wave
- Function 1258 38.4
- Other Atoms 1270 38.5 Lasers 1276

What We Have Learned/Exam Study Guide 1280 Multiple-Choice Questions/Questions/Problems 1283

# **39** Elementary Particle Physics 1286

- 39.1 Reductionism 1287
- 39.2 Probing Substructure 1290
- Elementary Particles 1297 39.3
- Extensions of the Standard Model 1305 39.4
- 39.5 Composite Particles 1309
- 39.6 Big Bang Cosmology 1315 What We Have Learned/Exam Study Guide 1319

Multiple-Choice Questions/Questions/Problems 1321

#### 40 Nuclear Physics 1325

40.1 Nuclear Properties 1326 40.2 Nuclear Decay 1334 Nuclear Models 1346 40.3 Nuclear Energy: Fission and Fusion 1351 40.4 40.5 Nuclear Astrophysics 1358 40.6 Nuclear Medicine 1359 What We Have Learned/Exam Study Guide 1361 Multiple-Choice Questions/Questions/Problems 1364

#### **Appendix A Mathematical Primer A-1**

Appendix B Isotope Masses, Binding Energies, and Half-Lives A-9

#### Appendix C Element Properties A-19

Answers to Selected Questions and Problems AP-1

Credits C-1 Index I-1









