

PHYSICS

For Scientists and Engineers | A Strategic Approach | 5e

WITH MODERN PHYSICS

GLOBAL EDITION



RANDALL D. KNIGHT

Detailed Contents

PART I

Newton's Laws



Overview Why Things Move 23

1 Concepts of Motion 24

- 1.1 Motion Diagrams 25
- 1.2 Models and Modeling 26
- 1.3 Position, Time, and Displacement 27
- 1.4 Velocity 30
- 1.5 Linear Acceleration 32
- 1.6 Motion in One Dimension 37
- 1.7 Solving Problems in Physics 39
- 1.8 Units and Significant Figures 43
- SUMMARY** 49
- QUESTIONS AND PROBLEMS** 50

2 Kinematics in One Dimension 54

- 2.1 Uniform Motion 55
- 2.2 Instantaneous Velocity 59
- 2.3 Finding Position from Velocity 62
- 2.4 Motion with Constant Acceleration 65
- 2.5 Free Fall 71
- 2.6 Motion on an Inclined Plane 73
- 2.7 **ADVANCED TOPIC** Instantaneous Acceleration 76
- SUMMARY** 79
- QUESTIONS AND PROBLEMS** 80

3 Vectors and Coordinate Systems 87

- 3.1 Scalars and Vectors 88
- 3.2 Using Vectors 88
- 3.3 Coordinate Systems and Vector Components 91
- 3.4 Unit Vectors and Vector Algebra 94
- SUMMARY** 98
- QUESTIONS AND PROBLEMS** 99

4 Kinematics in Two Dimensions 102

- 4.1 Motion in Two Dimensions 103
- 4.2 Projectile Motion 107
- 4.3 Relative Motion 112
- 4.4 Uniform Circular Motion 114
- 4.5 Centripetal Acceleration 118
- 4.6 Nonuniform Circular Motion 120
- SUMMARY** 125
- QUESTIONS AND PROBLEMS** 126

5 Force and Motion 132

- 5.1 Force 133
- 5.2 A Short Catalog of Forces 135
- 5.3 Identifying Forces 137
- 5.4 What Do Forces Do? 139
- 5.5 Newton's Second Law 142
- 5.6 Newton's First Law 143
- 5.7 Free-Body Diagrams 145
- SUMMARY** 148
- QUESTIONS AND PROBLEMS** 149

6 Dynamics I: Motion Along a Line 153

- 6.1 The Equilibrium Model 154
- 6.2 Using Newton's Second Law 156
- 6.3 Mass, Weight, and Gravity 159
- 6.4 Friction 163
- 6.5 Drag 167
- 6.6 More Examples of Newton's Second Law 174
- SUMMARY** 178
- QUESTIONS AND PROBLEMS** 179

7 Newton's Third Law 185

- 7.1 Interacting Objects 186
- 7.2 Analyzing Interacting Objects 187
- 7.3 Newton's Third Law 190
- 7.4 Ropes and Pulleys 195
- 7.5 Examples of Interacting-Objects Problems 198
- SUMMARY** 201
- QUESTIONS AND PROBLEMS** 202

8 Dynamics II: Motion in a Plane 208

- 8.1 Dynamics in Two Dimensions 209
- 8.2 Uniform Circular Motion 210
- 8.3 Circular Orbits 215
- 8.4 Reasoning About Circular Motion 217
- 8.5 Nonuniform Circular Motion 220
- SUMMARY** 223
- QUESTIONS AND PROBLEMS** 224

KNOWLEDGE STRUCTURE Part I Newton's Laws 230

PART II

Conservation Laws



Overview Why Some Things Don't Change 231

9 Work and Kinetic Energy 232

- 9.1 Energy Overview 233
- 9.2 Work and Kinetic Energy for a Single Particle 235
- 9.3 Calculating the Work Done 239
- 9.4 Restoring Forces and the Work Done by a Spring 245
- 9.5 Dissipative Forces and Thermal Energy 247
- 9.6 Power 250
- SUMMARY** 253
- QUESTIONS AND PROBLEMS** 254

10 Interactions and Potential Energy 259

- 10.1 Potential Energy 260
- 10.2 Gravitational Potential Energy 261
- 10.3 Elastic Potential Energy 267
- 10.4 Conservation of Energy 270
- 10.5 Energy Diagrams 272
- 10.6 Force and Potential Energy 276
- 10.7 Conservative and Nonconservative Forces 277
- 10.8 The Energy Principle Revisited 279
- SUMMARY** 282
- QUESTIONS AND PROBLEMS** 283

11 Impulse and Momentum 289

- 11.1 Momentum and Impulse 290
- 11.2 Conservation of Momentum 294
- 11.3 Collisions 300
- 11.4 Explosions 305
- 11.5 Momentum in Two Dimensions 307
- 11.6 **ADVANCED TOPIC** Rocket Propulsion 309
- SUMMARY** 313
- QUESTIONS AND PROBLEMS** 314

KNOWLEDGE STRUCTURE Part II Conservation Laws 320

PART III

Applications of Newtonian Mechanics



Overview Power Over Our Environment 321

12 Rotation of a Rigid Body 322

- 12.1 Rotational Motion 323
- 12.2 Rotation About the Center of Mass 324
- 12.3 Rotational Energy 327
- 12.4 Calculating Moment of Inertia 329
- 12.5 Torque 331
- 12.6 Rotational Dynamics 335
- 12.7 Rotation About a Fixed Axis 337
- 12.8 Static Equilibrium 339
- 12.9 Rolling Motion 342
- 12.10 The Vector Description of Rotational Motion 345
- 12.11 Angular Momentum 348
- 12.12 **ADVANCED TOPIC** Precession of a Gyroscope 352
- SUMMARY** 356
- QUESTIONS AND PROBLEMS** 357

13 Newton's Theory of Gravity 364

- 13.1 A Little History 365
- 13.2 Isaac Newton 366
- 13.3 Newton's Law of Gravity 367
- 13.4 Little g and Big G 369

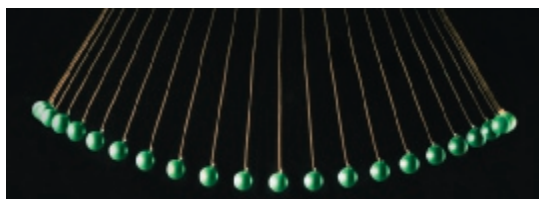
- 13.5 Gravitational Potential Energy 371
 13.6 Satellite Orbits and Energies 375
SUMMARY 380
QUESTIONS AND PROBLEMS 381

14 Fluids and Elasticity 386

- 14.1 Fluids 387
 14.2 Pressure 388
 14.3 Measuring and Using Pressure 394
 14.4 Buoyancy 398
 14.5 Fluid Dynamics 402
 14.6 Motion of a Viscous Fluid 408
 14.7 Elasticity 412
SUMMARY 416
QUESTIONS AND PROBLEMS 417

KNOWLEDGE STRUCTURE Part III Applications of Newtonian Mechanics 422

PART IV Oscillations and Waves



Overview The Wave Model 423

15 Oscillations 424

- 15.1 Simple Harmonic Motion 425
 15.2 SHM and Circular Motion 428
 15.3 Energy in SHM 431
 15.4 The Dynamics of SHM 433
 15.5 Vertical Oscillations 436
 15.6 The Pendulum 438
 15.7 Damped Oscillations 442
 15.8 Driven Oscillations and Resonance 445
 15.9 **ADVANCED TOPIC** Coupled Oscillations and Normal Modes 446
SUMMARY 451
QUESTIONS AND PROBLEMS 452

16 Traveling Waves 458

- 16.1 An Introduction to Waves 459
 16.2 One-Dimensional Waves 461
 16.3 Sinusoidal Waves 464

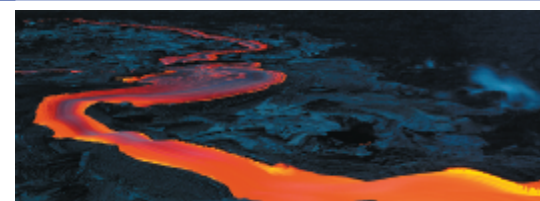
- 16.4 **ADVANCED TOPIC** The Wave Equation on a String 468
 16.5 Sound and Light 472
 16.6 **ADVANCED TOPIC** The Wave Equation in a Fluid 476
 16.7 Waves in Two and Three Dimensions 479
 16.8 Power, Intensity, and Decibels 481
 16.9 The Doppler Effect 483
SUMMARY 487
QUESTIONS AND PROBLEMS 488

17 Superposition 493

- 17.1 The Principle of Superposition 494
 17.2 Standing Waves 495
 17.3 Standing Waves on a String 497
 17.4 Standing Sound Waves and Musical Acoustics 501
 17.5 Interference in One Dimension 505
 17.6 The Mathematics of Interference 509
 17.7 Interference in Two and Three Dimensions 512
 17.8 Beats 515
SUMMARY 519
QUESTIONS AND PROBLEMS 520

KNOWLEDGE STRUCTURE Part IV Oscillations and Waves 526

PART V Thermodynamics



Overview It's All About Energy 527

18 A Macroscopic Description of Matter 528

- 18.1 Solids, Liquids, and Gases 529
 18.2 Atoms and Moles 530
 18.3 Temperature 532
 18.4 Thermal Expansion 534
 18.5 Phase Changes 535
 18.6 Ideal Gases 537
 18.7 Ideal-Gas Processes 541
SUMMARY 547
QUESTIONS AND PROBLEMS 548

19 Work, Heat, and the First Law of Thermodynamics 553

- 19.1 It's All About Energy 554
- 19.2 Work in Ideal-Gas Processes 555
- 19.3 Heat 559
- 19.4 The First Law of Thermodynamics 562
- 19.5 Thermal Properties of Matter 564
- 19.6 Calorimetry 567
- 19.7 The Specific Heats of Gases 569
- 19.8 Heat-Transfer Mechanisms 575

SUMMARY 579

QUESTIONS AND PROBLEMS 580

20 The Micro/Macro Connection 586

- 20.1 Connecting the Microscopic and the Macroscopic 587
- 20.2 Molecular Speeds and Collisions 587
- 20.3 Pressure in a Gas 589
- 20.4 Temperature 591
- 20.5 Thermal Energy and Specific Heat 593
- 20.6 Heat Transfer and Thermal Equilibrium 597
- 20.7 Irreversible Processes and the Second Law of Thermodynamics 599
- 20.8 Microstates, Multiplicity, and Entropy 603
- 20.9 Using Entropy 607

SUMMARY 614

QUESTIONS AND PROBLEMS 615

21 Heat Engines and Refrigerators 620

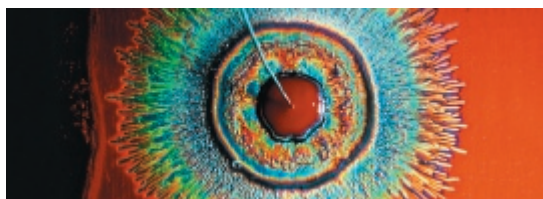
- 21.1 Turning Heat into Work 621
- 21.2 Heat Engines and Refrigerators 623
- 21.3 Ideal-Gas Heat Engines 628
- 21.4 Ideal-Gas Refrigerators 632
- 21.5 The Limits of Efficiency 634
- 21.6 The Carnot Cycle 637

SUMMARY 642

QUESTIONS AND PROBLEMS 643

KNOWLEDGE STRUCTURE Part V Thermodynamics 650

PART VI Electricity and Magnetism



Overview Forces and Fields 651

22 Electric Charges and Forces 652

- 22.1 The Charge Model 653
- 22.2 Charge 656
- 22.3 Insulators and Conductors 658
- 22.4 Coulomb's Law 662
- 22.5 The Electric Field 667

SUMMARY 673

QUESTIONS AND PROBLEMS 674

23 The Electric Field 681

- 23.1 Electric Field Models 682
- 23.2 The Electric Field of Point Charges 682
- 23.3 The Electric Field of a Continuous Charge Distribution 687
- 23.4 The Electric Fields of Some Common Charge Distributions 691
- 23.5 The Parallel-Plate Capacitor 695
- 23.6 Motion of a Charged Particle in an Electric Field 697
- 23.7 Motion of a Dipole in an Electric Field 700

SUMMARY 703

QUESTIONS AND PROBLEMS 704

24 Gauss's Law 710

- 24.1 Symmetry 711
- 24.2 The Concept of Flux 713
- 24.3 Calculating Electric Flux 715
- 24.4 Gauss's Law 721
- 24.5 Using Gauss's Law 724
- 24.6 Conductors in Electrostatic Equilibrium 728

SUMMARY 732

QUESTIONS AND PROBLEMS 733

25 The Electric Potential 739

- 25.1 Electric Potential Energy 740
- 25.2 The Potential Energy of Point Charges 743
- 25.3 The Potential Energy of a Dipole 746
- 25.4 The Electric Potential 747
- 25.5 The Electric Potential Inside a Parallel-Plate Capacitor 750
- 25.6 The Electric Potential of a Point Charge 754
- 25.7 The Electric Potential of Many Charges 756

SUMMARY 759

QUESTIONS AND PROBLEMS 760

26 Potential and Field 766

- 26.1 Connecting Potential and Field 767
- 26.2 Finding the Electric Field from the Potential 769

- 26.3 A Conductor in Electrostatic Equilibrium 772
- 26.4 Sources of Electric Potential 774
- 26.5 Capacitance and Capacitors 776
- 26.6 The Energy Stored in a Capacitor 781
- 26.7 Dielectrics 782
 - SUMMARY 787
 - QUESTIONS AND PROBLEMS 788

27 Current and Resistance 794

- 27.1 The Electron Current 795
- 27.2 Creating a Current 797
- 27.3 Current and Current Density 801
- 27.4 Conductivity and Resistivity 805
- 27.5 Resistance and Ohm's Law 807
 - SUMMARY 812
 - QUESTIONS AND PROBLEMS 813

28 Fundamentals of Circuits 818

- 28.1 Circuit Elements and Diagrams 819
- 28.2 Kirchhoff's Laws and the Basic Circuit 820
- 28.3 Energy and Power 823
- 28.4 Series Resistors 825
- 28.5 Real Batteries 827
- 28.6 Parallel Resistors 829
- 28.7 Resistor Circuits 832
- 28.8 Getting Grounded 834
- 28.9 RC Circuits 836
 - SUMMARY 840
 - QUESTIONS AND PROBLEMS 841

29 The Magnetic Field 848

- 29.1 Magnetism 849
- 29.2 The Discovery of the Magnetic Field 850
- 29.3 The Source of the Magnetic Field: Moving Charges 852
- 29.4 The Magnetic Field of a Current 854
- 29.5 Magnetic Dipoles 858
- 29.6 Ampère's Law and Solenoids 861
- 29.7 The Magnetic Force on a Moving Charge 867
- 29.8 Magnetic Forces on Current-Carrying Wires 872
- 29.9 Forces and Torques on Current Loops 875
- 29.10 Magnetic Properties of Matter 876
 - SUMMARY 880
 - QUESTIONS AND PROBLEMS 881

30 Electromagnetic Induction 888

- 30.1 Induced Currents 889
- 30.2 Motional emf 890

- 30.3 Magnetic Flux 894
- 30.4 Lenz's Law 897
- 30.5 Faraday's Law 900
- 30.6 Induced Fields 904
- 30.7 Induced Currents: Three Applications 907
- 30.8 Inductors 909
- 30.9 LC Circuits 913
- 30.10 LR Circuits 915
 - SUMMARY 919
 - QUESTIONS AND PROBLEMS 920

31 Electromagnetic Fields and Waves 928

- 31.1 E or B ? It Depends on Your Perspective 929
- 31.2 The Field Laws Thus Far 934
- 31.3 The Displacement Current 935
- 31.4 Maxwell's Equations 938
- 31.5 **ADVANCED TOPIC** Electromagnetic Waves 940
- 31.6 Properties of Electromagnetic Waves 945
- 31.7 Polarization 948
 - SUMMARY 951
 - QUESTIONS AND PROBLEMS 952

32 AC Circuits 957

- 32.1 AC Sources and Phasors 958
- 32.2 Capacitor Circuits 960
- 32.3 RC Filter Circuits 962
- 32.4 Inductor Circuits 965
- 32.5 The Series RLC Circuit 966
- 32.6 Power in AC Circuits 970
 - SUMMARY 974
 - QUESTIONS AND PROBLEMS 975

KNOWLEDGE STRUCTURE Part VI Electricity and Magnetism 980

PART VII Optics



Overview The Story of Light 981

33 Wave Optics 982

- 33.1 Models of Light 983
- 33.2 The Interference of Light 984
- 33.3 The Diffraction Grating 989

- 33.4 Single-Slit Diffraction 992
- 33.5 **ADVANCED TOPIC** A Closer Look at Diffraction 996
- 33.6 Circular-Aperture Diffraction 999
- 33.7 The Wave Model of Light 1000
- 33.8 Interferometers 1002
- SUMMARY** 1005
- QUESTIONS AND PROBLEMS** 1006

34 Ray Optics 1012

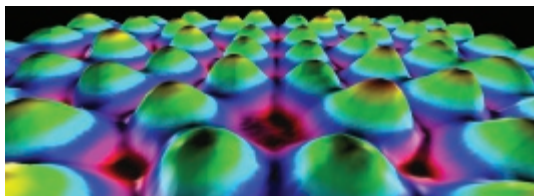
- 34.1 The Ray Model of Light 1013
- 34.2 Reflection 1015
- 34.3 Refraction 1018
- 34.4 Image Formation by Refraction at a Plane Surface 1023
- 34.5 Thin Lenses: Ray Tracing 1024
- 34.6 Thin Lenses: Refraction Theory 1030
- 34.7 Image Formation with Spherical Mirrors 1035
- SUMMARY** 1040
- QUESTIONS AND PROBLEMS** 1041

35 Optical Instruments 1047

- 35.1 Lenses in Combination 1048
- 35.2 The Camera 1050
- 35.3 Vision 1053
- 35.4 Optical Systems That Magnify 1056
- 35.5 Color and Dispersion 1060
- 35.6 The Resolution of Optical Instruments 1062
- SUMMARY** 1067
- QUESTIONS AND PROBLEMS** 1068

KNOWLEDGE STRUCTURE Part VII Optics 1072

PART VIII Relativity and Quantum Physics



Overview Contemporary Physics 1073

36 Relativity 1074

- 36.1 Relativity: What's It All About? 1075
- 36.2 Galilean Relativity 1075
- 36.3 Einstein's Principle of Relativity 1078
- 36.4 Events and Measurements 1081

- 36.5 The Relativity of Simultaneity 1084
- 36.6 Time Dilation 1087
- 36.7 Length Contraction 1091
- 36.8 The Lorentz Transformations 1095
- 36.9 Relativistic Momentum 1100
- 36.10 Relativistic Energy 1103
- SUMMARY** 1109
- QUESTIONS AND PROBLEMS** 1110

37 The Foundations of Modern Physics 1115

- 37.1 Matter and Light 1116
- 37.2 The Emission and Absorption of Light 1116
- 37.3 Cathode Rays and X Rays 1119
- 37.4 The Discovery of the Electron 1121
- 37.5 The Fundamental Unit of Charge 1124
- 37.6 The Discovery of the Nucleus 1125
- 37.7 Into the Nucleus 1129
- 37.8 Classical Physics at the Limit 1131
- SUMMARY** 1132
- QUESTIONS AND PROBLEMS** 1133

38 Quantization 1137

- 38.1 The Photoelectric Effect 1138
- 38.2 Einstein's Explanation 1141
- 38.3 Photons 1144
- 38.4 Matter Waves and Energy Quantization 1148
- 38.5 Bohr's Model of Atomic Quantization 1151
- 38.6 The Bohr Hydrogen Atom 1155
- 38.7 The Hydrogen Spectrum 1160
- SUMMARY** 1164
- QUESTIONS AND PROBLEMS** 1165

39 Wave Functions and Uncertainty 1170

- 39.1 Waves, Particles, and the Double-Slit Experiment 1171
- 39.2 Connecting the Wave and Photon Views 1174
- 39.3 The Wave Function 1176
- 39.4 Normalization 1178
- 39.5 Wave Packets 1180
- 39.6 The Heisenberg Uncertainty Principle 1183
- SUMMARY** 1187
- QUESTIONS AND PROBLEMS** 1188

40 One-Dimensional Quantum Mechanics 1193

- 40.1 The Schrödinger Equation 1194
- 40.2 Solving the Schrödinger Equation 1197
- 40.3 A Particle in a Rigid Box: Energies and Wave Functions 1199
- 40.4 A Particle in a Rigid Box: Interpreting the Solution 1202
- 40.5 The Correspondence Principle 1205
- 40.6 Finite Potential Wells 1207
- 40.7 Wave-Function Shapes 1212
- 40.8 The Quantum Harmonic Oscillator 1214
- 40.9 More Quantum Models 1217
- 40.10 Quantum-Mechanical Tunneling 1220
- SUMMARY** 1225
- QUESTIONS AND PROBLEMS** 1226

41 Atomic Physics 1230

- 41.1 The Hydrogen Atom: Angular Momentum and Energy 1231
- 41.2 The Hydrogen Atom: Wave Functions and Probabilities 1234
- 41.3 The Electron's Spin 1237
- 41.4 Multielectron Atoms 1239
- 41.5 The Periodic Table of the Elements 1242
- 41.6 Excited States and Spectra 1245

- 41.7 Lifetimes of Excited States 1250
- 41.8 Stimulated Emission and Lasers 1252
- SUMMARY** 1257
- QUESTIONS AND PROBLEMS** 1258

42 Nuclear Physics 1262

- 42.1 Nuclear Structure 1263
- 42.2 Nuclear Stability 1266
- 42.3 The Strong Force 1269
- 42.4 The Shell Model 1270
- 42.5 Radiation and Radioactivity 1272
- 42.6 Nuclear Decay Mechanisms 1277
- 42.7 Biological Applications of Nuclear Physics 1282
- SUMMARY** 1286
- QUESTIONS AND PROBLEMS** 1287

KNOWLEDGE STRUCTURE Part VIII Relativity and Quantum Physics 1292

APPENDIX A MATHEMATICS REVIEW A-1

APPENDIX B PERIODIC TABLE OF ELEMENTS A-4

APPENDIX C ATOMIC AND NUCLEAR DATA A-5

ANSWERS TO STOP TO THINK QUESTIONS AND ODD-NUMBERED EXERCISES AND PROBLEMS A-9

CREDITS C-1

INDEX I-1