

# Contents

Preface *xi*

## 1 Some Preliminaries 1

- 1-1 The Message 1
- 1-2 Textbook Physics 2
- 1-3 What's Where 2

## 2 Vectors and Force Equilibrium 5

- 2-1 Displacement as a Vector 5
- 2-2 Vector Components 9
- 2-3 Vector Addition by Components 10
- 2-4 Vectors in Three Dimensions 12
- 2-5 Unit Vectors and Vector Addition 15
- 2-6 Force Vectors and Equilibrium 16
- Summary 22
- Problems and Questions 23

## 3 Motion along a Line 29

- 3-1 Meaning of a Particle 29
- 3-2 Constant Velocity 30
- 3-3 Average Velocity 32
- 3-4 Instantaneous Velocity 34

- 3-5 Displacement as Area under the Velocity-Time Graph 35
- 3-6 Acceleration 36
- 3-7 Constant Acceleration 39
- 3-8 Graphs and Constant Acceleration 41
- 3-9 Calculus and Constant Acceleration 42
- 3-10 Freely Falling Bodies 48
- Summary 51
- Problems and Questions 51

## 4 Motion in a Plane 56

- 4-1 Velocity and Acceleration Vectors 57
- 4-2 Motion at Constant Acceleration 62
- 4-3 Projectile Motion 68
- 4-4 Uniform Circular Motion 73
- 4-5 Other Relations for Circular Motion 75
- 4-6 Relative Velocities 77
- Summary 79
- Problems and Questions 80

## 5 Newton's Laws I 85

- 5-1 The First Law 86
- 5-2 Mass 87

- 5-3 Force Defined 91
- 5-4 Newton's Second Law 95
- 5-5 Newton's Third Law 97
- 5-6 Weight 99
- 5-7 Procedures for Applying Newton's Laws: Constant Acceleration 102
- 5-8 Force and Mass Units in Other Systems (Optional) 107
- Summary 108
- Problems and Questions 108

## 6 Newton's Laws II 115

- 6-1 Friction 115
- 6-2 Uniform Circular Motion 121
- 6-3 Centrifugal Force and Other Inertial Forces (Optional) 126
- 6-4 Resistive Force Proportional to Speed (Optional) 131
- Summary 133
- Problems and Questions 133

## 7 Momentum 137

- 7-1 Momentum Defined 137
- 7-2 Momentum Conservation 138
- 7-3 Impulse and Momentum 144
- 7-4 General Proof of Momentum Conservation (Optional) 147
- Summary 150
- Problems and Questions 151

## 8 Center of Mass 155

- 8-1 Center of Mass Defined 155
- 8-2 Locating the Center of Mass 157
- 8-3 Velocity of the Center of Mass 161
- 8-4 Center-of-Mass Reference Frame 163
- 8-5 Acceleration of the Center of Mass 165
- Summary 167
- Problems and Questions 167

## 9 Work and Kinetic Energy 171

- 9-1 Kinetic Energy Defined 171
- 9-2 Work Defined and the Work-Energy Theorem 173
- 9-3 Properties of Work 175
- 9-4 The Dot (or Scalar) Product 179
- 9-5 Unit Vectors and the Dot Product 180
- 9-6 Work Done by Gravity 181
- 9-7 Conservative Force 184
- 9-8 Work Done by a Spring 185
- 9-9 Power 187
- Summary 188
- Problems and Questions 189

## 10 Potential Energy and Energy Conservation 194

- 10-1 Potential Energy Defined 194
- 10-2 Gravitational Potential Energy 196
- 10-3 Spring Potential Energy 200
- 10-4 Properties of Potential Energy 201
- 10-5 The Energy Conservation Law 204
- 10-6 Collisions 209
- 10-7 Energy and the Center-of-Mass Reference Frame (Optional) 215
- Summary 217
- Problems and Questions 217

## 11 Simple Harmonic Motion 222

- 11-1 Definitions 222
- 11-2 Dynamics of Simple Harmonic Motion 224
- 11-3 Energetics of Simple Harmonic Motion 228
- 11-4 Small Oscillations 229
- 11-5 The Simple Pendulum 230
- 11-6 Periodic Motion and the Fourier Theorem (Optional) 233
- 11-7 Damped Oscillations (Optional) 236
- 11-8 Forced Oscillations and Resonance (Optional) 237
- Summary 238
- Problems and Questions 239

## 12 Equilibrium of a Rigid Body 244

- 12-1 Definitions: Rigid Body, Translation, Rotation, Vector Representation of Rotation 244
- 12-2 The Cross (or Vector) Product 247
- 12-3 Unit Vectors and the Cross Product 249
- 12-4 Torque 249
- 12-5 Center of Gravity 252
- 12-6 Conditions for Rotational Equilibrium 253
- 12-7 Three Proofs (Optional) 256
- Summary 258
- Problems and Questions 258

## 13 Rotational Dynamics 265

- 13-1 Rotational Kinematics 265
- 13-2 Rotational Kinetic Energy, Work, and Power 268
- 13-3 Moment-of-Inertia Computations 271
- 13-4 Energy of a Rolling Object 276
- 13-5 Newton's Law for Rotation 277
- 13-6 Pendulums with Rigid Bodies 281
- Summary 284
- Problems and Questions 284

## 14 Angular Momentum 289

- 14-1 Angular Momentum of a Particle 289
- 14-2 Angular Momentum of a Rigid Body 291
- 14-3 Torque and Angular Momentum 293
- 14-4 Particle with Constant Angular Momentum 294
- 14-5 Angular Momentum Conservation Law 297
- 14-6 Precession of a Top (Optional) 302
- Summary 304
- Problems and Questions 304

## 15 Gravitation 310

- 15-1 The Law of Universal Gravitation 311
- 15-2 Gravitational Acceleration  $g$  314

- 15-3 The Cavendish Experiment 315
- 15-4 Kepler's Laws of Planetary Motion 316
- 15-5 Gravitational Potential Energy 321
- 15-6 Bound Orbits and Escape 326
- 15-7 Inertial Mass and Gravitational Mass (Optional) 329
- 15-8 The Principle of Equivalence (Optional) 331
- 15-9 Gravitational Effect of a Spherical Shell (Optional) 333
- Summary 335
- Problems and Questions 336

## 16 Fluid Mechanics 341

- 16-1 Fluids Defined 341
- 16-2 Pressure 342
- 16-3 Density 344
- 16-4 Variation of Static Pressure with Elevation 345
- 16-5 Archimedes' Principle 349
- 16-6 Streamline Flow 351
- 16-7 The Equation of Continuity 353
- 16-8 Bernoulli's Theorem 354
- Summary 358
- Problems and Questions 358

## 17 Mechanical Waves I 363

- 17-1 Basic Wave Properties 363
- 17-2 Speed of a Wave on a String 366
- 17-3 The Superposition Principle and Interference 368
- 17-4 Reflection of Waves 369
- 17-5 Sinusoidal Traveling Waves 371
- 17-6 Standing Waves and Resonance 375
- 17-7 Power of a Wave (Optional) 380
- Summary 381
- Problems and Questions 382

## 18 Mechanical Waves II 385

- 18-1 Longitudinal Waves 385
- 18-2 Superposition, Reflection, and Standing Waves 387

- 18-3 Sound and Acoustics 389
- 18-4 Wave Fronts, Rays, and Huygens's Principle 391
- 18-5 Intensity Variation with Distance from Source 392
- 18-6 Beats 394
- 18-7 Doppler Effect 395
- Summary 397
- Problems and Questions 398

## 19 Thermal Properties of an Ideal Gas, Macroscopic View 401

- 19-1 Temperature and the Zeroth Law of Thermodynamics 401
- 19-2 Thermometry 402
- 19-3 Thermal Expansion of Solids and Liquids 406
- 19-4 Thermal Properties of an Ideal Gas 409
- 19-5 Changes in State 412
- Summary 415
- Problems and Questions 415

## 20 Thermal Properties of an Ideal Gas, Microscopic View 419

- 20-1 Molecular Properties 419
- 20-2 Kinetic Theory and Gas Pressure 422
- 20-3 Kinetic-Theory Interpretation of Temperature 425
- 20-4 Internal Energy 427
- 20-5 Heat 428
- 20-6 First Law of Thermodynamics, Microscopic Interpretation 429
- 20-7 First Law of Thermodynamics, Macroscopic Interpretation 434
- 20-8 Specific Heats of an Ideal Gas 436
- 20-9 Disorder and the Second Law of Thermodynamics 439
- 20-10 Molecular Speed Distribution (Optional) 442
- Summary 444
- Problems and Questions 444

## 21 Thermal Properties of Solids and Liquids 448

- 21-1 Solids and Liquids as Thermal Systems 448
- 21-2 Specific Heats 450
- 21-3 Heats of Transformation 452
- 21-4 The Joule Experiment 455
- 21-5 Thermal Conduction 456
- 21-6 Thermal Resistance 459
- 21-7 Thermal-Energy Transfer through Radiation 461
- Summary 463
- Problems and Questions 463

## 22 The Second Law of Thermodynamics and Heat Engines 469

- 22-1 Energy Convertibility 469
- 22-2 Heat Engines, Heat Pumps, and the Second Law of Thermodynamics 471
- 22-3 Reversible and Irreversible Heat Engines 474
- 22-4 The Carnot Cycle and the Thermodynamic Scale of Temperature 476
- 22-5 Entropy 479
- 22-6 Entropy and the Second Law of Thermodynamics 483
- 22-7 Entropy and Disorder (Optional) 485
- Summary 487
- Problems and Questions 488

## 23 Point Electric Charges 491

- 23-1 Some Qualitative Features of the Electric Force 491
- 23-2 Coulomb's Law 495
- 23-3 Further Characteristics of Electric Charge 498
- 23-4 Electric Field Defined 501
- 23-5 Electric-Field Lines 505
- Summary 507
- Problems and Questions 508

## 24 Continuous Distributions of Electric Charge 512

- 24-1 Electric Field for Three Simple Geometries 512
- 24-2 Uniform Electric Field 516
- 24-3 Electric Flux 519
- 24-4 Gauss's Law 521
- 24-5 Electric Field and Charged Conductors 525
- 24-6 An Electric Dipole in an Electric Field (Optional) 530
- 24-7 General Proof of Gauss's Law (Optional) 531
- Summary 533
- Problems and Questions 534

## 25 Electric Potential 539

- 25-1 The Coulomb Force as a Conservative Force 539
- 25-2 Electric Potential Defined 541
- 25-3 Electric Potential for Point Charges 543
- 25-4 Electric Potential Energy 545
- 25-5 Equipotential Surfaces 547
- 25-6 Relations between  $V$  and  $E$  549
- 25-7 Electric Potential and Conductors 552
- Summary 554
- Problems and Questions 555

## 26 Capacitance and Dielectrics 560

- 26-1 Capacitance Defined 560
- 26-2 Capacitor Circuits 564
- 26-3 Dielectric Constant 567
- 26-4 Energy of a Charged Capacitor 569
- 26-5 Energy Density of the Electric Field 571
- 26-6 Electric Polarization and Microscopic Properties (Optional) 572
- Summary 574
- Problems and Questions 575

## 27 Electric Current and Resistance 582

- 27-1 Electric Current 582
- 27-2 Current and Energy Conservation 585

- 27-3 Resistance and Ohm's Law 585
- 27-4 Resistivity 587
- 27-5 RC Circuits 589
- 27-6 Electric Resistance from a Microscopic Point of View 591
- Summary 592
- Problems and Questions 593

## 28 DC Circuits 598

- 28-1 EMF 598
- 28-2 Single-Loop Circuits 601
- 28-3 Resistors in Series and Parallel 603
- 28-4 DC Circuit Instruments 606
- 28-5 Multiloop Circuits 609
- Summary 611
- Problems and Questions 612

## 29 The Magnetic Force 619

- 29-1 Magnetic Field Defined 620
- 29-2 Magnetic-Field Lines and Magnetic Flux 622
- 29-3 Charged Particle in a Uniform Magnetic Field 625
- 29-4 Charged Particles in Uniform  $B$  and  $E$  Fields 628
- 29-5 Magnetic Force on a Current-Carrying Conductor 630
- 29-6 The Hall Effect 632
- 29-7 Magnetic Torque on a Current Loop 633
- 29-8 Magnetic Dipole Moment 635
- Summary 631
- Problems and Questions 638

## 30 Sources of the Magnetic Field 643

- 30-1 The Oersted Effect 643
- 30-2 The Magnetic Force between Current-Carrying Conductors 646
- 30-3 The Magnetic Field from a Current Element; the Biot-Savart Relation 647
- 30-4 Gauss's Law for Magnetism 651
- 30-5 Ampère's Law 652
- 30-6 The Solenoid 656

- 30-7 Magnetic Materials** 658  
 Summary 661  
 Problems and Questions 661

## 31 Electromagnetic Induction 666

- 31-1 Induced Currents and EMF's** 667  
**31-2 EMF in a Moving Conductor** 671  
**31-3 Lenz's Law** 675  
**31-4 Faraday's Law and the Induced Electric Field** 677  
**31-5 Eddy Currents** 680  
**31-6 Diamagnetism** 681  
 Summary 683  
 Problems and Questions 683

## 32 Inductance and Electric Oscillations 689

- 32-1 Self-Inductance Defined** 689  
**32-2 The LR Circuit** 694  
**32-3 Energy of an Inductor** 696  
**32-4 Energy of the Magnetic Field** 697  
**32-5 Electrical Free Oscillations** 697  
**32-6 Electrical-Mechanical Analogs** 702  
**32-7 Mutual Inductance** 704  
 Summary 705  
 Problems and Questions 706

## 33 AC Circuits 710

- 33-1 Some Preliminaries** 710  
**33-2 Series RLC Circuit** 713  
**33-3 Phasors** 719  
**33-4 Series RLC Circuit with Phasors** 721  
**33-5 RMS Values for AC Current and Voltage** 724  
**33-6 Power in AC Circuits** 725  
**33-7 The Transformer** 729  
 Summary 730  
 Problems and Questions 731

## 34 Maxwell's Equations 737

- 34-1 The General Form of Ampère's Law** 737  
**34-2 Maxwell's Equations** 741  
**34-3 Electromagnetic Waves from Maxwell's Equations (Optional)** 745  
 Summary 749  
 Problems and Questions 749

## 35 Electromagnetic Waves 751

- 35-1 Basic Properties of Electromagnetic Waves** 751  
**35-2 Sinusoidal Electromagnetic Waves and the Electromagnetic Spectrum** 752  
**35-3 Energy Density, Intensity, and Poynting Vectors** 754  
**35-4 Electric-Dipole Oscillator** 757  
**35-5 The Speed of Light** 759  
**35-6 Radiation Force and Pressure, and the Linear Momentum of an Electromagnetic Wave** 762  
**35-7 Polarization** 765  
 Summary 768  
 Problems and Questions 769

## 36 Ray Optics 772

- 36-1 Ray Optics and Wave Optics** 772  
**36-2 The Reciprocity Principle** 774  
**36-3 Rules of Reflection and Refraction** 775  
**36-4 Reflection** 777  
**36-5 Index of Refraction** 779  
**36-6 Refraction** 781  
**36-7 Total Internal Reflection** 784  
 Summary 785  
 Problems and Questions 786

## 37 Thin Lenses 792

- 37-1 Focal Length of a Converging Lens** 792  
**37-2 Ray Tracing to Locate a Real Image** 795  
**37-3 Ray Tracing to Locate a Virtual Image** 798  
**37-4 Diverging Lens** 799

- 37-5 Lens Combinations 801
- 37-6 The Lens Maker's Formula 804
- 37-7 Lens Aberrations 807
- 37-8 Spherical Mirrors (Optional) 808
- Summary 810
- Problems and Questions 811

## 38 Interference 816

- 38-1 Superposition and Interference of Waves 816
- 38-2 Interference from Two Point Sources 818
- 38-3 More on Interference from Two Point Sources 822
- 38-4 Young's Interference Experiment 824
- 38-5 The Diffraction Grating 826
- 38-6 Coherent and Incoherent Sources 829
- 38-7 Reflection and Change in Phase 830
- 38-8 Interference with Thin Films 832
- 38-9 The Michelson Interferometer 834
- Summary 835
- Problems and Questions 836

## 39 Diffraction 841

- 39-1 Radiation from a Row of Point Sources 841
- 39-2 Single-Slit Diffraction 844
- 39-3 The Double Slit Revisited 846
- 39-4 Diffraction and Resolution 847
- 39-5 X-Ray Diffraction 850
- 39-6  $I(\theta)$  for Single Slit (Optional) 853
- 39-7 The Diffraction Grating Revisited (Optional) 855
- Summary 856
- Problems and Questions 857

## 40 Special Relativity 860

- 40-1 The Constancy of the Speed of Light 860
- 40-2 Relativistic Velocity Transformations 861
- 40-3 Space and Time in Special Relativity 865
- 40-4 Relativistic Momentum 873
- 40-5 Relativistic Energy 875
- 40-6 Mass-Energy Equivalence and Bound Systems 878

- 40-7 The Lorentz Transformations (Optional) 880
- Summary 881
- Problems and Questions 882

## 41 Quantum Theory 886

- 41-1 Quantization 886
- 41-2 Photoelectric Effect 887
- 41-3 X-Ray Production and Bremsstrahlung 891
- 41-4 Compton Effect 892
- 41-5 Pair Production and Annihilation 895
- 41-6 Matter Waves 897
- 41-7 Probability Interpretation of the Wave Function 899
- 41-8 Complementarity Principle 902
- 41-9 Uncertainty Principle 903
- 41-10 The Quantum Description of a Confined Particle 908
- Summary 911
- Problems and Questions 913

## 42 Atomic Structure 917

- 42-1 Nuclear Scattering 917
- 42-2 The Hydrogen Spectrum 920
- 42-3 Bohr Theory of Hydrogen 921
- 42-4 The Four Quantum Numbers for Atomic Structure 927
- 42-5 Pauli Exclusion Principle and the Periodic Table 933
- 42-6 The Laser 937
- Summary 941
- Problems and Questions 941

## Appendixes

- A International System of Units A-1
- B SI Prefixes for Factors of Ten A-2
- C Physical Constants A-2
- D Conversion Factors A-4
- E References A-5

Answers to Selected Problems A-7

Index A-19