

1 Measurement 1

1.1 MEASURING THINGS, INCLUDING LENGTHS 1

What Is Physics? 1
 Measuring Things 1
 The International System of Units 2
 Changing Units 3
 Length 3
 Significant Figures and Decimal Places 4

1.2 TIME 5

Time 5

1.3 MASS 6

Mass 7

REVIEW & SUMMARY 8 PROBLEMS 8

2 Motion Along a Straight Line 13

2.1 POSITION, DISPLACEMENT, AND AVERAGE VELOCITY 13

What Is Physics? 13
 Motion 14
 Position and Displacement 14
 Average Velocity and Average Speed 15

2.2 INSTANTANEOUS VELOCITY AND SPEED 18

Instantaneous Velocity and Speed 18

2.3 ACCELERATION 20

Acceleration 20

2.4 CONSTANT ACCELERATION 23

Constant Acceleration: A Special Case 23
 Another Look at Constant Acceleration 27

2.5 FREE-FALL ACCELERATION 28

Free-Fall Acceleration 28

2.6 GRAPHICAL INTEGRATION IN MOTION ANALYSIS 30

Graphical Integration in Motion Analysis 30

REVIEW & SUMMARY 32 QUESTIONS 32 PROBLEMS 33

3 Vectors 44

3.1 VECTORS AND THEIR COMPONENTS 44

What Is Physics? 44
 Vectors and Scalars 44
 Adding Vectors Geometrically 45
 Components of Vectors 46

3.2 UNIT VECTORS, ADDING VECTORS BY COMPONENTS 50

Unit Vectors 50
 Adding Vectors by Components 50
 Vectors and the Laws of Physics 51

3.3 MULTIPLYING VECTORS 52

Multiplying Vectors 53

REVIEW & SUMMARY 58 QUESTIONS 59 PROBLEMS 60

4 Motion in Two and Three Dimensions 67

4.1 POSITION AND DISPLACEMENT 67

What Is Physics? 67
 Position and Displacement 68

4.2 AVERAGE VELOCITY AND INSTANTANEOUS VELOCITY 70

Average Velocity and Instantaneous Velocity 70

4.3 AVERAGE ACCELERATION AND INSTANTANEOUS ACCELERATION 73

Average Acceleration and Instantaneous Acceleration 73

4.4 PROJECTILE MOTION 75

Projectile Motion 76

4.5 UNIFORM CIRCULAR MOTION 82

Uniform Circular Motion 82

4.6 RELATIVE MOTION IN ONE DIMENSION 84

Relative Motion in One Dimension 78

4.7 RELATIVE MOTION IN TWO DIMENSIONS 86

Relative Motion in Two Dimensions 86

REVIEW & SUMMARY 88 QUESTIONS 89 PROBLEMS 90

5 Force and Motion—I 101

5.1 NEWTON'S FIRST AND SECOND LAWS 101

What Is Physics? 101
 Newtonian Mechanics 102
 Newton's First Law 102
 Force 103
 Mass 104
 Newton's Second Law 105

5.2 SOME PARTICULAR FORCES 109

Some Particular Forces 109

| | | | |
|--|-----|--|-----|
| 5.3 APPLYING NEWTON'S LAWS | 113 | 8.3 READING A POTENTIAL ENERGY CURVE | 196 |
| Newton's Third Law | 113 | Reading a Potential Energy Curve | 197 |
| Applying Newton's Laws | 115 | 8.4 WORK DONE ON A SYSTEM BY AN EXTERNAL FORCE | 201 |
| REVIEW & SUMMARY | 121 | QUESTIONS | 122 |
| PROBLEMS | 124 | Work Done on a System by an External Force | 201 |
| 6 Force and Motion—II | 132 | 8.5 CONSERVATION OF ENERGY | 205 |
| 6.1 FRICTION | 132 | Conservation of Energy | 205 |
| What Is Physics? | 132 | REVIEW & SUMMARY | 209 |
| Friction | 132 | QUESTIONS | 210 |
| Properties of Friction | 135 | PROBLEMS | 212 |
| 6.2 THE DRAG FORCE AND TERMINAL SPEED | 138 | 9 Center of Mass and Linear Momentum | 225 |
| The Drag Force and Terminal Speed | 138 | 9.1 CENTER OF MASS | 225 |
| 6.3 UNIFORM CIRCULAR MOTION | 140 | What Is Physics? | 225 |
| Uniform Circular Motion | 141 | The Center of Mass | 226 |
| REVIEW & SUMMARY | 145 | 9.2 NEWTON'S SECOND LAW FOR A SYSTEM OF PARTICLES | 229 |
| QUESTIONS | 145 | Newton's Second Law for a System of Particles | 230 |
| PROBLEMS | 146 | 9.3 LINEAR MOMENTUM | 234 |
| 7 Kinetic Energy and Work | 156 | Linear Momentum | 234 |
| 7.1 KINETIC ENERGY | 156 | The Linear Momentum of a System of Particles | 235 |
| What Is Physics? | 156 | 9.4 COLLISION AND IMPULSE | 236 |
| What Is Energy? | 156 | Collision and Impulse | 236 |
| Kinetic Energy | 157 | 9.5 CONSERVATION OF LINEAR MOMENTUM | 240 |
| 7.2 WORK AND KINETIC ENERGY | 158 | Conservation of Linear Momentum | 240 |
| Work | 158 | 9.6 MOMENTUM AND KINETIC ENERGY IN COLLISIONS | 243 |
| Work and Kinetic Energy | 159 | Momentum and Kinetic Energy in Collisions | 243 |
| 7.3 WORK DONE BY THE GRAVITATIONAL FORCE | 163 | Inelastic Collisions in One Dimension | 244 |
| Work Done by the Gravitational Force | 163 | 9.7 ELASTIC COLLISIONS IN ONE DIMENSION | 247 |
| 7.4 WORK DONE BY A SPRING FORCE | 167 | Elastic Collisions in One Dimension | 247 |
| Work Done by a Spring Force | 167 | 9.8 COLLISIONS IN TWO DIMENSIONS | 251 |
| 7.5 WORK DONE BY A GENERAL VARIABLE FORCE | 170 | Collisions in Two Dimensions | 251 |
| Work Done by a General Variable Force | 171 | 9.9 SYSTEMS WITH VARYING MASS: A ROCKET | 252 |
| 7.6 POWER | 174 | Systems with Varying Mass: A Rocket | 252 |
| Power | 174 | REVIEW & SUMMARY | 254 |
| QUESTIONS | 177 | QUESTIONS | 256 |
| PROBLEMS | 179 | PROBLEMS | 257 |
| 8 Potential Energy and Conservation of Energy | 186 | 10 Rotation | 270 |
| 8.1 POTENTIAL ENERGY | 186 | 10.1 ROTATIONAL VARIABLES | 270 |
| What Is Physics? | 187 | What Is Physics? | 271 |
| Work and Potential Energy | 187 | Rotational Variables | 272 |
| Path Independence of Conservative Forces | 188 | Are Angular Quantities Vectors? | 277 |
| Determining Potential Energy Values | 190 | | |
| 8.2 CONSERVATION OF MECHANICAL ENERGY | 193 | | |
| Conservation of Mechanical Energy | 193 | | |

| | | | |
|--|------------|--|------------|
| 10.2 ROTATION WITH CONSTANT ANGULAR ACCELERATION | 279 | 11.8 CONSERVATION OF ANGULAR MOMENTUM | 328 |
| Rotation with Constant Angular Acceleration | 279 | Conservation of Angular Momentum | 328 |
| 10.3 RELATING THE LINEAR AND ANGULAR VARIABLES | 281 | 11.9 PRECESSION OF A GYROSCOPE | 333 |
| Relating the Linear and Angular Variables | 281 | Precession of a Gyroscope | 333 |
| 10.4 KINETIC ENERGY OF ROTATION | 285 | REVIEW & SUMMARY | 334 |
| Kinetic Energy of Rotation | 285 | QUESTIONS | 335 |
| 10.5 CALCULATING THE ROTATIONAL INERTIA | 286 | PROBLEMS | 336 |
| Calculating the Rotational Inertia | 287 | 12 Equilibrium and Elasticity | 344 |
| 10.6 TORQUE | 291 | 12.1 EQUILIBRIUM | 344 |
| Torque | 291 | What Is Physics? | 344 |
| 10.7 NEWTON'S SECOND LAW FOR ROTATION | 292 | Equilibrium | 344 |
| Newton's Second Law for Rotation | 293 | The Requirements of Equilibrium | 346 |
| 10.8 WORK AND ROTATIONAL KINETIC ENERGY | 296 | The Center of Gravity | 347 |
| Work and Rotational Kinetic Energy | 297 | 12.2 SOME EXAMPLES OF STATIC EQUILIBRIUM | 349 |
| REVIEW & SUMMARY | 299 | Some Examples of Static Equilibrium | 349 |
| QUESTIONS | 300 | 12.3 ELASTICITY | 355 |
| PROBLEMS | 301 | Indeterminate Structures | 355 |
| 11 Rolling, Torque, and Angular Momentum | 310 | Elasticity | 356 |
| 11.1 ROLLING AS TRANSLATION AND ROTATION COMBINED | 310 | REVIEW & SUMMARY | 360 |
| What Is Physics? | 310 | QUESTIONS | 360 |
| Rolling as Translation and Rotation Combined | 310 | PROBLEMS | 362 |
| 11.2 FORCES AND KINETIC ENERGY OF ROLLING | 313 | 13 Gravitation | 372 |
| The Kinetic Energy of Rolling | 313 | 13.1 NEWTON'S LAW OF GRAVITATION | 372 |
| The Forces of Rolling | 314 | What Is Physics? | 372 |
| 11.3 THE YO-YO | 316 | Newton's Law of Gravitation | 373 |
| The Yo-Yo | 317 | 13.2 GRAVITATION AND THE PRINCIPLE OF SUPERPOSITION | 375 |
| 11.4 TORQUE REVISITED | 317 | Gravitation and the Principle of Superposition | 375 |
| Torque Revisited | 318 | 13.3 GRAVITATION NEAR EARTH'S SURFACE | 377 |
| 11.5 ANGULAR MOMENTUM | 320 | Gravitation Near Earth's Surface | 378 |
| Angular Momentum | 320 | 13.4 GRAVITATION INSIDE EARTH | 381 |
| 11.6 NEWTON'S SECOND LAW IN ANGULAR FORM | 322 | Gravitation Inside Earth | 381 |
| Newton's Second Law in Angular Form | 322 | 13.5 GRAVITATIONAL POTENTIAL ENERGY | 383 |
| 11.7 ANGULAR MOMENTUM OF A RIGID BODY | 325 | Gravitational Potential Energy | 383 |
| The Angular Momentum of a System of Particles | 325 | 13.6 PLANETS AND SATELLITES: KEPLER'S LAWS | 387 |
| The Angular Momentum of a Rigid Body | | Planets and Satellites: Kepler's Laws | 388 |
| Rotating About a Fixed Axis | 326 | 13.7 SATELLITES: ORBITS AND ENERGY | 390 |
| | | Satellites: Orbits and Energy | 391 |
| | | 13.8 EINSTEIN AND GRAVITATION | 393 |
| | | Einstein and Gravitation | 393 |
| | | REVIEW & SUMMARY | 396 |
| | | QUESTIONS | 397 |
| | | PROBLEMS | 399 |

| | | | |
|--|-----|---|-----|
| 14 Fluids | 406 | 16 Waves—I | 468 |
| 14.1 FLUIDS, DENSITY, AND PRESSURE | 406 | 16.1 TRANSVERSE WAVES | 468 |
| What Is Physics? | 406 | What Is Physics? | 469 |
| What Is a Fluid? | 406 | Types of Waves | 469 |
| Density and Pressure | 407 | Transverse and Longitudinal Waves | 469 |
| 14.2 FLUIDS AT REST | 409 | Wavelength and Frequency | 470 |
| Fluids at Rest | 409 | The Speed of a Traveling Wave | 473 |
| 14.3 MEASURING PRESSURE | 412 | 16.2 WAVE SPEED ON A STRETCHED STRING | 476 |
| Measuring Pressure | 412 | Wave Speed on a Stretched String | 476 |
| 14.4 PASCAL'S PRINCIPLE | 413 | 16.3 ENERGY AND POWER OF A WAVE TRAVELING ALONG A STRING | 478 |
| Pascal's Principle | 413 | Energy and Power of a Wave Traveling Along a String | 478 |
| 14.5 ARCHIMEDES' PRINCIPLE | 415 | 16.4 THE WAVE EQUATION | 480 |
| Archimedes' Principle | 415 | The Wave Equation | 480 |
| 14.6 THE EQUATION OF CONTINUITY | 419 | 16.5 INTERFERENCE OF WAVES | 482 |
| Ideal Fluids in Motion | 420 | The Principle of Superposition for Waves | 483 |
| The Equation of Continuity | 421 | Interference of Waves | 483 |
| 14.7 BERNOULLI'S EQUATION | 423 | 16.6 PHASORS | 487 |
| Bernoulli's Equation | 424 | Phasors | 487 |
| REVIEW & SUMMARY | 426 | 16.7 STANDING WAVES AND RESONANCE | 490 |
| PROBLEMS | 428 | Standing Waves | 491 |
| 15 Oscillations | 436 | Standing Waves and Resonance | 493 |
| 15.1 SIMPLE HARMONIC MOTION | 436 | REVIEW & SUMMARY | 495 |
| What Is Physics? | 437 | QUESTIONS | 496 |
| Simple Harmonic Motion | 437 | PROBLEMS | 497 |
| The Force Law for Simple Harmonic Motion | 442 | 17 Waves—II | 505 |
| 15.2 ENERGY IN SIMPLE HARMONIC MOTION | 444 | 17.1 SPEED OF SOUND | 505 |
| Energy in Simple Harmonic Motion | 444 | What Is Physics? | 505 |
| 15.3 AN ANGULAR SIMPLE HARMONIC OSCILLATOR | 446 | Sound Waves | 505 |
| An Angular Simple Harmonic Oscillator | 446 | The Speed of Sound | 506 |
| 15.4 PENDULUMS, CIRCULAR MOTION | 448 | 17.2 TRAVELING SOUND WAVES | 508 |
| Pendulums | 448 | Traveling Sound Waves | 509 |
| Simple Harmonic Motion and Uniform Circular Motion | 451 | 17.3 INTERFERENCE | 511 |
| 15.5 DAMPED SIMPLE HARMONIC MOTION | 453 | Interference | 511 |
| Damped Simple Harmonic Motion | 453 | 17.4 INTENSITY AND SOUND LEVEL | 515 |
| 15.6 FORCED OSCILLATIONS AND RESONANCE | 456 | Intensity and Sound Level | 515 |
| Forced Oscillations and Resonance | 456 | 17.5 SOURCES OF MUSICAL SOUND | 518 |
| REVIEW & SUMMARY | 457 | Sources of Musical Sound | 518 |
| QUESTIONS | 458 | 17.6 BEATS | 522 |
| PROBLEMS | 459 | Beats | 522 |

17.7 THE DOPPLER EFFECT 524

The Doppler Effect 525

17.8 SUPERSONIC SPEEDS, SHOCK WAVES 529

Supersonic Speeds, Shock Waves 529

REVIEW & SUMMARY 530 QUESTIONS 531

PROBLEMS 532

18 Temperature, Heat, and the First Law of Thermodynamics 541

18.1 TEMPERATURE 541

What Is Physics? 541

Temperature 542

The Zeroth Law of Thermodynamics 542

Measuring Temperature 543

18.2 THE CELSIUS AND FAHRENHEIT SCALES 545

The Celsius and Fahrenheit Scales 546

18.3 THERMAL EXPANSION 547

Thermal Expansion 548

18.4 ABSORPTION OF HEAT 550

Temperature and Heat 551

The Absorption of Heat by Solids and Liquids 552

18.5 THE FIRST LAW OF THERMODYNAMICS 556

A Closer Look at Heat and Work 557

The First Law of Thermodynamics 559

Some Special Cases of the First Law of Thermodynamics 560

18.6 HEAT TRANSFER MECHANISMS 562

Heat Transfer Mechanisms 563

REVIEW & SUMMARY 567 QUESTIONS 569 PROBLEMS 570

19 The Kinetic Theory of Gases 578

19.1 AVOGADRO'S NUMBER 578

What Is Physics? 578

Avogadro's Number 579

19.2 IDEAL GASES 579

Ideal Gases 580

19.3 PRESSURE, TEMPERATURE, AND RMS SPEED 583

Pressure, Temperature, and RMS Speed 583

19.4 TRANSLATIONAL KINETIC ENERGY 586

Translational Kinetic Energy 586

19.5 MEAN FREE PATH 587

Mean Free Path 587

19.6 THE DISTRIBUTION OF MOLECULAR SPEEDS 589

The Distribution of Molecular Speeds 590

19.7 THE MOLAR SPECIFIC HEATS OF AN IDEAL GAS 593

The Molar Specific Heats of an Ideal Gas 593

19.8 DEGREES OF FREEDOM AND MOLAR SPECIFIC HEATS 597

Degrees of Freedom and Molar Specific Heats 597

A Hint of Quantum Theory 600

19.9 THE ADIABATIC EXPANSION OF AN IDEAL GAS 600

The Adiabatic Expansion of an Ideal Gas 601

REVIEW & SUMMARY 605 QUESTIONS 606 PROBLEMS 606

20 Entropy and the Second Law of Thermodynamics 613

20.1 ENTROPY 613

What Is Physics? 614

Irreversible Processes and Entropy 614

Change in Entropy 615

The Second Law of Thermodynamics 619

20.2 ENTROPY IN THE REAL WORLD: ENGINES 620

Entropy in the Real World: Engines 621

20.3 REFRIGERATORS AND REAL ENGINES 626

Entropy in the Real World: Refrigerators 627

The Efficiencies of Real Engines 628

20.4 A STATISTICAL VIEW OF ENTROPY 629

A Statistical View of Entropy 629

REVIEW & SUMMARY 633 QUESTIONS 634 PROBLEMS 635

21 Coulomb's Law 641

21.1 COULOMB'S LAW 641

What Is Physics? 642

Electric Charge 642

Conductors and Insulators 644

Coulomb's Law 645

21.2 CHARGE IS QUANTIZED 652

Charge Is Quantized 652

21.3 CHARGE IS CONSERVED 654

Charge Is Conserved 654

REVIEW & SUMMARY 656 QUESTIONS 657

PROBLEMS 659

| | | | |
|--|-----|--|-----|
| 22 Electric Fields | 665 | 24 Electric Potential | 724 |
| 22.1 THE ELECTRIC FIELD | 665 | 24.1 ELECTRIC POTENTIAL | 724 |
| What Is Physics? | 665 | What Is Physics? | 724 |
| The Electric Field | 666 | Electric Potential and Electric Potential Energy | 725 |
| Electric Field Lines | 666 | 24.2 EQUIPOTENTIAL SURFACES AND THE ELECTRIC FIELD | 729 |
| 22.2 THE ELECTRIC FIELD DUE TO A CHARGED PARTICLE | 668 | Equipotential Surfaces | 729 |
| The Electric Field Due to a Point Charge | 668 | Calculating the Potential from the Field | 730 |
| 22.3 THE ELECTRIC FIELD DUE TO A DIPOLE | 670 | 24.3 POTENTIAL DUE TO A CHARGED PARTICLE | 733 |
| The Electric Field Due to an Electric Dipole | 671 | Potential Due to a Charged Particle | 733 |
| 22.4 THE ELECTRIC FIELD DUE TO A LINE OF CHARGE | 673 | Potential Due to a Group of Charged Particles | 735 |
| The Electric Field Due to a Line of Charge | 674 | 24.4 POTENTIAL DUE TO AN ELECTRIC DIPOLE | 736 |
| 22.5 THE ELECTRIC FIELD DUE TO A CHARGED DISK | 679 | Potential Due to an Electric Dipole | 737 |
| The Electric Field Due to a Charged Disk | 679 | 24.5 POTENTIAL DUE TO A CONTINUOUS CHARGE DISTRIBUTION | 738 |
| 22.6 A POINT CHARGE IN AN ELECTRIC FIELD | 680 | Potential Due to a Continuous Charge Distribution | 738 |
| A Point Charge in an Electric Field | 681 | 24.6 CALCULATING THE FIELD FROM THE POTENTIAL | 741 |
| 22.7 A DIPOLE IN AN ELECTRIC FIELD | 683 | Calculating the Field from the Potential | 741 |
| A Dipole in an Electric Field | 684 | 24.7 ELECTRIC POTENTIAL ENERGY OF A SYSTEM OF CHARGED PARTICLES | 743 |
| REVIEW & SUMMARY | 687 | Electric Potential Energy of a System of Charged Particles | 743 |
| QUESTIONS | 687 | 24.8 POTENTIAL OF A CHARGED ISOLATED CONDUCTOR | 746 |
| PROBLEMS | 689 | Potential of a Charged Isolated Conductor | 746 |
| 23 Gauss' Law | 696 | REVIEW & SUMMARY | 749 |
| 23.1 ELECTRIC FLUX | 696 | QUESTIONS | 750 |
| What Is Physics? | 696 | PROBLEMS | 751 |
| Electric Flux | 697 | 25 Capacitance | 759 |
| 23.2 GAUSS' LAW | 701 | 25.1 CAPACITANCE | 759 |
| Gauss' Law | 702 | What Is Physics? | 759 |
| Gauss' Law and Coulomb's Law | 703 | Capacitance | 759 |
| 23.3 A CHARGED ISOLATED CONDUCTOR | 705 | 25.2 CALCULATING THE CAPACITANCE | 761 |
| A Charged Isolated Conductor | 705 | Calculating the Capacitance | 762 |
| 23.4 APPLYING GAUSS' LAW: CYLINDRICAL SYMMETRY | 708 | 25.3 CAPACITORS IN PARALLEL AND IN SERIES | 765 |
| Applying Gauss' Law: Cylindrical Symmetry | 708 | Capacitors in Parallel and in Series | 766 |
| 23.5 APPLYING GAUSS' LAW: PLANAR SYMMETRY | 710 | 25.4 ENERGY STORED IN AN ELECTRIC FIELD | 770 |
| Applying Gauss' Law: Planar Symmetry | 711 | Energy Stored in an Electric Field | 771 |
| 23.6 APPLYING GAUSS' LAW: SPHERICAL SYMMETRY | 713 | 25.5 CAPACITOR WITH A DIELECTRIC | 774 |
| Applying Gauss' Law: Spherical Symmetry | 714 | Capacitor with a Dielectric | 774 |
| REVIEW & SUMMARY | 715 | Dielectrics: An Atomic View | 776 |
| QUESTIONS | 715 | | |
| PROBLEMS | 717 | | |

25.6 DIELECTRICS AND GAUSS' LAW 778

Dielectrics and Gauss' Law 778

REVIEW & SUMMARY 781 QUESTIONS 781 PROBLEMS 782

26 Current and Resistance 789

26.1 ELECTRIC CURRENT 789

What Is Physics? 789

Electric Current 790

26.2 CURRENT DENSITY 792

Current Density 793

26.3 RESISTANCE AND RESISTIVITY 796

Resistance and Resistivity 797

26.4 OHM'S LAW 801

Ohm's Law 801

A Microscopic View of Ohm's Law 803

26.5 POWER, SEMICONDUCTORS, SUPERCONDUCTORS 805

Power in Electric Circuits 805

Semiconductors 807

Superconductors 808

REVIEW & SUMMARY 808 QUESTIONS 809 PROBLEMS 810

27 Circuits 816

27.1 SINGLE-LOOP CIRCUITS 816

What Is Physics? 817

"Pumping" Charges 817

Work, Energy, and Emf 818

Calculating the Current in a Single-Loop Circuit 819

Other Single-Loop Circuits 821

Potential Difference Between Two Points 823

27.2 MULTILoop CIRCUITS 826

Multiloop Circuits 826

27.3 THE AMMETER AND THE VOLTMETER 833

The Ammeter and the Voltmeter 833

27.4 RC CIRCUITS 833

RC Circuits 834

REVIEW & SUMMARY 838 QUESTIONS 839 PROBLEMS 840

28 Magnetic Fields 850

28.1 MAGNETIC FIELDS AND THE DEFINITION OF \vec{B} 850

What Is Physics? 850

What Produces a Magnetic Field? 851

The Definition of \vec{B} 851

28.2 CROSSED FIELDS: DISCOVERY OF THE ELECTRON 855

Crossed Fields: Discovery of the Electron 856

28.3 CROSSED FIELDS: THE HALL EFFECT 857

Crossed Fields: The Hall Effect 858

28.4 A CIRCULATING CHARGED PARTICLE 861

A Circulating Charged Particle 862

28.5 CYCLOTRONS AND SYNCHROTRONS 866

Cyclotrons and Synchrotrons 866

28.6 MAGNETIC FORCE ON A CURRENT-CARRYING WIRE 869

Magnetic Force on a Current-Carrying Wire 869

28.7 TORQUE ON A CURRENT LOOP 872

Torque on a Current Loop 872

28.8 THE MAGNETIC DIPOLE MOMENT 874

The Magnetic Dipole Moment 874

REVIEW & SUMMARY 876 QUESTIONS 877 PROBLEMS 879

29 Magnetic Fields Due to Currents 886

29.1 MAGNETIC FIELD DUE TO A CURRENT 886

What Is Physics? 886

Calculating the Magnetic Field Due to a Current 887

29.2 FORCE BETWEEN TWO PARALLEL CURRENTS 892

Force Between Two Parallel Currents 893

29.3 AMPERE'S LAW 894

Ampere's Law 894

29.4 SOLENOIDS AND TOROIDS 899

Solenoids and Toroids 899

29.5 A CURRENT-CARRYING COIL AS A MAGNETIC DIPOLE 901

A Current-Carrying Coil as a Magnetic Dipole 902

REVIEW & SUMMARY 904 QUESTIONS 905 PROBLEMS 906

30 Induction and Inductance 915

30.1 FARADAY'S LAW AND LENZ'S LAW 915

What Is Physics? 915

Two Experiments 916

Faraday's Law of Induction 916

Lenz's Law 919

30.2 INDUCTION AND ENERGY TRANSFERS 923

Induction and Energy Transfers 923

30.3 INDUCED ELECTRIC FIELDS 927

Induced Electric Fields 928

30.4 INDUCTORS AND INDUCTANCE 932

Inductors and Inductance 932

30.5 SELF-INDUCTION 934

Self-Induction 934

30.6 *RL* CIRCUITS 935*RL* Circuits 936**30.7 ENERGY STORED IN A MAGNETIC FIELD 940**

Energy Stored in a Magnetic Field 940

30.8 ENERGY DENSITY OF A MAGNETIC FIELD 942

Energy Density of a Magnetic Field 942

30.9 MUTUAL INDUCTION 943

Mutual Induction 943

REVIEW & SUMMARY 945 QUESTIONS 946
PROBLEMS 947**31 Electromagnetic Oscillations and Alternating Current 956****31.1 *LC* OSCILLATIONS 956**

What Is Physics? 957

LC Oscillations, Qualitatively 957

The Electrical–Mechanical Analogy 959

LC Oscillations, Quantitatively 960**31.2 DAMPED OSCILLATIONS IN AN *RLC* CIRCUIT 963**Damped Oscillations in an *RLC* Circuit 964**31.3 FORCED OSCILLATIONS OF THREE SIMPLE CIRCUITS 966**

Alternating Current 966

Forced Oscillations 967

Three Simple Circuits 968

31.4 THE SERIES *RLC* CIRCUIT 974The Series *RLC* Circuit 975**31.5 POWER IN ALTERNATING-CURRENT CIRCUITS 982**

Power in Alternating-Current Circuits 982

31.6 TRANSFORMERS 985

Transformers 985

REVIEW & SUMMARY 989 QUESTIONS 990
PROBLEMS 991**32 Maxwell's Equations; Magnetism of Matter 998****32.1 GAUSS' LAW FOR MAGNETIC FIELDS 998**

What Is Physics? 998

Gauss' Law for Magnetic Fields 999

32.2 INDUCED MAGNETIC FIELDS 1000

Induced Magnetic Fields 1000

32.3 DISPLACEMENT CURRENT 1003

Displacement Current 1004

Maxwell's Equations 1007

32.4 MAGNETS 1007

Magnets 1007

32.5 MAGNETISM AND ELECTRONS 1009

Magnetism and Electrons 1010

Magnetic Materials 1014

32.6 DIAMAGNETISM 1015

Diamagnetism 1015

32.7 PARAMAGNETISM 1016

Paramagnetism 1017

32.8 FERROMAGNETISM 1019

Ferromagnetism 1019

REVIEW & SUMMARY 1023 QUESTIONS 1024
PROBLEMS 1026**33 Electromagnetic Waves 1032****33.1 ELECTROMAGNETIC WAVES 1032**

What Is Physics? 1032

Maxwell's Rainbow 1033

The Traveling Electromagnetic Wave, Qualitatively 1034

The Traveling Electromagnetic Wave, Quantitatively 1037

33.2 ENERGY TRANSPORT AND THE POYNTING VECTOR 1040

Energy Transport and the Poynting Vector 1041

33.3 RADIATION PRESSURE 1043

Radiation Pressure 1043

33.4 POLARIZATION 1045

Polarization 1045

33.5 REFLECTION AND REFRACTION 1050

Reflection and Refraction 1051

33.6 TOTAL INTERNAL REFLECTION 1056

Total Internal Reflection 1056

33.7 POLARIZATION BY REFLECTION 1059

Polarization by Reflection 1059

REVIEW & SUMMARY 1061 QUESTIONS 1062

PROBLEMS 1063

34 Images 1072**34.1 IMAGES AND PLANE MIRRORS** 1072

What Is Physics? 1072

Two Types of Image 1072

Plane Mirrors 1074

34.2 SPHERICAL MIRRORS 1076

Spherical Mirrors 1077

Images from Spherical Mirrors 1078

34.3 SPHERICAL REFRACTING SURFACES 1083

Spherical Refracting Surfaces 1084

34.4 THIN LENSES 1086

Thin Lenses 1087

34.5 OPTICAL INSTRUMENTS 1094

Optical Instruments 1094

34.6 THREE PROOFS 1098

REVIEW & SUMMARY 1100 QUESTIONS 1101

PROBLEMS 1102

35 Interference 1111**35.1 LIGHT AS A WAVE** 1111

What Is Physics? 1111

Light as a Wave 1112

35.2 YOUNG'S INTERFERENCE EXPERIMENT 1117

Diffraction 1117

Young's Interference Experiment 1118

35.3 INTERFERENCE AND DOUBLE-SLIT INTENSITY 1122

Coherence 1122

Intensity in Double-Slit Interference 1123

35.4 INTERFERENCE FROM THIN FILMS 1126

Interference from Thin Films 1127

35.5 MICHELSON'S INTERFEROMETER 1135

Michelson's Interferometer 1135

REVIEW & SUMMARY 1138 QUESTIONS 1139

PROBLEMS 1140

36 Diffraction 1148**36.1 SINGLE-SLIT DIFFRACTION** 1148

What Is Physics? 1148

Diffraction and the Wave Theory of Light 1149

Diffraction by a Single Slit: Locating the Minima 1150

36.2 INTENSITY IN SINGLE-SLIT DIFFRACTION 1153

Intensity in Single-Slit Diffraction, Qualitatively 1153

Intensity in Single-Slit Diffraction, Quantitatively 1155

36.3 DIFFRACTION BY A CIRCULAR APERTURE 1158

Diffraction by a Circular Aperture 1158

36.4 DIFFRACTION BY A DOUBLE SLIT 1162

Diffraction by a Double Slit 1162

36.5 DIFFRACTION GRATINGS 1166

Diffraction Gratings 1166

36.6 GRATINGS: DISPERSION AND RESOLVING POWER 1170

Gratings: Dispersion and Resolving Power 1170

36.7 X-RAY DIFFRACTION 1173

X-Ray Diffraction 1173

REVIEW & SUMMARY 1176 QUESTIONS 1177

PROBLEMS 1178

37 Relativity 1186**37.1 SIMULTANEITY AND TIME DILATION** 1186

What Is Physics? 1186

The Postulates 1187

Measuring an Event 1188

The Relativity of Simultaneity 1190

The Relativity of Time 1191

37.2 THE RELATIVITY OF LENGTH 1196

The Relativity of Length 1196

37.3 THE LORENTZ TRANSFORMATION 1199

The Lorentz Transformation 1200

Some Consequences of the Lorentz Equations 1202

37.4 THE RELATIVITY OF VELOCITIES 1204

The Relativity of Velocities 1204

37.5 DOPPLER EFFECT FOR LIGHT 1205

Doppler Effect for Light 1206

37.6 MOMENTUM AND ENERGY 1209

A New Look at Momentum 1209

| | | | |
|---|------|--|------|
| A New Look at Energy | 1210 | More Electron Traps | 1271 |
| REVIEW & SUMMARY | 1215 | Two- and Three-Dimensional Electron Traps | 1272 |
| QUESTIONS | 1216 | | |
| PROBLEMS | 1217 | | |
| 38 Photons and Matter Waves | 1225 | 39.5 THE HYDROGEN ATOM | 1275 |
| 38.1 THE PHOTON, THE QUANTUM OF LIGHT | 1225 | The Hydrogen Atom Is an Electron Trap | 1276 |
| What Is Physics? | 1225 | The Bohr Model of Hydrogen, a Lucky Break | 1276 |
| The Photon, the Quantum of Light | 1226 | Schrödinger's Equation and the Hydrogen Atom | 1278 |
| | | REVIEW & SUMMARY | 1286 |
| 38.2 THE PHOTOELECTRIC EFFECT | 1227 | QUESTIONS | 1287 |
| The Photoelectric Effect | 1228 | PROBLEMS | 1288 |
| 38.3 PHOTONS, MOMENTUM, COMPTON SCATTERING, LIGHT INTERFERENCE | 1230 | 40 All About Atoms | 1293 |
| Photons Have Momentum | 1231 | 40.1 PROPERTIES OF ATOMS | 1293 |
| Light as a Probability Wave | 1234 | What Is Physics? | 1294 |
| | | Some Properties of Atoms | 1294 |
| 38.4 THE BIRTH OF QUANTUM PHYSICS | 1236 | Angular Momentum, Magnetic Dipole Moments | 1296 |
| The Birth of Quantum Physics | 1237 | 40.2 THE STERN–GERLACH EXPERIMENT | 1300 |
| 38.5 ELECTRONS AND MATTER WAVES | 1238 | The Stern–Gerlach Experiment | 1300 |
| Electrons and Matter Waves | 1239 | 40.3 MAGNETIC RESONANCE | 1303 |
| 38.6 SCHRÖDINGER'S EQUATION | 1242 | Magnetic Resonance | 1303 |
| Schrödinger's Equation | 1242 | 40.4 EXCLUSION PRINCIPLE AND MULTIPLE ELECTRONS IN A TRAP | 1304 |
| 38.7 HEISENBERG'S UNCERTAINTY PRINCIPLE | 1244 | The Pauli Exclusion Principle | 1304 |
| Heisenberg's Uncertainty Principle | 1245 | Multiple Electrons in Rectangular Traps | 1305 |
| 38.8 REFLECTION FROM A POTENTIAL STEP | 1246 | 40.5 BUILDING THE PERIODIC TABLE | 1308 |
| Reflection from a Potential Step | 1246 | Building the Periodic Table | 1308 |
| 38.9 TUNNELING THROUGH A POTENTIAL BARRIER | 1248 | 40.6 X RAYS AND THE ORDERING OF THE ELEMENTS | 1310 |
| Tunneling Through a Potential Barrier | 1248 | X Rays and the Ordering of the Elements | 1311 |
| REVIEW & SUMMARY | 1251 | 40.7 LASERS | 1314 |
| QUESTIONS | 1252 | Lasers and Laser Light | 1315 |
| PROBLEMS | 1253 | How Lasers Work | 1316 |
| 39 More About Matter Waves | 1258 | REVIEW & SUMMARY | 1319 |
| 39.1 ENERGIES OF A TRAPPED ELECTRON | 1258 | QUESTIONS | 1320 |
| What Is Physics? | 1258 | PROBLEMS | 1321 |
| String Waves and Matter Waves | 1259 | 41 Conduction of Electricity in Solids | 1327 |
| Energies of a Trapped Electron | 1260 | 41.1 THE ELECTRICAL PROPERTIES OF METALS | 1327 |
| 39.2 WAVE FUNCTIONS OF A TRAPPED ELECTRON | 1264 | What Is Physics? | 1328 |
| Wave Functions of a Trapped Electron | 1264 | The Electrical Properties of Solids | 1328 |
| 39.3 AN ELECTRON IN A FINITE WELL | 1268 | Energy Levels in a Crystalline Solid | 1329 |
| An Electron in a Finite Well | 1268 | Insulators | 1330 |
| 39.4 TWO- AND THREE-DIMENSIONAL ELECTRON TRAPS | 1270 | Metals | 1330 |
| | | 41.2 SEMICONDUCTORS AND DOPING | 1336 |
| | | Semiconductors | 1337 |
| | | Doped Semiconductors | 1338 |

41.3 THE p - n JUNCTION AND THE TRANSISTOR 1341

The p - n Junction 1341

The Junction Rectifier 1343

The Light-Emitting Diode (LED) 1344

The Transistor 1345

REVIEW & SUMMARY 1346 QUESTIONS 1347

PROBLEMS 1348

42 Nuclear Physics 1352

42.1 DISCOVERING THE NUCLEUS 1352

What Is Physics? 1352

Discovering the Nucleus 1352

42.2 SOME NUCLEAR PROPERTIES 1355

Some Nuclear Properties 1356

42.3 RADIOACTIVE DECAY 1362

Radioactive Decay 1362

42.4 ALPHA DECAY 1365

Alpha Decay 1365

42.5 BETA DECAY 1368

Beta Decay 1368

42.6 RADIOACTIVE DATING 1371

Radioactive Dating 1371

42.7 MEASURING RADIATION DOSAGE 1372

Measuring Radiation Dosage 1372

42.8 NUCLEAR MODELS 1373

Nuclear Models 1373

REVIEW & SUMMARY 1376 QUESTIONS 1377

PROBLEMS 1378

43 Energy from the Nucleus 1385

43.1 NUCLEAR FISSION 1385

What Is Physics? 1385

Nuclear Fission: The Basic Process 1386

A Model for Nuclear Fission 1388

43.2 THE NUCLEAR REACTOR 1392

The Nuclear Reactor 1392

43.3 A NATURAL NUCLEAR REACTOR 1396

A Natural Nuclear Reactor 1396

43.4 THERMONUCLEAR FUSION: THE BASIC PROCESS 1398

Thermonuclear Fusion: The Basic Process 1398

43.5 THERMONUCLEAR FUSION IN THE SUN AND OTHER STARS 1400

Thermonuclear Fusion in the Sun and Other Stars 1400

43.6 CONTROLLED THERMONUCLEAR FUSION 1402

Controlled Thermonuclear Fusion 1402

REVIEW & SUMMARY 1405 QUESTIONS 1405

PROBLEMS 1406

44 Quarks, Leptons, and the Big Bang 1410

44.1 GENERAL PROPERTIES OF ELEMENTARY PARTICLES 1410

What Is Physics? 1410

Particles, Particles, Particles 1411

An Interlude 1415

44.2 LEPTONS, HADRONS, AND STRANGENESS 1419

The Leptons 1419

The Hadrons 1421

Still Another Conservation Law 1422

The Eightfold Way 1423

44.3 QUARKS AND MESSENGER PARTICLES 1425

The Quark Model 1425

The Basic Forces and Messenger Particles 1428

44.4 COSMOLOGY 1431

A Pause for Reflection 1431

The Universe Is Expanding 1432

The Cosmic Background Radiation 1433

Dark Matter 1434

The Big Bang 1434

A Summing Up 1437

REVIEW & SUMMARY 1438 QUESTIONS 1438

PROBLEMS 1439

APPENDICES

A The International System of Units (SI) A-1

B Some Fundamental Constants of Physics A-3

C Some Astronomical Data A-4

D Conversion Factors A-5

E Mathematical Formulas A-9

F Properties of the Elements A-12

G Periodic Table of the Elements A-15

ANSWERS

To Checkpoints and Odd-Numbered Questions and Problems AN-1

INDEX I-1