CONTENTS

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 6

REVIEW & SUMMARY 8 PROBLEMS 8

2 Motion Along a Straight Line 11

2-1 POSITION, DISPLACEMENT, AND AVERAGE VELOCITY 11

What Is Physics? 11

Motion 12

Position and Displacement 12

Average Velocity and Average Speed 13

2-2 INSTANTANEOUS VELOCITY AND SPEED 16

Instantaneous Velocity and Speed 16

2-3 ACCELERATION 18

Acceleration 18

2-4 CONSTANT ACCELERATION 21

Constant Acceleration: A Special Case 21

Another Look at Constant Acceleration 24

2-5 FREE-FALL ACCELERATION 25

Free-Fall Acceleration 25

2-6 GRAPHICAL INTEGRATION IN MOTION ANALYSIS 27

Graphical Integration in Motion Analysis 27

REVIEW & SUMMARY 28 PROBLEMS 29

3 Vectors 34

3-1 VECTORS AND THEIR COMPONENTS 34

What Is Physics? 34

Vectors and Scalars 34

Adding Vectors Geometrically 35

Components of Vectors 36

3-2 UNIT VECTORS, ADDING VECTORS BY COMPONENTS 40

Unit Vectors 40

Adding Vectors by Components 40

Vectors and the Laws of Physics 41

3-3 MULTIPLYING VECTORS 44

Multiplying Vectors 44

REVIEW & SUMMARY 49 PROBLEMS 50

4 Motion in Two and Three Dimensions 53

4-1 POSITION AND DISPLACEMENT 53

What Is Physics? 53

Position and Displacement 54

4-2 AVERAGE VELOCITY AND INSTANTANEOUS VELOCITY 55

Average Velocity and Instantaneous Velocity 56

4-3 AVERAGE ACCELERATION AND INSTANTANEOUS ACCELERATION 58

Average Acceleration and Instantaneous Acceleration 59

4-4 PROJECTILE MOTION 61

Projectile Motion 61

4-5 UNIFORM CIRCULAR MOTION 67

Uniform Circular Motion 67

4-6 RELATIVE MOTION IN ONE DIMENSION 69

Relative Motion in One Dimension 69

4-7 RELATIVE MOTION IN TWO DIMENSIONS 71

Relative Motion in Two Dimensions 71

REVIEW & SUMMARY 72 PROBLEMS 73

5 Force and Motion—I 80

5-1 NEWTON'S FIRST AND SECOND LAWS 80

What Is Physics? 80

Newtonian Mechanics 81

Newton's First Law 81

Force 82

Mass 83

Newton's Second Law 84

5-2 SOME PARTICULAR FORCES 88

Some Particular Forces 88

5-3 APPLYING NEWTON'S LAWS 92

Newton's Third Law 92

Applying Newton's Laws 94

REVIEW & SUMMARY 100 PROBLEMS 100

6 Force and Motion—II 106
6-1 FRICTION 106
What Is Physics? 106
Friction 106
Properties of Friction 108
6-2 THE DRAG FORCE AND TERMINAL SPEED 112
The Drag Force and Terminal Speed 112
6-3 UNIFORM CIRCULAR MOTION 115
Uniform Circular Motion 115
REVIEW & SUMMARY 120 PROBLEMS 121

7 Kinetic Energy and Work 127
7-1 KINETIC ENERGY 127
What Is Physics? 127
What Is Energy? 127
Kinetic Energy 128
7-2 WORK AND KINETIC ENERGY 129
Work 129
Work and Kinetic Energy 130
7-3 WORK DONE BY THE GRAVITATIONAL FORCE 133
Work Done by the Gravitational Force 134
7-4 WORK DONE BY A SPRING FORCE 137
Work Done by a Spring Force 137
7-5 WORK DONE BY A GENERAL VARIABLE FORCE 140
Work Done by a General Variable Force 140
7-6 POWER 144
Power 144
REVIEW & SUMMARY 146 PROBLEMS 147

8 Potential Energy and Conservation of Energy 151
8-1 POTENTIAL ENERGY 151
What Is Physics? 151
Work and Potential Energy 152
Path Independence of Conservative Forces 153
Determining Potential Energy Values 155
8-2 CONSERVATION OF MECHANICAL ENERGY 158
Conservation of Mechanical Energy 158
8-3 READING A POTENTIAL ENERGY CURVE 161
Reading a Potential Energy Curve 161
8-4 WORK DONE ON A SYSTEM BY AN EXTERNAL FORCE 165
Work Done on a System by an External Force 166
8-5 CONSERVATION OF ENERGY 169
Conservation of Energy 169
REVIEW & SUMMARY 173 PROBLEMS 174

9 Center of Mass and Linear Momentum 182
9-1 CENTER OF MASS 182
What Is Physics? 182
The Center of Mass 183
9-2 NEWTON'S SECOND LAW FOR A SYSTEM OF PARTICLES 188
Newton's Second Law for a System of Particles 188
9-3 LINEAR MOMENTUM 192
Linear Momentum 192
The Linear Momentum of a System of Particles 193
9-4 COLLISION AND IMPULSE 194
Collision and Impulse 194
9-5 CONSERVATION OF LINEAR MOMENTUM 198
Conservation of Linear Momentum 198
9-6 MOMENTUM AND KINETIC ENERGY IN COLLISIONS 201
Momentum and Kinetic Energy in Collisions 201
Inelastic Collisions in One Dimension 202
9-7 ELASTIC COLLISIONS IN ONE DIMENSION 205
Elastic Collisions in One Dimension 205
9-8 COLLISIONS IN TWO DIMENSIONS 208
Collisions in Two Dimensions 208
9-9 SYSTEMS WITH VARYING MASS: A ROCKET 209
Systems with Varying Mass: A Rocket 209
REVIEW & SUMMARY 211 PROBLEMS 212

10 Rotation 221
10-1 ROTATIONAL VARIABLES 221
What Is Physics? 222
Rotational Variables 223
Are Angular Quantities Vectors? 228
10-2 ROTATION WITH CONSTANT ANGULAR ACCELERATION 230
Rotation with Constant Angular Acceleration 230
10-3 RELATING THE LINEAR AND ANGULAR VARIABLES 232
Relating the Linear and Angular Variables 232

10-4 KINETIC ENERGY OF ROTATION 235
Kinetic Energy of Rotation 235

10-5 CALCULATING THE ROTATIONAL INERTIA 237
Calculating the Rotational Inertia 237

10-6 TORQUE 241
Torque 242

10-7 NEWTON'S SECOND LAW FOR ROTATION 243
Newton's Second Law for Rotation 243

10-8 WORK AND ROTATIONAL KINETIC ENERGY 246
Work and Rotational Kinetic Energy 246
REVIEW & SUMMARY 249 PROBLEMS 250

11 Rolling, Torque, and Angular Momentum 255
11-1 ROLLING AS TRANSLATION AND ROTATION COMBINED 255
What Is Physics? 255
Rolling as Translation and Rotation Combined 255

11-2 FORCES AND KINETIC ENERGY OF ROLLING 258
The Kinetic Energy of Rolling 258
The Forces of Rolling 259

11-3 THE YO-YO 261
The Yo-Yo 261

11-4 TORQUE REVISITED 262
Torque Revisited 263

11-5 ANGULAR MOMENTUM 265
Angular Momentum 265

11-6 NEWTON'S SECOND LAW IN ANGULAR FORM 267
Newton's Second Law in Angular Form 267

11-7 ANGULAR MOMENTUM OF A RIGID BODY 270
The Angular Momentum of a System of Particles 270
The Angular Momentum of a Rigid Body Rotating About a Fixed Axis 271

11-8 CONSERVATION OF ANGULAR MOMENTUM 272
Conservation of Angular Momentum 272

11-9 PRECESSION OF A GYROSCOPE 277
Precession of a Gyroscope 277
REVIEW & SUMMARY 278 PROBLEMS 279

12 Equilibrium and Elasticity 285
12-1 EQUILIBRIUM 285
What Is Physics? 285
Equilibrium 285
The Requirements of Equilibrium 287
The Center of Gravity 288

12-2 SOME EXAMPLES OF STATIC EQUILIBRIUM 290
Some Examples of Static Equilibrium 290

12-3 ELASTICITY 296
Indeterminate Structures 296
Elasticity 297
REVIEW & SUMMARY 301 PROBLEMS 301

13 Gravitation 308
13-1 NEWTON'S LAW OF GRAVITATION 308
What Is Physics? 308
Newton's Law of Gravitation 309

13-2 GRAVITATION AND THE PRINCIPLE OF SUPERPOSITION 311
Gravitation and the Principle of Superposition 311

13-3 GRAVITATION NEAR EARTH'S SURFACE 313
Gravitation Near Earth's Surface 314

13-4 GRAVITATION INSIDE EARTH 316
Gravitation Inside Earth 317

13-5 GRAVITATIONAL POTENTIAL ENERGY 318
Gravitational Potential Energy 318

13-6 PLANETS AND SATELLITES: KEPLER'S LAWS 322
Planets and Satellites: Kepler's Laws 323

13-7 SATELLITES: ORBITS AND ENERGY 325
Satellites: Orbits and Energy 325

13-8 EINSTEIN AND GRAVITATION 328
Einstein and Gravitation 328
REVIEW & SUMMARY 330 PROBLEMS 331

14 Fluids 338
14-1 FLUIDS, DENSITY, AND PRESSURE 338
What Is Physics? 338
What Is a Fluid? 338
Density and Pressure 339

14-2 FLUIDS AT REST 340
Fluids at Rest 341

14-3 MEASURING PRESSURE 344
Measuring Pressure 344

14-4 PASCAL'S PRINCIPLE 345
Pascal's Principle 345

14-5 ARCHIMEDES' PRINCIPLE 346
Archimedes' Principle 347

14-6 THE EQUATION OF CONTINUITY 350
Ideal Fluids in Motion 350
The Equation of Continuity 351

14-7 BERNOULLI'S EQUATION 353
Bernoulli's Equation 353
REVIEW & SUMMARY 357 PROBLEMS 357

15 Oscillations 365
15-1 SIMPLE HARMONIC MOTION 365
What Is Physics? 366
Simple Harmonic Motion 366
The Force Law for Simple Harmonic Motion 371

15-2 ENERGY IN SIMPLE HARMONIC MOTION 373
Energy in Simple Harmonic Motion 373

15-3 AN ANGULAR SIMPLE HARMONIC OSCILLATOR 375
An Angular Simple Harmonic Oscillator 375

15-4 PENDULUMS, CIRCULAR MOTION 376
Pendulums 377
Simple Harmonic Motion and Uniform Circular Motion 380

15-5 DAMPED SIMPLE HARMONIC MOTION 382
Damped Simple Harmonic Motion 382

15-6 FORCED OSCILLATIONS AND RESONANCE 384
Forced Oscillations and Resonance 384
REVIEW & SUMMARY 386 PROBLEMS 386

16 Waves—I 392
16-1 TRANSVERSE WAVES 392
What Is Physics? 393
Types of Waves 393
Transverse and Longitudinal Waves 393
Wavelength and Frequency 394
The Speed of a Traveling Wave 397

16-2 WAVE SPEED ON A STRETCHED STRING 400
Wave Speed on a Stretched String 400

16-3 ENERGY AND POWER OF A WAVE TRAVELING ALONG A STRING 402
Energy and Power of a Wave Traveling Along a String 402

16-4 THE WAVE EQUATION 404
The Wave Equation 404

16-5 INTERFERENCE OF WAVES 406
The Principle of Superposition for Waves 406
Interference of Waves 407

16-6 PHASORS 410
Phasors 410

16-7 STANDING WAVES AND RESONANCE 413
Standing Waves 413
Standing Waves and Resonance 415
REVIEW & SUMMARY 418 PROBLEMS 419

17 Waves—II 423
17-1 SPEED OF SOUND 423
What Is Physics? 423
Sound Waves 423
The Speed of Sound 424

17-2 TRAVELING SOUND WAVES 426
Traveling Sound Waves 426

17-3 INTERFERENCE 429
Interference 429

17-4 INTENSITY AND SOUND LEVEL 432
Intensity and Sound Level 433

17-5 SOURCES OF MUSICAL SOUND 436
Sources of Musical Sound 437

17-6 BEATS 440
Beats 441

17-7 THE DOPPLER EFFECT 442
The Doppler Effect 443

17-8 SUPERSONIC SPEEDS, SHOCK WAVES 447
Supersonic Speeds, Shock Waves 447
REVIEW & SUMMARY 448 PROBLEMS 449

18 Temperature, Heat, and the First Law of Thermodynamics 454
18-1 TEMPERATURE 454
What Is Physics? 454
Temperature 455
The Zeroth Law of Thermodynamics 455
Measuring Temperature 456

18-2 THE CELSIUS AND FAHRENHEIT SCALES 458
The Celsius and Fahrenheit Scales 458

18-3 THERMAL EXPANSION 460
Thermal Expansion 460

18-4 ABSORPTION OF HEAT 462
Temperature and Heat 463
The Absorption of Heat by Solids and Liquids 464

18-5 THE FIRST LAW OF THERMODYNAMICS 468
A Closer Look at Heat and Work 468
The First Law of Thermodynamics 471
Some Special Cases of the First Law of Thermodynamics 472

18-6 HEAT TRANSFER MECHANISMS 474
Heat Transfer Mechanisms 474
REVIEW & SUMMARY 478 PROBLEMS 480

19 The Kinetic Theory of Gases 485
19-1 AVOGADRO'S NUMBER 485
What Is Physics? 485
Avogadro's Number 486

19-2 IDEAL GASES 486
Ideal Gases 487

19-3 PRESSURE, TEMPERATURE, AND RMS SPEED 490
Pressure, Temperature, and RMS Speed 490

19-4 TRANSLATIONAL KINETIC ENERGY 493
Translational Kinetic Energy 493

19-5 MEAN FREE PATH 494
Mean Free Path 494

19-6 THE DISTRIBUTION OF MOLECULAR SPEEDS 496
The Distribution of Molecular Speeds 497

19-7 THE MOLAR SPECIFIC HEATS OF AN IDEAL GAS 500
The Molar Specific Heats of an Ideal Gas 500

19-8 DEGREES OF FREEDOM AND MOLAR SPECIFIC HEATS 504
Degrees of Freedom and Molar Specific Heats 504
A Hint of Quantum Theory 506

19-9 THE ADIABATIC EXPANSION OF AN IDEAL GAS 507
The Adiabatic Expansion of an Ideal Gas 507
REVIEW & SUMMARY 511 PROBLEMS 512

20 Entropy and the Second Law of Thermodynamics 517
20-1 ENTROPY 517
What Is Physics? 518
Irreversible Processes and Entropy 518
Change in Entropy 519
The Second Law of Thermodynamics 522

20-2 ENTROPY IN THE REAL WORLD: ENGINES 524
Entropy in the Real World: Engines 524

20-3 REFRIGERATORS AND REAL ENGINES 529
Entropy in the Real World: Refrigerators 530
The Efficiencies of Real Engines 531

20-4 A STATISTICAL VIEW OF ENTROPY 532
A Statistical View of Entropy 532
REVIEW & SUMMARY 536 PROBLEMS 537

21 Coulomb's Law 541
21-1 COULOMB'S LAW 541
What Is Physics? 542
Electric Charge 542
Conductors and Insulators 544
Coulomb's Law 545

21-2 CHARGE IS QUANTIZED 551
Charge Is Quantized 551

21-3 CHARGE IS CONSERVED 553
Charge Is Conserved 553
REVIEW & SUMMARY 554 PROBLEMS 555

22 Electric Fields 558
22-1 THE ELECTRIC FIELD 558
What Is Physics? 558
The Electric Field 559
Electric Field Lines 559

22-2 THE ELECTRIC FIELD DUE TO A CHARGED PARTICLE 561
The Electric Field Due to a Point Charge 561

22-3 THE ELECTRIC FIELD DUE TO A DIPOLE 563
The Electric Field Due to an Electric Dipole 564

22-4 THE ELECTRIC FIELD DUE TO A LINE OF CHARGE 566
The Electric Field Due to Line of Charge 566

22-5 THE ELECTRIC FIELD DUE TO A CHARGED DISK 571
The Electric Field Due to a Charged Disk 571

22-6 A POINT CHARGE IN AN ELECTRIC FIELD 573
A Point Charge in an Electric Field 573

22-7 A DIPOLE IN AN ELECTRIC FIELD 575
A Dipole in an Electric Field 576
REVIEW & SUMMARY 578 PROBLEMS 579

23 Gauss' Law 585

23-1 ELECTRIC FLUX 585
What Is Physics 585
Electric Flux 586

23-2 GAUSS' LAW 590
Gauss' Law 590
Gauss' Law and Coulomb's Law 592

23-3 A CHARGED ISOLATED CONDUCTOR 594
A Charged Isolated Conductor 594

23-4 APPLYING GAUSS' LAW: CYLINDRICAL SYMMETRY 597
Applying Gauss' Law: Cylindrical Symmetry 597

23-5 APPLYING GAUSS' LAW: PLANAR SYMMETRY 599
Applying Gauss' Law: Planar Symmetry 599

23-6 APPLYING GAUSS' LAW: SPHERICAL SYMMETRY 601
Applying Gauss' Law: Spherical Symmetry 601
REVIEW & SUMMARY 603 PROBLEMS 603

24 Electric Potential 609

24-1 ELECTRIC POTENTIAL 609
What Is Physics? 609
Electric Potential and Electric Potential Energy 610

24-2 EQUIPOTENTIAL SURFACES AND THE ELECTRIC FIELD 614
Equipotential Surfaces 614
Calculating the Potential from the Field 615

24-3 POTENTIAL DUE TO A CHARGED PARTICLE 618
Potential Due to a Charged Particle 618
Potential Due a Group of Charged Particles 619

24-4 POTENTIAL DUE TO AN ELECTRIC DIPOLE 621
Potential Due to an Electric Dipole 621

24-5 POTENTIAL DUE TO A CONTINUOUS CHARGE DISTRIBUTION 622
Potential Due to a Continuous Charge Distribution 622

24-6 CALCULATING THE FIELD FROM THE POTENTIAL 625
Calculating the Field from the Potential 625

24-7 ELECTRIC POTENTIAL ENERGY OF A SYSTEM OF CHARGED PARTICLES 627
Electric Potential Energy of a System of Charged Particles 627

24-8 POTENTIAL OF A CHARGED ISOLATED CONDUCTOR 630
Potential of Charged Isolated Conductor 630
REVIEW & SUMMARY 631 PROBLEMS 632

25 Capacitance 639

25-1 CAPACITANCE 639
What Is Physics? 639
Capacitance 639

25-2 CALCULATING THE CAPACITANCE 641
Calculating the Capacitance 642

25-3 CAPACITORS IN PARALLEL AND IN SERIES 645
Capacitors in Parallel and in Series 646

25-4 ENERGY STORED IN AN ELECTRIC FIELD 650
Energy Stored in an Electric Field 650

25-5 CAPACITOR WITH A DIELECTRIC 653
Capacitor with a Dielectric 653
Dielectrics: An Atomic View 655

25-6 DIELECTRICS AND GAUSS' LAW 657
Dielectrics and Gauss' Law 657
REVIEW & SUMMARY 660 PROBLEMS 660

26 Current and Resistance 665

26-1 ELECTRIC CURRENT 665
What Is Physics? 665
Electric Current 666

26-2 CURRENT DENSITY 668
Current Density 669

26-3 RESISTANCE AND RESISTIVITY 672
Resistance and Resistivity 673

26-4 OHM'S LAW 676
Ohm's Law 676
A Microscopic View of Ohm's Law 678

26-5 POWER, SEMICONDUCTORS, SUPERCONDUCTORS 680
Power in Electric Circuits 680
Semiconductors 682
Superconductors 683
REVIEW & SUMMARY 683 PROBLEMS 684

27 Circuits 689

27-1 SINGLE-LOOP CIRCUITS 689
What Is Physics? 690
"Pumping" Charges 690
Work, Energy, and Emf 691
Calculating the Current in a Single-Loop Circuit 692
Other Single-Loop Circuits 694
Potential Difference Between Two Points 695

27-2 MULTILOOP CIRCUITS 699
Multiloop Circuits 699

27-3 THE AMMETER AND THE VOLTMETER 706
The Ammeter and the Voltmeter 706

27-4 RC CIRCUITS 706
RC Circuits 707
REVIEW & SUMMARY 711 PROBLEMS 711

28 Magnetic Fields 719

28-1 MAGNETIC FIELDS AND THE DEFINITION OF $\vec{B}$ 719
What Is Physics? 719
What Produces a Magnetic Field? 720
The Definition of $\vec{B}$ 720

28-2 CROSSED FIELDS: DISCOVERY OF THE ELECTRON 724
Crossed Fields: Discovery of the Electron 725

28-3 CROSSED FIELDS: THE HALL EFFECT 726
Crossed Fields: The Hall Effect 727

28-4 A CIRCULATING CHARGED PARTICLE 730
A Circulating Charged Particle 730

28-5 CYCLOTRONS AND SYNCHROTRONS 733
Cyclotrons and Synchrotrons 734

28-6 MAGNETIC FORCE ON A CURRENT-CARRYING WIRE 736
Magnetic Force on a Current-Carrying Wire 736

28-7 TORQUE ON A CURRENT LOOP 738
Torque on a Current Loop 738

28-8 THE MAGNETIC DIPOLE MOMENT 740
The Magnetic Dipole Moment 741
REVIEW & SUMMARY 743 PROBLEMS 743

29 Magnetic Fields Due to Currents 748

29-1 MAGNETIC FIELD DUE TO A CURRENT 748
What Is Physics? 748
Calculating the Magnetic Field Due to a Current 749

29-2 FORCE BETWEEN TWO PARALLEL CURRENTS 754
Force Between Two Parallel Currents 754

29-3 AMPERE'S LAW 756
Ampere's Law 756

29-4 SOLENOIDS AND TOROIDS 760
Solenoids and Toroids 760

29-5 A CURRENT-CARRYING COIL AS A MAGNETIC DIPOLE 763
A Current-Carrying Coil as a Magnetic Dipole 763
REVIEW & SUMMARY 766 PROBLEMS 767

30 Induction and Inductance 774

30-1 FARADAY'S LAW AND LENZ'S LAW 774
What Is Physics 774
Two Experiments 775
Faraday's Law of Induction 775
Lenz's Law 778

30-2 INDUCTION AND ENERGY TRANSFERS 781
Induction and Energy Transfers 7811

30-3 INDUCED ELECTRIC FIELDS 784
Induced Electric Fields 785

30-4 INDUCTORS AND INDUCTANCE 789
Inductors and Inductance 789

30-5 SELF-INDUCTION 791
Self-Induction 791

30-6 *RL* CIRCUITS 792
RL Circuits 793

30-7 ENERGY STORED IN A MAGNETIC FIELD 797
Energy Stored in a Magnetic Field 797

30-8 ENERGY DENSITY OF A MAGNETIC FIELD 799
Energy Density of a Magnetic Field 799

30-9 MUTUAL INDUCTION 800
Mutual Induction 800
REVIEW & SUMMARY 803 PROBLEMS 803

31 Electromagnetic Oscillations and Alternating Current 811

31-1 *LC* OSCILLATIONS 811
What Is Physics? 812
LC Oscillations, Qualitatively 812
The Electrical-Mechanical Analogy 814
LC Oscillations, Quantitatively 815

31-2 DAMPED OSCILLATIONS IN AN *RLC* CIRCUIT 818
Damped Oscillations in an *RLC* Circuit 819

31-3 FORCED OSCILLATIONS OF THREE SIMPLE CIRCUITS 820
Alternating Current 821
Forced Oscillations 822
Three Simple Circuits 822

31-4 THE SERIES *RLC* CIRCUIT 829
The Series *RLC* Circuit 829

31-5 POWER IN ALTERNATING-CURRENT CIRCUITS 835
Power in Alternating-Current Circuits 835

31-6 TRANSFORMERS 838
Transformers 838
REVIEW & SUMMARY 841 PROBLEMS 842

32 Maxwell's Equations; Magnetism of Matter 847
32-1 GAUSS' LAW FOR MAGNETIC FIELDS 847
What Is Physics? 847
Gauss' Law for Magnetic Fields 848

32-2 INDUCED MAGNETIC FIELDS 849
Induced Magnetic Fields 849

32-3 DISPLACEMENT CURRENT 852
Displacement Current 853
Maxwell's Equations 855

32-4 MAGNETS 856
Magnets 856

32-5 MAGNETISM AND ELECTRONS 858
Magnetism and Electrons 859
Magnetic Materials 862

32-6 DIAMAGNETISM 863
Diamagnetism 863

32-7 PARAMAGNETISM 865
Paramagnetism 865

32-8 FERROMAGNETISM 867
Ferromagnetism 867
REVIEW & SUMMARY 870 PROBLEMS 871

33 Electromagnetic Waves 876
33-1 ELECTROMAGNETIC WAVES 876
What Is Physics? 876
Maxwell's Rainbow 877
The Traveling Electromagnetic Wave, Qualitatively 878
The Traveling Electromagnetic Wave, Quantitatively 881

33-2 ENERGY TRANSPORT AND THE POYNTING VECTOR 884
Energy Transport and the Poynting Vector 885

33-3 RADIATION PRESSURE 887
Radiation Pressure 887

33-4 POLARIZATION 889
Polarization 889

33-5 REFLECTION AND REFRACTION 894
Reflection and Refraction 895

33-6 TOTAL INTERNAL REFLECTION 900
Total Internal Reflection 900

33-7 POLARIZATION BY REFLECTION 901
Polarization by Reflection 902
REVIEW & SUMMARY 903 PROBLEMS 904

34 Images 910
34-1 IMAGES AND PLANE MIRRORS 910
What Is Physics? 910
Two Types of Image 910
Plane Mirrors 912

34-2 SPHERICAL MIRRORS 914
Spherical Mirrors 915
Images from Spherical Mirrors 916

34-3 SPHERICAL REFRACTING SURFACES 920
Spherical Refracting Surfaces 920

34-4 THIN LENSES 923
Thin Lenses 923

34-5 OPTICAL INSTRUMENTS 930
Optical Instruments 930

34-6 THREE PROOFS 933
REVIEW & SUMMARY 936 PROBLEMS 937

35 Interference 943
35-1 LIGHT AS A WAVE 943
What Is Physics? 943
Light as a Wave 944

35-2 YOUNG'S INTERFERENCE EXPERIMENT 949
Diffraction 949
Young's Interference Experiment 950

35-3 INTERFERENCE AND DOUBLE-SLIT INTENSITY 955
Coherence 955
Intensity in Double-Slit Interference 956

35-4 INTERFERENCE FROM THIN FILMS 959
Interference from Thin Films 960

35-5 MICHELSON'S INTERFEROMETER 966
Michelson's Interferometer 967
REVIEW & SUMMARY 968 PROBLEMS 968

36 Diffraction 975

36-1 SINGLE-SLIT DIFFRACTION 975
What Is Physics? 975
Diffraction and the Wave Theory of Light 975
Diffraction by a Single Slit: Locating the Minima 977

36-2 INTENSITY IN SINGLE-SLIT DIFFRACTION 980
Intensity in Single-Slit Diffraction 980
Intensity in Single-Slit Diffraction, Quantitatively 980

36-3 DIFFRACTION BY A CIRCULAR APERTURE 984
Diffraction by a Circular Aperture 985

36-4 DIFFRACTION BY A DOUBLE SLIT 988
Diffraction by a Double Slit 989

36-5 DIFFRACTION GRATINGS 992
Diffraction Gratings 992

36-6 GRATINGS: DISPERSION AND RESOLVING POWER 995
Gratings: Dispersion and Resolving Power 995

36-7 X-RAY DIFFRACTION 998
X-Ray Diffraction 998
REVIEW & SUMMARY 1001 PROBLEMS 1001

37 Relativity 1008

37-1 SIMULTANEITY AND TIME DILATION 1008
What Is Physics? 1008
The Postulates 1009
Measuring an Event 1010
The Relativity of Simultaneity 1012
The Relativity of Time 1013

37-2 THE RELATIVITY OF LENGTH 1017
The Relativity of Length 1018

37-3 THE LORENTZ TRANSFORMATION 1021
The Lorentz Transformation 1021
Some Consequences of the Lorentz Equations 1023

37-4 THE RELATIVITY OF VELOCITIES 1025
The Relativity of Velocities 1025

37-5 DOPPLER EFFECT FOR LIGHT 1026
Doppler Effect for Light 1027

37-6 MOMENTUM AND ENERGY 1029
A New Look at Momentum 1030
A New Look at Energy 1030
REVIEW & SUMMARY 1035 PROBLEMS 1036

38 Photons and Matter Waves 1041

38-1 THE PHOTON, THE QUANTUM OF LIGHT 1041
What Is Physics? 1041
The Photon, the Quantum of Light 1042

38-2 THE PHOTOELECTRIC EFFECT 1043
The Photoelectric Effect 1044

38-3 PHOTONS, MOMENTUM, COMPTON SCATTERING, LIGHT INTERFERENCE 1046
Photons Have Momentum 1047
Light as a Probability Wave 1050

38-4 THE BIRTH OF QUANTUM PHYSICS 1052
The Birth of Quantum Physics 1053

38-5 ELECTRONS AND MATTER WAVES 1054
Electrons and Matter Waves 1055

38-6 SCHRÖDINGER'S EQUATION 1058
Schrödinger's Equation 1058

38-7 HEISENBERG'S UNCERTAINTY PRINCIPLE 1060
Heisenberg's Uncertainty Principle 1061

38-8 REFLECTION FROM A POTENTIAL STEP 1062
Reflection from a Potential Step 1062

38-9 TUNNELING THROUGH A POTENTIAL BARRIER 1064
Tunneling Through a Potential Barrier 1064
REVIEW & SUMMARY 1067 PROBLEMS 1068

39 More About Matter Waves 1072

39-1 ENERGIES OF A TRAPPED ELECTRON 1072
What Is Physics? 1072
String Waves and Matter Waves 1073
Energies of a Trapped Electron 1073

39-2 WAVE FUNCTIONS OF A TRAPPED ELECTRON 1077
Wave Functions of a Trapped Electron 1078

39-3 AN ELECTRON IN A FINITE WELL 1081
An Electron in a Finite Well 1081

39-4 TWO- AND THREE-DIMENSIONAL ELECTRON TRAPS 1083
More Electron Traps 1083
Two- and Three-Dimensional Electron Traps 1086

39-5 THE HYDROGEN ATOM 1087
The Hydrogen Atom Is an Electron Trap 1088
The Bohr Model of Hydrogen, a Lucky Break 1089
Schrödinger's Equation and the Hydrogen Atom 1091
REVIEW & SUMMARY 1099 PROBLEMS 1099

40 All About Atoms 1103

40-1 PROPERTIES OF ATOMS 1103
What Is Physics? 1104
Some Properties of Atoms 1104
Angular Momentum, Magnetic Dipole Moments 1106

40-2 THE STERN-GERLACH EXPERIMENT 1110
The Stern-Gerlach Experiment 1110

40-3 MAGNETIC RESONANCE 1113
Magnetic Resonance 1113

40-4 EXCLUSION PRINCIPLE AND MULTIPLE ELECTRONS IN A TRAP 1114
The Pauli Exclusion Principle 1114
Multiple Electrons in Rectangular Traps 1115

40-5 BUILDING THE PERIODIC TABLE 1118
Building the Periodic Table 1118

40-6 X RAYS AND THE ORDERING OF THE ELEMENTS 1120
X Rays and the Ordering of the Elements 1121

40-7 LASERS 1124
Lasers and Laser Light 1125
How Lasers Work 1126
REVIEW & SUMMARY 1129 PROBLEMS 1130

41 Conduction of Electricity in Solids 1134

41-1 THE ELECTRICAL PROPERTIES OF METALS 1134
What Is Physics? 1135
The Electrical Properties of Solids 1135
Energy Levels in a Crystalline Solid 1136
Insulators 1136
Metals 1137

41-2 SEMICONDUCTORS AND DOPING 1143
Semiconductors 1144
Doped Semiconductors 1145

41-3 THE *p-n* JUNCTION AND THE TRANSISTOR 1147
The *p-n* Junction 1148
The Junction Rectifier 1149
The Light-Emitting Diode (LED) 1150
The Transistor 1152
REVIEW & SUMMARY 1153 PROBLEMS 1154

42 Nuclear Physics 1158

42-1 DISCOVERING THE NUCLEUS 1158
What Is Physics? 1158
Discovering the Nucleus 1158

42-2 SOME NUCLEAR PROPERTIES 1161
Some Nuclear Properties 1162

42-3 RADIOACTIVE DECAY 1168
Radioactive Decay 1168

42-4 ALPHA DECAY 1171
Alpha Decay 1171

42-5 BETA DECAY 1174
Beta Decay 1174

42-6 RADIOACTIVE DATING 1177
Radioactive Dating 1177

42-7 MEASURING RADIATION DOSAGE 1178
Measuring Radiation Dosage 1178

42-8 NUCLEAR MODELS 1179
Nuclear Models 1179
REVIEW & SUMMARY 1182 PROBLEMS 1183

43 Energy from the Nucleus 1189

43-1 NUCLEAR FISSION 1189
What Is Physics? 1189
Nuclear Fission: The Basic Process 1190
A Model for Nuclear Fission 1192

43-2 THE NUCLEAR REACTOR 1196
The Nuclear Reactor 1196

43-3 A NATURAL NUCLEAR REACTOR 1200
A Natural Nuclear Reactor 1200

43-4 THERMONUCLEAR FUSION: THE BASIC PROCESS 1202
Thermonuclear Fusion: The Basic Process 1202

43-5 THERMONUCLEAR FUSION IN THE SUN AND OTHER STARS 1204
Thermonuclear Fusion in the Sun and Other Stars 1204

43-6 CONTROLLED THERMONUCLEAR FUSION 1206
Controlled Thermonuclear Fusion 1206
REVIEW & SUMMARY 1209 PROBLEMS 1209

44 Quarks, Leptons, and the Big Bang 1214

44-1 GENERAL PROPERTIES OF ELEMENTARY PARTICLES 1214
What Is Physics? 1214
Particles, Particles, Particles 1215
An Interlude 1219

44-2 LEPTONS, HADRONS, AND STRANGENESS 1223
The Leptons 1223

The Hadrons 1225
Still Another Conservation Law 1226
The Eightfold Way 1227

44-3 QUARKS AND MESSENGER PARTICLES 1229
The Quark Model 1229
Basic Forces and Messenger Particles 1232

44-4 COSMOLOGY 1235
A Pause for Reflection 1235
The Universe Is Expanding 1236
The Cosmic Background Radiation 1237
Dark Matter 1238
The Big Bang 1238
A Summing Up 1241
REVIEW & SUMMARY 1242 PROBLEMS 1242

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 Problems AN-1

INDEX I-1