BRIEF CONTENTS

VOLUME 1

1 Measurement
2 Motion Along a Straight Line
3 Vectors
4 Motion in Two and Three Dimensions
5 Force and Motion—I
6 Force and Motion—II
7 Kinetic Energy and Work
8 Potential Energy and Conservation of Energy
9 Center of Mass and Linear Momentum
10 Rotation
11 Rolling, Torque, and Angular Momentum
12 Equilibrium and Elasticity
13 Gravitation
14 Fluids
15 Oscillations
16 Waves—I
17 Waves—II
18 Temperature, Heat, and the First Law of Thermodynamics
19 The Kinetic Theory of Gases
20 Entropy and the Second Law of Thermodynamics

VOLUME 2

21 Coulomb's Law
22 Electric Fields
23 Gauss' Law
24 Electric Potential
25 Capacitance
26 Current and Resistance
27 Circuits
28 Magnetic Fields
29 Magnetic Fields Due to Currents
30 Induction and Inductance
31 Electromagnetic Oscillations and Alternating Current
32 Maxwell's Equations; Magnetism of Matter
33 Electromagnetic Waves
34 Images
35 Interference
36 Diffraction
37 Relativity
38 Photons and Matter Waves
39 More About Matter Waves
40 All About Atoms
41 Conduction of Electricity in Solids
42 Nuclear Physics
43 Energy from the Nucleus
44 Quarks, Leptons, and the Big Bang

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 79

5-1 NEWTON'S FIRST AND SECOND LAWS 79

What Is Physics? 79
Newtonian Mechanics 80
Newton's First Law 80
Force 81
Mass 82
Newton's Second Law 83

5-2 SOME PARTICULAR FORCES 87

Some Particular Forces 87

5-3 APPLYING NEWTON'S LAWS 91

Newton's Third Law 91
Applying Newton's Laws 93

REVIEW & SUMMARY 99 PROBLEMS 99

6 Force and Motion—II 104
6-1 FRICTION 104
What Is Physics? 104
Friction 104
Properties of Friction 107
6-2 THE DRAG FORCE AND TERMINAL SPEED 110
The Drag Force and Terminal Speed 110
6-3 UNIFORM CIRCULAR MOTION 113
Uniform Circular Motion 113
REVIEW & SUMMARY 118 PROBLEMS 119

7 Kinetic Energy and Work 125
7-1 KINETIC ENERGY 125
What Is Physics? 125
What Is Energy? 125
Kinetic Energy 126
7-2 WORK AND KINETIC ENERGY 127
Work 127
Work and Kinetic Energy 128
7-3 WORK DONE BY THE GRAVITATIONAL FORCE 131
Work Done by the Gravitational Force 132
7-4 WORK DONE BY A SPRING FORCE 135
Work Done by a Spring Force 135
7-5 WORK DONE BY A GENERAL VARIABLE FORCE 138
Work Done by a General Variable Force 138
7-6 POWER 142
Power 142
REVIEW & SUMMARY 144 PROBLEMS 145

8 Potential Energy and Conservation of Energy 150
8-1 POTENTIAL ENERGY 150
What Is Physics? 150
Work and Potential Energy 151
Path Independence of Conservative Forces 152
Determining Potential Energy Values 154
8-2 CONSERVATION OF MECHANICAL ENERGY 157
Conservation of Mechanical Energy 157
8-3 READING A POTENTIAL ENERGY CURVE 160
Reading a Potential Energy Curve 160
8-4 WORK DONE ON A SYSTEM BY AN EXTERNAL FORCE 164
Work Done on a System by an External Force 165
8-5 CONSERVATION OF ENERGY 168
Conservation of Energy 168
REVIEW & SUMMARY 172 PROBLEMS 173

9 Center of Mass and Linear Momentum 181
9-1 CENTER OF MASS 181
What Is Physics? 181
The Center of Mass 182
9-2 NEWTON'S SECOND LAW FOR A SYSTEM OF PARTICLES 187
Newton's Second Law for a System of Particles 187
9-3 LINEAR MOMENTUM 191
Linear Momentum 191
The Linear Momentum of a System of Particles 192
9-4 COLLISION AND IMPULSE 193
Collision and Impulse 193
9-5 CONSERVATION OF LINEAR MOMENTUM 197
Conservation of Linear Momentum 197
9-6 MOMENTUM AND KINETIC ENERGY IN COLLISIONS 200
Momentum and Kinetic Energy in Collisions 200
Inelastic Collisions in One Dimension 201
9-7 ELASTIC COLLISIONS IN ONE DIMENSION 204
Elastic Collisions in One Dimension 204
9-8 COLLISIONS IN TWO DIMENSIONS 207
Collisions in Two Dimensions 207
9-9 SYSTEMS WITH VARYING MASS: A ROCKET 208
Systems with Varying Mass: A Rocket 208
REVIEW & SUMMARY 210 PROBLEMS 212

10 Rotation 217
10-1 ROTATIONAL VARIABLES 217
What Is Physics? 218
Rotational Variables 219
Are Angular Quantities Vectors? 224
10-2 ROTATION WITH CONSTANT ANGULAR ACCELERATION 226
Rotation with Constant Angular Acceleration 226

10-3 RELATING THE LINEAR AND ANGULAR VARIABLES 228
Relating the Linear and Angular Variables 228

10-4 KINETIC ENERGY OF ROTATION 231
Kinetic Energy of Rotation 231

10-5 CALCULATING THE ROTATIONAL INERTIA 233
Calculating the Rotational Inertia 233

10-6 TORQUE 237
Torque 238

10-7 NEWTON'S SECOND LAW FOR ROTATION 239
Newton's Second Law for Rotation 239

10-8 WORK AND ROTATIONAL KINETIC ENERGY 242
Work and Rotational Kinetic Energy 242

REVIEW & SUMMARY 245 PROBLEMS 246

11 Rolling, Torque, and Angular Momentum 251

11-1 ROLLING AS TRANSLATION AND ROTATION COMBINED 251
What Is Physics? 251
Rolling as Translation and Rotation Combined 251

11-2 FORCES AND KINETIC ENERGY OF ROLLING 254
The Kinetic Energy of Rolling 254
The Forces of Rolling 255

11-3 THE YO-YO 257
The Yo-Yo 258

11-4 TORQUE REVISITED 258
Torque Revisited 259

11-5 ANGULAR MOMENTUM 261
Angular Momentum 261

11-6 NEWTON'S SECOND LAW IN ANGULAR FORM 263
Newton's Second Law in Angular Form 263

11-7 ANGULAR MOMENTUM OF A RIGID BODY 266
The Angular Momentum of a System of Particles 266
The Angular Momentum of a Rigid Body Rotating About a Fixed Axis 267

11-8 CONSERVATION OF ANGULAR MOMENTUM 268
Conservation of Angular Momentum 268

11-9 PRECESSION OF A GYROSCOPE 273
Precession of a Gyroscope 273

REVIEW & SUMMARY 274 PROBLEMS 275

12 Equilibrium and Elasticity 280

12-1 EQUILIBRIUM 280
What Is Physics? 280
Equilibrium 280
The Requirements of Equilibrium 282
The Center of Gravity 283

12-2 SOME EXAMPLES OF STATIC EQUILIBRIUM 285
Some Examples of Static Equilibrium 285

12-3 ELASTICITY 291
Indeterminate Structures 291
Elasticity 292

REVIEW & SUMMARY 296 PROBLEMS 296

13 Gravitation 302

13-1 NEWTON'S LAW OF GRAVITATION 302
What Is Physics? 302
Newton's Law of Gravitation 303

13-2 GRAVITATION AND THE PRINCIPLE OF SUPERPOSITION 305
Gravitation and the Principle of Superposition 305

13-3 GRAVITATION NEAR EARTH'S SURFACE 307
Gravitation Near Earth's Surface 308

13-4 GRAVITATION INSIDE EARTH 310
Gravitation Inside Earth 311

13-5 GRAVITATIONAL POTENTIAL ENERGY 312
Gravitational Potential Energy 312

13-6 PLANETS AND SATELLITES: KEPLER'S LAWS 316
Planets and Satellites: Kepler's Laws 317

13-7 SATELLITES: ORBITS AND ENERGY 319
Satellites: Orbits and Energy 319

13-8 EINSTEIN AND GRAVITATION 322
Einstein and Gravitation 322

REVIEW & SUMMARY 324 PROBLEMS 325

14 Fluids 330

14-1 FLUIDS, DENSITY, AND PRESSURE 330
What Is Physics? 330
What Is a Fluid? 330
Density and Pressure 331

14-2 FLUIDS AT REST 332
Fluids at Rest 333

14-3 MEASURING PRESSURE 336
Measuring Pressure 336

14-4 PASCAL'S PRINCIPLE 337
Pascal's Principle 337

14-5 ARCHIMEDES' PRINCIPLE 338
Archimedes' Principle 339

14-6 THE EQUATION OF CONTINUITY 342
Ideal Fluids in Motion 342
The Equation of Continuity 343

14-7 BERNOULLI'S EQUATION 345
Bernoulli's Equation 345

REVIEW & SUMMARY 349 PROBLEMS 349

15 Oscillations 354

15-1 SIMPLE HARMONIC MOTION 354
What Is Physics? 355
Simple Harmonic Motion 355
The Force Law for Simple Harmonic Motion 360

15-2 ENERGY IN SIMPLE HARMONIC MOTION 362
Energy in Simple Harmonic Motion 362

15-3 AN ANGULAR SIMPLE HARMONIC OSCILLATOR 364
An Angular Simple Harmonic Oscillator 364

15-4 PENDULUMS, CIRCULAR MOTION 365
Pendulums 366
Simple Harmonic Motion and Uniform Circular Motion 369

15-5 DAMPED SIMPLE HARMONIC MOTION 371
Damped Simple Harmonic Motion 371

15-6 FORCED OSCILLATIONS AND RESONANCE 373
Forced Oscillations and Resonance 373

REVIEW & SUMMARY 375 PROBLEMS 375

16 Waves—I 380

16-1 TRANSVERSE WAVES 380
What Is Physics? 381
Types of Waves 381
Transverse and Longitudinal Waves 381
Wavelength and Frequency 382
The Speed of a Traveling Wave 385

16-2 WAVE SPEED ON A STRETCHED STRING 388
Wave Speed on a Stretched String 388

16-3 ENERGY AND POWER OF A WAVE TRAVELING ALONG A STRING 390
Energy and Power of a Wave Traveling Along a String 390

16-4 THE WAVE EQUATION 392
The Wave Equation 392

16-5 INTERFERENCE OF WAVES 394
The Principle of Superposition for Waves 394
Interference of Waves 395

16-6 PHASORS 398
Phasors 398

16-7 STANDING WAVES AND RESONANCE 401
Standing Waves 401
Standing Waves and Resonance 403

REVIEW & SUMMARY 406 PROBLEMS 407

17 Waves—II 411

17-1 SPEED OF SOUND 411
What Is Physics? 411
Sound Waves 411
The Speed of Sound 412

17-2 TRAVELING SOUND WAVES 414
Traveling Sound Waves 414

17-3 INTERFERENCE 417
Interference 417

17-4 INTENSITY AND SOUND LEVEL 420
Intensity and Sound Level 421

17-5 SOURCES OF MUSICAL SOUND 424
Sources of Musical Sound 425

17-6 BEATS 428
Beats 429

17-7 THE DOPPLER EFFECT 430
The Doppler Effect 431

17-8 SUPERSONIC SPEEDS, SHOCK WAVES 435
Supersonic Speeds, Shock Waves 435

REVIEW & SUMMARY 436 PROBLEMS 437

18 Temperature, Heat, and the First Law of Thermodynamics 442

18-1 TEMPERATURE 442
What Is Physics? 442
Temperature 443

The Zeroth Law of Thermodynamics 443
Measuring Temperature 444

18-2 THE CELSIUS AND FAHRENHEIT SCALES 446
The Celsius and Fahrenheit Scales 446

18-3 THERMAL EXPANSION 448
Thermal Expansion 448

18-4 ABSORPTION OF HEAT 450
Temperature and Heat 451
The Absorption of Heat by Solids and Liquids 452

18-5 THE FIRST LAW OF THERMODYNAMICS 456
A Closer Look at Heat and Work 456
The First Law of Thermodynamics 459
Some Special Cases of the First Law of Thermodynamics 460

18-6 HEAT TRANSFER MECHANISMS 462
Heat Transfer Mechanisms 462

REVIEW & SUMMARY 466 PROBLEMS 468

19 The Kinetic Theory of Gases 472

19-1 AVOGADRO'S NUMBER 472
What Is Physics? 472
Avogadro's Number 473

19-2 IDEAL GASES 473
Ideal Gases 474

19-3 PRESSURE, TEMPERATURE, AND RMS SPEED 477
Pressure, Temperature, and RMS Speed 477

19-4 TRANSLATIONAL KINETIC ENERGY 480
Translational Kinetic Energy 480

19-5 MEAN FREE PATH 481
Mean Free Path 481

19-6 THE DISTRIBUTION OF MOLECULAR SPEEDS 483
The Distribution of Molecular Speeds 484

19-7 THE MOLAR SPECIFIC HEATS OF AN IDEAL GAS 487
The Molar Specific Heats of an Ideal Gas 487

19-8 DEGREES OF FREEDOM AND MOLAR SPECIFIC HEATS 491
Degrees of Freedom and Molar Specific Heats 491
A Hint of Quantum Theory 493

19-9 THE ADIABATIC EXPANSION OF AN IDEAL GAS 494
The Adiabatic Expansion of an Ideal Gas 494

REVIEW & SUMMARY 498 PROBLEMS 500

20 Entropy and the Second Law of Thermodynamics 503

20-1 ENTROPY 503
What Is Physics? 504
Irreversible Processes and Entropy 504
Change in Entropy 505
The Second Law of Thermodynamics 508

20-2 ENTROPY IN THE REAL WORLD: ENGINES 510
Entropy in the Real World: Engines 510

20-3 REFRIGERATORS AND REAL ENGINES 515
Entropy in the Real World: Refrigerators 516
The Efficiencies of Real Engines 517

20-4 A STATISTICAL VIEW OF ENTROPY 518
A Statistical View of Entropy 518

REVIEW & SUMMARY 522 PROBLEMS 523

21 Coulomb's Law 527

21-1 COULOMB'S LAW 527
What Is Physics? 528
Electric Charge 528
Conductors and Insulators 530
Coulomb's Law 531

21-2 CHARGE IS QUANTIZED 537
Charge Is Quantized 537

21-3 CHARGE IS CONSERVED 539
Charge Is Conserved 539

REVIEW & SUMMARY 540 PROBLEMS 541

22 Electric Fields 544

22-1 THE ELECTRIC FIELD 544
What Is Physics? 544
The Electric Field 545
Electric Field Lines 545

22-2 THE ELECTRIC FIELD DUE TO A CHARGED PARTICLE 547
The Electric Field Due to a Point Charge 547

22-3 THE ELECTRIC FIELD DUE TO A DIPOLE 549
The Electric Field Due to an Electric Dipole 550

22-4 THE ELECTRIC FIELD DUE TO A LINE OF CHARGE 552
The Electric Field Due to Line of Charge 552

22-5 THE ELECTRIC FIELD DUE TO A CHARGED DISK 557
The Electric Field Due to a Charged Disk 557

22-6 A POINT CHARGE IN AN ELECTRIC FIELD 559
A Point Charge in an Electric Field 559

22-7 A DIPOLE IN AN ELECTRIC FIELD 561
A Dipole in an Electric Field 562

REVIEW & SUMMARY 564 PROBLEMS 565

23 Gauss' Law 569

23-1 ELECTRIC FLUX 569
What Is Physics? 569
Electric Flux 570

23-2 GAUSS' LAW 574
Gauss' Law 574
Gauss' Law and Coulomb's Law 576

23-3 A CHARGED ISOLATED CONDUCTOR 578
A Charged Isolated Conductor 578

23-4 APPLYING GAUSS' LAW: CYLINDRICAL SYMMETRY 581
Applying Gauss' Law: Cylindrical Symmetry 581

23-5 APPLYING GAUSS' LAW: PLANAR SYMMETRY 583
Applying Gauss' Law: Planar Symmetry 583

23-6 APPLYING GAUSS' LAW: SPHERICAL SYMMETRY 585
Applying Gauss' Law: Spherical Symmetry 585

REVIEW & SUMMARY 587 PROBLEMS 587

24 Electric Potential 592

24-1 ELECTRIC POTENTIAL 592
What Is Physics? 592
Electric Potential and Electric Potential Energy 593

24-2 EQUIPOTENTIAL SURFACES AND THE ELECTRIC FIELD 597
Equipotential Surfaces 597
Calculating the Potential from the Field 598

24-3 POTENTIAL DUE TO A CHARGED PARTICLE 601
Potential Due to a Charged Particle 601
Potential Due to a Group of Charged Particles 602

24-4 POTENTIAL DUE TO AN ELECTRIC DIPOLE 604
Potential Due to an Electric Dipole 604

24-5 POTENTIAL DUE TO A CONTINUOUS CHARGE DISTRIBUTION 605
Potential Due to a Continuous Charge Distribution 605

24-6 CALCULATING THE FIELD FROM THE POTENTIAL 608
Calculating the Field from the Potential 608

24-7 ELECTRIC POTENTIAL ENERGY OF A SYSTEM OF CHARGED PARTICLES 610
Electric Potential Energy of a System of Charged Particles 610

24-8 POTENTIAL OF A CHARGED ISOLATED CONDUCTOR 613
Potential of a Charged Isolated Conductor 613

REVIEW & SUMMARY 614 PROBLEMS 615

25 Capacitance 620

25-1 CAPACITANCE 620
What Is Physics? 620
Capacitance 620

25-2 CALCULATING THE CAPACITANCE 622
Calculating the Capacitance 623

25-3 CAPACITORS IN PARALLEL AND IN SERIES 626
Capacitors in Parallel and in Series 627

25-4 ENERGY STORED IN AN ELECTRIC FIELD 631
Energy Stored in an Electric Field 631

25-5 CAPACITOR WITH A DIELECTRIC 634
Capacitor with a Dielectric 634
Dielectrics: An Atomic View 636

25-6 DIELECTRICS AND GAUSS' LAW 638
Dielectrics and Gauss' Law 638

REVIEW & SUMMARY 641 PROBLEMS 641

26 Current and Resistance 646

26-1 ELECTRIC CURRENT 646
What Is Physics? 646
Electric Current 647

26-2 CURRENT DENSITY 649
Current Density 650

26-3 RESISTANCE AND RESISTIVITY 653
Resistance and Resistivity 654

26-4 OHM'S LAW 657
Ohm's Law 657
A Microscopic View of Ohm's Law 659

26-5 POWER, SEMICONDUCTORS, SUPERCONDUCTORS 661
Power in Electric Circuits 661
Semiconductors 663
Superconductors 664
REVIEW & SUMMARY 664 PROBLEMS 665

27 Circuits 669
27-1 SINGLE-LOOP CIRCUITS 669
What Is Physics? 670
"Pumping" Charges 670
Work, Energy, and Emf 671
Calculating the Current in a Single-Loop Circuit 672
Other Single-Loop Circuits 674
Potential Difference Between Two Points 675
27-2 MULTILOOP CIRCUITS 679
Multiloop Circuits 679
27-3 THE AMMETER AND THE VOLTMETER 686
The Ammeter and the Voltmeter 686
27-4 *RC* CIRCUITS 686
RC Circuits 687
REVIEW & SUMMARY 691 PROBLEMS 691

28 Magnetic Fields 697
28-1 MAGNETIC FIELDS AND THE DEFINITION OF $\vec{B}$ 697
What Is Physics? 697
What Produces a Magnetic Field? 698
The Definition of $\vec{B}$ 698
28-2 CROSSED FIELDS: DISCOVERY OF THE ELECTRON 702
Crossed Fields: Discovery of the Electron 703
28-3 CROSSED FIELDS: THE HALL EFFECT 704
Crossed Fields: The Hall Effect 705
28-4 A CIRCULATING CHARGED PARTICLE 708
A Circulating Charged Particle 708
28-5 CYCLOTRONS AND SYNCHROTRONS 711
Cyclotrons and Synchrotrons 712
28-6 MAGNETIC FORCE ON A CURRENT-CARRYING WIRE 714
Magnetic Force on a Current-Carrying Wire 714
28-7 TORQUE ON A CURRENT LOOP 716
Torque on a Current Loop 716
28-8 THE MAGNETIC DIPOLE MOMENT 718
The Magnetic Dipole Moment 719
REVIEW & SUMMARY 721 PROBLEMS 721

29 Magnetic Fields Due to Currents 726
29-1 MAGNETIC FIELD DUE TO A CURRENT 726
What Is Physics? 726
Calculating the Magnetic Field Due to a Current 727
29-2 FORCE BETWEEN TWO PARALLEL CURRENTS 732
Force Between Two Parallel Currents 732
29-3 AMPERE'S LAW 734
Ampere's Law 734
29-4 SOLENOIDS AND TOROIDS 738
Solenoids and Toroids 738
29-5 A CURRENT-CARRYING COIL AS A MAGNETIC DIPOLE 741
A Current-Carrying Coil as a Magnetic Dipole 741
REVIEW & SUMMARY 744 PROBLEMS 745

30 Induction and Inductance 750
30-1 FARADAY'S LAW AND LENZ'S LAW 750
What Is Physics? 750
Two Experiments 751
Faraday's Law of Induction 751
Lenz's Law 754
30-2 INDUCTION AND ENERGY TRANSFERS 757
Induction and Energy Transfers 757
30-3 INDUCED ELECTRIC FIELDS 760
Induced Electric Fields 761
30-4 INDUCTORS AND INDUCTANCE 765
Inductors and Inductance 765
30-5 SELF-INDUCTION 767
Self-Induction 767
30-6 *RL* CIRCUITS 768
RL Circuits 769
30-7 ENERGY STORED IN A MAGNETIC FIELD 773
Energy Stored in a Magnetic Field 773
30-8 ENERGY DENSITY OF A MAGNETIC FIELD 775
Energy Density of a Magnetic Field 775
30-9 MUTUAL INDUCTION 776
Mutual Induction 776
REVIEW & SUMMARY 779 PROBLEMS 779

31 Electromagnetic Oscillations and Alternating Current 784

31-1 *LC* OSCILLATIONS 784

What Is Physics? 785

LC Oscillations, Qualitatively 785

The Electrical-Mechanical Analogy 787

LC Oscillations, Quantitatively 788

31-2 DAMPED OSCILLATIONS IN AN *RLC* CIRCUIT 791

Damped Oscillations in an *RLC* Circuit 792

31-3 FORCED OSCILLATIONS OF THREE SIMPLE CIRCUITS 793

Alternating Current 794

Forced Oscillations 795

Three Simple Circuits 795

31-4 THE SERIES *RLC* CIRCUIT 802

The Series *RLC* Circuit 802

31-5 POWER IN ALTERNATING-CURRENT CIRCUITS 808

Power in Alternating-Current Circuits 808

31-6 TRANSFORMERS 811

Transformers 811

REVIEW & SUMMARY 814 PROBLEMS 815

32 Maxwell's Equations; Magnetism of Matter 819

32-1 GAUSS' LAW FOR MAGNETIC FIELDS 819

What Is Physics? 819

Gauss' Law for Magnetic Fields 820

32-2 INDUCED MAGNETIC FIELDS 821

Induced Magnetic Fields 821

32-3 DISPLACEMENT CURRENT 824

Displacement Current 825

Maxwell's Equations 827

32-4 MAGNETS 828

Magnets 828

32-5 MAGNETISM AND ELECTRONS 830

Magnetism and Electrons 831

Magnetic Materials 834

32-6 DIAMAGNETISM 835

Diamagnetism 835

32-7 PARAMAGNETISM 837

Paramagnetism 837

32-8 FERROMAGNETISM 839

Ferromagnetism 839

REVIEW & SUMMARY 842 PROBLEMS 843

33 Electromagnetic Waves 848

33-1 ELECTROMAGNETIC WAVES 848

What Is Physics? 848

Maxwell's Rainbow 849

The Traveling Electromagnetic Wave, Qualitatively 850

The Traveling Electromagnetic Wave, Quantitatively 853

33-2 ENERGY TRANSPORT AND THE POYNTING VECTOR 856

Energy Transport and the Poynting Vector 857

33-3 RADIATION PRESSURE 859

Radiation Pressure 859

33-4 POLARIZATION 861

Polarization 861

33-5 REFLECTION AND REFRACTION 866

Reflection and Refraction 867

33-6 TOTAL INTERNAL REFLECTION 872

Total Internal Reflection 872

33-7 POLARIZATION BY REFLECTION 873

Polarization by Reflection 874

REVIEW & SUMMARY 875 PROBLEMS 876

34 Images 881

34-1 IMAGES AND PLANE MIRRORS 881

What Is Physics? 881

Two Types of Image 881

Plane Mirrors 883

34-2 SPHERICAL MIRRORS 885

Spherical Mirrors 886

Images from Spherical Mirrors 887

34-3 SPHERICAL REFRACTING SURFACES 891

Spherical Refracting Surfaces 891

34-4 THIN LENSES 894

Thin Lenses 894

34-5 OPTICAL INSTRUMENTS 901

Optical Instruments 901

34-6 THREE PROOFS 904

REVIEW & SUMMARY 907 PROBLEMS 908

35 Interference 915

35-1 LIGHT AS A WAVE 915

What Is Physics? 915

Light as a Wave 916

35-2 YOUNG'S INTERFERENCE EXPERIMENT 921

Diffraction 921

Young's Interference Experiment 922

35-3 INTERFERENCE AND DOUBLE-SLIT INTENSITY 927

Coherence 927

Intensity in Double-Slit Interference 928

35-4 INTERFERENCE FROM THIN FILMS 931

Interference from Thin Films 932

35-5 MICHELSON'S INTERFEROMETER 938

Michelson's Interferometer 939

REVIEW & SUMMARY 940 PROBLEMS 940

36 Diffraction 946

36-1 SINGLE-SLIT DIFFRACTION 946

What Is Physics? 946

Diffraction and the Wave Theory of Light 946

Diffraction by a Single Slit: Locating the Minima 948

36-2 INTENSITY IN SINGLE-SLIT DIFFRACTION 951

Intensity in Single-Slit Diffraction, Qualitatively 951

Intensity in Single-Slit Diffraction, Quantitatively 953

36-3 DIFFRACTION BY A CIRCULAR APERTURE 955

Diffraction by a Circular Aperture 956

36-4 DIFFRACTION BY A DOUBLE SLIT 959

Diffraction by a Double Slit 960

36-5 DIFFRACTION GRATINGS 963

Diffraction Gratings 963

36-6 GRATINGS: DISPERSION AND RESOLVING POWER 966

Gratings: Dispersion and Resolving Power 966

36-7 X-RAY DIFFRACTION 969

X-Ray Diffraction 969

REVIEW & SUMMARY 972 PROBLEMS 972

37 Relativity 976

37-1 SIMULTANEITY AND TIME DILATION 976

What Is Physics? 976

The Postulates 977

Measuring an Event 978

The Relativity of Simultaneity 980

The Relativity of Time 981

37-2 THE RELATIVITY OF LENGTH 985

The Relativity of Length 986

37-3 THE LORENTZ TRANSFORMATION 989

The Lorentz Transformation 989

Some Consequences of the Lorentz Equations 991

37-4 THE RELATIVITY OF VELOCITIES 993

The Relativity of Velocities 993

37-5 DOPPLER EFFECT FOR LIGHT 994

Doppler Effect for Light 995

37-6 MOMENTUM AND ENERGY 997

A New Look at Momentum 998

A New Look at Energy 998

REVIEW & SUMMARY 1003 PROBLEMS 1004

38 Photons and Matter Waves 1009

38-1 THE PHOTON, THE QUANTUM OF LIGHT 1009

What Is Physics? 1009

The Photon, the Quantum of Light 1010

38-2 THE PHOTOELECTRIC EFFECT 1011

The Photoelectric Effect 1012

38-3 PHOTONS, MOMENTUM, COMPTON SCATTERING, LIGHT INTERFERENCE 1014

Photons Have Momentum 1015

Light as a Probability Wave 1018

38-4 THE BIRTH OF QUANTUM PHYSICS 1020

The Birth of Quantum Physics 1021

38-5 ELECTRONS AND MATTER WAVES 1022

Electrons and Matter Waves 1023

38-6 SCHRÖDINGER'S EQUATION 1026

Schrödinger's Equation 1026

38-7 HEISENBERG'S UNCERTAINTY PRINCIPLE 1028

Heisenberg's Uncertainty Principle 1029

38-8 REFLECTION FROM A POTENTIAL STEP 1030

Reflection from a Potential Step 1030

38-9 TUNNELING THROUGH A POTENTIAL BARRIER 1032

Tunneling Through a Potential Barrier 1032

REVIEW & SUMMARY 1035 PROBLEMS 1036

39 More About Matter Waves 1040

39-1 ENERGIES OF A TRAPPED ELECTRON 1040

What Is Physics? 1040

String Waves and Matter Waves 1041

Energies of a Trapped Electron 1041

39-2 WAVE FUNCTIONS OF A TRAPPED ELECTRON 1045

Wave Functions of a Trapped Electron 1046

39-3 AN ELECTRON IN A FINITE WELL 1049

An Electron in a Finite Well 1049

39-4 TWO- AND THREE-DIMENSIONAL ELECTRON TRAPS 1051

More Electron Traps 1051

Two- and Three-Dimensional Electron Traps 1054

39-5 THE HYDROGEN ATOM 1055

The Hydrogen Atom Is an Electron Trap 1056

The Bohr Model of Hydrogen, a Lucky Break 1057

Schrödinger's Equation and the Hydrogen Atom 1059

REVIEW & SUMMARY 1067 PROBLEMS 1067

40 All About Atoms 1071

40-1 PROPERTIES OF ATOMS 1071

What Is Physics? 1072

Some Properties of Atoms 1072

Angular Momentum, Magnetic Dipole Moments 1074

40-2 THE STERN–GERLACH EXPERIMENT 1078

The Stern–Gerlach Experiment 1078

40-3 MAGNETIC RESONANCE 1081

Magnetic Resonance 1081

40-4 EXCLUSION PRINCIPLE AND MULTIPLE ELECTRONS IN A TRAP 1082

The Pauli Exclusion Principle 1082

Multiple Electrons in Rectangular Traps 1083

40-5 BUILDING THE PERIODIC TABLE 1086

Building the Periodic Table 1086

40-6 X RAYS AND THE ORDERING OF THE ELEMENTS 1088

X Rays and the Ordering of the Elements 1089

40-7 LASERS 1092

Lasers and Laser Light 1093

How Lasers Work 1094

REVIEW & SUMMARY 1097 PROBLEMS 1098

41 Conduction of Electricity in Solids 1102

41-1 THE ELECTRICAL PROPERTIES OF METALS 1102

What Is Physics? 1103

The Electrical Properties of Solids 1103

Energy Levels in a Crystalline Solid 1104

Insulators 1104

Metals 1105

41-2 SEMICONDUCTORS AND DOPING 1111

Semiconductors 1112

Doped Semiconductors 1113

41-3 THE *p-n* JUNCTION AND THE TRANSISTOR 1115

The *p-n* Junction 1116

The Junction Rectifier 1117

The Light-Emitting Diode (LED) 1118

The Transistor 1120

REVIEW & SUMMARY 1121 PROBLEMS 1122

42 Nuclear Physics 1125

42-1 DISCOVERING THE NUCLEUS 1125

What Is Physics? 1125

Discovering the Nucleus 1125

42-2 SOME NUCLEAR PROPERTIES 1128

Some Nuclear Properties 1129

42-3 RADIOACTIVE DECAY 1135

Radioactive Decay 1135

42-4 ALPHA DECAY 1138

Alpha Decay 1138

42-5 BETA DECAY 1141

Beta Decay 1141

42-6 RADIOACTIVE DATING 1144

Radioactive Dating 1144

42-7 MEASURING RADIATION DOSAGE 1145

Measuring Radiation Dosage 1145

42-8 NUCLEAR MODELS 1146

Nuclear Models 1146

REVIEW & SUMMARY 1149 PROBLEMS 1150

43 Energy from the Nucleus 1155

43-1 NUCLEAR FISSION 1155

What Is Physics? 1155

Nuclear Fission: The Basic Process 1156

A Model for Nuclear Fission 1158

43-2 THE NUCLEAR REACTOR 1162

The Nuclear Reactor 1162

43-3 A NATURAL NUCLEAR REACTOR 1166

A Natural Nuclear Reactor 1166

43-4 THERMONUCLEAR FUSION: THE BASIC PROCESS 1168

Thermonuclear Fusion: The Basic Process 1168

43-5 THERMONUCLEAR FUSION IN THE SUN AND OTHER STARS 1170

Thermonuclear Fusion in the Sun and Other Stars 1170

43-6 CONTROLLED THERMONUCLEAR FUSION 1172

Controlled Thermonuclear Fusion 1172

REVIEW & SUMMARY 1175 PROBLEMS 1175

44 Quarks, Leptons, and the Big Bang 1180

44-1 GENERAL PROPERTIES OF ELEMENTARY PARTICLES 1180

What Is Physics? 1180

Particles, Particles, Particles 1181

An Interlude 1185

44-2 LEPTONS, HADRONS, AND STRANGENESS 1189

The Leptons 1189

The Hadrons 1191

Still Another Conservation Law 1192

The Eightfold Way 1193

44-3 QUARKS AND MESSENGER PARTICLES 1195

The Quark Model 1195

The Basic Forces and Messenger Particles 1198

44-4 COSMOLOGY 1201

A Pause for Reflection 1201

The Universe Is Expanding 1202

The Cosmic Background Radiation 1203

Dark Matter 1204

The Big Bang 1204

A Summing Up 1207

REVIEW & SUMMARY 1208 PROBLEMS 1208

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