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B R I E F C O N T E N T S

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

<p>1 Measurement 1</p> <p>1-1 MEASURING THINGS, INCLUDING LENGTHS 1</p> <p>What Is Physics? 1</p> <p>Measuring Things 1</p> <p>The International System of Units 2</p> <p>Changing Units 3</p> <p>Length 3</p> <p>Significant Figures and Decimal Places 4</p> <p>1-2 TIME 5</p> <p>Time 5</p> <p>1-3 MASS 6</p> <p>Mass 6</p> <p>REVIEW & SUMMARY 8 PROBLEMS 8</p> <p>2 Motion Along a Straight Line 13</p> <p>2-1 POSITION, DISPLACEMENT, AND AVERAGE VELOCITY 13</p> <p>What Is Physics? 13</p> <p>Motion 14</p> <p>Position and Displacement 14</p> <p>Average Velocity and Average Speed 15</p> <p>2-2 INSTANTANEOUS VELOCITY AND SPEED 18</p> <p>Instantaneous Velocity and Speed 18</p> <p>2-3 ACCELERATION 20</p> <p>Acceleration 20</p> <p>2-4 CONSTANT ACCELERATION 23</p> <p>Constant Acceleration: A Special Case 23</p> <p>Another Look at Constant Acceleration 26</p> <p>2-5 FREE-FALL ACCELERATION 27</p> <p>Free-Fall Acceleration 27</p> <p>2-6 GRAPHICAL INTEGRATION IN MOTION ANALYSIS 29</p> <p>Graphical Integration in Motion Analysis 29</p> <p>REVIEW & SUMMARY 30 QUESTIONS 31 PROBLEMS 32</p> <p>3 Vectors 40</p> <p>3-1 VECTORS AND THEIR COMPONENTS 40</p> <p>What Is Physics? 40</p> <p>Vectors and Scalars 40</p> <p>Adding Vectors Geometrically 41</p> <p>Components of Vectors 42</p> <p>3-2 UNIT VECTORS, ADDING VECTORS BY COMPONENTS 46</p> <p>Unit Vectors 46</p>	<p>Adding Vectors by Components 46</p> <p>Vectors and the Laws of Physics 47</p> <p>3-3 MULTIPLYING VECTORS 50</p> <p>Multiplying Vectors 50</p> <p>REVIEW & SUMMARY 55 QUESTIONS 56 PROBLEMS 57</p> <p>4 Motion in Two and Three Dimensions 62</p> <p>4-1 POSITION AND DISPLACEMENT 62</p> <p>What Is Physics? 62</p> <p>Position and Displacement 63</p> <p>4-2 AVERAGE VELOCITY AND INSTANTANEOUS VELOCITY 64</p> <p>Average Velocity and Instantaneous Velocity 65</p> <p>4-3 AVERAGE ACCELERATION AND INSTANTANEOUS ACCELERATION 67</p> <p>Average Acceleration and Instantaneous Acceleration 68</p> <p>4-4 PROJECTILE MOTION 70</p> <p>Projectile Motion 70</p> <p>4-5 UNIFORM CIRCULAR MOTION 76</p> <p>Uniform Circular Motion 76</p> <p>4-6 RELATIVE MOTION IN ONE DIMENSION 78</p> <p>Relative Motion in One Dimension 78</p> <p>4-7 RELATIVE MOTION IN TWO DIMENSIONS 80</p> <p>Relative Motion in Two Dimensions 80</p> <p>REVIEW & SUMMARY 81 QUESTIONS 82 PROBLEMS 84</p> <p>5 Force and Motion— 94</p> <p>5-1 NEWTON'S FIRST AND SECOND LAWS 94</p> <p>What Is Physics? 94</p> <p>Newtonian Mechanics 95</p> <p>Newton's First Law 95</p> <p>Force 96</p> <p>Mass 97</p> <p>Newton's Second Law 98</p> <p>5-2 SOME PARTICULAR FORCES 102</p> <p>Some Particular Forces 102</p> <p>5-3 APPLYING NEWTON'S LAWS 106</p> <p>Newton's Third Law 106</p> <p>Applying Newton's Laws 108</p> <p>REVIEW & SUMMARY 114 QUESTIONS 114 PROBLEMS 116</p>
---	--

6 Force and Motion—II	124	8-4 WORK DONE ON A SYSTEM BY AN EXTERNAL FORCE	191
6-1 FRICTION	124	Work Done on a System by an External Force	192
What Is Physics?	124	8-5 CONSERVATION OF ENERGY	195
Friction	124	Conservation of Energy	195
Properties of Friction	127	REVIEW & SUMMARY	199
6-2 THE DRAG FORCE AND TERMINAL SPEED	130	QUESTIONS	200
The Drag Force and Terminal Speed	130	PROBLEMS	202
6-3 UNIFORM CIRCULAR MOTION	133	9 Center of Mass and Linear Momentum	214
Uniform Circular Motion	133	9-1 CENTER OF MASS	214
REVIEW & SUMMARY	138	What Is Physics?	214
QUESTIONS	139	The Center of Mass	215
PROBLEMS	140	9-2 NEWTON'S SECOND LAW FOR A SYSTEM OF PARTICLES	220
7 Kinetic Energy and Work	149	Newton's Second Law for a System of Particles	220
7-1 KINETIC ENERGY	149	9-3 LINEAR MOMENTUM	224
What Is Physics?	149	Linear Momentum	224
What Is Energy?	149	The Linear Momentum of a System of Particles	225
Kinetic Energy	150	9-4 COLLISION AND IMPULSE	226
7-2 WORK AND KINETIC ENERGY	151	Collision and Impulse	226
Work	151	9-5 CONSERVATION OF LINEAR MOMENTUM	230
Work and Kinetic Energy	152	Conservation of Linear Momentum	230
7-3 WORK DONE BY THE GRAVITATIONAL FORCE	155	9-6 MOMENTUM AND KINETIC ENERGY IN COLLISIONS	233
Work Done by the Gravitational Force	156	Momentum and Kinetic Energy in Collisions	233
7-4 WORK DONE BY A SPRING FORCE	159	Inelastic Collisions in One Dimension	234
Work Done by a Spring Force	159	9-7 ELASTIC COLLISIONS IN ONE DIMENSION	237
7-5 WORK DONE BY A GENERAL VARIABLE FORCE	162	Elastic Collisions in One Dimension	237
Work Done by a General Variable Force	162	9-8 COLLISIONS IN TWO DIMENSIONS	240
7-6 POWER	166	Collisions in Two Dimensions	240
Power	166	9-9 SYSTEMS WITH VARYING MASS: A ROCKET	241
REVIEW & SUMMARY	168	Systems with Varying Mass: A Rocket	241
QUESTIONS	169	REVIEW & SUMMARY	243
PROBLEMS	170	QUESTIONS	245
8 Potential Energy and Conservation of Energy	177	PROBLEMS	246
8-1 POTENTIAL ENERGY	177	10 Rotation	257
What Is Physics?	177	10-1 ROTATIONAL VARIABLES	257
Work and Potential Energy	178	What Is Physics?	258
Path Independence of Conservative Forces	179	Rotational Variables	259
Determining Potential Energy Values	181	Are Angular Quantities Vectors?	264
8-2 CONSERVATION OF MECHANICAL ENERGY	184	10-2 ROTATION WITH CONSTANT ANGULAR ACCELERATION	266
Conservation of Mechanical Energy	184	Rotation with Constant Angular Acceleration	266
8-3 READING A POTENTIAL ENERGY CURVE	187		
Reading a Potential Energy Curve	187		

10-3 RELATING THE LINEAR AND ANGULAR VARIABLES 268

Relating the Linear and Angular Variables 268

10-4 KINETIC ENERGY OF ROTATION 271

Kinetic Energy of Rotation 271

10-5 CALCULATING THE ROTATIONAL INERTIA 273

Calculating the Rotational Inertia 273

10-6 TORQUE 277

Torque 278

10-7 NEWTON'S SECOND LAW FOR ROTATION 279

Newton's Second Law for Rotation 279

10-8 WORK AND ROTATIONAL KINETIC ENERGY 282

Work and Rotational Kinetic Energy 282

REVIEW & SUMMARY 285 QUESTIONS 286 PROBLEMS 287

11 Rolling, Torque, and Angular Momentum 295**11-1 ROLLING AS TRANSLATION AND ROTATION COMBINED** 295

What Is Physics? 295

Rolling as Translation and Rotation Combined 295

11-2 FORCES AND KINETIC ENERGY OF ROLLING 298

The Kinetic Energy of Rolling 298

The Forces of Rolling 299

11-3 THE YO-YO 301

The Yo-Yo 302

11-4 TORQUE REVISITED 302

Torque Revisited 303

11-5 ANGULAR MOMENTUM 305

Angular Momentum 305

11-6 NEWTON'S SECOND LAW IN ANGULAR FORM 307

Newton's Second Law in Angular Form 307

11-7 ANGULAR MOMENTUM OF A RIGID BODY 310

The Angular Momentum of a System of Particles 310

The Angular Momentum of a Rigid Body Rotating About a Fixed Axis 311

11-8 CONSERVATION OF ANGULAR MOMENTUM 312

Conservation of Angular Momentum 312

11-9 PRECESSION OF A GYROSCOPE 317

Precession of a Gyroscope 317

REVIEW & SUMMARY 318 QUESTIONS 319 PROBLEMS 320

12 Equilibrium and Elasticity 327**12-1 EQUILIBRIUM** 327

What Is Physics? 327

Equilibrium 327

The Requirements of Equilibrium 329

The Center of Gravity 330

12-2 SOME EXAMPLES OF STATIC EQUILIBRIUM 332

Some Examples of Static Equilibrium 332

12-3 ELASTICITY 338

Indeterminate Structures 338

Elasticity 339

REVIEW & SUMMARY 343 QUESTIONS 343 PROBLEMS 345

13 Gravitation 354**13-1 NEWTON'S LAW OF GRAVITATION** 354

What Is Physics? 354

Newton's Law of Gravitation 355

13-2 GRAVITATION AND THE PRINCIPLE OF SUPERPOSITION 357

Gravitation and the Principle of Superposition 357

13-3 GRAVITATION NEAR EARTH'S SURFACE 359

Gravitation Near Earth's Surface 360

13-4 GRAVITATION INSIDE EARTH 362

Gravitation Inside Earth 363

13-5 GRAVITATIONAL POTENTIAL ENERGY 364

Gravitational Potential Energy 364

13-6 PLANETS AND SATELLITES: KEPLER'S LAWS 368

Planets and Satellites: Kepler's Laws 369

13-7 SATELLITES: ORBITS AND ENERGY 371

Satellites: Orbits and Energy 371

13-8 EINSTEIN AND GRAVITATION 374

Einstein and Gravitation 374

REVIEW & SUMMARY 376 QUESTIONS 377 PROBLEMS 378

14 Fluids 386**14-1 FLUIDS, DENSITY, AND PRESSURE** 386

What Is Physics? 386

What Is a Fluid? 386

Density and Pressure 387

14-2 FLUIDS AT REST 388

Fluids at Rest 389

14-3 MEASURING PRESSURE 392

Measuring Pressure 392

14-4 PASCAL'S PRINCIPLE 393

Pascal's Principle 393

14-5 ARCHIMEDES' PRINCIPLE 394

Archimedes' Principle 395

14-6 THE EQUATION OF CONTINUITY 398

Ideal Fluids in Motion 398

The Equation of Continuity 399

14-7 BERNOULLI'S EQUATION 401

Bernoulli's Equation 401

REVIEW & SUMMARY 405 QUESTIONS 405 PROBLEMS 406

15 Oscillations 413**15-1 SIMPLE HARMONIC MOTION** 413

What Is Physics? 414

Simple Harmonic Motion 414

The Force Law for Simple Harmonic Motion 419

15-2 ENERGY IN SIMPLE HARMONIC MOTION 421

Energy in Simple Harmonic Motion 421

15-3 AN ANGULAR SIMPLE HARMONIC OSCILLATOR 423

An Angular Simple Harmonic Oscillator 423

15-4 PENDULUMS, CIRCULAR MOTION 424

Pendulums 425

Simple Harmonic Motion and Uniform Circular Motion 428

15-5 DAMPED SIMPLE HARMONIC MOTION 430

Damped Simple Harmonic Motion 430

15-6 FORCED OSCILLATIONS AND RESONANCE 432

Forced Oscillations and Resonance 432

REVIEW & SUMMARY 434 QUESTIONS 434 PROBLEMS 436

16 Waves—I 444**16-1 TRANSVERSE WAVES** 444

What Is Physics? 445

Types of Waves 445

Transverse and Longitudinal Waves 445

Wavelength and Frequency 446

The Speed of a Traveling Wave 449

16-2 WAVE SPEED ON A STRETCHED STRING 452

Wave Speed on a Stretched String 452

16-3 ENERGY AND POWER OF A WAVE TRAVELING ALONG A STRING 454

Energy and Power of a Wave Traveling Along a String 454

16-4 THE WAVE EQUATION 456

The Wave Equation 456

16-5 INTERFERENCE OF WAVES 458

The Principle of Superposition for Waves 458

Interference of Waves 459

16-6 PHASORS 462

Phasors 462

16-7 STANDING WAVES AND RESONANCE 465

Standing Waves 465

Standing Waves and Resonance 467

REVIEW & SUMMARY 470 QUESTIONS 471 PROBLEMS 472

17 Waves—II 479**17-1 SPEED OF SOUND** 479

What Is Physics? 479

Sound Waves 479

The Speed of Sound 480

17-2 TRAVELING SOUND WAVES 482

Traveling Sound Waves 482

17-3 INTERFERENCE 485

Interference 485

17-4 INTENSITY AND SOUND LEVEL 488

Intensity and Sound Level 489

17-5 SOURCES OF MUSICAL SOUND 492

Sources of Musical Sound 493

17-6 BEATS 496

Beats 497

17-7 THE DOPPLER EFFECT 498

The Doppler Effect 499

17-8 SUPERSONIC SPEEDS, SHOCK WAVES 503

Supersonic Speeds, Shock Waves 503

REVIEW & SUMMARY 504 QUESTIONS 505 PROBLEMS 506

18 Temperature, Heat, and the First Law of Thermodynamics 514**18-1 TEMPERATURE** 514

What Is Physics? 514

Temperature 515

The Zeroth Law of Thermodynamics 515
 Measuring Temperature 516

18-2 THE CELSIUS AND FAHRENHEIT SCALES 518
 The Celsius and Fahrenheit Scales 518

18-3 THERMAL EXPANSION 520
 Thermal Expansion 520

18-4 ABSORPTION OF HEAT 522
 Temperature and Heat 523
 The Absorption of Heat by Solids and Liquids 524

18-5 THE FIRST LAW OF THERMODYNAMICS 528
 A Closer Look at Heat and Work 528
 The First Law of Thermodynamics 531
 Some Special Cases of the First Law of Thermodynamics 532

18-6 HEAT TRANSFER MECHANISMS 534
 Heat Transfer Mechanisms 534

REVIEW & SUMMARY 538 QUESTIONS 540 PROBLEMS 541

19 The Kinetic Theory of Gases 549

19-1 AVOGADRO'S NUMBER 549
 What Is Physics? 549
 Avogadro's Number 550

19-2 IDEAL GASES 550
 Ideal Gases 551

19-3 PRESSURE, TEMPERATURE, AND RMS SPEED 554
 Pressure, Temperature, and RMS Speed 554

19-4 TRANSLATIONAL KINETIC ENERGY 557
 Translational Kinetic Energy 557

19-5 MEAN FREE PATH 558
 Mean Free Path 558

19-6 THE DISTRIBUTION OF MOLECULAR SPEEDS 560
 The Distribution of Molecular Speeds 561

19-7 THE MOLAR SPECIFIC HEATS OF AN IDEAL GAS 564
 The Molar Specific Heats of an Ideal Gas 564

19-8 DEGREES OF FREEDOM AND MOLAR SPECIFIC HEATS 568
 Degrees of Freedom and Molar Specific Heats 568
 A Hint of Quantum Theory 570

19-9 THE ADIABATIC EXPANSION OF AN IDEAL GAS 571
 The Adiabatic Expansion of an Ideal Gas 571

REVIEW & SUMMARY 575 QUESTIONS 576 PROBLEMS 577

20 Entropy and the Second Law of Thermodynamics 583

20-1 ENTROPY 583
 What Is Physics? 584
 Irreversible Processes and Entropy 584
 Change in Entropy 585
 The Second Law of Thermodynamics 588

20-2 ENTROPY IN THE REAL WORLD: ENGINES 590
 Entropy in the Real World: Engines 590

20-3 REFRIGERATORS AND REAL ENGINES 595
 Entropy in the Real World: Refrigerators 596
 The Efficiencies of Real Engines 597

20-4 A STATISTICAL VIEW OF ENTROPY 598
 A Statistical View of Entropy 598

REVIEW & SUMMARY 602 QUESTIONS 603 PROBLEMS 604

21 Coulomb's Law 609

21-1 COULOMB'S LAW 609
 What Is Physics? 610
 Electric Charge 610
 Conductors and Insulators 612
 Coulomb's Law 613

21-2 CHARGE IS QUANTIZED 619
 Charge Is Quantized 619

21-3 CHARGE IS CONSERVED 621
 Charge Is Conserved 621

REVIEW & SUMMARY 622 QUESTIONS 623 PROBLEMS 624

22 Electric Fields 630

22-1 THE ELECTRIC FIELD 630
 What Is Physics? 630
 The Electric Field 631
 Electric Field Lines 631

22-2 THE ELECTRIC FIELD DUE TO A CHARGED PARTICLE 633
 The Electric Field Due to a Point Charge 633

22-3 THE ELECTRIC FIELD DUE TO A DIPOLE 635
 The Electric Field Due to an Electric Dipole 636

22-4 THE ELECTRIC FIELD DUE TO A LINE OF CHARGE	638	24-5 POTENTIAL DUE TO A CONTINUOUS CHARGE DISTRIBUTION	698
The Electric Field Due to Line of Charge	638	Potential Due to a Continuous Charge Distribution	698
22-5 THE ELECTRIC FIELD DUE TO A CHARGED DISK	643	24-6 CALCULATING THE FIELD FROM THE POTENTIAL	701
The Electric Field Due to a Charged Disk	643	Calculating the Field from the Potential	701
22-6 A POINT CHARGE IN AN ELECTRIC FIELD	645	24-7 ELECTRIC POTENTIAL ENERGY OF A SYSTEM OF CHARGED PARTICLES	703
A Point Charge in an Electric Field	645	Electric Potential Energy of a System of Charged Particles	703
22-7 A DIPOLE IN AN ELECTRIC FIELD	647	24-8 POTENTIAL OF A CHARGED ISOLATED CONDUCTOR	706
A Dipole in an Electric Field	648	Potential of a Charged Isolated Conductor	706
REVIEW & SUMMARY	650	QUESTIONS	651
PROBLEMS	652	REVIEW & SUMMARY	707
QUESTIONS	651	QUESTIONS	708
PROBLEMS	652	PROBLEMS	710
23 Gauss' Law	659	25 Capacitance	717
23-1 ELECTRIC FLUX	659	25-1 CAPACITANCE	717
What Is Physics?	659	What Is Physics?	717
Electric Flux	660	Capacitance	717
23-2 GAUSS' LAW	664	25-2 CALCULATING THE CAPACITANCE	719
Gauss' Law	664	Calculating the Capacitance	720
Gauss' Law and Coulomb's Law	666	25-3 CAPACITORS IN PARALLEL AND IN SERIES	723
23-3 A CHARGED ISOLATED CONDUCTOR	668	Capacitors in Parallel and in Series	724
A Charged Isolated Conductor	668	25-4 ENERGY STORED IN AN ELECTRIC FIELD	728
23-4 APPLYING GAUSS' LAW: CYLINDRICAL SYMMETRY	671	Energy Stored in an Electric Field	728
Applying Gauss' Law: Cylindrical Symmetry	671	25-5 CAPACITOR WITH A DIELECTRIC	731
23-5 APPLYING GAUSS' LAW: PLANAR SYMMETRY	673	Capacitor with a Dielectric	731
Applying Gauss' Law: Planar Symmetry	673	Dielectrics: An Atomic View	733
23-6 APPLYING GAUSS' LAW: SPHERICAL SYMMETRY	675	25-6 DIELECTRICS AND GAUSS' LAW	735
Applying Gauss' Law: Spherical Symmetry	675	Dielectrics and Gauss' Law	735
REVIEW & SUMMARY	677	QUESTIONS	738
QUESTIONS	677	PROBLEMS	739
PROBLEMS	679	26 Current and Resistance	745
24 Electric Potential	685	26-1 ELECTRIC CURRENT	745
24-1 ELECTRIC POTENTIAL	685	What Is Physics?	745
What Is Physics?	685	Electric Current	746
Electric Potential and Electric Potential Energy	686	26-2 CURRENT DENSITY	748
24-2 EQUIPOTENTIAL SURFACES AND THE ELECTRIC FIELD	690	Current Density	749
Equipotential Surfaces	690	26-3 RESISTANCE AND RESISTIVITY	752
Calculating the Potential from the Field	691	Resistance and Resistivity	753
24-3 POTENTIAL DUE TO A CHARGED PARTICLE	694	26-4 OHM'S LAW	756
Potential Due to a Charged Particle	694	Ohm's Law	756
Potential Due to a Group of Charged Particles	695	A Microscopic View of Ohm's Law	758
24-4 POTENTIAL DUE TO AN ELECTRIC DIPOLE	697		
Potential Due to an Electric Dipole	697		

**26-5 POWER, SEMICONDUCTORS,
SUPERCONDUCTORS** 760

Power in Electric Circuits 760

Semiconductors 762

Superconductors 763

REVIEW & SUMMARY 763 QUESTIONS 764 PROBLEMS 765

27 Circuits 771**27-1 SINGLE-LOOP CIRCUITS** 771

What Is Physics? 772

“Pumping” Charges 772

Work, Energy, and Emf 773

Calculating the Current in a Single-Loop Circuit 774

Other Single-Loop Circuits 776

Potential Difference Between Two Points 777

27-2 MULTILoop CIRCUITS 781

Multiloop Circuits 781

27-3 THE AMMETER AND THE VOLTMETER 788

The Ammeter and the Voltmeter 788

27-4 RC CIRCUITS 788

RC Circuits 789

REVIEW & SUMMARY 793 QUESTIONS 793 PROBLEMS 795

28 Magnetic Fields 803**28-1 MAGNETIC FIELDS AND THE DEFINITION OF \vec{B}** 803

What Is Physics? 803

What Produces a Magnetic Field? 804

The Definition of \vec{B} 804**28-2 CROSSED FIELDS: DISCOVERY OF THE
ELECTRON** 808

Crossed Fields: Discovery of the Electron 809

28-3 CROSSED FIELDS: THE HALL EFFECT 810

Crossed Fields: The Hall Effect 811

28-4 A CIRCULATING CHARGED PARTICLE 814

A Circulating Charged Particle 814

28-5 CYCLOTRONS AND SYNCHROTRONS 817

Cyclotrons and Synchrotrons 818

**28-6 MAGNETIC FORCE ON A CURRENT-CARRYING
WIRE** 820

Magnetic Force on a Current-Carrying Wire 820

28-7 TORQUE ON A CURRENT LOOP 822

Torque on a Current Loop 822

28-8 THE MAGNETIC DIPOLE MOMENT 824

The Magnetic Dipole Moment 825

REVIEW & SUMMARY 827 QUESTIONS 827 PROBLEMS 829

29 Magnetic Fields Due to Currents 836**29-1 MAGNETIC FIELD DUE TO A CURRENT** 836

What Is Physics? 836

Calculating the Magnetic Field Due to a Current 837

29-2 FORCE BETWEEN TWO PARALLEL CURRENTS 842

Force Between Two Parallel Currents 842

29-3 AMPERE’S LAW 844

Ampere’s Law 844

29-4 SOLENOIDS AND TOROIDS 848

Solenoids and Toroids 848

29-5 A CURRENT-CARRYING COIL AS A MAGNETIC DIPOLE 851

A Current-Carrying Coil as a Magnetic Dipole 851

REVIEW & SUMMARY 854 QUESTIONS 855 PROBLEMS 856

30 Induction and Inductance 864**30-1 FARADAY’S LAW AND LENZ’S LAW** 864

What Is Physics? 864

Two Experiments 865

Faraday’s Law of Induction 865

Lenz’s Law 868

30-2 INDUCTION AND ENERGY TRANSFERS 871

Induction and Energy Transfers 871

30-3 INDUCED ELECTRIC FIELDS 874

Induced Electric Fields 875

30-4 INDUCTORS AND INDUCTANCE 879

Inductors and Inductance 879

30-5 SELF-INDUCTION 881

Self-Induction 881

30-6 RL CIRCUITS 882

RL Circuits 883

30-7 ENERGY STORED IN A MAGNETIC FIELD 887

Energy Stored in a Magnetic Field 887

30-8 ENERGY DENSITY OF A MAGNETIC FIELD 889

Energy Density of a Magnetic Field 889

30-9 MUTUAL INDUCTION 890

Mutual Induction 890

REVIEW & SUMMARY 893 QUESTIONS 893 PROBLEMS 895

31 Electromagnetic Oscillations and Alternating Current 903

31-1 LC OSCILLATIONS 903

What Is Physics? 904

LC Oscillations, Qualitatively 904

The Electrical-Mechanical Analogy 906

LC Oscillations, Quantitatively 907

31-2 DAMPED OSCILLATIONS IN AN RLC CIRCUIT 910

Damped Oscillations in an RLC Circuit 911

31-3 FORCED OSCILLATIONS OF THREE SIMPLE CIRCUITS 912

Alternating Current 913

Forced Oscillations 914

Three Simple Circuits 914

31-4 THE SERIES RLC CIRCUIT 921

The Series RLC Circuit 921

31-5 POWER IN ALTERNATING-CURRENT CIRCUITS 927

Power in Alternating-Current Circuits 927

31-6 TRANSFORMERS 930

Transformers 930

REVIEW & SUMMARY 933 QUESTIONS 934 PROBLEMS 935

32 Maxwell's Equations; Magnetism of Matter 941

32-1 GAUSS' LAW FOR MAGNETIC FIELDS 941

What Is Physics? 941

Gauss' Law for Magnetic Fields 942

32-2 INDUCED MAGNETIC FIELDS 943

Induced Magnetic Fields 943

32-3 DISPLACEMENT CURRENT 946

Displacement Current 947

Maxwell's Equations 949

32-4 MAGNETS 950

Magnets 950

32-5 MAGNETISM AND ELECTRONS 952

Magnetism and Electrons 953

Magnetic Materials 956

32-6 DIAMAGNETISM 957

Diamagnetism 957

32-7 PARAMAGNETISM 959

Paramagnetism 959

32-8 FERROMAGNETISM 961

Ferromagnetism 961

REVIEW & SUMMARY 964 QUESTIONS 965 PROBLEMS 967

33 Electromagnetic Waves 972

33-1 ELECTROMAGNETIC WAVES 972

What Is Physics? 972

Maxwell's Rainbow 973

The Traveling Electromagnetic Wave, Qualitatively 974

The Traveling Electromagnetic Wave, Quantitatively 977

33-2 ENERGY TRANSPORT AND THE POYNTING VECTOR 980

Energy Transport and the Poynting Vector 981

33-3 RADIATION PRESSURE 983

Radiation Pressure 983

33-4 POLARIZATION 985

Polarization 985

33-5 REFLECTION AND REFRACTION 990

Reflection and Refraction 991

33-6 TOTAL INTERNAL REFLECTION 996

Total Internal Reflection 996

33-7 POLARIZATION BY REFLECTION 997

Polarization by Reflection 998

REVIEW & SUMMARY 999 QUESTIONS 1000 PROBLEMS 1001

34 Images 1010

34-1 IMAGES AND PLANE MIRRORS 1010

What Is Physics? 1010

Two Types of Image 1010

Plane Mirrors 1012

34-2 SPHERICAL MIRRORS 1014

Spherical Mirrors 1015

Images from Spherical Mirrors 1016

34-3 SPHERICAL REFRACTING SURFACES 1020

Spherical Refracting Surfaces 1020

34-4 THIN LENSES 1023

Thin Lenses 1023

34-5 OPTICAL INSTRUMENTS 1030

Optical Instruments 1030

34-6 THREE PROOFS 1033

REVIEW & SUMMARY 1036 QUESTIONS 1037 PROBLEMS 1038

35 Interference 1047**35-1 LIGHT AS A WAVE** 1047

What Is Physics? 1047

Light as a Wave 1048

35-2 YOUNG'S INTERFERENCE EXPERIMENT 1053

Diffraction 1053

Young's Interference Experiment 1054

35-3 INTERFERENCE AND DOUBLE-SLIT INTENSITY 1059

Coherence 1059

Intensity in Double-Slit Interference 1060

35-4 INTERFERENCE FROM THIN FILMS 1063

Interference from Thin Films 1064

35-5 MICHELSON'S INTERFEROMETER 1070

Michelson's Interferometer 1071

REVIEW & SUMMARY 1072 QUESTIONS 1072 PROBLEMS 1074

36 Diffraction 1081**36-1 SINGLE-SLIT DIFFRACTION** 1081

What Is Physics? 1081

Diffraction and the Wave Theory of Light 1081

Diffraction by a Single Slit: Locating the Minima 1083

36-2 INTENSITY IN SINGLE-SLIT DIFFRACTION 1086

Intensity in Single-Slit Diffraction 1086

Intensity in Single-Slit Diffraction, Quantitatively 1088

36-3 DIFFRACTION BY A CIRCULAR APERTURE 1090

Diffraction by a Circular Aperture 1091

36-4 DIFFRACTION BY A DOUBLE SLIT 1094

Diffraction by a Double Slit 1095

36-5 DIFFRACTION GRATINGS 1098

Diffraction Gratings 1098

36-6 GRATINGS: DISPERSION AND RESOLVING POWER 1101

Gratings: Dispersion and Resolving Power 1101

36-7 X-RAY DIFFRACTION 1104

X-Ray Diffraction 1104

REVIEW & SUMMARY 1107 QUESTIONS 1107 PROBLEMS 1108

37 Relativity 1116**37-1 SIMULTANEITY AND TIME DILATION** 1116

What Is Physics? 1116

The Postulates 1117

Measuring an Event 1118

The Relativity of Simultaneity 1120

The Relativity of Time 1121

37-2 THE RELATIVITY OF LENGTH 1125

The Relativity of Length 1126

37-3 THE LORENTZ TRANSFORMATION 1129

The Lorentz Transformation 1129

Some Consequences of the Lorentz Equations 1131

37-4 THE RELATIVITY OF VELOCITIES 1133

The Relativity of Velocities 1133

37-5 DOPPLER EFFECT FOR LIGHT 1134

Doppler Effect for Light 1135

37-6 MOMENTUM AND ENERGY 1137

A New Look at Momentum 1138

A New Look at Energy 1138

REVIEW & SUMMARY 1143 QUESTIONS 1144 PROBLEMS 1145

38 Photons and Matter Waves 1153**38-1 THE PHOTON, THE QUANTUM OF LIGHT** 1153

What Is Physics? 1153

The Photon, the Quantum of Light 1154

38-2 THE PHOTOELECTRIC EFFECT 1155

The Photoelectric Effect 1156

38-3 PHOTONS, MOMENTUM, COMPTON SCATTERING, LIGHT INTERFERENCE 1158

Photons Have Momentum 1159

Light as a Probability Wave 1162

38-4 THE BIRTH OF QUANTUM PHYSICS 1164

The Birth of Quantum Physics 1165

38-5 ELECTRONS AND MATTER WAVES 1166

Electrons and Matter Waves 1167

38-6 SCHRÖDINGER'S EQUATION 1170

Schrödinger's Equation 1170

38-7 HEISENBERG'S UNCERTAINTY PRINCIPLE 1172

Heisenberg's Uncertainty Principle 1173

38-8 REFLECTION FROM A POTENTIAL STEP 1174

Reflection from a Potential Step 1174

38-9 TUNNELING THROUGH A POTENTIAL BARRIER 1176

Tunneling Through a Potential Barrier 1176

REVIEW & SUMMARY 1179 QUESTIONS 1180 PROBLEMS 1181

- 39 More About Matter Waves** 1186
- 39-1 ENERGIES OF A TRAPPED ELECTRON** 1186
- What Is Physics? 1186
- String Waves and Matter Waves 1187
- Energies of a Trapped Electron 1187
- 39-2 WAVE FUNCTIONS OF A TRAPPED ELECTRON** 1191
- Wave Functions of a Trapped Electron 1192
- 39-3 AN ELECTRON IN A FINITE WELL** 1195
- An Electron in a Finite Well 1195
- 39-4 TWO- AND THREE-DIMENSIONAL ELECTRON TRAPS** 1197
- More Electron Traps 1197
- Two- and Three-Dimensional Electron Traps 1200
- 39-5 THE HYDROGEN ATOM** 1201
- The Hydrogen Atom Is an Electron Trap 1202
- The Bohr Model of Hydrogen, a Lucky Break 1203
- Schrödinger's Equation and the Hydrogen Atom 1205
- REVIEW & SUMMARY 1213 QUESTIONS 1213 PROBLEMS 1214
- 40 All About Atoms** 1219
- 40-1 PROPERTIES OF ATOMS** 1219
- What Is Physics? 1220
- Some Properties of Atoms 1220
- Angular Momentum, Magnetic Dipole Moments 1222
- 40-2 THE STERN–GERLACH EXPERIMENT** 1226
- The Stern–Gerlach Experiment 1226
- 40-3 MAGNETIC RESONANCE** 1229
- Magnetic Resonance 1229
- 40-4 EXCLUSION PRINCIPLE AND MULTIPLE ELECTRONS IN A TRAP** 1230
- The Pauli Exclusion Principle 1230
- Multiple Electrons in Rectangular Traps 1231
- 40-5 BUILDING THE PERIODIC TABLE** 1234
- Building the Periodic Table 1234
- 40-6 X RAYS AND THE ORDERING OF THE ELEMENTS** 1236
- X Rays and the Ordering of the Elements 1237
- 40-7 LASERS** 1240
- Lasers and Laser Light 1241
- How Lasers Work 1242
- REVIEW & SUMMARY 1245 QUESTIONS 1246 PROBLEMS 1247
- 41 Conduction of Electricity in Solids** 1252
- 41-1 THE ELECTRICAL PROPERTIES OF METALS** 1252
- What Is Physics? 1253
- The Electrical Properties of Solids 1253
- Energy Levels in a Crystalline Solid 1254
- Insulators 1254
- Metals 1255
- 41-2 SEMICONDUCTORS AND DOPING** 1261
- Semiconductors 1262
- Doped Semiconductors 1263
- 41-3 THE p - n JUNCTION AND THE TRANSISTOR** 1265
- The p - n Junction 1266
- The Junction Rectifier 1267
- The Light-Emitting Diode (LED) 1268
- The Transistor 1270
- REVIEW & SUMMARY 1271 QUESTIONS 1272 PROBLEMS 1272
- 42 Nuclear Physics** 1276
- 42-1 DISCOVERING THE NUCLEUS** 1276
- What Is Physics? 1276
- Discovering the Nucleus 1276
- 42-2 SOME NUCLEAR PROPERTIES** 1279
- Some Nuclear Properties 1280
- 42-3 RADIOACTIVE DECAY** 1286
- Radioactive Decay 1286
- 42-4 ALPHA DECAY** 1289
- Alpha Decay 1289
- 42-5 BETA DECAY** 1292
- Beta Decay 1292
- 42-6 RADIOACTIVE DATING** 1295
- Radioactive Dating 1295
- 42-7 MEASURING RADIATION DOSAGE** 1296
- Measuring Radiation Dosage 1296
- 42-8 NUCLEAR MODELS** 1297
- Nuclear Models 1297
- REVIEW & SUMMARY 1300 QUESTIONS 1301 PROBLEMS 1302
- 43 Energy from the Nucleus** 1309
- 43-1 NUCLEAR FISSION** 1309
- What Is Physics? 1309
- Nuclear Fission: The Basic Process 1310
- A Model for Nuclear Fission 1312

43-2 THE NUCLEAR REACTOR 1316
 The Nuclear Reactor 1316

43-3 A NATURAL NUCLEAR REACTOR 1320
 A Natural Nuclear Reactor 1320

43-4 THERMONUCLEAR FUSION: THE BASIC PROCESS 1322
 Thermonuclear Fusion: The Basic Process 1322

43-5 THERMONUCLEAR FUSION IN THE SUN AND OTHER STARS 1324
 Thermonuclear Fusion in the Sun and Other Stars 1324

43-6 CONTROLLED THERMONUCLEAR FUSION 1326
 Controlled Thermonuclear Fusion 1326
 REVIEW & SUMMARY 1329 QUESTIONS 1329 PROBLEMS 1330

44 Quarks, Leptons, and the Big Bang 1334

44-1 GENERAL PROPERTIES OF ELEMENTARY PARTICLES 1334
 What Is Physics? 1334
 Particles, Particles, Particles 1335
 An Interlude 1339

44-2 LEPTONS, HADRONS, AND STRANGENESS 1343
 The Leptons 1343
 The Hadrons 1345
 Still Another Conservation Law 1346
 The Eightfold Way 1347

44-3 QUARKS AND MESSENGER PARTICLES 1349
 The Quark Model 1349
 The Basic Forces and Messenger Particles 1352

44-4 COSMOLOGY 1355
 A Pause for Reflection 1355
 The Universe Is Expanding 1356
 The Cosmic Background Radiation 1357
 Dark Matter 1358
 The Big Bang 1358
 A Summing Up 1361

REVIEW & SUMMARY 1362 QUESTIONS 1362 PROBLEMS 1363

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

HOW TO USE THE 11TH EDITION OF FUNDAMENTALS OF PHYSICS

The *WileyPLUS* Course for *Fundamentals of Physics* is now in its 11th edition. You will note that this print component does not have an edition number. This is because while we completely overhauled the WP course for the 11th edition, we did not change anything in the print version other than this preface. It is our hope that students will use the 11th edition of *Fundamentals of Physics* in *WileyPLUS* as their sole course material. If they do need a print companion, the edition previously sold as the 10th edition is available to them.

A LETTER FROM THE AUTHOR

PHYSICS FOR RACHAEL

The eleventh edition of *Fundamentals of Physics* is an online, interactive, digital learning center within *WileyPLUS*. My working title for the “book” portion of the center is *Physics for Rachael* because I originated its design when Rachael Catrina was in my first semester physics class.



Rachael Catrina and Jearl Walker
Photo courtesy of Rachael Catrina

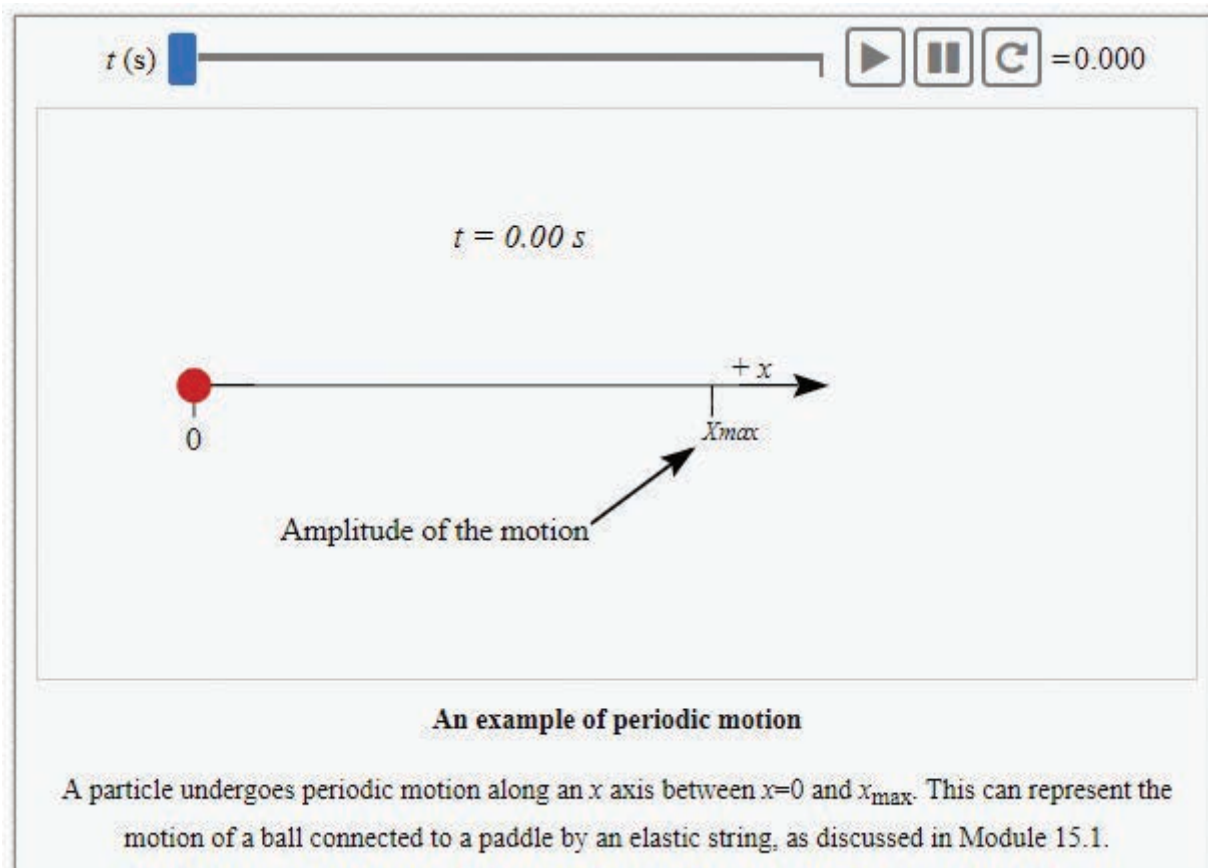
Within the first few weeks, Rachael began to come to my office for help. I soon realized that, although she was eager to succeed, she was not learning enough by reading the textbook and she was not gaining enough information from my lectures to do the homework or prepare for the exams. So, we began discussions of the physics in two-hour sessions each week for the rest of the semester. I would explain some physics and then ask guiding questions. She would respond. If she was wrong, I would tell her the correct answer and why. Instead of passive reading in the textbook or passive listening to the lectures, we had a back-and-forth exchange of questions and explanations. *Passive* switched to *engaged*. She learned the physics. I learned how a modern student thinks.

At the end of the semester, I pitched the idea of converting *Fundamentals 10e* to be an online, digital, interactive “book” to the publisher, John Wiley & Sons. Together we have now transformed the traditional book of thousands of declarative sentences into a Rachael-type of discourse. In each chapter section, I explain some physics and then ask guiding questions, which the online student will answer. If the student’s answer is wrong, then I indicate the correct answer and why. In that way I guide the student through the chapter. The book is now much more than just a book. Rather, it is part of a learning center with information, interactive challenges, activities, games (which can be group activities), and embedded media. The reality is that today most students taking the introductory physics course are like Rachael in that they need lots of guidance and interaction. Although I cannot be available in person for each student as I was for Rachael, this digital and interactive resource is available 24/7.

Brad Trees of Ohio Wesleyan University has contributed many interactive exercises and simulations within the *Rachael* chapters and within *WileyPLUS*. They will engage the students in visual ways, challenging them to dig deeper into the physics than the standard homework problems. Many are based on real-world applications of physics and offer animations of time dependent phenomena.

WHAT'S NEW IN THE ELEVENTH EDITION

Interactive Exercises and Simulations by Brad Trees of Ohio Wesleyan University. How do we help students understand challenging concepts in physics? How do we motivate students to engage with core content in a meaningful way? The new simulations accompanying the eleventh edition of *Fundamentals of Physics* are intended to address these key questions. Each module in the Etext is linked to one or more simulations that convey concepts visually. A simulation depicts a physical situation in which time dependent phenomena are animated and information is presented in multiple representations including a visual representation of the physical system as well as a plot of related variables. Often, adjustable parameters allow the user to change a property of the system and to see the effects of that change on the subsequent behavior. For visual learners, the simulations provide an opportunity to “see” the physics in action. Each simulation is also linked to a set of interactive exercises, which guides the student through a deeper interaction with the physics underlying the simulation. The exercises consist of a series of practice questions with feedback and detailed solutions. Instructors may choose to assign the exercises for practice, to recommend the exercises to students as additional practice, and to show individual simulations during class time to demonstrate a concept and to motivate class discussion.



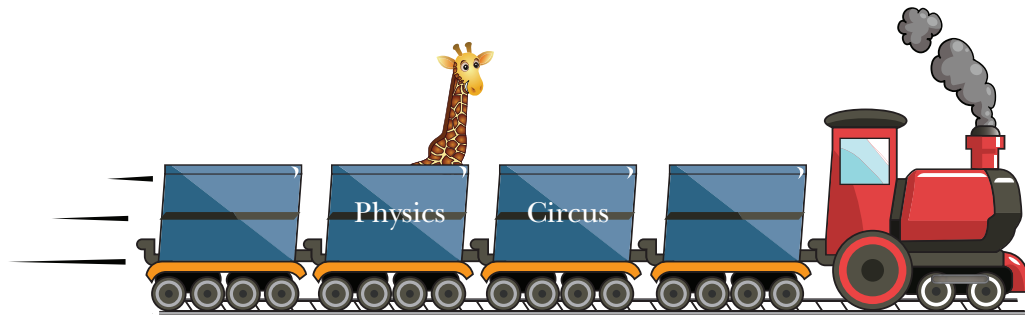
An example of periodic motion

A particle undergoes periodic motion along an x axis between $x=0$ and x_{\max} . This can represent the motion of a ball connected to a paddle by an elastic string, as discussed in Module 15.1.

Questions throughout the chapter narratives Every section (module) of a chapter contains questions that guide a student through the physics or explore a figure or video. An answer and an explanation are provided for each question. There are no “traps” that prevent a student from

progressing through the chapter. A student's progress is reported to an online gradebook, for a student's personal use or for an instructor's grade assessment.

Games and opportunities for group work Each chapter contains a game based on key ideas in the chapter and presented in a fun manner. The games can also be used as group exercises or a break in a long lecture or for flipped classrooms. Answers and explanations are always provided.



Derivations In a print book, students very rarely read a derivation, much less study it. In the Rachael version of *Fundamentals of Physics*, the student will work through every derivation by answering several questions along the way, with the results reported to the online gradebook. Thus, the student can understand the result and its limitations rather than merely using it as a plug-in equation.

Sample Problems Every Sample Problem (about 15 per chapter) has been transformed from a passive reading experience to a series of interactive steps, with the results reported to the online gradebook. In some Sample Problems, a student works through the calculations with a series of guiding questions. In others, a student follows a link to one of my videos and then answers several questions after the video.

Video Links Links to video explanations, interactive figures, and demonstrations are now embedded in the narrative, and every link is followed by an interactive series of questions, with the results reported to the online gradebook.

Roll-over figures Some of the more challenging figures have been converted so that a student can see different aspects by rolling over the figure.

WileyPLUS WILEYPLUS

WileyPLUS is a dynamic learning center stocked with many different learning aids, including just-in-time problem-solving tutorials, reading quizzes (to encourage reading about the physics prior to lectures), animated figures, hundreds of sample problems with worked-out solutions, numerous demonstrations, and over 1500 videos ranging from math reviews to mini-lectures to examples. All are available 24/7 and can be repeated as many times as desired. Thus, if a student gets stuck on a homework problem at, say, 2:00 AM (which appears to be a popular time for doing physics homework), friendly and helpful resources are available.

Learning Tools When I learned first-year physics in the first edition of Halliday and Resnick, I caught on by repeatedly rereading a chapter. These days we better understand that students have a wide range of learning styles. So, *Physics for Rachael* and *WileyPLUS* contain many different learning tools. Here are a few.

Free-body diagrams In chapters involving vector addition (such as the chapters on Newton's laws, Coulomb's law, and electric fields), a number of the homework problems require a student to construct a free-body diagram.

Links between homework problems and learning objectives Every homework question and problem are linked to a learning objective, to answer the (usually unspoken) questions, “Why am I working this problem? What am I supposed to learn from it?” By being explicit about a problem’s purpose, I believe that a student might better transfer the learning objective to other problems with a different wording but the same key idea. Such transference would defeat the common trouble that a student learns to work a particular problem but cannot then apply its key idea to a problem in a different setting.

Video Illustrations David Maiullo of Rutgers University has created video versions of approximately 30 of the photographs and figures from 10e. Links to many of them are embedded in the chapters and all are linked out of *WileyPLUS*. Much of physics is the study of things that move, and video can often provide better representation than a static photo or figure.

Animations Each chapter contains an embedded link to an animation of a key figure. I chose the figures that are rich in information so that a student can see the physics in action and played out over a minute or two.

Videos I have made well over 1500 instructional videos, with more coming. Students can watch me draw or type on the screen as they hear me talk about a solution, tutorial, sample problem, or review, very much as they would experience were they sitting next to me in my office while I worked out something on a notepad. An instructor’s lectures and tutoring will always be the most valuable learning tools, but my videos are available 24 hours a day, 7 days a week, and can be repeated indefinitely.

- **Video tutorials on subjects in the chapters.** I chose the subjects that challenge the students the most, the ones that my students scratch their heads about.
- **Video reviews of high school math,** such as basic algebraic manipulations, trig functions, and simultaneous equations.
- **Video introductions to math,** such as vector multiplication, that will be new to the students.
- **Video presentations of Sample Problems.** My intent is to work out the physics, starting with the Key Ideas instead of just grabbing a formula. However, I also want to demonstrate how to read a sample problem, that is, how to read technical material to learn problem-solving procedures that can be transferred to other types of problems.
- **Video solutions to 20% of the end-of chapter problems.** The availability and timing of these solutions are controlled by the instructor. For example, they might be available after a homework deadline or a quiz. Each solution is not simply a plug-and-chug recipe. Rather I build a solution from the Key Ideas to the first step of reasoning and to a final solution. The student learns not just how to solve a particular problem but how to tackle any problem, even those that require *physics courage*.

- **Video examples of how to read data from graphs** (more than simply reading off a number with no comprehension of the physics).

Problem-Solving Help I have written a large number of resources for *WileyPLUS* designed to help build the students' problem-solving skills.

- **Hundreds of additional sample problems.** These are available as stand-alone resources but (at the discretion of the instructor) they are also linked out of the homework problems. So, if a homework problem deals with, say, forces on a block on a ramp, a link to a related sample problem is provided. However, the sample problem is not just a replica of the homework problem and thus does not provide a solution that can be merely duplicated without comprehension.
- **GO Tutorials** for 15% of the end-of-chapter homework problems. In multiple steps, I lead a student through a homework problem, starting with the Key Ideas and giving hints when wrong answers are submitted. However, I purposely leave the last step (for the final answer) to the students so that they are responsible at the end. Some online tutorial systems trap a student when wrong answers are given, which can generate a lot of frustration. My GO Tutorials are not traps, because at any step along the way, a student can return to the main problem.
- **Hints on every end-of-chapter homework problem** are available (at the discretion of the instructor). I wrote these as true hints about the main ideas and the general procedure for a solution, not as recipes that provide an answer without any comprehension.

Evaluation Materials

- **Pre-lecture reading questions are available in *WileyPLUS* for each chapter section.** I wrote these so that they do not require analysis or any deep understanding; rather they simply test whether a student has read the section. When a student opens up a section, a randomly chosen reading question (from a bank of questions) appears at the end. The instructor can decide whether the question is part of the grading for that section or whether it is just for the benefit of the student.
- **Checkpoints are available within chapter sections.** I wrote these so that they require analysis and decisions about the physics in the section. Answers and explanations are given for each, and the results are reported to the online gradebook.
- **All end-of-chapter homework Problems** (and many more problems) are available in *WileyPLUS*. The instructor can construct a homework assignment and control how it is graded when the answers are submitted online. For example, the instructor controls the deadline for submission and how many attempts a student is allowed on an answer. The instructor also controls which, if any, learning aids are available with each homework problem. Such links can include hints, sample problems, in-chapter reading materials, video tutorials, video math reviews, and even video solutions (which can be made available to the students after, say, a homework deadline).
- **Symbolic notation problems** that require algebraic answers are available in every chapter.
- **All end-of-chapter homework Questions** are available for assignment in *WileyPLUS*. These Questions (in a multiple choice format) are designed to evaluate the students' conceptual understanding.

FUNDAMENTALS OF PHYSICS-FORMAT OPTIONS

Fundamentals of Physics was designed to optimize students' online learning experience. We highly recommend that students use the digital course within *WileyPLUS* as their primary course material. If, however, a print version is required, it is available, but please note that the content in the text differs from the content in the *WileyPLUS* course. Here are students' purchase options and ISBNs:

- 11E *WileyPLUS* course
- *Fundamentals of Physics* Looseleaf Print Companion bundled with *WileyPLUS*
- *Fundamentals of Physics* vol 1 bundled with *WileyPLUS*
- *Fundamentals of Physics* vol 2 bundled with *WileyPLUS*
- *Fundamentals of Physics* Vitalsource etext

INSTRUCTOR SUPPLEMENTS

Instructor's Solutions Manual by Sen-Ben Liao, Lawrence Livermore National Laboratory. This manual provides worked-out solutions for all problems found at the end of each chapter. It is available in both MSWord and PDF.

Instructor Companion Site <http://www.wiley.com/college/halliday>

- **Instructor's Manual** This resource contains lecture notes outlining the most important topics of each chapter; demonstration experiments; laboratory and computer projects; film and video sources; answers to all Questions, Exercises, Problems, and Checkpoints; and a correlation guide to the Questions, Exercises, and Problems in the previous edition. It also contains a complete list of all problems for which solutions are available to students (SSM, WWW, and ILW).
- **Classroom Response Systems ("Clicker") Questions** by David Marx, Illinois State University. There are two sets of questions available: Reading Quiz questions and Interactive Lecture questions. The Reading Quiz questions are intended to be relatively straightforward for any student who reads the assigned material. The Interactive Lecture questions are intended for use in an interactive lecture setting.
- **Wiley Physics Simulations** by Andrew Duffy, Boston University and John Gastineau, Vernier Software. This is a collection of 50 interactive simulations (Java applets) that can be used for classroom demonstrations.
- **Wiley Physics Demonstrations** by David Maiullo, Rutgers University. This is a collection of digital videos of 80 standard physics demonstrations. They can be shown in class or accessed from *WileyPLUS*. There is an accompanying Instructor's Guide that includes "clicker" questions.
- **Test Bank** by Suzanne Willis, Northern Illinois University. The Test Bank includes more than 2200 multiple-choice questions. These items are also available in the Computerized Test Bank, which provides full editing features to help you customize tests (available in both IBM and Macintosh versions).
- **All text illustrations** suitable for both classroom projection and printing.
- **Lecture PowerPoint Slides** These PowerPoint slides serve as a helpful starter pack for instructors, outlining key concepts and incorporating figures and equations from the text (available upon request).

STUDENT SUPPLEMENTS

Student Solutions Manual (ISBN 9781119455127) by Sen-Ben Liao, Lawrence Livermore National Laboratory. This manual provides students with complete worked-out solutions to 15 percent of the problems found at the end of each chapter within the text. The Student Solutions Manual for the 10th edition is written using an innovative approach called TEAL, which stands for Think, Express, Analyze, and Learn. This learning strategy was originally developed at the Massachusetts Institute of Technology and has proven to be an effective learning tool for students. These problems with TEAL solutions are indicated with an SSM icon in the text.

Introductory Physics with Calculus as a Second Language (ISBN 9780471739104) *Mastering Problem Solving* by Thomas Barrett of Ohio State University. This brief paperback teaches the student how to approach problems more efficiently and effectively. The student will learn how to recognize common patterns in physics problems, break problems down into manageable steps, and apply appropriate techniques. The book takes the student step by step through the solutions to numerous examples.

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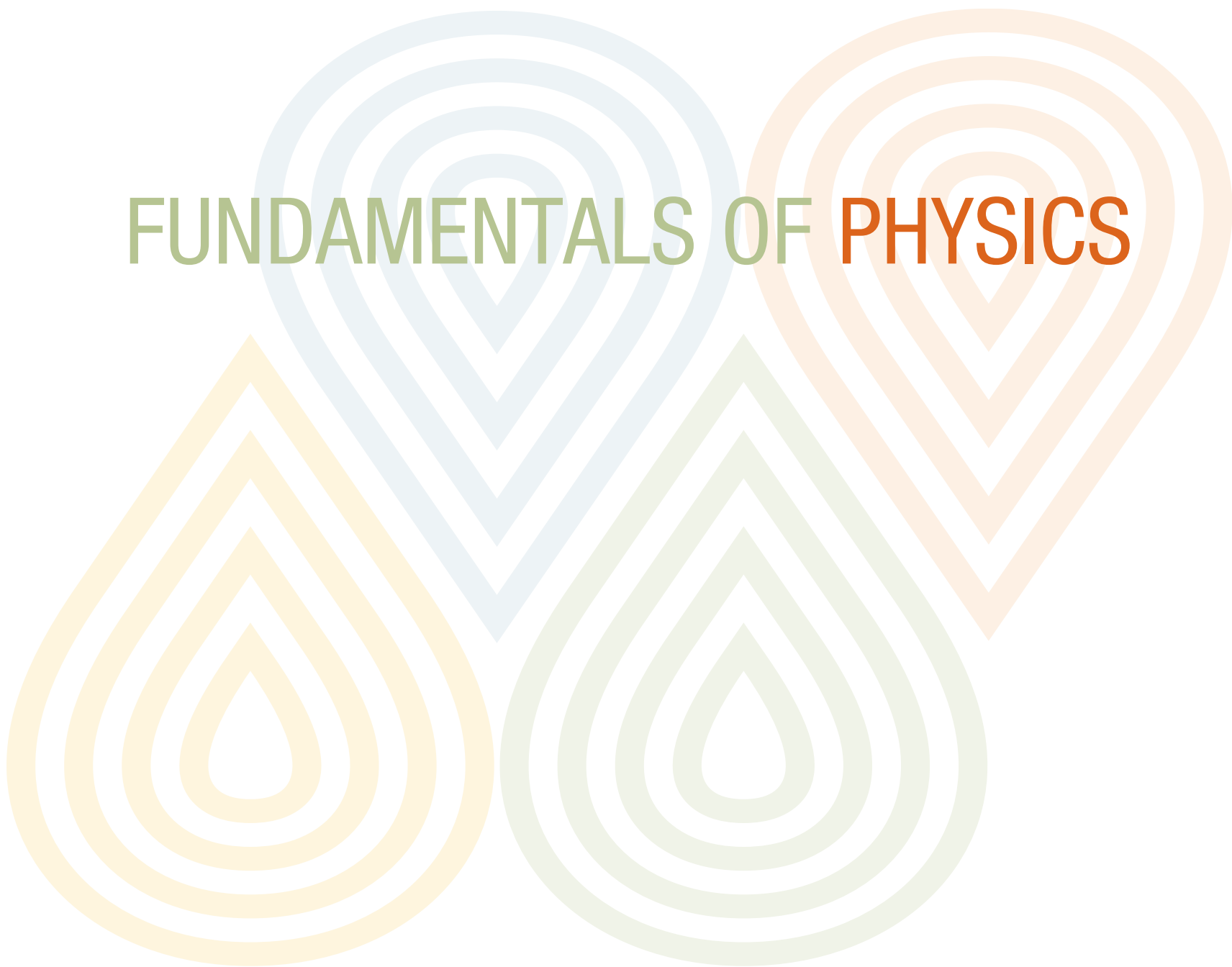
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FUNDAMENTALS OF PHYSICS



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Measurement

1-1 MEASURING THINGS, INCLUDING LENGTHS

Learning Objectives

After reading this module, you should be able to . . .

- 1.01 Identify the base quantities in the SI system.
- 1.02 Name the most frequently used prefixes for SI units.

1.03 Change units (here for length, area, and volume) by using chain-link conversions.

1.04 Explain that the meter is defined in terms of the speed of light in vacuum.

Key Ideas

- Physics is based on measurement of physical quantities. Certain physical quantities have been chosen as base quantities (such as length, time, and mass); each has been defined in terms of a standard and given a unit of measure (such as meter, second, and kilogram). Other physical quantities are defined in terms of the base quantities and their standards and units.
- The unit system emphasized in this book is the International System of Units (SI). The three physical quantities displayed in Table 1-1 are used in the early chapters. Standards, which must be both accessible and invariable, have been established for these base quantities by

international agreement. These standards are used in all physical measurement, for both the base quantities and the quantities derived from them. Scientific notation and the prefixes of Table 1-2 are used to simplify measurement notation.

- Conversion of units may be performed by using chain-link conversions in which the original data are multiplied successively by conversion factors written as unity and the units are manipulated like algebraic quantities until only the desired units remain.

- The meter is defined as the distance traveled by light during a precisely specified time interval.

What Is Physics?

Science and engineering are based on measurements and comparisons. Thus, we need rules about how things are measured and compared, and we need experiments to establish the units for those measurements and comparisons. One purpose of physics (and engineering) is to design and conduct those experiments.

For example, physicists strive to develop clocks of extreme accuracy so that any time or time interval can be precisely determined and compared. You may wonder whether such accuracy is actually needed or worth the effort. Here is one example of the worth: Without clocks of extreme accuracy, the Global Positioning System (GPS) that is now vital to worldwide navigation would be useless.

Measuring Things

We discover physics by learning how to measure the quantities involved in physics. Among these quantities are length, time, mass, temperature, pressure, and electric current.

We measure each physical quantity in its own units, by comparison with a **standard**. The **unit** is a unique name we assign to measures of that quantity—for example, meter (m) for the quantity length. The standard corresponds to exactly 1.0 unit of the quantity. As you will see, the standard for length, which corresponds

to exactly 1.0 m, is the distance traveled by light in a vacuum during a certain fraction of a second. We can define a unit and its standard in any way we care to. However, the important thing is to do so in such a way that scientists around the world will agree that our definitions are both sensible and practical.

Once we have set up a standard—say, for length—we must work out procedures by which any length whatever, be it the radius of a hydrogen atom, the wheelbase of a skateboard, or the distance to a star, can be expressed in terms of the standard. Rulers, which approximate our length standard, give us one such procedure for measuring length. However, many of our comparisons must be indirect. You cannot use a ruler, for example, to measure the radius of an atom or the distance to a star.

Base Quantities. There are so many physical quantities that it is a problem to organize them. Fortunately, they are not all independent; for example, speed is the ratio of a length to a time. Thus, what we do is pick out—by international agreement—a small number of physical quantities, such as length and time, and assign standards to them alone. We then define all other physical quantities in terms of these *base quantities* and their standards (called *base standards*). Speed, for example, is defined in terms of the base quantities length and time and their base standards.

Base standards must be both accessible and invariable. If we define the length standard as the distance between one’s nose and the index finger on an outstretched arm, we certainly have an accessible standard—but it will, of course, vary from person to person. The demand for precision in science and engineering pushes us to aim first for invariability. We then exert great effort to make duplicates of the base standards that are accessible to those who need them.

Table 1-1 Units for Three SI Base Quantities

Quantity	Unit Name	Unit Symbol
Length	meter	m
Time	second	s
Mass	kilogram	kg

Table 1-2 Prefixes for SI Units

Factor	Prefix ^a	Symbol
10 ²⁴	yotta-	Y
10 ²¹	zetta-	Z
10 ¹⁸	exa-	E
10 ¹⁵	peta-	P
10 ¹²	tera-	T
10⁹	giga-	G
10⁶	mega-	M
10³	kilo-	k
10 ²	hecto-	h
10 ¹	deka-	da
10 ⁻¹	deci-	d
10⁻²	centi-	c
10⁻³	milli-	m
10⁻⁶	micro-	μ
10⁻⁹	nano-	n
10⁻¹²	pico-	p
10 ⁻¹⁵	femto-	f
10 ⁻¹⁸	atto-	a
10 ⁻²¹	zepto-	z
10 ⁻²⁴	yocto-	y

^aThe most frequently used prefixes are shown in bold type.

The International System of Units

In 1971, the 14th General Conference on Weights and Measures picked seven quantities as base quantities, thereby forming the basis of the International System of Units, abbreviated SI from its French name and popularly known as the *metric system*. Table 1-1 shows the units for the three base quantities—length, mass, and time—that we use in the early chapters of this book. These units were defined to be on a “human scale.”

Many SI *derived units* are defined in terms of these base units. For example, the SI unit for power, called the **watt** (W), is defined in terms of the base units for mass, length, and time. Thus, as you will see in Chapter 7,

$$1 \text{ watt} = 1 \text{ W} = 1 \text{ kg} \cdot \text{m}^2/\text{s}^3, \quad (1-1)$$

where the last collection of unit symbols is read as kilogram-meter squared per second cubed.

To express the very large and very small quantities we often run into in physics, we use *scientific notation*, which employs powers of 10. In this notation,

$$3\,560\,000\,000 \text{ m} = 3.56 \times 10^9 \text{ m} \quad (1-2)$$

and

$$0.000\,000\,492 \text{ s} = 4.92 \times 10^{-7} \text{ s}. \quad (1-3)$$

Scientific notation on computers sometimes takes on an even briefer look, as in 3.56 E9 and 4.92 E-7, where E stands for “exponent of ten.” It is briefer still on some calculators, where E is replaced with an empty space.

As a further convenience when dealing with very large or very small measurements, we use the prefixes listed in Table 1-2. As you can see, each prefix represents a certain power of 10, to be used as a multiplication factor. Attaching a prefix to an SI unit has the effect of multiplying by the associated factor. Thus, we can express a particular electric power as

$$1.27 \times 10^9 \text{ watts} = 1.27 \text{ gigawatts} = 1.27 \text{ GW} \quad (1-4)$$

or a particular time interval as

$$2.35 \times 10^{-9} \text{ s} = 2.35 \text{ nanoseconds} = 2.35 \text{ ns.} \quad (1-5)$$

Some prefixes, as used in milliliter, centimeter, kilogram, and megabyte, are probably familiar to you.

Changing Units

We often need to change the units in which a physical quantity is expressed. We do so by a method called *chain-link conversion*. In this method, we multiply the original measurement by a **conversion factor** (a ratio of units that is equal to unity). For example, because 1 min and 60 s are identical time intervals, we have

$$\frac{1 \text{ min}}{60 \text{ s}} = 1 \quad \text{and} \quad \frac{60 \text{ s}}{1 \text{ min}} = 1.$$

Thus, the ratios (1 min)/(60 s) and (60 s)/(1 min) can be used as conversion factors. This is *not* the same as writing $\frac{1}{60} = 1$ or $60 = 1$; each *number* and its *unit* must be treated together.

Because multiplying any quantity by unity leaves the quantity unchanged, we can introduce conversion factors wherever we find them useful. In chain-link conversion, we use the factors to cancel unwanted units. For example, to convert 2 min to seconds, we have

$$2 \text{ min} = (2 \text{ min})(1) = (2 \text{ min}) \left(\frac{60 \text{ s}}{1 \text{ min}} \right) = 120 \text{ s.} \quad (1-6)$$

If you introduce a conversion factor in such a way that unwanted units do *not* cancel, invert the factor and try again. In conversions, the units obey the same algebraic rules as variables and numbers.

Appendix D gives conversion factors between SI and other systems of units, including non-SI units still used in the United States. However, the conversion factors are written in the style of “1 min = 60 s” rather than as a ratio. So, you need to decide on the numerator and denominator in any needed ratio.

Length

In 1792, the newborn Republic of France established a new system of weights and measures. Its cornerstone was the meter, defined to be one ten-millionth of the distance from the north pole to the equator. Later, for practical reasons, this Earth standard was abandoned and the meter came to be defined as the distance between two fine lines engraved near the ends of a platinum–iridium bar, the **standard meter bar**, which was kept at the International Bureau of Weights and Measures near Paris. Accurate copies of the bar were sent to standardizing laboratories throughout the world. These **secondary standards** were used to produce other, still more accessible standards, so that ultimately every measuring device derived its authority from the standard meter bar through a complicated chain of comparisons.

Eventually, a standard more precise than the distance between two fine scratches on a metal bar was required. In 1960, a new standard for the meter, based on the wavelength of light, was adopted. Specifically, the standard for the meter was redefined to be 1 650 763.73 wavelengths of a particular orange-red light emitted by atoms of krypton-86 (a particular isotope, or type, of krypton) in a gas discharge tube that can be set up anywhere in the world. This awkward number of wavelengths was chosen so that the new standard would be close to the old meter-bar standard.