



FUNDAMENTALS OF
PHYSICS

Halliday & Resnick
10th edition

JEARL WALKER

EXTENDED

WILEY

MATHEMATICAL FORMULAS*

Quadratic Formula

If $ax^2 + bx + c = 0$, then $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

Binomial Theorem

$$(1 + x)^n = 1 + \frac{nx}{1!} + \frac{n(n-1)x^2}{2!} + \dots \quad (x^2 < 1)$$

Products of Vectors

Let θ be the smaller of the two angles between \vec{a} and \vec{b} .

Then

$$\vec{a} \cdot \vec{b} = \vec{b} \cdot \vec{a} = a_x b_x + a_y b_y + a_z b_z = ab \cos \theta$$

$$\vec{a} \times \vec{b} = -\vec{b} \times \vec{a} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix}$$

$$= \hat{i} \begin{vmatrix} a_y & a_z \\ b_y & b_z \end{vmatrix} - \hat{j} \begin{vmatrix} a_x & a_z \\ b_x & b_z \end{vmatrix} + \hat{k} \begin{vmatrix} a_x & a_y \\ b_x & b_y \end{vmatrix}$$

$$= (a_y b_z - b_y a_z)\hat{i} + (a_z b_x - b_z a_x)\hat{j} + (a_x b_y - b_x a_y)\hat{k}$$

$$|\vec{a} \times \vec{b}| = ab \sin \theta$$

Trigonometric Identities

$$\sin \alpha \pm \sin \beta = 2 \sin \frac{1}{2}(\alpha \pm \beta) \cos \frac{1}{2}(\alpha \mp \beta)$$

$$\cos \alpha + \cos \beta = 2 \cos \frac{1}{2}(\alpha + \beta) \cos \frac{1}{2}(\alpha - \beta)$$

*See Appendix E for a more complete list.

Derivatives and Integrals

$$\frac{d}{dx} \sin x = \cos x \quad \int \sin x \, dx = -\cos x$$

$$\frac{d}{dx} \cos x = -\sin x \quad \int \cos x \, dx = \sin x$$

$$\frac{d}{dx} e^x = e^x \quad \int e^x \, dx = e^x$$

$$\int \frac{dx}{\sqrt{x^2 + a^2}} = \ln(x + \sqrt{x^2 + a^2})$$

$$\int \frac{x \, dx}{(x^2 + a^2)^{3/2}} = -\frac{1}{(x^2 + a^2)^{1/2}}$$

$$\int \frac{dx}{(x^2 + a^2)^{3/2}} = \frac{x}{a^2(x^2 + a^2)^{1/2}}$$

Cramer's Rule

Two simultaneous equations in unknowns x and y ,

$$a_1x + b_1y = c_1 \quad \text{and} \quad a_2x + b_2y = c_2,$$

have the solutions

$$x = \frac{\begin{vmatrix} c_1 & b_1 \\ c_2 & b_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}} = \frac{c_1 b_2 - c_2 b_1}{a_1 b_2 - a_2 b_1}$$

and

$$y = \frac{\begin{vmatrix} a_1 & c_1 \\ a_2 & c_2 \end{vmatrix}}{\begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix}} = \frac{a_1 c_2 - a_2 c_1}{a_1 b_2 - a_2 b_1}$$

SI PREFIXES*

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

*In all cases, the first syllable is accented, as in ná-no-mé-ter.

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Halliday & Resnick

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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

C O N T E N T S

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 13

2-1 POSITION, DISPLACEMENT, AND AVERAGE VELOCITY 13

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

2-2 INSTANTANEOUS VELOCITY AND SPEED 18

- Instantaneous Velocity and Speed 18

2-3 ACCELERATION 20

- Acceleration 20

2-4 CONSTANT ACCELERATION 23

- Constant Acceleration: A Special Case 23
- Another Look at Constant Acceleration 26

2-5 FREE-FALL ACCELERATION 27

- Free-Fall Acceleration 27

2-6 GRAPHICAL INTEGRATION IN MOTION ANALYSIS 29

- Graphical Integration in Motion Analysis 29

REVIEW & SUMMARY 30 QUESTIONS 31 PROBLEMS 32

3 Vectors 40

3-1 VECTORS AND THEIR COMPONENTS 40

- What Is Physics? 40
- Vectors and Scalars 40
- Adding Vectors Geometrically 41
- Components of Vectors 42

3-2 UNIT VECTORS, ADDING VECTORS BY COMPONENTS 46

- Unit Vectors 46

- Adding Vectors by Components 46

- Vectors and the Laws of Physics 47

3-3 MULTIPLYING VECTORS 50

- Multiplying Vectors 50

REVIEW & SUMMARY 55 QUESTIONS 56 PROBLEMS 57

4 Motion in Two and Three Dimensions 62

4-1 POSITION AND DISPLACEMENT 62

- What Is Physics? 62
- Position and Displacement 63

4-2 AVERAGE VELOCITY AND INSTANTANEOUS VELOCITY 64

- Average Velocity and Instantaneous Velocity 65

4-3 AVERAGE ACCELERATION AND INSTANTANEOUS ACCELERATION 67

- Average Acceleration and Instantaneous Acceleration 68

4-4 PROJECTILE MOTION 70

- Projectile Motion 70

4-5 UNIFORM CIRCULAR MOTION 76

- Uniform Circular Motion 76

4-6 RELATIVE MOTION IN ONE DIMENSION 78

- Relative Motion in One Dimension 78

4-7 RELATIVE MOTION IN TWO DIMENSIONS 80

- Relative Motion in Two Dimensions 80

REVIEW & SUMMARY 81 QUESTIONS 82 PROBLEMS 84

5 Force and Motion—I 94

5-1 NEWTON'S FIRST AND SECOND LAWS 94

- What Is Physics? 94
- Newtonian Mechanics 95
- Newton's First Law 95
- Force 96
- Mass 97
- Newton's Second Law 98

5-2 SOME PARTICULAR FORCES 102

- Some Particular Forces 102

5-3 APPLYING NEWTON'S LAWS 106

- Newton's Third Law 106
- Applying Newton's Laws 108

REVIEW & SUMMARY 114 QUESTIONS 114 PROBLEMS 116

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	
Friction 124	8-5 CONSERVATION OF ENERGY 195
Properties of Friction 127	Conservation of Energy 195
	REVIEW & SUMMARY 199 QUESTIONS 200 PROBLEMS 202
6-2 THE DRAG FORCE AND TERMINAL SPEED 130	
The Drag Force and Terminal Speed 130	
6-3 UNIFORM CIRCULAR MOTION 133	
Uniform Circular Motion 133	
REVIEW & SUMMARY 138 QUESTIONS 139 PROBLEMS 140	
7 Kinetic Energy and Work 149	9 Center of Mass and Linear Momentum 214
7-1 KINETIC ENERGY 149	9-1 CENTER OF MASS 214
What Is Physics? 149	What Is Physics? 214
What Is Energy? 149	The Center of Mass 215
Kinetic Energy 150	
7-2 WORK AND KINETIC ENERGY 151	9-2 NEWTON'S SECOND LAW FOR A SYSTEM OF PARTICLES 220
Work 151	Newton's Second Law for a System of Particles 220
Work and Kinetic Energy 152	
7-3 WORK DONE BY THE GRAVITATIONAL FORCE 155	9-3 LINEAR MOMENTUM 224
Work Done by the Gravitational Force 156	Linear Momentum 224
7-4 WORK DONE BY A SPRING FORCE 159	The Linear Momentum of a System of Particles 225
Work Done by a Spring Force 159	
7-5 WORK DONE BY A GENERAL VARIABLE FORCE 162	9-4 COLLISION AND IMPULSE 226
Work Done by a General Variable Force 162	Collision and Impulse 226
7-6 POWER 166	9-5 CONSERVATION OF LINEAR MOMENTUM 230
Power 166	Conservation of Linear Momentum 230
REVIEW & SUMMARY 168 QUESTIONS 169 PROBLEMS 170	9-6 MOMENTUM AND KINETIC ENERGY IN COLLISIONS 233
	Momentum and Kinetic Energy in Collisions 233
	Inelastic Collisions in One Dimension 234
	9-7 ELASTIC COLLISIONS IN ONE DIMENSION 237
	Elastic Collisions in One Dimension 237
	9-8 COLLISIONS IN TWO DIMENSIONS 240
	Collisions in Two Dimensions 240
	9-9 SYSTEMS WITH VARYING MASS: A ROCKET 241
	Systems with Varying Mass: A Rocket 241
	REVIEW & SUMMARY 243 QUESTIONS 245 PROBLEMS 246
8 Potential Energy and Conservation of Energy 177	10 Rotation 257
8-1 POTENTIAL ENERGY 177	10-1 ROTATIONAL VARIABLES 257
What Is Physics? 177	What Is Physics? 258
Work and Potential Energy 178	Rotational Variables 259
Path Independence of Conservative Forces 179	Are Angular Quantities Vectors? 264
Determining Potential Energy Values 181	
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	10-3 RELATING THE LINEAR AND ANGULAR VARIABLES 268
Reading a Potential Energy Curve 187	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			
The Electric Field Due to Line of Charge	638			
22-5 THE ELECTRIC FIELD DUE TO A CHARGED DISK	643			
The Electric Field Due to a Charged Disk	643			
22-6 A POINT CHARGE IN AN ELECTRIC FIELD	645			
A Point Charge in an Electric Field	645			
22-7 A DIPOLE IN AN ELECTRIC FIELD	647			
A Dipole in an Electric Field	648			
REVIEW & SUMMARY	650	QUESTIONS	651	PROBLEMS 652

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 677 PROBLEMS 679	REVIEW & SUMMARY 738 QUESTIONS 738 PROBLEMS 739
24 Electric Potential 685	26 Current and Resistance 745
24-1 ELECTRIC POTENTIAL 685	26-1 ELECTRIC CURRENT 745
What Is Physics? 685	What Is Physics? 745
Electric Potential and Electric Potential Energy 686	Electric Current 746
24-2 EQUIPOTENTIAL SURFACES AND THE ELECTRIC FIELD 690	26-2 CURRENT DENSITY 748
Equipotential Surfaces 690	Current Density 749
Calculating the Potential from the Field 691	26-3 RESISTANCE AND RESISTIVITY 752
24-3 POTENTIAL DUE TO A CHARGED PARTICLE 694	Resistance and Resistivity 753
Potential Due to a Charged Particle 694	26-4 OHM'S LAW 756
Potential Due a Group of Charged Particles 695	Ohm's Law 756
24-4 POTENTIAL DUE TO AN ELECTRIC DIPOLE 697	A Microscopic View of Ohm's Law 758
Potential Due to an Electric Dipole 697	26-5 POWER, SEMICONDUCTORS, SUPERCONDUCTORS 760
24-5 POTENTIAL DUE TO A CONTINUOUS CHARGE DISTRIBUTION 698	Power in Electric Circuits 760
Potential Due to a Continuous Charge Distribution 698	Semiconductors 762
24-6 CALCULATING THE FIELD FROM THE POTENTIAL 701	Superconductors 763
Calculating the Field from the Potential 701	REVIEW & SUMMARY 763 QUESTIONS 764 PROBLEMS 765
24-7 ELECTRIC POTENTIAL ENERGY OF A SYSTEM OF CHARGED PARTICLES 703	27 Circuits 771
Electric Potential Energy of a System of Charged Particles 703	27-1 SINGLE-LOOP CIRCUITS 771
24-8 POTENTIAL OF A CHARGED ISOLATED CONDUCTOR 706	What Is Physics? 772
Potential of Charged Isolated Conductor 706	"Pumping" Charges 772
REVIEW & SUMMARY 707 QUESTIONS 708 PROBLEMS 710	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? 1252
- 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
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

WHY I WROTE THIS BOOK

Fun with a big challenge. That is how I have regarded physics since the day when Sharon, one of the students in a class I taught as a graduate student, suddenly demanded of me, “What has any of this got to do with my life?” Of course I immediately responded, “Sharon, this has everything to do with your life—this is physics.”

She asked me for an example. I thought and thought but could not come up with a single one. That night I began writing the book *The Flying Circus of Physics* (John Wiley & Sons Inc., 1975) for Sharon but also for me because I realized her complaint was mine. I had spent six years slugging my way through many dozens of physics textbooks that were carefully written with the best of pedagogical plans, but there was something missing. Physics is the most interesting subject in the world because it is about how the world works, and yet the textbooks had been thoroughly wrung of any connection with the real world. The fun was missing.

I have packed a lot of real-world physics into *Fundamentals of Physics*, connecting it with the new edition of *The Flying Circus of Physics*. Much of the material comes from the introductory physics classes I teach, where I can judge from the faces and blunt comments what material and presentations work and what do not. The notes I make on my successes and failures there help form the basis of this book. My message here is the same as I had with every student I’ve met since Sharon so long ago: “Yes, you *can* reason from basic physics concepts all the way to valid conclusions about the real world, and that understanding of the real world is where the fun is.”

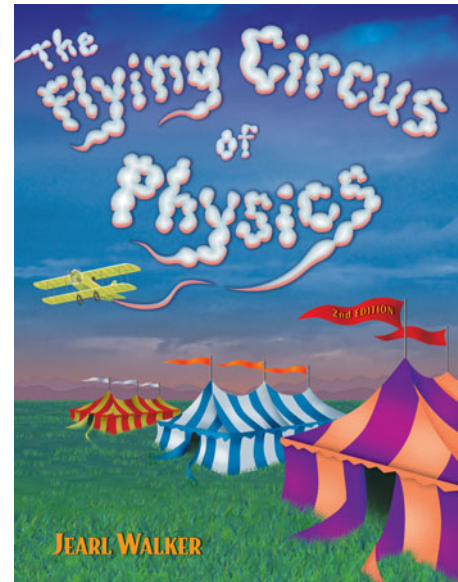
I have many goals in writing this book but the overriding one is to provide instructors with tools by which they can teach students how to effectively read scientific material, identify fundamental concepts, reason through scientific questions, and solve quantitative problems. This process is not easy for either students or instructors. Indeed, the course associated with this book may be one of the most challenging of all the courses taken by a student. However, it can also be one of the most rewarding because it reveals the world’s fundamental clockwork from which all scientific and engineering applications spring.

Many users of the ninth edition (both instructors and students) sent in comments and suggestions to improve the book. These improvements are now incorporated into the narrative and problems throughout the book. The publisher John Wiley & Sons and I regard the book as an ongoing project and encourage more input from users. You can send suggestions, corrections, and positive or negative comments to John Wiley & Sons or Jearl Walker (mail address: Physics Department, Cleveland State University, Cleveland, OH 44115 USA; or the blog site at www.flyingcircusofphysics.com). We may not be able to respond to all suggestions, but we keep and study each of them.

WHAT’S NEW?

Modules and Learning Objectives “What was I supposed to learn from this section?” Students have asked me this question for decades, from the weakest student to the strongest. The problem is that even a thoughtful student may not feel confident that the important points were captured while reading a section. I felt the same way back when I was using the first edition of Halliday and Resnick while taking first-year physics.

To ease the problem in this edition, I restructured the chapters into concept modules based on a primary theme and begin each module with a list of the module’s learning objectives. The list is an explicit statement of the skills and learning points that should be gathered in reading the module. Each list is followed by a brief summary of the key ideas that should also be gathered. For example, check out the first module in Chapter 16, where a student faces a truck load of concepts and terms. Rather than depending on the student’s ability to gather and sort those ideas, I now provide an explicit checklist that functions somewhat like the checklist a pilot works through before taxiing out to the runway for takeoff.





Links Between Homework Problems and Learning Objectives In *WileyPLUS*, every question and problem at the end of the chapter is 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 help 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.

Rewritten Chapters My students have continued to be challenged by several key chapters and by spots in several other chapters and so, in this edition, I rewrote a lot of the material. For example, I redesigned the chapters on Gauss’ law and electric potential, which have proved to be tough-going for my students. The presentations are now smoother and more direct to the key points. In the quantum chapters, I expanded the coverage of the Schrödinger equation, including reflection of matter waves from a step potential. At the request of several instructors, I decoupled the discussion of the Bohr atom from the Schrödinger solution for the hydrogen atom so that the historical account of Bohr’s work can be bypassed. Also, there is now a module on Planck’s blackbody radiation.

New Sample Problems and Homework Questions and Problems Sixteen new sample problems have been added to the chapters, written so as to spotlight some of the difficult areas for my students. Also, about 250 problems and 50 questions have been added to the homework sections of the chapters. Some of these problems come from earlier editions of the book, as requested by several instructors.

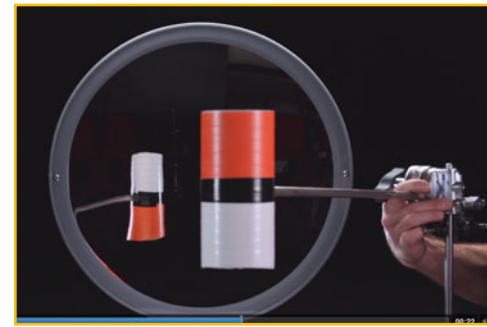


Video Illustrations In the eVersion of the text available in *WileyPLUS*, David Maiullo of Rutgers University has created video versions of approximately 30 of the photographs and figures from the text. Much of physics is the study of things that move and video can often provide a better representation than a static photo or figure.



Online Aid *WileyPLUS* is not just an online grading program. Rather, it is a dynamic learning center stocked with many different learning aids, including just-in-time problem-solving tutorials, embedded reading quizzes to encourage reading, animated figures, hundreds of sample problems, loads of simulations and demonstrations, and over 1500 videos ranging from math reviews to mini-lectures to examples. More of these learning aids are added every semester. For this 10th edition of HRW, some of the photos involving motion have been converted into videos so that the motion can be slowed and analyzed.

These thousands of learning aids 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 at the click of a mouse.

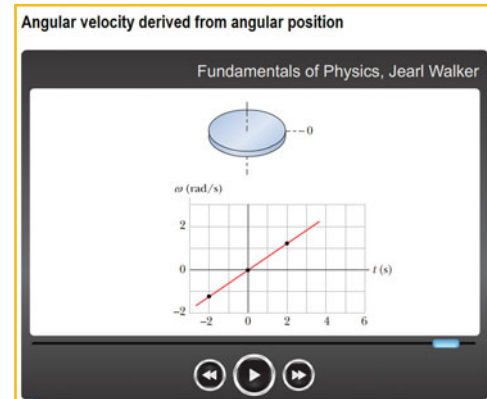


LEARNINGS TOOLS

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, I have produced a wide range of learning tools, both in this new edition and online in *WileyPLUS*:



Animations of one of the key figures in each chapter. Here in the book, those figures are flagged with the swirling icon. In the online chapter in *WileyPLUS*, a mouse click begins the animation. I have chosen 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



instead of just being flat on a printed page. Not only does this give life to the physics, but the animation can be repeated as many times as a student wants.



Videos I have made well over 1500 instructional videos, with more coming each semester. 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 every Sample Problem** in the textbook chapters. 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.

- **Every sample problem in the textbook** is available online in both reading and video formats.
- **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 student 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

Starts from rest.

Interval 2: This time interval with given data
Interval 1: From rest to the start of that time interval

GO Tutorial [Close]

This GO Tutorial will provide you with a step-by-step guide on how to approach this problem. When you are finished, go back and try the problem again on your own. To view the original question while you work, you can just drag this screen to the side. (This GO Tutorial consists of 4 steps).

Step 1 : Solution Step 1 of GO Tutorial 10-30

KEY IDEAS:

- (1) When an object rotates at constant angular acceleration, we can use the constant-acceleration equations of Table 10-1 modified for angular motion:
 - (1) $\omega = \omega_0 + \alpha t$
 - (2) $\theta - \theta_0 = \omega_0 t + \frac{1}{2} \alpha t^2$
 - (3) $\omega^2 = \omega_0^2 + 2\alpha(\theta - \theta_0)$
 - (4) $\theta - \theta_0 = \frac{1}{2}(\omega_0 + \omega)t$
 - (5) $\theta - \theta_0 = \omega t - \frac{1}{2} \alpha t^2$
- (2) Counterclockwise is the positive direction of rotation, and clockwise is the negative direction. If a particle moves around a rotation axis at radius r , the magnitude of its radial (centripetal) acceleration a_r at any moment is related to its tangential speed v (the speed along the circular path) and its angular speed at that moment by

$$a_r = \frac{v^2}{r} = \omega^2 r$$
- (3) If a particle moves around a rotation axis at radius r , the magnitude of its tangential acceleration at (the acceleration along the circular path) at any moment is related to angular acceleration a at that moment by

$$a_t = r\alpha$$
- (4) If a particle moves around a rotation axis at radius r , the angular displacement through which it rotates is related to the distance s it moves along its circular path by

$$s = r\Delta\theta$$

GETTING STARTED: What is the radius of rotation (in meters) of a point on the rim of the flywheel?

Number Unit

exact number, no tolerance

[Check Your Input]

Step 2 : Solution Step 2 of GO Tutorial 10-30

What is the final angular speed in radians per second?

Number Unit

the tolerance is +/-2%

[Check Your Input]

Step 3 : Solution Step 3 of GO Tutorial 10-30

What was the initial angular speed?

Number Unit

exact number, no tolerance

[Check Your Input]

Step 4 : Solution Step 4 of GO Tutorial 10-30

Through what angular distance does the flywheel rotate to reach the final angular speed?

Number Unit

the tolerance is +/-2%

[Check Your Input]

Now that you know how to solve the problem, go back and try again on your own. [Close]

answer without any



Evaluation Materials

- **Reading questions are available within each online 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 most sections.** I wrote these so that they require analysis and decisions about the physics in the section. *Answers to all checkpoints are in the back of the book.*



Checkpoint 1

Here are three pairs of initial and final positions, respectively, along an x axis. Which pairs give a negative displacement: (a) -3 m, $+5$ m; (b) -3 m, -7 m; (c) 7 m, -3 m?

- **All end-of-chapter homework Problems** in the book (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** in the book are available for assignment in *WileyPLUS*. These Questions (in a multiple choice format) are designed to evaluate the students' conceptual understanding.

Icons for Additional Help When worked-out solutions are provided either in print or electronically for certain of the odd-numbered problems, the statements for those problems include an icon to alert both student and instructor as to where the solutions are located. There are also icons indicating which problems have GO Tutorial, an Interactive LearningWare, or a link to the *The Flying Circus of Physics*. An icon guide is provided here and at the beginning of each set of problems.



Tutoring problem available (at instructor's discretion) in *WileyPLUS* and WebAssign



Worked-out solution available in Student Solutions Manual



Worked-out solution is at



Number of dots indicates level of problem difficulty



Interactive solution is at



Additional information available in *The Flying Circus of Physics* and at flyingcircusofphysics.com

<http://www.wiley.com/college/halliday>

VERSIONS OF THE TEXT

To accommodate the individual needs of instructors and students, the ninth edition of *Fundamentals of Physics* is available in a number of different versions.

The **Regular Edition** consists of Chapters 1 through 37 (ISBN 9781118230718).

The **Extended Edition** contains seven additional chapters on quantum physics and cosmology, Chapters 1–44 (ISBN 9781118230725).

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Volume 2 — Chapters 21–44 (E&M, Optics, and Quantum Physics), hardcover, ISBN 9781118230732

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).
- **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.
- **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** For the 10th edition, the Test Bank has been completely over-hauled 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).
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Online Homework and Quizzing. In addition to *WileyPLUS*, *Fundamentals of Physics*, tenth edition, also supports WebAssignPLUS and LON-CAPA, which are other programs that give instructors the ability to deliver and grade homework and quizzes online. WebAssign PLUS also offers students an online version of the text.

STUDENT SUPPLEMENTS

Student Companion Site. The web site <http://www.wiley.com/college/halliday> was developed specifically for *Fundamentals of Physics*, tenth edition, and is designed to further assist students in the study of physics. It includes solutions to selected end-of-chapter problems (which are identified with a www icon in the text); simulation exercises; tips on how to make best use of a programmable calculator; and the Interactive LearningWare tutorials that are described below.

Student Study Guide (ISBN 9781118230787) by Thomas Barrett of Ohio State University. The Student Study Guide consists of an overview of the chapter's important concepts, problem solving techniques and detailed examples.

Student Solutions Manual (ISBN 9781118230664) 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.

Interactive Learningware. This software guides students through solutions to 200 of the end-of-chapter problems. These problems are indicated with an ILW icon in the text. The solutions process is developed interactively, with appropriate feedback and access to error-specific help for the most common mistakes.

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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