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Physics



James S. Walker

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About the Author

James Walker obtained his Ph.D. in theoretical physics from the University of Washington in 1978. He subsequently served as a post-doc at the University of Pennsylvania, the Massachusetts Institute of Technology, and the University of California at San Diego before joining the physics faculty at Washington State University in 1983. Professor Walker's research interests include statistical mechanics, critical phenomena, and chaos. His many publications on the application of renormalization group theory to systems ranging from adsorbed monolayers to binary-fluid mixtures have appeared in *Physical Review*, *Physical Review Letters*, *Physica*, and a host of other publications. He has also participated in observations on the summit of Mauna Kea, looking for evidence of extrasolar planets.

Jim Walker likes to work with students at all levels, from judging elementary school science fairs to writing research papers with graduate students, and has taught introductory physics for many years. His enjoyment of this course and his empathy for students have earned him a reputation as an innovative, enthusiastic, and effective teacher. Jim's educational publications include "Reappearing Phases" (*Scientific American*, May 1987) as well as articles in the *American Journal of Physics* and *The Physics Teacher*. In recognition of his contributions to the teaching of physics at Washington State University, Jim was named Boeing Distinguished Professor of Science and Mathematics Education for 2001–2003.

When he is not writing, conducting research, teaching, or developing new classroom demonstrations and pedagogical materials, Jim enjoys amateur astronomy, eclipse chasing, bird and dragonfly watching, photography, juggling, unicycling, boogie boarding, and kayaking. Jim is also an avid jazz pianist and organist. He has served as ballpark organist for a number of Class A minor league baseball teams, including the Bellingham Mariners, an affiliate of the Seattle Mariners, and the Salem-Keizer Volcanoes, an affiliate of the San Francisco Giants. He can play "Take Me Out to the Ball Game" in his sleep.



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- **Relevant connections** that tie abstract concepts to everyday experiences and modern technologies.
- **Rich lab explorations** and **study support** that allow students to practice and reinforce essential skills.
- **Cutting-edge technology** that offers multiple options for interacting with—and mastering—the content.

The following pages showcase several key elements of Pearson Physics that will lead students to success.

6

Work and Energy

Inside

- 6.1 Work 189
- 6.2 Work and Energy 197
- 6.3 Conservation of Energy 206
- 6.4 Power 211



Though steinstossen (stone throwing) is not an Olympic sport, it has many fans. Launching a stone like this competitor is doing requires a mighty effort—in which work is converted to kinetic energy. (Note to photographers: Look out!)

Big Idea

Everyone knows what work and energy mean in everyday life. You get up in the morning and “go to work,” or you “work up a sweat” hiking up a mountain. Later in the day you eat lunch and get the “energy” to continue working or hiking. In this chapter you’ll learn what work and energy mean in physics and how to apply these definitions to a variety of everyday situations.

The **Big Idea** emphasizes the central concept of the chapter.

Inquiry Lab

What factors affect energy transformations?

Explore

1. Obtain a rubber “popper” from your teacher.
2. Press your thumbs into the center of the popper and turn it inside out. Carefully place the popper on a tabletop, with its flat side down.
3. Hold a meterstick upright next to the popper and use it to measure how high the popper rises above the tabletop when it springs upward. Record the height in centimeters.
4. Repeat Steps 2 and 3, except this time place the popper on a soft surface, such as a cushion or a sponge.
5. Repeat Steps 2 and 3, except this time place the popper on the eraser end of a pencil held vertically.

Think

1. **Identify** Based on what you currently know about energy, describe the energy changes that took place during the motion of the popper in each trial.
2. **Compare** Rank the heights attained by the popper in all your trials, from lowest to highest. Explain why you think the popper went higher in some cases.
3. **Predict** Imagine that you dropped the inverted popper, flat side down, onto the tabletop rather than just placing it there. What effect do you think this would have on the height attained by the popper? Explain your answer.

6.1 Work

The concept of force is one of the foundations of physics. A key concept in this lesson, force times distance is also an important physical quantity.

Work depends on force and distance. Pushing a heavy shopping cart in a store or pulling a big suitcase through an airport requires considerable effort. The greater the force you exert, the greater the effort. The greater the distance you move the object, the greater the effort. If you push or pull long and hard enough, your exertions can even make you tired. These observations are the basis for our definition of work.

Work In the simplest case work is done when a force is applied to an object and the object moves in the direction of the applied force. In a situation like this, **work, W** , is defined as force times the distance moved.

Definition of Work, W (force in the direction of displacement)

work = force \times distance

$W = Fd$

SI unit: newton-meter ($N \cdot m$) = joule (J)

Key Questions in each lesson call out important concepts and highlight their answers in the discussion.

How is work done?

Leading by Example

Every class contains a unique and diverse group of students. Pearson Physics supports each student's unique learning style, offering all students a path to success. A key element of this approach is the program's use of four distinct Example types, each with a particular purpose.

QUICK Example 5.2 What's the Force?

An 1800-kg car has an acceleration of 3.8 m/s^2 . What is the force acting on the car?

Solution
 Substitution: $m = 1800 \text{ kg}$ and $a = 3.8 \text{ m/s}^2$ in $F = ma$:

$$F = ma$$

$$= (1800 \text{ kg})(3.8 \text{ m/s}^2)$$

$$= 6840 \text{ N}$$

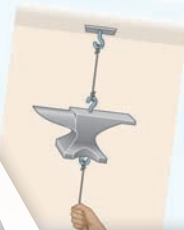
Quick Examples offer simple and concise solutions that model how newly introduced equations and units are used.

CONCEPTUAL Example 5.1 Which String Breaks?

A heavy anvil hangs from a string attached to a ceiling, as shown on the right. An identical string hangs from the bottom of the anvil. Which string breaks if you jerk the lower string downward rapidly?

Reasoning and Discussion
 If the lower string is pulled downward rapidly, the inertia of the massive anvil keeps it from responding quickly. Since the anvil barely moves, the force in the lower string quickly becomes large. As a result, the lower string breaks before the anvil has a chance to move. (Pulling slowly on the lower string causes the upper string to break, instead.)

Answer



Conceptual Examples pose a thought-provoking question and then explain the logical reasoning and physics concepts needed to answer it.

ACTIVE Example 6.8 Determine the Final Speed

A boy does 19 J of work as he pulls a 6.4-kg sled through a distance of 2.0 m. No other work is done on the sled. If the initial speed of the sled is 1.50 m/s, what is its final speed?



Solution (Perform the calculations indicated in each step.)

1. Rearrange the work-energy theorem to solve for the final kinetic energy:

$$\frac{1}{2}mv_f^2 = W_{\text{total}}$$

$$v_f = \sqrt{\frac{2W_{\text{total}}}{m}}$$

$$v_f = 2.5 \text{ m/s}$$

Active Examples ask students to take an active role in solving the problem by thinking through the logic described on the left and verifying their answers on the right.

GUIDED Example 17.6 | Prisms

A flint-glass prism has a cross section in the shape of a 30° - 60° - 90° triangle, as shown in the diagram. Red and violet light are incident on the prism at right angles to its vertical side. Given that the index of refraction of flint glass is 1.66 for red light and 1.70 for violet light, find the difference in the refraction angles as the rays emerge from the prism.

Picture the Problem

The prism and the red and violet rays are shown in our sketch. Notice that the angle of incidence on the vertical side of the prism is 0° . Therefore, the angle of refraction is also 0° for both incidence equal to 30.0° . Their angles of refraction are different.

Strategy

To find the final angle of refraction for each ray, we apply Snell's law with the appropriate index of refraction. We then subtract the angles to find the difference.

Solution

1. Solve Snell's law ($n_1 \sin \theta_1 = n_2 \sin \theta_2$) for the angle of refraction, θ_2 . Next, substitute the known values of $n_1 = 1.66$, $\theta_1 = 30.0^\circ$, and $n_2 = 1.00$ to calculate θ_2 for red light:

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2} \sin \theta_1\right)$$

$$= \sin^{-1}\left(\frac{1.66}{1.00} \sin 30.0^\circ\right)$$

$$= 56.1^\circ$$

$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2} \sin \theta_1\right)$$

$$= \sin^{-1}\left(\frac{1.70}{1.00} \sin 30.0^\circ\right)$$

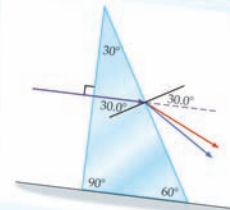
$$= 58.2^\circ$$

$$58.2^\circ - 56.1^\circ = 2.1^\circ$$

Insight

This kind of difference in refraction angles is the reason for the dispersion seen with a prism.

Dispersion



Known

angles for the triangle: 30° , 60° , 90°
 $n = 1.66$ (red light)
 $n = 1.70$ (violet light)

Unknown

difference in refraction angles = ?

Math HELP
 Trigonometric Functions
 See Math Review, Section VI

Guided Examples present a visual model of the physical situation and outline the key concepts that apply to it before proceeding to the detailed step-by-step solution.

Relevant Connections

Pearson Physics emphasizes the fact that physics applies to everything in your world, connecting ideas and concepts to everyday experience.

Physics & You

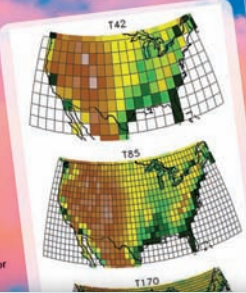
Careers

Climate Modelers

Climate describes the weather conditions in a region over a long period of time. Interactions between ocean, land, biosphere, and atmosphere produce Earth's climates. Climate modelers use complex computer models to simulate past and future climatic conditions. Leaders in governments, communities, and a range of industries plan how to deal with possible future climate fluctuations.

Climate modelers work closely with other scientists, including oceanographers, atmospheric chemists, and meteorologists, to obtain the most accurate environmental data. The data are used in the complex mathematical calculations of the climate model, which are carried out by supercomputers. The results are resolved over a grid that covers Earth's surface. The points that lie between the grid lines are filled in through interpolation, a mathematical technique for estimating values that lie between data points.

Climate modeling is a rapidly changing field. Climate modelers must stay informed about the latest technologies and the simulations are refined as new data become available.

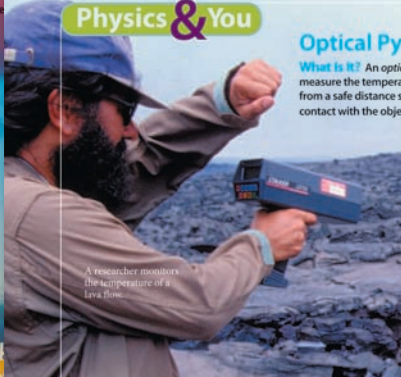


Physics & You

How Things Work

Optical Pyrometer

What is It? An optical pyrometer is a telescope-like instrument used to measure the temperature of very hot objects. It determines the temperature from a safe distance so that the operator does not have to make physical contact with the object.



A researcher monitors the temperature of a lava flow.

How Does It Work? An optical pyrometer uses the light emitted by very hot objects to determine their temperature. When the operator views the target object through the pyrometer, he or she also sees a thin, glowing filament. This filament is inside the pyrometer between lenses. The filament appears as a light or dark line superimposed on the image of the object. The operator then adjusts the voltage that is applied to the filament. The voltage controls the brightness of the filament; when the brightness of the filament matches that of the object, the line disappears. Internal electronics determine the temperature that corresponds to the voltage. The displayed temperature is the temperature of the object.

Because the filament target is likely made of materials, they do not have the same color or light about light waves in the visible spectrum. To correct for this, the pyrometer emits a narrow range of colors. The filament line is completely white. Calibrated materials and coatings are used to correct for this. What Are Its Applications? Optical pyrometers are used in industrial, medical, and scientific applications.

Physics & You

Technology and Society

In the tidal stream system illustrated here, energy from flowing tides powers turbines that generate electricity.



Tidal Energy

What is It? Tides are the periodic rises and falls of sea level caused by the gravitational tug-of-war between the Sun, the Moon, and Earth. Tides provide a source of natural, clean, renewable energy. Tidal energy is harvested by converting the kinetic energy of the moving water into electricity.

When Was It Invented? Tidal power plants known as barrage plants began harnessing the power of tides in the 1960s. Tidal stream systems, which use a different technology, are planned or under development in several countries.

How Does It Work? Tidal stream systems, like the one illustrated here, are one way to produce electrical power from tides. They use a shrouded turbine to harvest the kinetic energy of water flowing in the tides. The tidal stream system is placed along a coastline or in a river that is free of features that could obstruct or deflect the tidal flow. The latest tidal stream systems are designed to pivot, allowing them to follow the direction of peak tidal flow.

Tidal energy is generated when the force of tidal water turns the blades on a turbine. The turbine converts tidal energy first into mechanical energy and then into electrical energy. The amount of energy contained in a flowing tide is related to the cube of the tide's velocity. Thus, a slight increase in tidal velocity corresponds to a very large increase in the power generated by tidal velocities available energy. For example, compare water velocities of 1.5 m/s and 3.0 m/s. Though the water velocities differ by a factor of 2, the faster velocity yields 8 times more tidal energy.

Why is It Important? Tidal energy is a consistent form of energy that can be harnessed to provide a clean energy alternative to coastal communities. Once in place, tidal power plants require little maintenance. This renewable energy resource does not produce any waste or greenhouse gases.

Take It Further

- 1. Compare** Use information from the Internet to evaluate the pros and cons of tidal, solar, and wind energy. Summarize your findings in a one-page written report.
- 2. Critical Thinking** Research the environmental and economic implications of using a barrage power plant versus a tidal stream system. Which type of tidal energy system would you recommend to the city council of a coastal community?

333

Physics & You features throughout the book explain the physics behind interesting technologies, the impact of technology on society, and the role of physics in various careers.

Physics & You: Technology The wheels on older cars often lock during panic braking, causing the car to skid uncontrollably. In general, sliding or skidding tires are subject to kinetic friction, whereas tires that roll experience static friction, as discussed in Conceptual Example 5.13. Since static friction is usually greater than kinetic friction, a car will stop over a shorter distance if its wheels are rolling (static friction) than if its wheels are locked up and skidding (kinetic friction)!

This is the idea behind antilock braking systems (ABS). When the brakes are applied in a car with ABS, an electronic rotation sensor on each wheel detects when the wheel is about to skid. To prevent the skidding, a small computer automatically begins to pump the brakes. This pumping allows the wheels to continue rotating, even in an emergency stop, and thus static friction determines the stopping distance. Figure 5.17 shows a comparison of braking distances for cars with and without ABS.

Physics & You: Technology passages in the discussion explain how various modern technologies make use of the physics concepts just learned.

In-text Labs and Study Tools

Pearson Physics provides hands-on lab explorations in the text itself and through a separate Lab Manual. Extra study support features appear throughout the chapters when students need them most.

Physics Lab Centripetal Force

This lab explores the relationship between the speed of an object in uniform circular motion and the centripetal force acting on the object. You will whirl a mass overhead at the speed needed to balance the force exerted by a hanging mass that varies from trial to trial.

Materials

- 1.25 m of nylon cord or string
- 15 cm of tape-wrapped polished glass tube
- number 4 or 5 one-hole rubber stopper
- mass set
- meterstick
- stopwatch
- marking tape

Procedure

- After passing one end of the nylon cord through the stopper, thread the cord through the tape-wrapped glass tube and attach a 0.05-kg mass to the other end of the cord.
- Pull on the cord through the tube so that there is a small amount of slack.
- Hold the 0.05-kg mass in one hand and the glass tube in the other. Begin whirling the stopper in a horizontal circle above your head, as shown. Release the tube and increase the speed of the stopper until the tape marker moves to a position just below the end of the tube.

Caution: Take care to prevent hitting yourself or anyone else with the whirling rubber stopper; all other students should stand clear of the whirling stopper.

4. Have your lab partner measure the time required to complete 20 revolutions of the stopper. Record this in the data table for Trial 1.

Steps 3 and 4 for Trials 2-5. Increase the mass in successive trials by 0.05 kg, as shown in the data table for Trial 1.

Trial	Speed of Stopper (m/s)	Speed of Stopper Squared (m ² /s ²)
1		
2	0.10	
3	0.15	
4	0.20	
5	0.25	

Conclusions

- When the stopper is moving in a circle, what provides the centripetal force? Describe the path the stopper would follow if this force were suddenly removed.
- Based on your data, describe what happens to the speed of the stopper moving in a circle as the mass increases.

Analysis

- Calculate the weight of the hanging mass (in newtons) for each trial. Record your results in the data table.
- Because the weight of the hanging mass supplies the centripetal force, calculate the centripetal force on the stopper for each trial. Record your results in the data table.
- Calculate the centripetal force on the stopper for each trial. Record your results in the data table.
- Create a graph of centripetal force versus the square of the speed of the stopper.
- Create a graph of centripetal force versus the speed of the stopper.

Figure 6 The exponential function $y = e^x$ becomes large with increasing x . The inverse of the exponential function, $y = 1/e^x = e^{-x}$, approaches zero as x increases.

Table 3 Rules for Logarithms

$\ln(ab) = \ln a + \ln b$
$\ln\left(\frac{a}{b}\right) = \ln a - \ln b$
$\ln a^x = x \ln a$

Combining Logarithms The basic rules of logarithms follow directly from the rules given for combining exponents. These rules summarize several important rules. Though these are natural logarithms, they are satisfied by logarithms of any base.

As an example of the above results, consider $\log\left(\frac{1}{2}\right) = \log(1/2) = -0.301$. The result is negative, between 0 and 1. We can also write this result in the following form:

$$\log\left(\frac{1}{2}\right) = \log 1 - \log 2 = 0 - \log 2 = -\log 2$$

Thus, not only is $\log(1/2)$ negative, it is the negative of $\log 2 = 0.301$, which means that the results are consistent.

The exponential function Raising e to the power x results in $y = e^x$, which is the exponential function. This function is equal to 1 when $x = 0$, and for $x > 0$, the function increases rapidly with increasing x . The inverse of the exponential function is $y = 1/e^x = e^{-x}$. This function is equal to 1 when $x = 0$, and for $x < 0$, the function approaches zero as x becomes more negative. Figure 6 also shows a plot of e^{-x} . The exponential function plays an important role in many real-world situations. Examples are given in Figure 7.

Physics Labs are traditional single-page lab activities that use easy to obtain materials.

Short, simple, and interesting Inquiry Labs open each chapter and offer a chance to explore some of the chapter's fundamental concepts.

Inquiry Lab What is thin-film interference?

Explore

- Thoroughly clean and dry two microscope slides.
- After placing the slides on top of one another, lay them on a dark surface.
- Illuminate the slides with white light. Tilt the slides so that you are able to see an image of the light source. What do you notice about the appearance of the surface of the slide?
- Gently apply pressure to the top slide and describe how its appearance changes.

Describe What happened when pressure was applied to the top slide in Step 4?

Predict How do you think your observations would change if the slides were illuminated with monochromatic light (light of a single wavelength) instead of white light?

Think

- Observe What did you observe when viewing the illuminated slides in Step 3?

18.1 Interference

As you learned in Chapter 13, waves can interfere with one another. Interfering waves can add to produce a larger amplitude, subtract to produce a smaller amplitude, or even cancel one another. This lesson explores the various effects that occur when light waves interfere.

Interference is caused by the superposition of waves One fine summer day you watch boats zip across a quiet lake. The waves they make travel outward and overlap. If you look closely, you'll see that the waves formed by the overlapping are sometimes higher and sometimes lower than the original waves. This is an example of *superposition*, where the displacement of two or more waves is the sum of the displacements of the individual waves. When waves combine to cause a larger displacement, they interfere *constructively*; when they combine to cause a smaller displacement, they interfere *destructively*. Interference between light waves results in an increase in brightness for constructive interference and a decrease in brightness for destructive interference.

Light wave interference is most noticeable when the light sources are coherent and monochromatic. **Coherent light** is light of a single color, or frequency. Because a laser emits light that is both monochromatic and coherent, it is perfect for showing interference.

The phase difference between **incoherent light** sources varies randomly with time. Incoherent light sources—which include incandescent light bulbs, fluorescent lights, and the Sun—do not form noticeable interference patterns.

Vocabulary

- monochromatic light
- coherent light
- incoherent light
- Huygens's principle

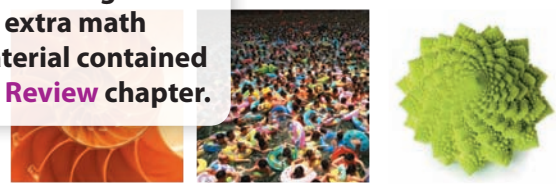
Under what conditions is the interference of light most noticeable?

CONNECTING IDEAS

Superposition and interference of waves were introduced in Chapter 13 for waves on a string. The concepts were extended to sound waves in Chapter 14. Here we apply the same concepts—superposition and interference—to light waves.

Math HELP boxes in example problems guide students to extra math support material contained in the Math Review chapter.

Connecting Ideas features the important concepts from lesson to lesson and chapter to chapter, helping students see the bigger picture.



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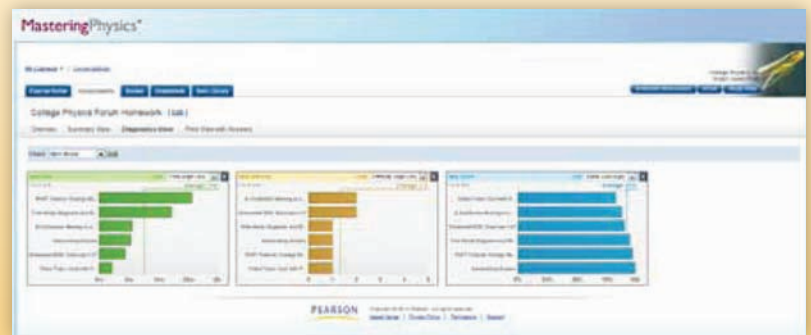
Prelecture Questions

Assignable Prelecture Concept Questions encourage students to read the textbook so they're more engaged in class.



Gradebook Diagnostics

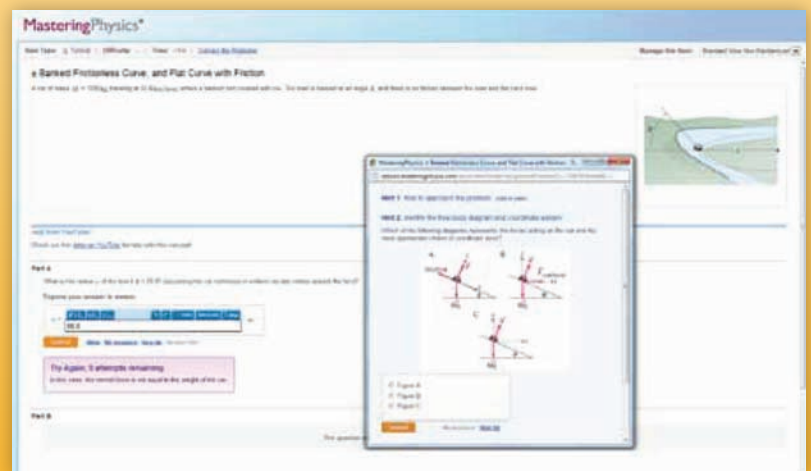
The Gradebook Diagnostics screen provides instructors with weekly diagnostics. With a single click, charts identify the most difficult problems, vulnerable students, and grade distribution.



Tutorials with Hints and Feedback

Mastering's easy-to-assign tutorials provide students with individualized coaching.

- Hints and Feedback offer "scaffolded" instruction similar to what students would experience in an after-school study session.
- Hints often provide problem-solving strategies or break the main problem into simpler exercises.
- Wrong-answer-specific feedback gives students exactly the help they need by addressing their particular mistake without giving away the answer.



Contents



1 Introduction to Physics 2

Big Idea Physics applies to everything.

- 1.1 Physics and the Scientific Method 3
- 1.2 Physics and Society 10
- 1.3 Units and Dimensions 15
- 1.4 Basic Math for Physics 23
- 1.5 Problem Solving in Physics 33

2 Introduction to Motion 42

Big Idea Motion can be represented by a position-time graph.

- 2.1 Describing Motion 43
- 2.2 Speed and Velocity 48
- 2.3 Position-Time Graphs 54
- 2.4 Equation of Motion 58

3 Acceleration and Accelerated Motion 72

Big Idea All objects in free fall move with the same constant acceleration.

- 3.1 Acceleration 73
- 3.2 Motion with Constant Acceleration 82
- 3.3 Position-Time Graphs for Constant Acceleration 92
- 3.4 Free Fall 97

4 Motion in Two Dimensions 112

Big Idea The horizontal and vertical motions of an object are independent of one another.

- 4.1 Vectors in Physics 113
- 4.2 Adding and Subtracting Vectors 121

- 4.3 Relative Motion 127
- 4.4 Projectile Motion 131

5 Newton's Laws of Motion 150

Big Idea All motion is governed by Newton's laws.

- 5.1 Newton's Laws of Motion 151
- 5.2 Applying Newton's Laws 161
- 5.3 Friction 170

6 Work and Energy 188

Big Idea Energy can change from one form to another, but the total amount of energy in the universe stays the same.

- 6.1 Work 189
- 6.2 Work and Energy 197
- 6.3 Conservation of Energy 206
- 6.4 Power 211

7 Linear Momentum and Collisions 228

Big Idea Momentum is conserved in all collisions, as long as external forces do not act.

- 7.1 Momentum 229
- 7.2 Impulse 234
- 7.3 Conservation of Momentum 242
- 7.4 Collisions 248

8 Rotational Motion and Equilibrium 266

Big Idea Forces can produce torques, and torques can produce rotation.

- 8.1 Describing Angular Motion 267
- 8.2 Rolling Motion and the Moment of Inertia 276
- 8.3 Torque 281
- 8.4 Static Equilibrium 290

9 Gravity and Circular Motion 306

Big Idea Gravity acts on everything in the universe.

- 9.1 Newton's Law of Universal Gravity 307
- 9.2 Applications of Gravity 313
- 9.3 Circular Motion 320
- 9.4 Planetary Motion and Orbits 327

10 Temperature and Heat 342

Big Idea Heat is a form of energy that is transferred because of temperature differences.

- 10.1 Temperature, Energy, and Heat 343
- 10.2 Thermal Expansion and Energy Transfer 350
- 10.3 Heat Capacity 358
- 10.4 Phase Changes and Latent Heat 366

11 Thermodynamics 384

Big Idea Energy conservation applies to thermal energy and heat.

- 11.1 The First Law of Thermodynamics 385
- 11.2 Thermal Processes 393
- 11.3 The Second and Third Laws of Thermodynamics 400

12 Gases, Liquids, and Solids 414

Big Idea Fluids flow and change shape easily, whereas solids maintain a definite shape unless acted on by a force.

- 12.1 Gases 415
- 12.2 Fluids at Rest 424
- 12.3 Fluids in Motion 435
- 12.4 Solids 440

13 Oscillations and Waves 452

Big Idea Waves are traveling oscillations that carry energy.

- 13.1 Oscillations and Periodic Motion 453
- 13.2 The Pendulum 462
- 13.3 Waves and Wave Properties 470
- 13.4 Interacting Waves 476

14 Sound 492

Big Idea Sound carries energy in the form of a traveling wave of compressions and expansions.

- 14.1 Sound Waves and Beats 493
- 14.2 Standing Sound Waves 501
- 14.3 The Doppler Effect 507
- 14.4 Human Perception of Sound 513

15 The Properties of Light 528

Big Idea Light is a small but important part of the electromagnetic spectrum. Everything you see either emits or reflects light.

- 15.1 The Nature of Light 529

- 15.2 Color and the Electromagnetic Spectrum 536
- 15.3 Polarization and Scattering of Light 545

16 Reflection and Mirrors 564

Big Idea Mirrors are particularly good at reflecting light; a mirror's shape determines the size, location, and orientation of the reflected image.

- 16.1 The Reflection of Light 565
- 16.2 Plane Mirrors 570
- 16.3 Curved Mirrors 575



17 Refraction and Lenses 596

Big Idea Lenses take advantage of refraction to bend light and form images.

- 17.1 Refraction 597
- 17.2 Applications of Refraction 606
- 17.3 Lenses 612
- 17.4 Applications of Lenses 619

18 Interference and Diffraction 636

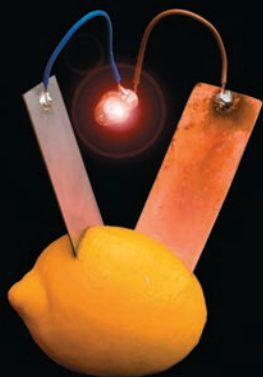
Big Idea Like all waves, light waves show the effects of superposition and interference.

- 18.1 Interference 637
- 18.2 Interference in Thin Films 647
- 18.3 Diffraction 654
- 18.4 Diffraction Gratings 662

19 Electric Charges and Forces 674

Big Idea Matter is made of electric charges, and electric charges exert forces on one another.

- 19.1 Electric Charge 675
- 19.2 Electric Force 683
- 19.3 Combining Electric Forces 690



20 Electric Fields and Electric Energy 704

Big Idea Electric charges produce fields that exert forces and store energy.

- 20.1 The Electric Field 705
- 20.2 Electric Potential Energy and Electric Potential 718
- 20.3 Capacitance and Energy Storage 728

21 Electric Current and Electric Circuits 744

Big Idea Electrons flow through electric circuits in response to differences in electric potential.

- 21.1 Electric Current, Resistance, and Semiconductors 745
- 21.2 Electric Circuits 757
- 21.3 Power and Energy in Electric Circuits 765

22 Magnetism and Magnetic Fields 782

Big Idea Moving charges produce magnetic fields, and magnetic fields exert forces on moving charges.

- 22.1 Magnets and Magnetic Fields 783
- 22.2 Magnetism and Electric Currents 789
- 22.3 The Magnetic Force 796

23 Electromagnetic Induction 816

Big Idea Changing magnetic fields produce electric fields, and the electric fields can be used to generate electric currents.

- 23.1 Electricity from Magnetism 817
- 23.2 Electric Generators and Motors 828
- 23.3 AC Circuits and Transformers 832

24 Quantum Physics 850

Big Idea At the atomic level, energy is quantized and particles have wavelike properties.

- 24.1 Quantized Energy and Photons 851
- 24.2 Wave-Particle Duality 864
- 24.3 The Heisenberg Uncertainty Principle 868

25 Atomic Physics 882

Big Idea The wave properties of matter mean that the atomic-level world must be described in terms of probability.

- 25.1 Early Models of the Atom 883
- 25.2 Bohr's Model of the Hydrogen Atom 888
- 25.3 The Quantum Physics of Atoms 897

26 Nuclear Physics 910

Big Idea The nuclei of atoms can release tremendous amounts of energy when part of their mass is converted to energy.

- 26.1 The Nucleus 911
- 26.2 Radioactivity 917
- 26.3 Applications of Nuclear Physics 925
- 26.4 Fundamental Forces and Elementary Particles 936

27 Relativity 948

Big Idea Nature behaves differently near the speed of light.

- 27.1 The Postulates of Relativity 949
- 27.2 The Relativity of Time and Length 953
- 27.3 $E = mc^2$ 958
- 27.4 General Relativity 962

Math Review R1

Appendices

Appendix A Selected Answers R26

Appendix B Additional Problems R37

Appendix C Data Tables R60

Appendix D Safety in the Physics Lab R72

Credits R93

Index R95

Program Components

MasteringPhysics®

MasteringPhysics® is the most effective and widely used online homework, tutorial, and assessment system for science courses. It delivers self-paced tutorials that focus on your course objectives, provides individualized coaching, and responds to each student's progress. The Mastering system helps teachers maximize class time with easy-to-assign, customizable, and automatically graded assessments that motivate students to learn.

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Electronic teacher supplements are also available within the Instructor's tab of MasteringPhysics.

INQUIRY LABS

Use readily available materials and easy procedures to produce reliable lab results.

How well do you give directions?	3	Do objects make characteristic sounds when dropped?	493
How do the cars move?	43	How do colors combine?	529
What does acceleration look like?	73	What do you see in a curved mirror?	565
What does independence of motion mean?	113	What is total internal reflection?	597
What are action and reaction forces?	151	What is thin-film interference?	637
What factors affect energy transformations?	189	What is the nature of electric force?	675
Which shoots the fastest and the farthest?	229	How can an electric field be made stronger?	705
What does a torque feel like?	267	How can you make a simple battery?	745
What keeps an object moving along a circular path?	307	How can you detect a magnetic field?	783
How can you make a cloud?	343	What are the components of a simple electric motor?	817
How does doing work on an object affect it?	385	What is blacker than black?	851
What makes water move through a straw?	415	How did Rutherford discover the nucleus?	883
How do waves move in water?	453	How can nuclear fusion be modeled?	911
		Is velocity always relative?	949

PHYSICS LABS

Apply physics concepts and skills with these quick, effective hands-on opportunities.

Measuring Devices and Units	36	Determining the Speed of Sound in Air	521
Position versus Time for a Constant-Velocity Car	64	Polarization	555
Investigating Acceleration	103	Focal Length of a Concave Mirror	588
Projectile Motion	142	Investigating Refraction	627
Static and Kinetic Friction	178	An Application of Diffraction	666
Investigating Work on Inclined Planes	218	Investigating Coulomb's Law	696
Momentum Conservation during a Collision	258	Mapping an Electric Field	736
Investigating Torque and Equilibrium	298	Ohm's Law	773
Centripetal Force	334	Mapping Magnetic Fields	808
Investigating Specific Heat Capacity	376	Electromagnetic Induction	842
The Mechanical Equivalent of Heat	408	Investigating Quanta	874
Investigating Hooke's Law	444	Spectra of Common Light Sources	904
Standing Waves on a Coiled Spring	484	Modeling Radioactive Decay	942
		Time Dilation	969

PHYSICS & YOU FEATURE PAGES

Learn more about how physics applies to real-world situations. You'll read about the impact physics has on society and technology, and survey some interesting careers that apply physics.

1 Technology and Society Atmospheric Modeling and Weather Prediction	35	15 Technology and Society Lighting Technologies and Energy Usage	554
2 Careers Climate Modelers	63	16 How Things Work The Hubble Space Telescope (HST)	587
3 How Things Work Microbursts	102	17 Careers Ophthalmology	626
4 Technology and Society Global Positioning Systems	141	18 How Things Work X-ray Diffraction	665
5 Careers Earthquake Scientists and Engineers	177	19 Careers Electrocardiogram Technician	695
6 Technology and Society Hybrid Vehicles	217	20 How Things Work Faraday Cages	735
7 How Things Work Ballistic Pendulum	257	21 Careers Semiconductor Industry	772
8 Careers Commercial Pilot	297	22 How Things Work Particle Accelerators	807
9 Technology and Society Tidal Energy	333	23 How Things Work The Induction Motor	841
10 How Things Work Optical Pyrometer	375	24 Careers Solar Installation	873
11 How Things Work Cryogenics	407	25 Technology and Society Hydrogen as Fuel	903
12 Careers Meteorologist	443	26 Careers Archeologist	941
13 How Things Work Tuned Mass Damper	483	27 How Things Work Miniature Nuclear Reactors	968
14 How Things Work Sonar Mapping	520		

PHYSICS & YOU TECHNOLOGY

Learn how chapter content applies to a wide range of devices and technologies.

Cesium fountain atomic clock	18	Digital micromirror devices (DMD)	568	Magnetic resonance imaging (MRI)	795
Tracking hurricanes using computer models and atmospheric data	130	Heads-up displays	573	Mass spectrometer	801
Antilock braking systems in cars	176	Corner reflector	574	Dynamic microphones	823
Bicycle helmets	240	Binoculars	608	Magnetic braking	827
Heartbeat recoil detectors	246	Charge-coupled devices (CCD)	619	Household electrical circuits	836
Bimetallic strips	352	Compound microscopes	620	The photoelectric effect	862
Adiabatic heating	397	Telescopes	621	Scanning tunneling microscopes (STM)	871
Body mass measurement device (BMMD)	460	Destructive interference	653	Laser induced breakdown spectroscopy (LIBS)	887
Gravity maps	465	Pixels and pointillism	660	Laser eye surgery	900
Active noise reduction (ANR)	478	Endoscopic surgery	681	Lasers and holograms	900
Ultrasound	498	Lightning rods	716	Fluorescence	901
Pipe organs	506	Capacitance and plate separation	732	Controlled nuclear chain reaction	928
Doppler radar	512	Energy released from a capacitor	732	Carbon-14 dating	932
Pixels and additive primary colors	542	Bolometers	753	Positron-emission tomography (PET)	934
Photoelastic stress analysis	550	Thermistors	754		
		Refrigerator magnets	786		

Guide to Examples

- QUICK Example 1.1** | What's the Length in Meters? 19

GUIDED Example 1.2 | A High-Volume Warehouse (Unit Conversion) 21

ACTIVE Example 1.3 | Convert the Units of Speed 22

GUIDED Example 1.4 | It's the Tortoise by a Hare (Significant Figures) 27

QUICK Example 1.5 | What's the Mass? 28

QUICK Example 1.6 | Which Digits Are Significant? 29

ACTIVE Example 1.7 | Estimate the Speed of Hair Growth 30
- QUICK Example 2.1** | What's the Distance? 45

QUICK Example 2.2 | What's the Displacement? 47

GUIDED Example 2.3 | The Kingfisher Takes a Plunge (Elapsed Time) 49

CONCEPTUAL Example 2.4 | What Is the Average Speed? 50

GUIDED Example 2.5 | Sprint Training (Average Velocity) 51

QUICK Example 2.6 | What's the Equation of Motion? 59

GUIDED Example 2.7 | Catch Me If You Can (Intersecting Motion) 61
- CONCEPTUAL Example 3.1** | Accelerating or Not? 74

QUICK Example 3.2 | What's the Acceleration? 75

CONCEPTUAL Example 3.3 | Comparing Accelerations 77

QUICK Example 3.4 | How Much Time to Get Up to Speed? 78

GUIDED Example 3.5 | The Ferry Docks (Average Acceleration) 80

QUICK Example 3.6 | What's the Velocity? 83

QUICK Example 3.7 | What's the Velocity? 85

GUIDED Example 3.8 | Put the Pedal to the Metal (Constant Acceleration) 87

GUIDED Example 3.9 | Hit the Brakes! (Negative Acceleration) 89

GUIDED Example 3.10 | Catching a Speeder (Graphing Multiple Motions) 94
- CONCEPTUAL Example 3.11** | Does the Separation Change? 98

GUIDED Example 3.12 | Do the Cannonball! (Free Fall) 99
- QUICK Example 4.1** | What's the Velocity? 114

GUIDED Example 4.2 | Need a Lift? (Vector Components) 117

GUIDED Example 4.3 | Skateboard Ramp (Vectors) 119

CONCEPTUAL Example 4.4 | How Does the Angle Change? 120

CONCEPTUAL Example 4.5 | Which Is the Vector Sum? 123

ACTIVE Example 4.6 | Finding the Treasure 125

ACTIVE Example 4.7 | Determining the Speed and Direction 128

GUIDED Example 4.8 | Crossing a River (Relative Velocity) 129

ACTIVE Example 4.9 | Determining the Position of a Dropped Ball 133

QUICK Example 4.10 | What's the Speed in Each Direction? 135

CONCEPTUAL Example 4.11 | Comparing Splashdown Speeds 135

GUIDED Example 4.12 | A Rough Shot (Projectile Motion) 137

CONCEPTUAL Example 4.13 | How Does the Speed of the Ball Change? 138
- CONCEPTUAL Example 5.1** | Which String Breaks? 153

QUICK Example 5.2 | What's the Force? 155

CONCEPTUAL Example 5.3 | Tightening a Hammer 156

GUIDED Example 5.4 | The Three Forces (Newton's Laws) 157

GUIDED Example 5.5 | Tippy Canoe (Newton's Laws) 159

ACTIVE Example 5.6 | Determine the Acceleration 162

GUIDED Example 5.7 | Where's the Fire? (Newton's Laws) 164

QUICK Example 5.8 | What's the Force? 166

Guide to Examples

- CONCEPTUAL Example 5.9** | Comparing Tensions 168
- ACTIVE Example 5.10** | Find the Tension 169
- GUIDED Example 5.11** | Pass the Salt—Please (Kinetic Friction) 172
- GUIDED Example 5.12** | Stranger Than Friction (Static Friction) 174
- CONCEPTUAL Example 5.13** | Static or Kinetic? 175
- 6 GUIDED Example 6.1** | Heading for the ER (Work) 191
- GUIDED Example 6.2** | Gravity Escape System (Work) 193
- CONCEPTUAL Example 6.3** | Rank the Work Done 194
- GUIDED Example 6.4** | Jamming with Rock Hero (Work) 195
- QUICK Example 6.5** | What's the Kinetic Energy? 199
- QUICK Example 6.6** | What's the Work? 199
- GUIDED Example 6.7** | Hit the Books (Work-Energy Theorem) 200
- ACTIVE Example 6.8** | Determine the Final Speed 201
- CONCEPTUAL Example 6.9** | How Much Work Is Required? 202
- QUICK Example 6.10** | What's the Potential Energy? 203
- GUIDED Example 6.11** | Converting Food Energy to Mechanical Energy (Potential Energy) 204
- QUICK Example 6.12** | What's the Potential Energy? 205
- GUIDED Example 6.13** | Catching a Home Run (Conservation of Energy) 208
- CONCEPTUAL Example 6.14** | Comparing Final Speeds 209
- ACTIVE Example 6.15** | Determine the Final Speed 210
- GUIDED Example 6.16** | Passing Fancy (Power) 214
- ACTIVE Example 6.17** | Find the Maximum Speed 215
- 7 QUICK Example 7.1** | What's the Momentum? 230
- GUIDED Example 7.2** | Duck, Duck, Goose (Total Momentum) 232
- QUICK Example 7.3** | What's the Impulse? 235
- QUICK Example 7.4** | What's the Force? 236
- CONCEPTUAL Example 7.5** | Rain versus Hail 238
- GUIDED Example 7.6** | Lending a Hand (Impulse-Momentum Theorem) 239
- GUIDED Example 7.7** | Tippy Canoe (Conservation of Momentum) 244
- CONCEPTUAL Example 7.8** | Momentum versus Kinetic Energy 247
- CONCEPTUAL Example 7.9** | How Much Kinetic Energy Is Lost? 250
- GUIDED Example 7.10** | Goal-Line Stand (Completely Inelastic Collision) 251
- GUIDED Example 7.11** | Analyzing a Traffic Accident (Completely Inelastic Collision) 253
- ACTIVE Example 7.12** | Determine the Final Velocities 256
- 8 QUICK Example 8.1** | How Many Degrees? 269
- QUICK Example 8.2** | What's the Angular Velocity? 270
- GUIDED Example 8.3** | Playing a CD (Angular Speed) 272
- CONCEPTUAL Example 8.4** | Compare the Speeds 273
- QUICK Example 8.5** | What's the Stopping Time? 274
- QUICK Example 8.6** | What's the Angular Speed? 277
- CONCEPTUAL Example 8.7** | Which Object Wins the Race? 279
- ACTIVE Example 8.8** | Find the Required Force 282
- GUIDED Example 8.9** | Torques to the Left and Torques to the Right (Torque) 285
- GUIDED Example 8.10** | A Fish Takes the Line (Angular Acceleration) 286
- CONCEPTUAL Example 8.11** | Which Block Lands First? 288
- ACTIVE Example 8.12** | Find the Forces 292
- GUIDED Example 8.13** | A Well-Balanced Meal (Equilibrium) 294
- CONCEPTUAL Example 8.14** | Compare the Masses 296

Guide to Examples

- 9 QUICK Example 9.1** | What's the Force? 309
CONCEPTUAL Example 9.2 | Rank the Forces 310
GUIDED Example 9.3 | How Much Force Is with You? (Universal Gravitation) 310
GUIDED Example 9.4 | The Dependence of Gravity on Altitude (Earth's Gravity) 315
QUICK Example 9.5 | What's the Value of g on the Moon? 317
QUICK Example 9.6 | What's the Mass of Earth? 318
CONCEPTUAL Example 9.7 | Choose the Path 321
GUIDED Example 9.8 | Rounding a Corner (Circular Motion) 322
ACTIVE Example 9.9 | Find the Normal Force 324
CONCEPTUAL Example 9.10 | Weighing In 324
CONCEPTUAL Example 9.11 | Comparing Orbital Speeds 329
ACTIVE Example 9.12 | Find the Altitude of the Orbit 331
- 10 GUIDED Example 10.1** | Temperature Conversions (Temperature Scales) 347
QUICK Example 10.2 | What's the Kelvin Temperature? 348
CONCEPTUAL Example 10.3 | Comparing Expansions 350
QUICK Example 10.4 | What's the Increase in Height? 351
CONCEPTUAL Example 10.5 | Expand or Contract? 353
CONCEPTUAL Example 10.6 | Warmer or Cooler? 355
GUIDED Example 10.7 | Stair Master (Mechanical Equivalent of Heat) 360
QUICK Example 10.8 | What Is the Temperature Change? 362
GUIDED Example 10.9 | Cooling Off (Calorimetry) 364
ACTIVE Example 10.10 | Find the Final Temperature 365
CONCEPTUAL Example 10.11 | Boiling Temperature 368
CONCEPTUAL Example 10.12 | Which Is Worse? 372
- QUICK Example 10.13** | What's the Thermal Energy? 373
- 11 GUIDED Example 11.1** | The Energetic Jogger (First Law of Thermodynamics) 388
GUIDED Example 11.2 | Heat into Work (Heat Engine) 391
CONCEPTUAL Example 11.3 | Engine Efficiency 392
QUICK Example 11.4 | How Much Work? 394
GUIDED Example 11.5 | Work Area (Pressure-Volume Graph) 395
GUIDED Example 11.6 | Work into Energy (Adiabatic Process) 398
CONCEPTUAL Example 11.7 | Comparing Efficiencies 402
ACTIVE Example 11.8 | Find the Temperature 403
GUIDED Example 11.9 | Melts in Your Hand (Entropy) 404
- 12 GUIDED Example 12.1** | Pressuring the Ball (Gauge Pressure) 417
GUIDED Example 12.2 | Take a Deep Breath (Ideal Gas Equation) 419
CONCEPTUAL Example 12.3 | Does the Number of Molecules Change? 420
ACTIVE Example 12.4 | Calculate the Amount of Air 421
QUICK Example 12.5 | What's the Mass? 425
QUICK Example 12.6 | What's the Pressure? 426
GUIDED Example 12.7 | Pressure and Depth (Density) 428
CONCEPTUAL Example 12.8 | Do the Bubbles Change in Size? 429
QUICK Example 12.9 | What's the Force? 431
CONCEPTUAL Example 12.10 | How Is the Scale Reading Affected? 433
CONCEPTUAL Example 12.11 | Does the Water Level Change? 433
GUIDED Example 12.12 | Spray Nozzle (Continuity Equation) 436
CONCEPTUAL Example 12.13 | What Happens to the Ragtop Roof? 438
QUICK Example 12.14 | What's the Force? 441

Guide to Examples

- 13 QUICK Example 13.1** | What Are the Frequency and the Period? 455
- GUIDED Example 13.2** | Spring Time (Simple Harmonic Motion) 458
- QUICK Example 13.3** | What's the Period? 459
- ACTIVE Example 13.4** | Find the Period 461
- QUICK Example 13.5** | What's the Period? 463
- CONCEPTUAL Example 13.6** | Raise or Lower the Weight? 465
- GUIDED Example 13.7** | Drop Time (Acceleration due to Gravity) 466
- QUICK Example 13.8** | What's the Wavelength? 474
- CONCEPTUAL Example 13.9** | What's the Amplitude? 477
- GUIDED Example 13.10** | It's Fundamental (Standing Waves) 480
- 14 CONCEPTUAL Example 14.1** | How Far Away Is the Lightning? 495
- GUIDED Example 14.2** | Wishing Well (Speed of Sound) 496
- CONCEPTUAL Example 14.3** | Comparing String Frequencies 499
- GUIDED Example 14.4** | Getting a Tune-up (Beats) 500
- GUIDED Example 14.5** | Pop Music (Standing Waves) 504
- QUICK Example 14.6** | What's the Length? 505
- GUIDED Example 14.7** | Whistle Stop (Doppler Effect) 509
- ACTIVE Example 14.8** | Determine the Frequency 511
- QUICK Example 14.9** | What's the Intensity? 514
- GUIDED Example 14.10** | The Power of Song (Sound Intensity) 516
- QUICK Example 14.11** | What's the Intensity? 517
- CONCEPTUAL Example 14.12** | Does the Intensity Change? 518
- 15 QUICK Example 15.1** | How Long Does It Take? 530
- GUIDED Example 15.2** | Fizeau's Results (Speed of Light) 532
- QUICK Example 15.3** | What's the Change in Frequency? 533
- GUIDED Example 15.4** | Roses Are Red, Violets Are Violet (Electromagnetic Spectrum) 538
- CONCEPTUAL Example 15.5** | How Many of Each Color? 542
- QUICK Example 15.6** | What's the Intensity? 547
- GUIDED Example 15.7** | Analyze This (Polarization) 548
- CONCEPTUAL Example 15.8** | Is the Light Completely Blocked? 549
- 16 CONCEPTUAL Example 16.1** | How Does the Direction Change? 567
- GUIDED Example 16.2** | Reflecting on a Flower (Reflection) 571
- CONCEPTUAL Example 16.3** | How Tall Is the Mirror? 572
- GUIDED Example 16.4** | Two-Dimensional Corner Reflector (Reflection) 573
- CONCEPTUAL Example 16.5** | Which Mirror Works Best? 577
- GUIDED Example 16.6** | Image Formation (Concave Mirrors) 579
- CONCEPTUAL Example 16.7** | Concave or Convex? 580
- QUICK Example 16.8** | Where's the Image? 582
- QUICK Example 16.9** | Where's the Image? 582
- GUIDED Example 16.10** | Checking It Twice (Magnification) 584
- ACTIVE Example 16.11** | Determine the Magnification and the Focal Length 585
- 17 QUICK Example 17.1** | What's the Travel Time? 598
- QUICK Example 17.2** | What's the Angle of Refraction? 600
- GUIDED Example 17.3** | Sitting on a Dock of the Bay (Refraction) 602
- CONCEPTUAL Example 17.4** | Which Way Is the Beam Refracted? 604
- GUIDED Example 17.5** | Light Totally Reflected (Total Internal Reflection) 607
- GUIDED Example 17.6** | Prisms (Dispersion) 609

Guide to Examples

- CONCEPTUAL Example 17.7** | Is the Focal Length Affected? 615
- GUIDED Example 17.8** | Object Distance and Focal Length (Convex Lenses) 617
- ACTIVE Example 17.9** | Find the Displacement of the Lens 619
- CONCEPTUAL Example 17.10** | Which Glasses Should They Use? 625
- 18 GUIDED Example 18.1** | Two May Not Be Better Than One (Interference) 639
- QUICK Example 18.2** | What Are the Angles? 644
- GUIDED Example 18.3** | Blue Light Special (Two-Slit Interference) 645
- CONCEPTUAL Example 18.4** | Is the Fringe Dark or Bright? 649
- GUIDED Example 18.5** | Splitting Hairs (Air Wedge) 649
- GUIDED Example 18.6** | Red Light Special (Thin-Film Interference) 652
- QUICK Example 18.7** | What's the Wavelength? 656
- GUIDED Example 18.8** | Exploring the Dark Side (Single-Slit Diffraction) 657
- QUICK Example 18.9** | What's the Angle? 659
- QUICK Example 18.10** | What's the Spacing? 663
- 19 QUICK Example 19.1** | How Much Charge? 678
- CONCEPTUAL Example 19.2** | Does the Mass Change? 680
- CONCEPTUAL Example 19.3** | Where Do They Collide? 685
- GUIDED Example 19.4** | The Bohr Orbit (Electric Force) 687
- QUICK Example 19.5** | What's the Force? 688
- GUIDED Example 19.6** | Total Force (Electric Force) 691
- CONCEPTUAL Example 19.7** | Comparing Forces 692
- ACTIVE Example 19.8** | Find the Force Exerted by a Charged Sphere 693
- 20 GUIDED Example 20.1** | Force Field (Electric Force) 707
- QUICK Example 20.2** | What's the Electric Field? 709
- CONCEPTUAL Example 20.3** | What's the Sign? 711
- GUIDED Example 20.4** | Superposition in the Field (Electric Field) 712
- CONCEPTUAL Example 20.5** | Do They Intersect? 714
- QUICK Example 20.6** | What's the Change in Electric Potential Energy? 720
- GUIDED Example 20.7** | Plates at Different Potentials (Electric Fields and Potentials) 722
- CONCEPTUAL Example 20.8** | How Do the Speeds Compare? 724
- QUICK Example 20.9** | What's the Electric Potential? 726
- CONCEPTUAL Example 20.10** | A Peak or a Valley? 727
- QUICK Example 20.11** | What's the Charge? 729
- GUIDED Example 20.12** | All Charged Up (Capacitors) 730
- CONCEPTUAL Example 20.13** | How Does the Field Change? 731
- GUIDED Example 20.14** | Delivering a Shock to the System (Capacitors) 733
- 21 CONCEPTUAL Example 21.1** | Comparing Currents 746
- GUIDED Example 21.2** | Mega Blaster (Electric Current) 747
- ACTIVE Example 21.3** | Determine the Charge and the Work 749
- QUICK Example 21.4** | What's the Current? 751
- GUIDED Example 21.5** | Three Resistors in Series (Series Circuit) 758
- GUIDED Example 21.6** | Three Resistors in Parallel (Parallel Circuit) 761
- GUIDED Example 21.7** | Combination Special (Combination Circuit) 763
- QUICK Example 21.8** | What's the Current? 766
- CONCEPTUAL Example 21.9** | Comparing Currents and Resistances 767
- GUIDED Example 21.10** | Heated Resistance (Power Dissipation) 768
- CONCEPTUAL Example 21.11** | Brightness of the Lights 769

Guide to Examples

GUIDED Example 21.12 | Your Goose Is Cooked
(Energy Cost) 770

22 CONCEPTUAL Example 22.1 | Can They
Cross? 785

CONCEPTUAL Example 22.2 | Which
Direction? 790

QUICK Example 22.3 | What's the Magnetic
Field? 791

ACTIVE Example 22.4 | Determine the Magnetic
Field 791

CONCEPTUAL Example 22.5 | Double the Loops
or the Length? 794

GUIDED Example 22.6 | The Care of a Solenoid
(Solenoids) 794

GUIDED Example 22.7 | A Tale of Two Charges
(Magnetic Force) 797

CONCEPTUAL Example 22.8 | Positive, Negative,
or Zero? 799

QUICK Example 22.9 | What's the Speed? 801

GUIDED Example 22.10 | Uranium Separation
(Circular Paths) 802

GUIDED Example 22.11 | Magnetic Levity
(Magnetic Force) 804

23 GUIDED Example 23.1 | A System in Flux
(Magnetic Flux) 820

CONCEPTUAL Example 23.2 | Does the Magnetic
Flux Change? 821

GUIDED Example 23.3 | Bar Magnet Induction
(Induced emf and Current) 822

CONCEPTUAL Example 23.4 | Falling Magnets 824

CONCEPTUAL Example 23.5 | The Direction of
Induced Current 826

GUIDED Example 23.6 | Generator Next (Electric
Generator) 829

QUICK Example 23.7 | What's the Maximum
Voltage? 833

GUIDED Example 23.8 | A Resistor Circuit
(Average AC Power) 834

ACTIVE Example 23.9 | Determine the Number of
Loops 839

24 QUICK Example 24.1 | What Is the
Temperature? 854

GUIDED Example 24.2 | Quantum Numbers
(Quantum Energy) 856

QUICK Example 24.3 | What's the Energy? 858

GUIDED Example 24.4 | When Oxygens Split
(Photons) 858

QUICK Example 24.5 | What's the Cutoff
Frequency? 860

GUIDED Example 24.6 | White Light on Sodium
(Photoelectric Effect) 861

ACTIVE Example 24.7 | Determine the Speed and
the Wavelength 865

CONCEPTUAL Example 24.8 | More Certain or
Less? 870

25 QUICK Example 25.1 | What's the Radius? 890

QUICK Example 25.2 | What's the Energy? 891

GUIDED Example 25.3 | The Hydrogen Lineup
(Hydrogen Spectrum) 892

ACTIVE Example 25.4 | Determine the
Frequency 895

CONCEPTUAL Example 25.5 | Finding the
Electron 898

26 QUICK Example 26.1 | What's the Symbol? 913

CONCEPTUAL Example 26.2 | Identify the
Radiation 918

GUIDED Example 26.3 | Alpha Decay of
Uranium-238 (Alpha Decay) 920

GUIDED Example 26.4 | Beta Decay of Carbon-14
(Beta Decay) 922

GUIDED Example 26.5 | A Fission Reaction of
Uranium-235 (Fission) 926

GUIDED Example 26.6 | You Don't Look a Day
over 5000 (Carbon-14 Dating) 933

27 QUICK Example 27.1 | What's the Elapsed
Time? 955

QUICK Example 27.2 | What's the Length? 957

QUICK Example 27.3 | What's the Rest Energy? 959

CONCEPTUAL Example 27.4 | Compare the
Mass 960

Math Review GUIDED Example 1 | Highway to
Heaven (Using Trig Functions) R21