PEARSON

# 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 absorbed 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, unicyling, 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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**Pearson Physics offers a new path to mastery—**
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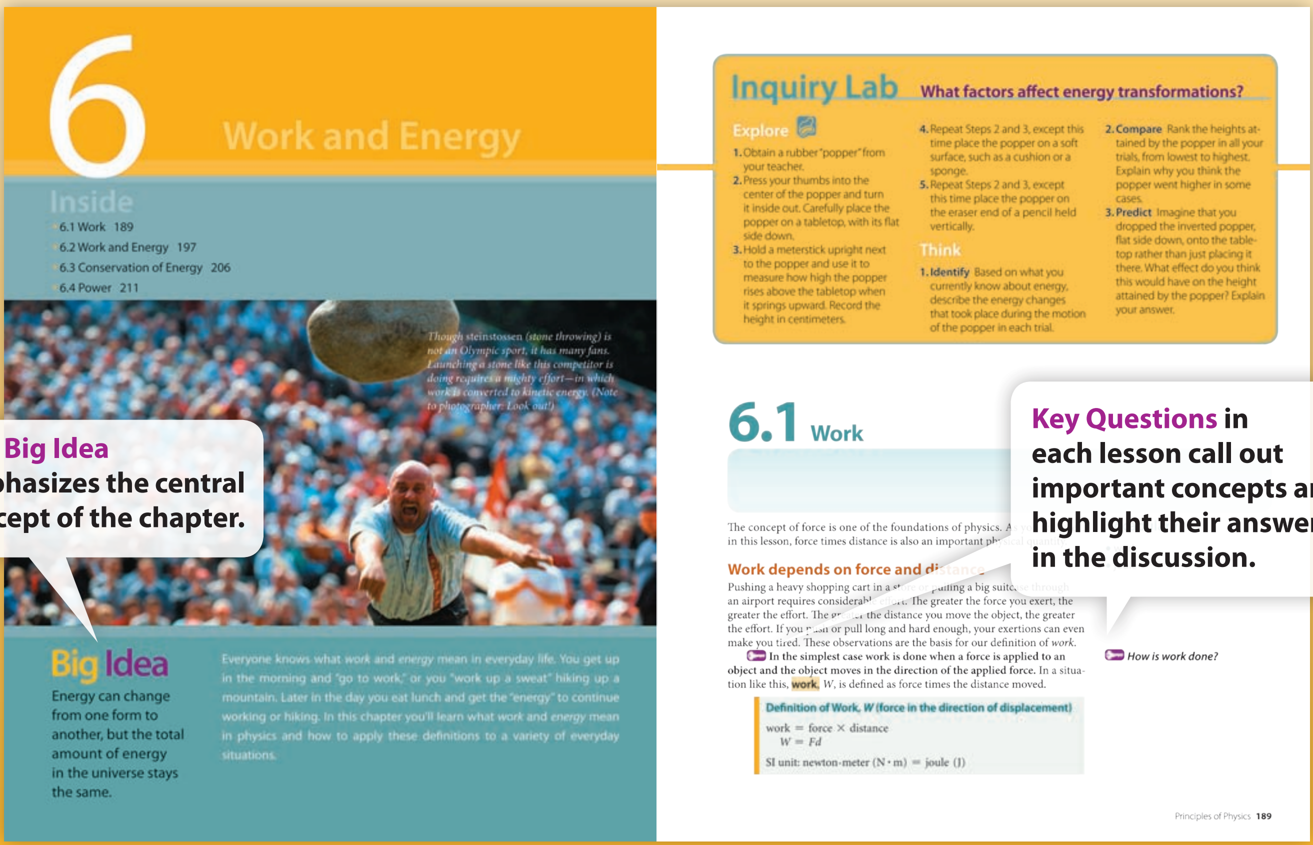
## In your new program, you'll find:

- **Example problems** that build reasoning and problem-solving skills.
- **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.***



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

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

6

Work and Energy

Inside

6.1 Work 189
6.2 Work and Energy 197
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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 photographer: Look out!)*

**Big Idea**

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

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.

**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 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*.

**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.

*How is work done?*

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

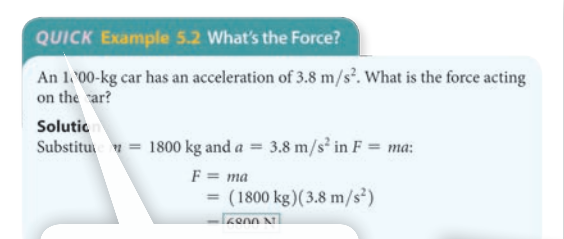
work = force × distance
$W = Fd$

SI unit: newton-meter (N · m) = joule (J)

Principles of Physics 189

# 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?

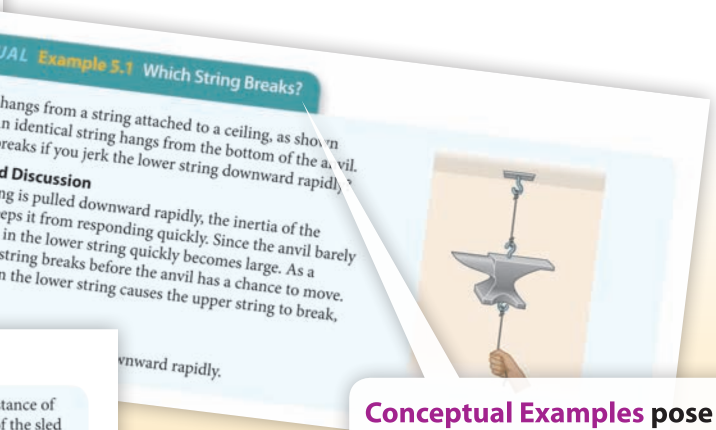
An 1,00-kg car has an acceleration of 3.8 m/s². What is the force acting on the ar?

**Soluti**

Substitu $m$ = 1800 kg and $a$ = 3.8 m/s² in $F = ma$:

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

**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?

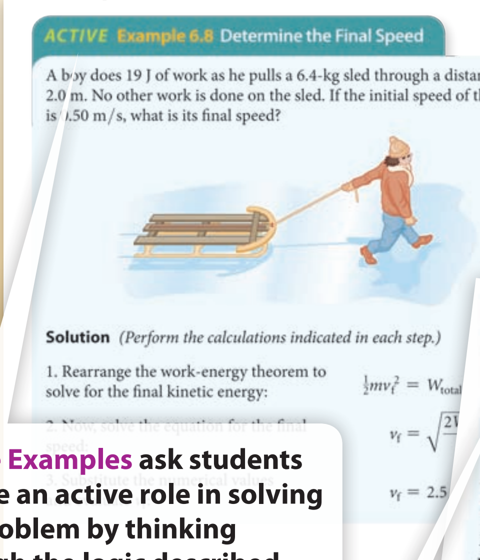
**Reasoning and Discussion**

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**

wnward rapidly.

**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 .50 m/s, what is its final speed?

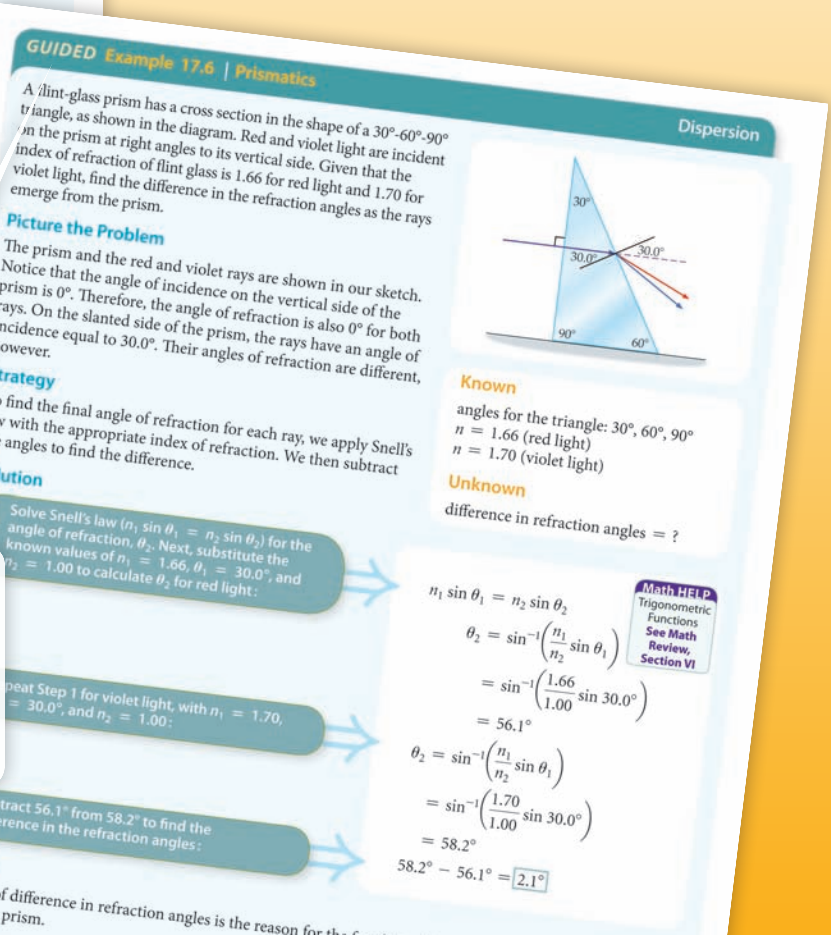
**Solution** *(Perform the calculations indicated in each step.)*

1. Rearrange the work-energy theorem to solve for the final kinetic energy: $\frac{1}{2}mv_f^2 = W_{\text{total}}$

2. Now, solve the equation for the final speed: $v_f = \sqrt{2}$

3. Substitute the numerical values: $v_f = 2.5$

**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 | Prismatics

Dispersion

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 rays. On the slanted side of the prism, the rays have an angle of incidence equal to 30.0°. Their angles of refraction are different, however.

**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.

**Known**

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

**Unknown**

difference in refraction angles = ?

**Solution**

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

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$
$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2}\sin\theta_1\right)$$
$$= \sin^{-1}\left(\frac{1.66}{1.00}\sin 30.0°\right)$$
$$= 56.1°$$

Math HELP Trigonometric Functions See Math Review, Section VI

peat Step 1 for violet light, with $n_1$ = 1.70, = 30.0°, and $n_2$ = 1.00:

$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2}\sin\theta_1\right)$$
$$= \sin^{-1}\left(\frac{1.70}{1.00}\sin 30.0°\right)$$
$$= 58.2°$$

3 Subtract 56.1° from 58.2° to find the difference in the refraction angles:

$$58.2° - 56.1° = \boxed{2.1°}$$

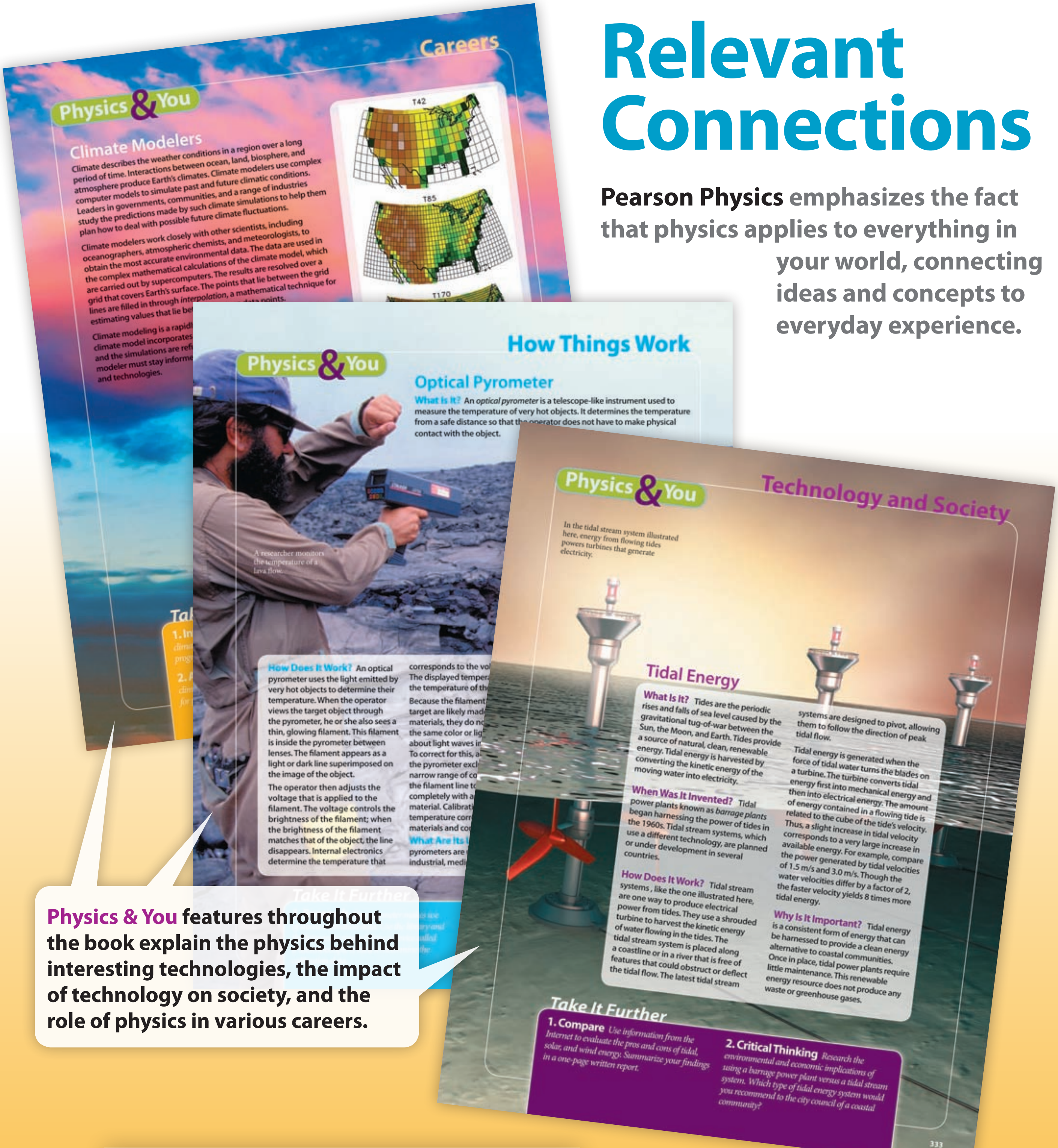
**Insight**

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

**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.



Careers

Physics & You

## 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 study the predictions made by such climate simulations to help them 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 bet

Climate modeling is a rapidl climate model incorporates and the simulations are refi modeler must stay informe and technologies.

Tal

1. In

2. A

How Things Work

Physics & You

## 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 vol The displayed temper the temperature of th

Because the filament target are likely mad materials, they do n the same color or lig about light waves in To correct for this, a the pyrometer excl narrow range of co the filament line to completely with a material. Calibrati temperature corr materials and co

**What Are Its U** pyrometers are industrial, medi

Take It Further

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 available energy. For example, compare the power generated by tidal 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?*

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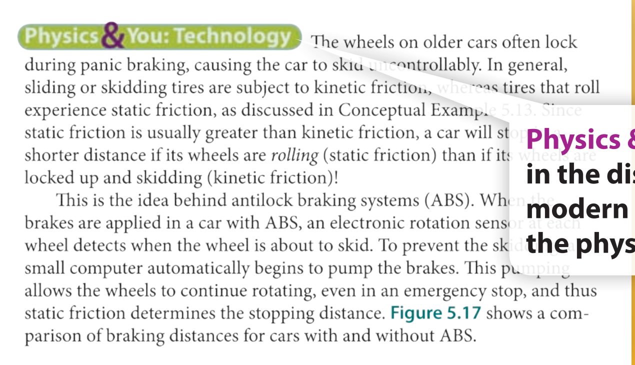
**Physics & You** features throughout the book explain the physics behind interesting technologies, the impact of technology on society, and the role of physics in various careers.



**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 in 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 at 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—a 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
- masking tape

**Procedure**

**1.** After tying one end of the nylon cord to the rubber stopper, pass the cord through the tape-wrapped glass tube and attach a 0.05-kg mass to the other end of the cord.

**2.** Pull enough cord through the tube so that there is 70 cm of cord between the stopper and the end of the tube. Attach a small piece of tape to the cord just below the tube. This tape marker will enable you to keep the radius constant while the stopper is in motion.

**3.** 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 weight 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 time in the data table for Trial 1.

**5.** Repeat Steps 3 and 4 for Trials 2–5. Increase the mass in each successive trial by 0.05 kg, as shown in the data table.

Data Table

| Trial | Mass (kg) | Weight of | Centripetal | Time for 20 Revolutions (s) | Speed of Stopper (m/s) | Speed of Stopper Squared ($m^2/s^2$) |
|---|---|---|---|---|---|---|
| 1 | 0.05 | | | | | |
| 2 | 0.10 | | | | | |
| 3 | 0.15 | | | | | |
| 4 | 0.20 | | | | | |
| 5 | 0.25 | | | | | |

**Analysis**

**1.** Calculate the weight of the hanging mass (in newtons) for each trial. Record your results in the data table.

**2.** Because the w the centripetal f mass into the ce

**3.** Calculate the Record your re

**4.** Create a gra speed of the st

**5.** Create a gr speed of the s

**Conclusions**

**1.** 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.

**2.** Based on your data, describe what happens to the

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

**Figure 6** The exponential function
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**

| |
|---|
| $\ln(xy) = \ln x + \ln y$ |
| $\ln\left(\frac{x}{y}\right) = \ln x - \ln y$ |
| $\ln x^n = n \ln x$ |

**Combining Logarithms** The basic rules obe follow directly from the rules given for combining ex summarizes several important rules. Though these r of natural logarithms, they are satisfied by logarithm

As an example of the above results, consider log ( we find $\log(1/2) = -0.301$. The result is negative, between 0 and 1. We can also write this result in th

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

Thus, not only is $\log(1/2)$ negative, it is the neg $\log 2 = 0.301$, we see that the results are consis

*How does the exponential function, $e^x$, change in value as x increases?*

### The exponential function

Raising e to the power x results in $y = e^x$, whi **exponential function.** This function is equal the exponential function is less than 1, and for A plot of $y = e^x$ is shown in Figure 6. N **function $e^x$ increases rapidly with increasing x.** button labeled $e^x$ to represent e raised to the power x.

The inverse of the exponential function is $y = 1/e^x = e^{-x}$. This function is greater than 1 for $x < 0$, equal to 1 for $x = 0$, and less than 1 for $x > 0$. 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.

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

R8 Section II

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**

1. Thoroughly clean and dry two microscope slides.
2. After placing the slides on top of one another, lay them on a dark surface.
3. 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?
4. Gently apply pressure to the top slide and describe how its appearance changes.

**Think**

1. **Observe** What did you observe when viewing the illuminated slides in Step 3?
2. **Describe** What happened when pressure was applied to the top slide in Step 4?
3. **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?

## 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.

**Vocabulary**

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

### 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*.** **Monochromatic light** is light of a single color, or frequency. **Coherent light** sources maintain a constant *phase* relative to one another. 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 lightbulbs, fluorescent lights, and the Sun—do not form noticeable interference patterns.

*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.

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

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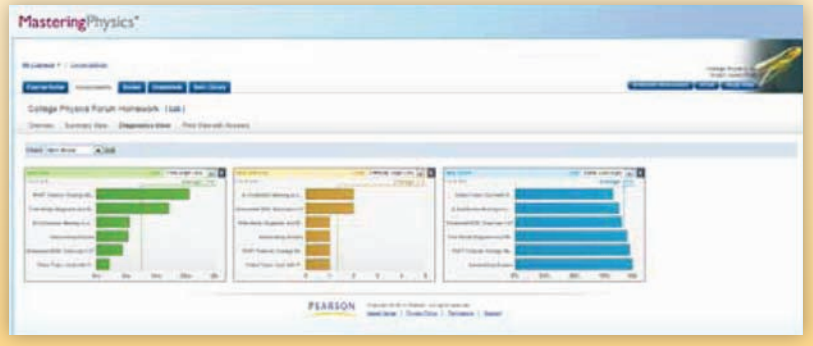
## Gradebook Diagnostics

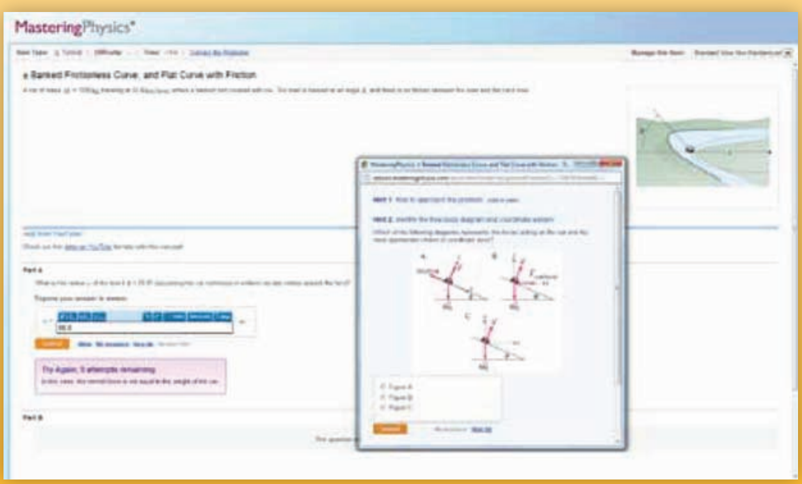
The Gradebook Diagnostics screen provides instructors with weekly diagnostics. With a single click, charts identify the most difficult problems, vulnerable students, and grade distribution.



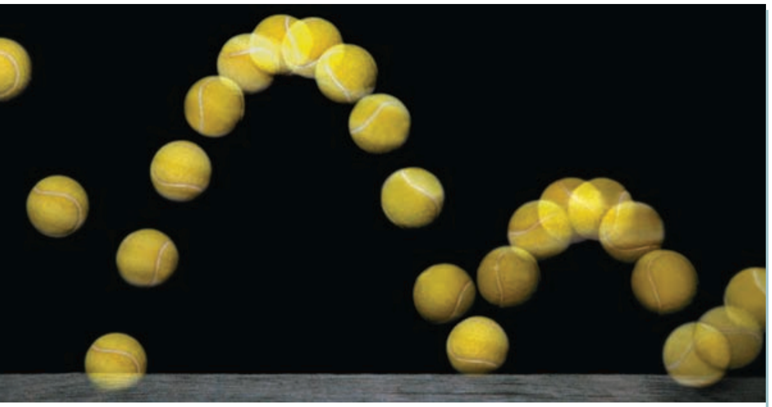
## Tutorials with Hints and Feedback

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



## 10 Temperature and Heat 342

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

## 11 Thermodynamics 384

**Big Idea** Energy conservation applies to thermal energy and heat.

## 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.

## 13 Oscillations and Waves 452

**Big Idea** Waves are traveling oscillations that carry energy.

## 14 Sound 492

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

## 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.

## 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.

## 17 Refraction and Lenses 596

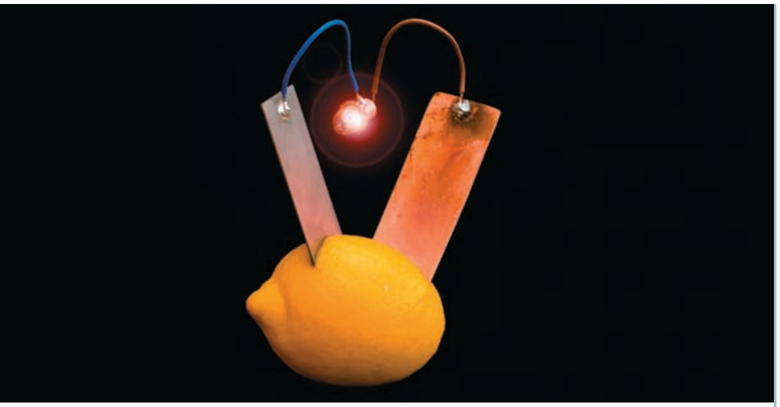
**Big Idea** Lenses take advantage of refraction to bend light and form images.

## 18 Interference and Diffraction 636

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

## 19 Electric Charges and Forces 674

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



# 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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OR

- Visit **PearsonSchool.com/Access_Request** (choose option 3). Adoption access information will be sent to the teacher via email.

Students, ask your teacher for access.

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