PEARSON

Physics

James S. Walker

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ISBN-13: 978-0-13-137115-6
ISBN-10: 0-13-137115-0

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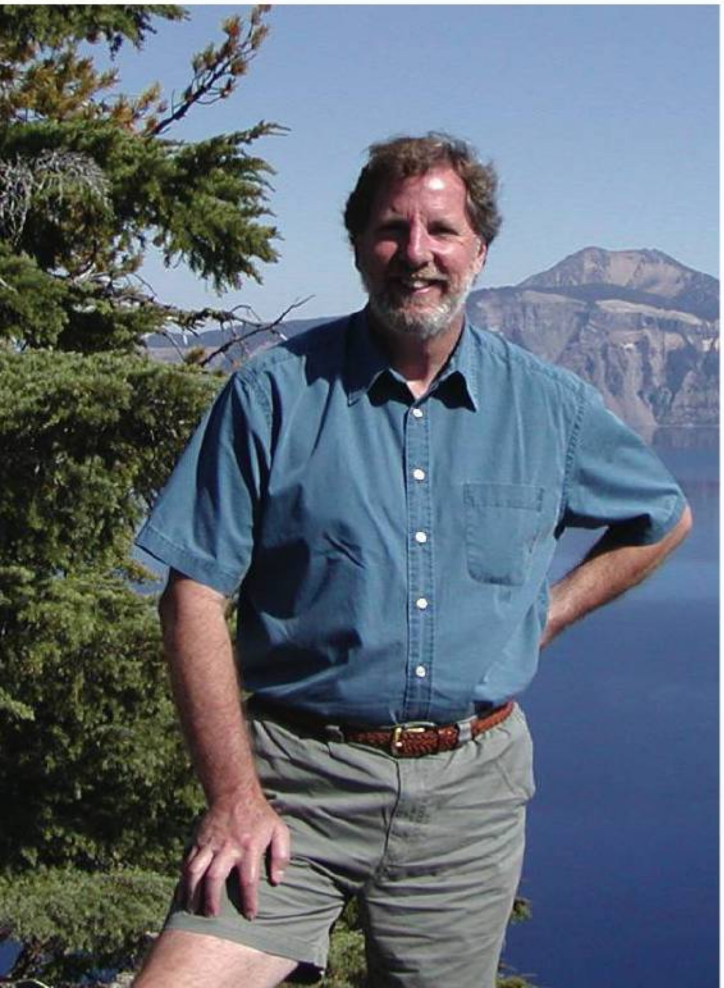
1 2 3 4 5 6 7 8 9 10 CRK 18 17 16 15 14 13

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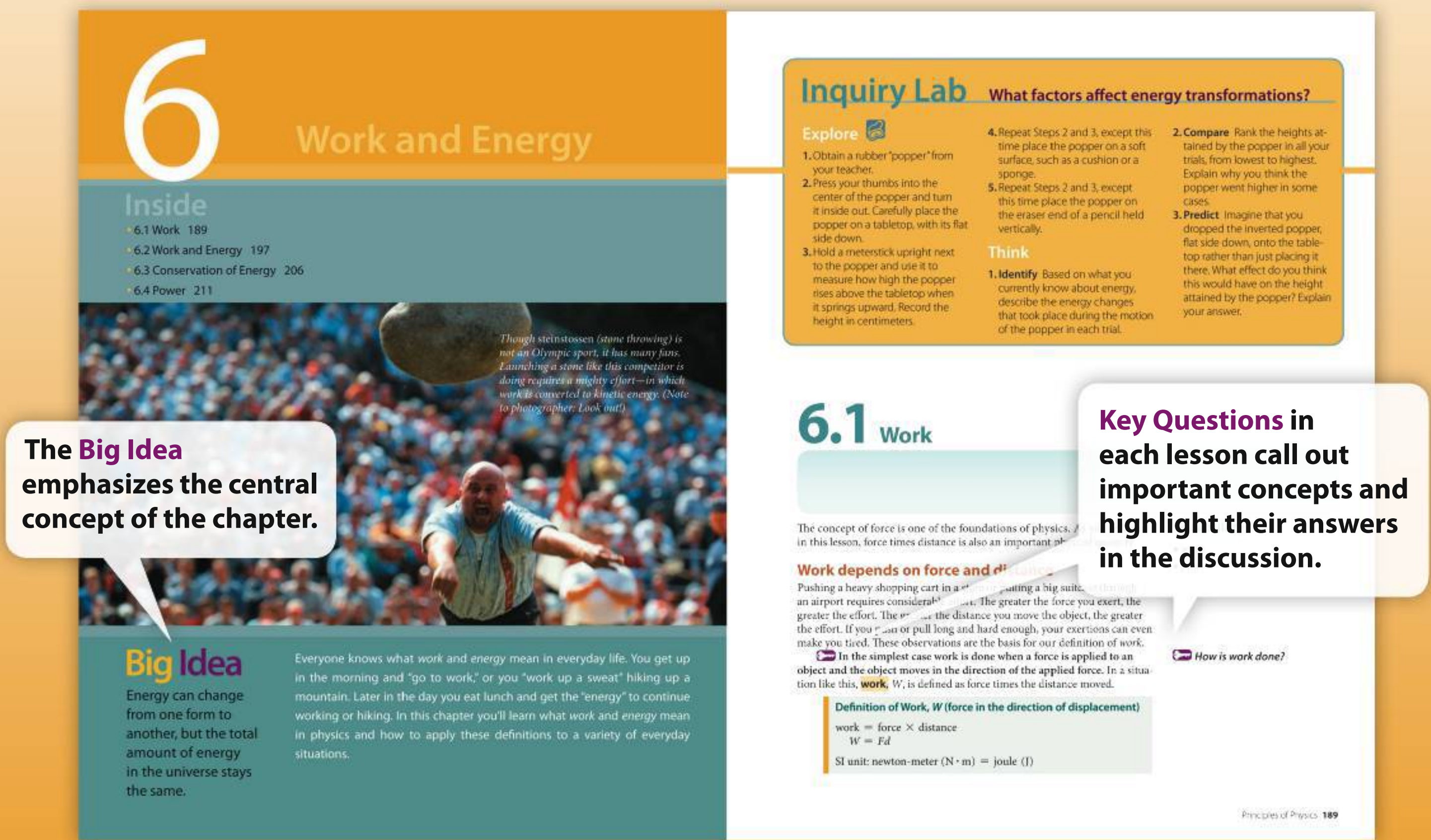
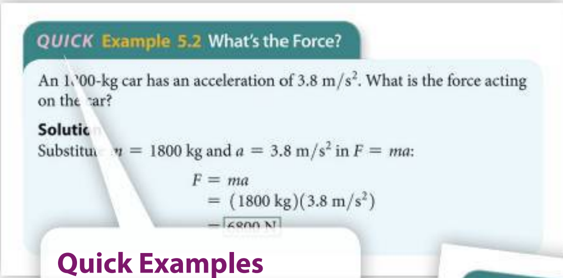
The following pages showcase several key elements of **Pearson Physics** ***that will lead students to success.***



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?

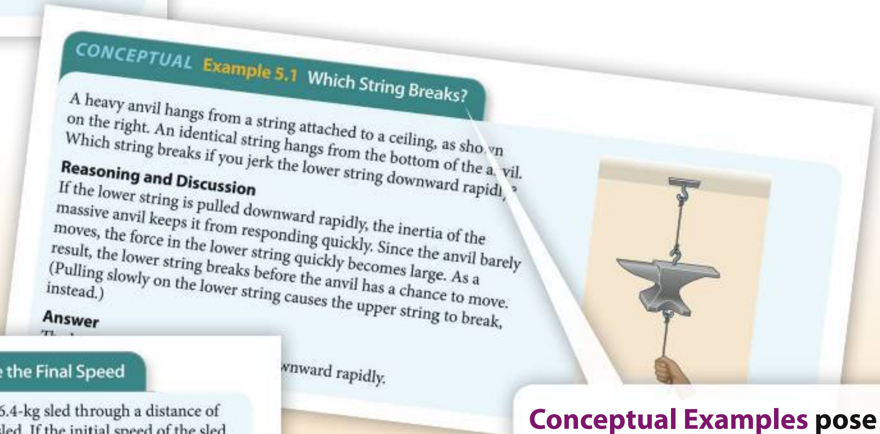
An 1‚00-kg car has an acceleration of 3.8 m/s². What is the force acting on the car?

Solution

Substitute $m = 1800$ kg and $a = 3.8\ \mathrm{m/s^2}$ in $F = ma$:

$$F = ma = (1800\ \mathrm{kg})(3.8\ \mathrm{m/s^2}) = \boxed{6800\ \mathrm{N}}$$

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?

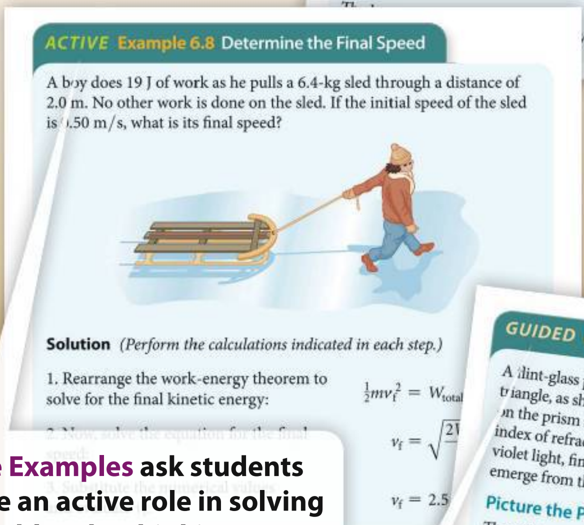
Reasoning and Discussion

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

...wnward rapidly.

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

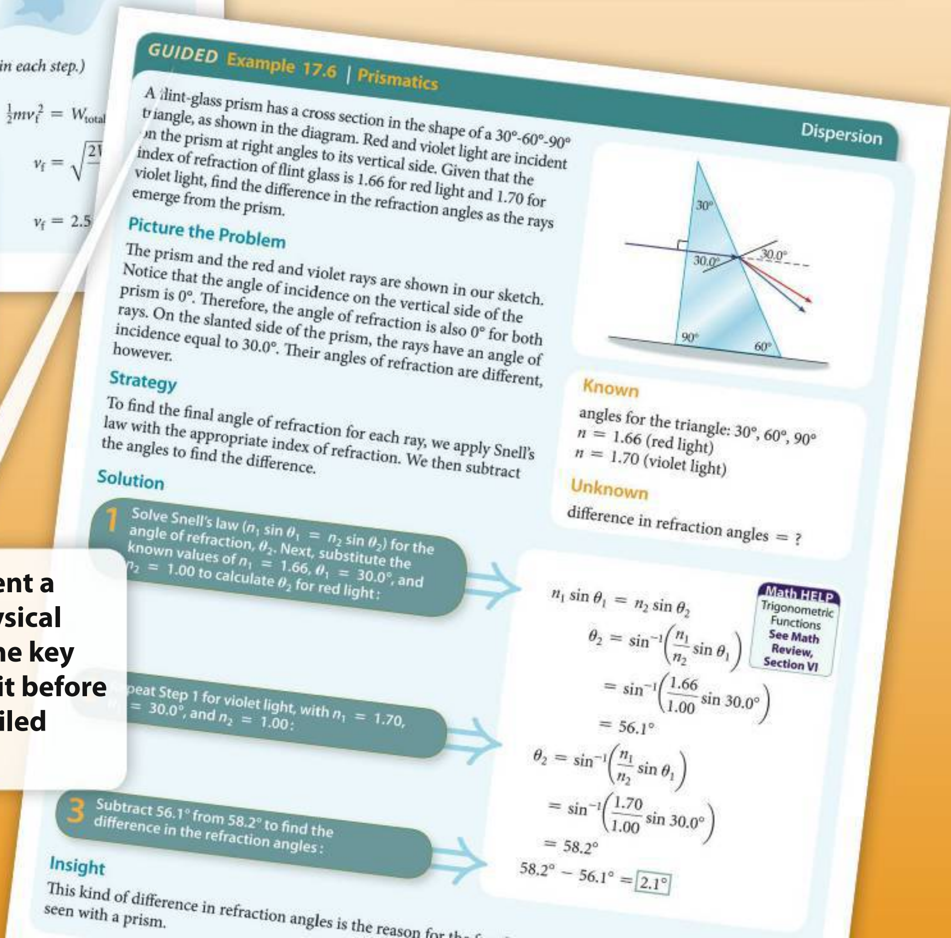

ACTIVE Example 6.8 Determine the Final Speed

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

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 on the vertical side of the 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, θ_2. Next, substitute the known values of $n_1 = 1.66$, $\theta_1 = 30.0°$, and $n_2 = 1.00$ to calculate θ_2 for red light:

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

Math HELP Trigonometric Functions See Math Review, Section VI

2 Repeat Step 1 for violet light, with $n_1 = 1.70$, $\theta_1 = 30.0°$, 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:

$$58.2° - 56.1° = \boxed{2.1°}$$

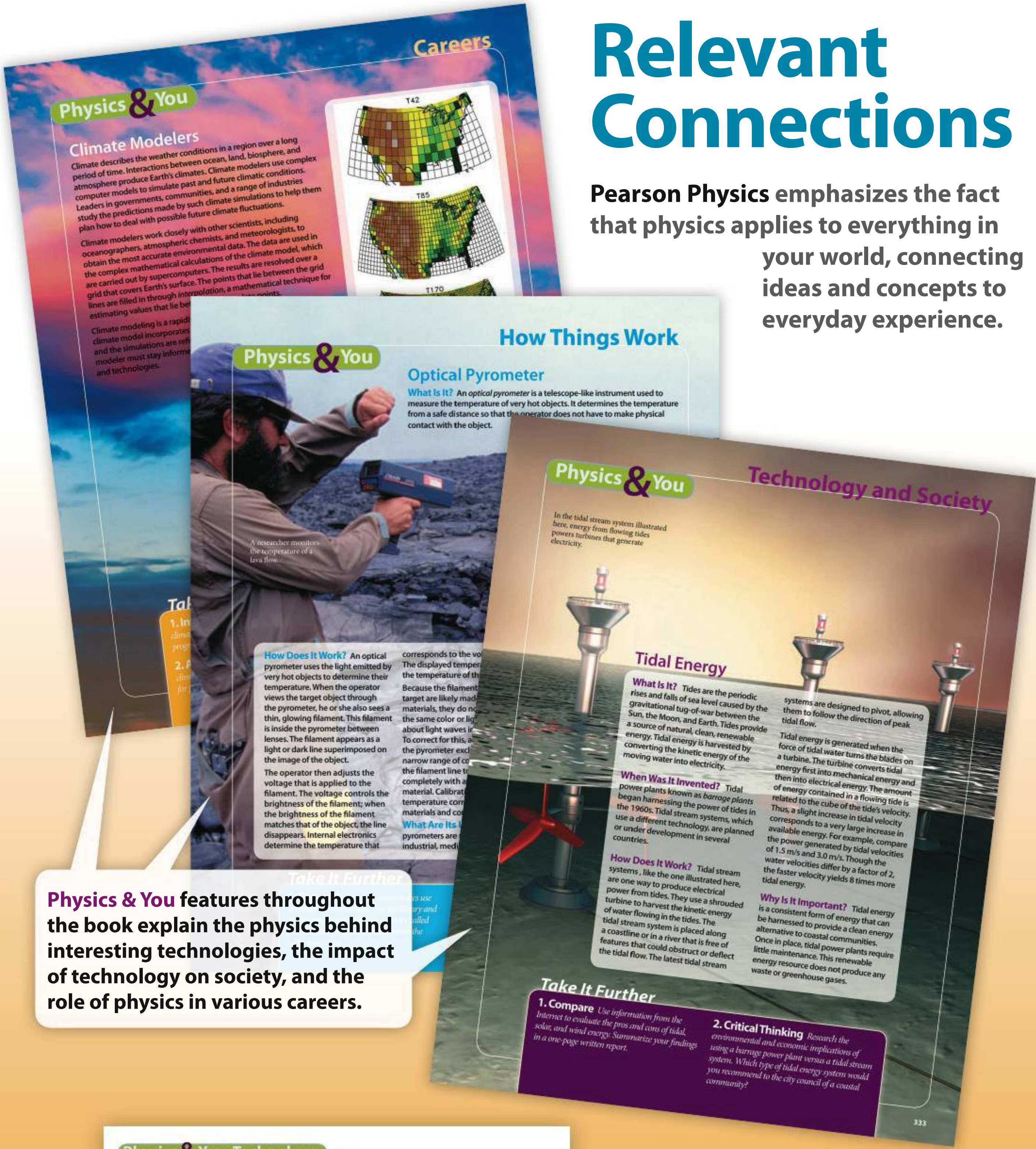
Insight

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

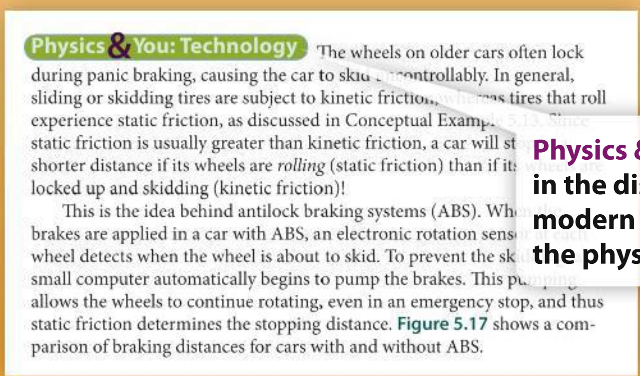
Guided Examples present a visual model of the physical situation and outline the key concepts that apply to it before proceeding to the detailed step-by-step solution.

Relevant Connections

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



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 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 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.

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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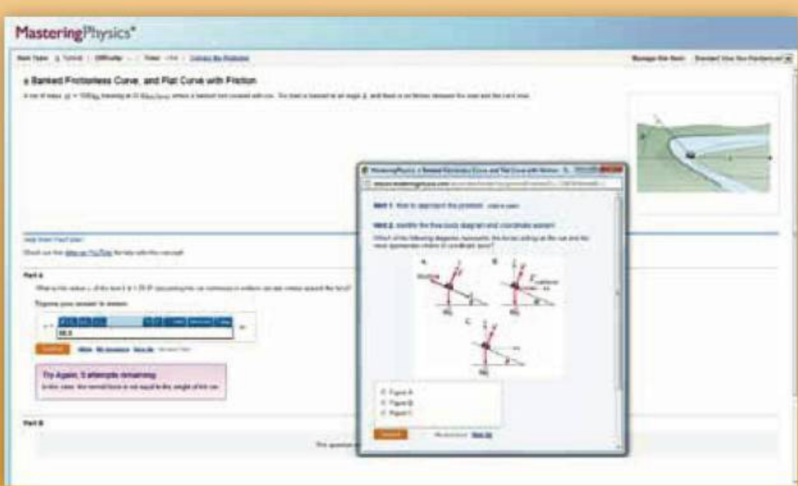
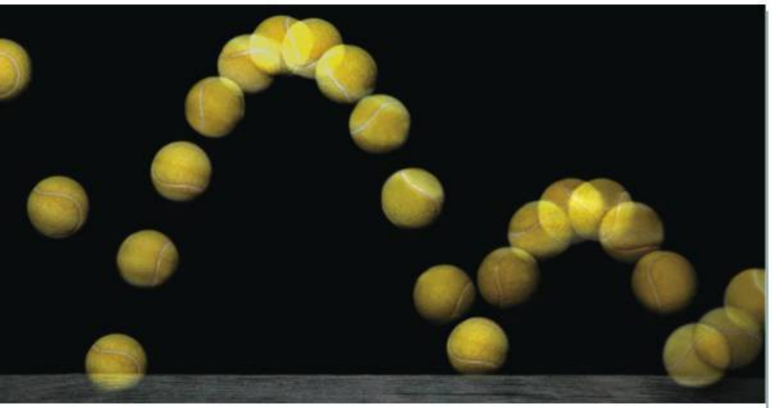
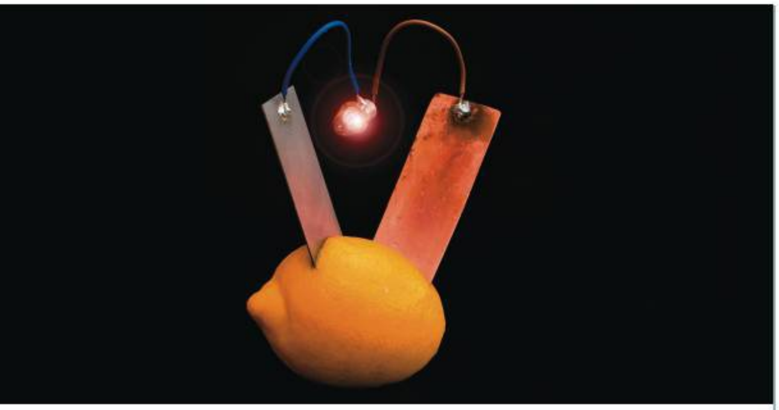


Contents





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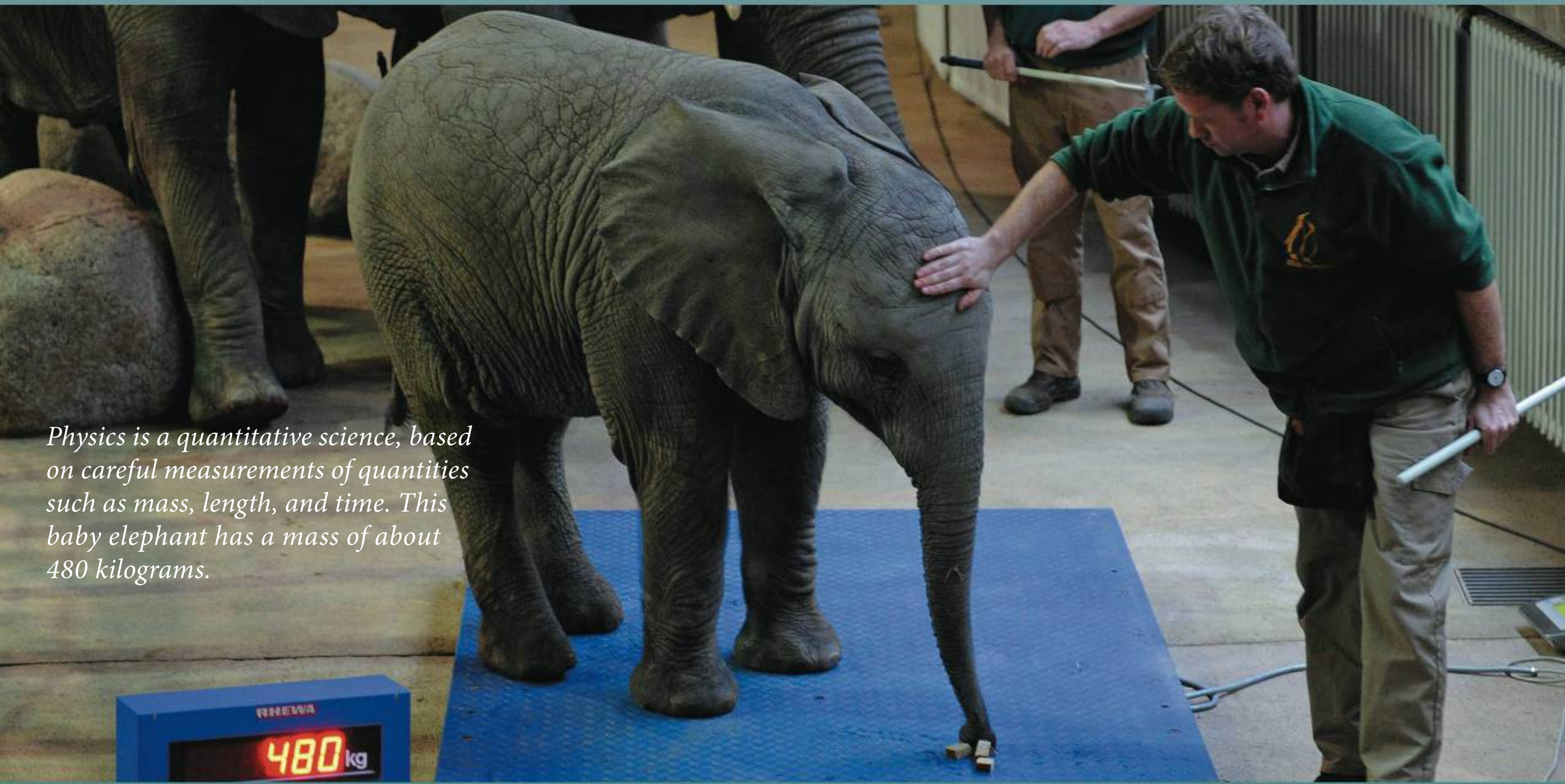
1 Introduction to Physics

Inside



Physics is a quantitative science, based on careful measurements of quantities such as mass, length, and time. This baby elephant has a mass of about 480 kilograms.

Big Idea

Physics applies to everything.

The goal of physics is to gain a deeper understanding of the world in which we live. In fact, everything in nature—from atoms and subatomic particles to solar systems and galaxies—obeys the laws of physics. Everything!

We begin our study of physics with a few fundamental topics. These topics provide a basic language of physics that describes its units, measurements, equations, and logical thinking. This language is used throughout the book and can be applied to any science you study. With this in mind, let's start on a wonderful journey of discovery into physics.

Inquiry Lab How well do you give directions?

Explore

1. Sit back to back with a partner. One person (the narrator) should have a picture, and the other person (the recorder) should have a blank sheet of paper and a pencil. Do not let the recorder see the picture.
2. The recorder draws a picture on the paper based on the narrator's description.
3. When the drawing is complete, compare it with the original picture.
4. Use another picture and switch places with your partner. Repeat Steps 1–3.

Think

1. **Evaluate** On a scale of 1 (worst) to 10 (best), how would you rate the accuracy of each drawing? Was the second drawing better than the first? If so, explain the changes you made that led to a better result.
2. **Recommend** How can you improve your results? What type of information is needed in order to draw an accurate picture?
3. **Apply** Imagine trying to find a treasure buried in a field. Given a starting point, what do you need to know in order to locate the treasure?

1.1 Physics and the Scientific Method

What Is Physics?

Physicists want to know how things work. They observe nature and figure out the rules—or laws—that govern its operation. This basic curiosity is at the heart of all the advances made in physics over the centuries.

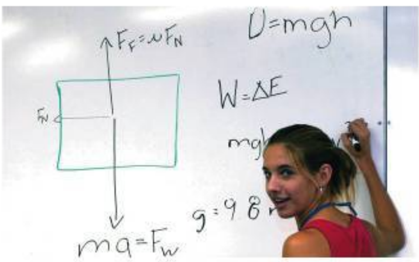
Physics studies the laws of nature

Physics is the study of the fundamental laws of nature. Physicists have found that these laws can be expressed in terms of mathematical equations. As a result, it is possible to compare the predictions of theories with the observations of experiments. Physics, then, is rooted equally in theory and experiment, as indicated in **Figure 1.1**. As physicists make new observations, they constantly test and—if necessary—refine the present theories.

Creativity plays an important role in interpreting nature, and in finding ways to solve problems. Physics helps develop creative, logical, and consistent ways of thinking. Because of these attributes, people who study physics go on to careers in many interesting fields.

Vocabulary

- physics
- science
- scientific method
- observation
- inference
- hypothesis
- independent variable
- dependent variable
- theory



▶ **Figure 1.1 Physics combines theory and experiment**
(a) A physics theory is expressed in terms of mathematical equations. The equations give predictions that can be tested with experiments. **(b)** Careful experiments are required to verify a physics theory.

Visual Summary

The Major Principles of Physics

What makes physics particularly fascinating is that it applies to all of nature. Physics shows that the complexity and variety in the world around us, and in the universe as a whole, are manifestations of just a few fundamental laws and principles. The fact that we can discover and apply these basic laws of nature is both astounding and exhilarating.

The snowboarder featured here illustrates several important principles, including Newton's laws of motion, energy, and momentum. Several important physics principles are described in this Visual Summary.

These men accelerate the bobsled before jumping on board.

Force, Acceleration, and Motion

Motion does not require a force. A force is needed to cause a change in motion, however. The connection between a force and the resulting change in motion is given by Newton's laws of motion.
Chapter 5

The pole-vaulter is propelled upward by energy stored in the bent pole.

Energy and Energy Conservation

The concept of energy is a surprisingly recent addition to physics. In fact, Galileo and Newton knew nothing about energy. Energy was difficult to discover because it can't be seen or touched, and because it takes so many different forms. Nevertheless, energy is of central importance to modern society. In fact, the total energy of the universe always stays the same—it is conserved.
Chapter 6

The momentum of the cue ball is used to "break" the other balls apart.

Momentum and Momentum Conservation

When Newton wrote his laws of motion, he expressed them in terms of an object's mass times its velocity — a quantity known as momentum. Momentum has been of central importance in physics ever since. The total momentum of the universe is conserved, just like the total energy.
Chapter 7

Hot exhaust gases increase the disorder, or entropy, of the universe.

Entropy and Thermodynamics

Physicists studying heat engines discovered a new physical quantity — entropy. The future of the universe is shaped by the fact that the total entropy can only increase.
Chapter 11

Lightning strikes transfer large amounts of electric charge.

This image of a fly was made using a beam of electrons, not with light.

Electricity and Magnetism

Electricity and magnetism at first seem quite unrelated. Physicists have discovered, however, that they are actually different aspects of the same physical force. The discovery of electromagnetism paved the way for much of our modern technology, including electronics and telecommunications.
Chapters 19–23

Waves and Particles

We usually think of waves (like a water wave or a sound wave) as being completely different from particles (like a baseball or a billiard ball). Modern physics has shown that they are not so different after all. We now know that waves have particle-like properties, and particles have wave-like properties. This insight forms the basis of quantum physics.
Chapter 24

▲ Positron emission tomography (PET) scans of the inside of the human body are used by doctors when making diagnoses.

What Is Science?

Physics is one of many natural sciences. Others include chemistry, biology, and geology. These disciplines study different aspects of nature, but they all share certain key characteristics that define a science.

Science is a way of understanding nature

Science is an organized way of thinking about nature and understanding how it works. Thus, science is a process—it is not a thing or an object. Science provides a method for gaining knowledge and increasing our understanding of the natural world. Science is never applied to supernatural phenomena of any kind.

Science is constantly evolving and developing. In fact, some subjects of research, like positron-emission tomography, didn't even exist a short time ago. Even well-established disciplines like physics continue to grow and change over time. Scientific breakthroughs and revolutions—like the development of quantum physics and the theory of relativity—expand our knowledge of nature. When a scientific revolution occurs, it revises and deepens our previous understanding of nature. It also produces a whole new set of questions that may lead to even more breakthroughs. The progress of science is a fascinating story, and where it will take us next can never be predicted.

Science seeks explanations

It's important to note that science isn't just a collection of facts. Scientists attempt to find explanations for the knowledge that has been gained about natural processes. These explanations provide the basis for a better understanding of nature, as well as a means of predicting the outcomes of future natural events. For example, when a powerful earthquake occurs, scientific knowledge about the behavior of water waves gives scientists the ability to predict areas that are vulnerable to a tsunami—and even when the tsunami will arrive. Predictions like these can save lives and protect property.

The Scientific Method

Have you ever tried to learn a new video game when no one was around and you didn't have a user's manual? You might say to yourself, "I wonder what happens if I push this button?" or "What happens if I move this joystick?" You try the button and the joystick, and you observe what happens on the screen. After a while you begin to learn the "rules" that govern the game—the rules of its make-believe world.

Science is a lot like that, only with science you're trying to learn the rules of the *real world*. There's no user's manual, and no one to tell you all the answers. You have to figure out the rules—the laws of nature—on your own. Of course, the real world is a bit more complicated than a video-game world, but it's a lot more interesting, too.

The **systematic** approach scientists use to learn about the laws of nature is referred to as the **scientific method**. Though each situation is handled a bit differently, the scientific method has certain steps that are always taken when conducting a scientific study. These steps are as follows:

- Observe
- Infer and hypothesize
- Test
- Conclude

Reading Support

Vocabulary Builder

systematic

[sis tuh MAT ik]

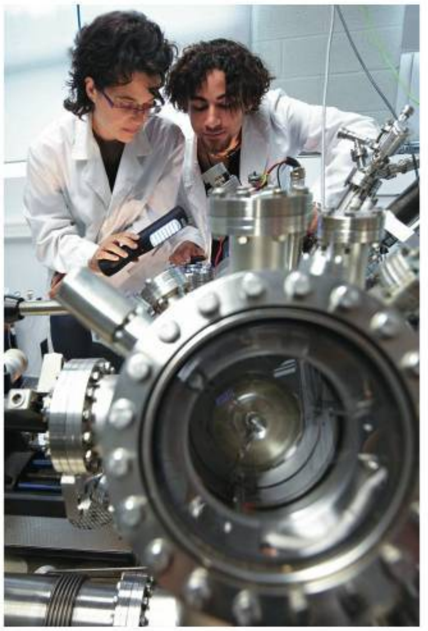
(adjective) acting according to a system, set plan, or method; methodical

The gardener used a systematic approach to rid his yard of weeds.

Science begins with careful observations

The starting point of any scientific investigation is careful **observation**, in which you describe events in a logical and orderly way. For example, you might observe how an object moves. Does it speed up or slow down? Does it move in a straight line or on a curved path? Does it start and stop or move constantly? All of these properties are relevant to a physical description of the motion.

It's also important to be creative in your observations. You may be looking at something that people have looked at a thousand times, but perhaps you see it in a way that no one has thought of before. For example, people had seen apples falling from trees for millennia. They had also seen the Moon in the night sky. What Isaac Newton realized as he observed a falling apple was that the Moon moves in a way that is similar to the apple—both objects fall toward the center of the Earth (see Chapter 9 for details). The simple observation of a falling apple led Newton to a completely new way of thinking about the Moon and the force of gravity.



▲ No matter how simple or complex the laboratory equipment, careful observation is the key to accurate and reproducible experimental results.

Observations lead to inferences and a hypothesis

Thinking about your observations often leads to inferences about what is going on. In general, an **inference** is a logical interpretation of your observations. Your observations combined with your inferences might allow you to develop a hypothesis. A **hypothesis** is a detailed scientific explanation for a set of observations that can be verified or rejected by careful experiments.

Hypotheses are tested with experiments

A useful hypothesis makes predictions that can be tested with experiments. If an experiment verifies a prediction, the hypothesis gains support—though no one experiment can prove a hypothesis to be correct. If an experiment disagrees with a prediction, the hypothesis must be rejected or modified.

This is an important aspect of the scientific method. A hypothesis must be rejected if it disagrees with experiment, even if the hypothesis has agreed with other experiments, and even if the hypothesis is very popular. Scientists must be open-minded, willing to let the results of experiments guide their thinking, even if the results are not what they expected. Significant breakthroughs in science often start off as hypotheses that seem to go against intuition (are counterintuitive). For example, most people thought Galileo was wrong when he said that heavy objects fall at the same rate as light objects. He was right, however, as he knew from his own careful experiments.

Applying the scientific method: a case study

How is the validity of a hypothesis determined?

Figure 1.2 shows the testing of a physics hypothesis about a pendulum, a system that Galileo also studied. (A pendulum is basically a weight that swings back and forth on a string.) Suppose you want a pendulum that takes a specific amount of time to complete one back-and-forth swing. This amount of time is called the *period* of the pendulum, as illustrated in Figure 1.2 (a). Let's see how the scientific method might apply to this case.

Observe the Pendulum Let a pendulum swing back and forth and measure the period. Change the length of the pendulum and repeat the time measurement. What effect does changing the length have on the pendulum?

Form a Hypothesis Observations indicate that a longer pendulum takes more time to swing back and forth, as indicated in Figure 1.2 (b). Thus, we hypothesize that the period of a pendulum increases with increasing length.

Test the Hypothesis Conduct an experiment in which you measure the period of a pendulum for a variety of lengths. The variable you change in the experiment—the length of the pendulum in this case—is called the **independent variable**. The variable you measure to see how it depends on the independent variable is called the **dependent variable**. The period is the dependent variable in this case. Changing only one variable at a time lets you isolate the effect of that change on the system. Record the results of your experiments and then create a graph of period versus length, as in Figure 1.2 (c).

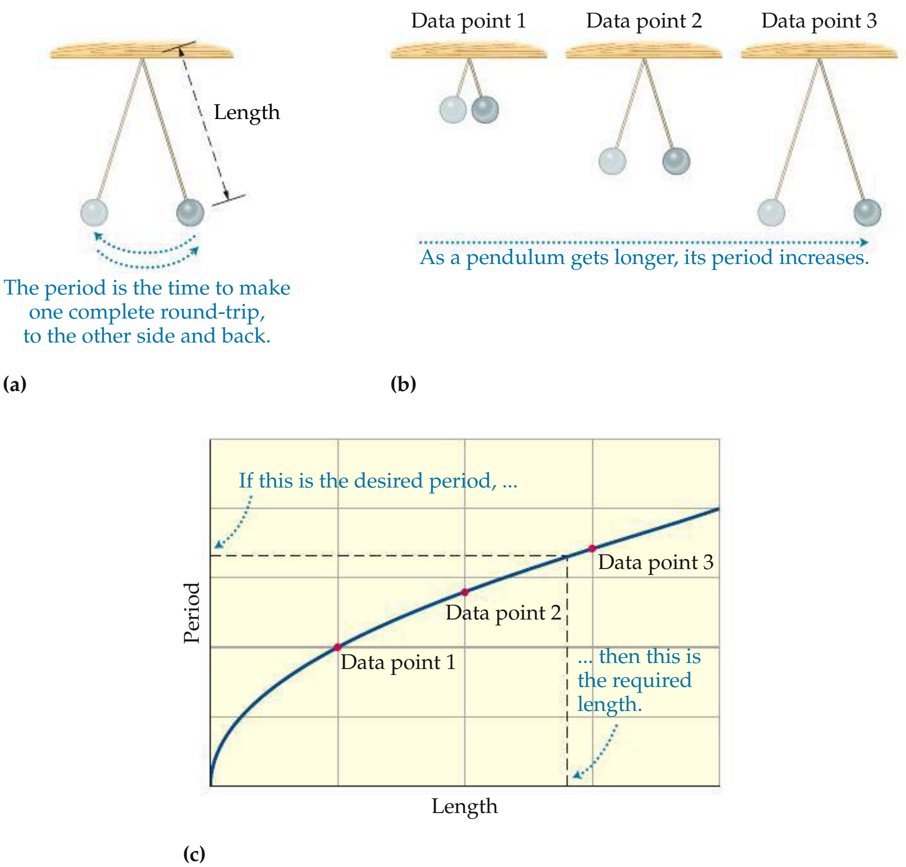


Figure 1.2 Studying a pendulum
(a) A simple pendulum is a weight (bob) that swings back and forth at the end of a string. The length of the pendulum is the length of the string (for a small bob), and its period is the time to complete one round-trip, from one side of its swing to the other side and back to its starting point. **(b)** Observations indicate that the period of a pendulum increases with increasing length. Experiments measure the period for different lengths, yielding data points that can be plotted. **(c)** A graph of period versus length for a simple pendulum. The data points from part (b) are shown, as is a smooth curve that connects the points. (The equation for this curve is given in Chapter 13.) The curve can be used to determine the length required to give a desired period.

Draw a Conclusion The experimental results in Figure 1.2 (c) show that the period of a pendulum does indeed increase with increasing length. (See Chapter 13 for details.) You could use that graph to select the length of the pendulum that has the desired period.

Again, although the precise way to implement the scientific method varies from case to case, the basic elements remain the same:

- Make observations.
- Form inferences and hypotheses.
- Conduct detailed tests of the hypotheses, using experiments.

The validity of a hypothesis is based solely on its ability to account for known observations and to correctly predict new observations.

Well-tested hypotheses lead to theories

A scientific **theory** is a detailed explanation of some aspect of nature that accounts for a set of well-tested hypotheses. For example, Galileo made the hypothesis that falling objects move with constant acceleration. He verified his hypothesis with a variety of experiments. Later, Newton proposed a mathematical theory of gravity that explained why the acceleration of a falling object is constant. His theory also predicted other effects of gravity, like the orbits of planets, moons, and comets. These predictions were verified by later observations. Building up from tested hypotheses to verified theories is the hallmark of the scientific method.

In general, theories are well-supported *explanations* of nature. An example is the theory of gravity, which explains why objects fall with constant acceleration on Earth's surface. On the other hand, laws of nature—like the law of conservation of energy—are well-supported *descriptions* of nature. Laws do not provide explanations, but instead describe specific relationships under given conditions. As you study physics, you will encounter a number of theories and laws.

If new observations disagree with a theory, the theory has to be discarded or revised. It's exciting when this happens, because it usually signals a profound breakthrough in science. It also means that an entirely new area of research, full of things to be discovered, will be opened for exploration.

1.1 LessonCheck

Checking Concepts

1. Explain How do you verify a scientific hypothesis?

2. Describe How are the fundamental laws and principles of physics related to the complexity that we see in nature?

3. Big Idea How do the laws of physics apply to other sciences such as biology, chemistry, and earth science? Give a specific example to show the connection.

Solving Problems

4. Solve Einstein's most famous equation is $E = mc^2$. In this equation, E stands for energy, m stands for mass, and c stands for the speed of light. Use algebra to solve this equation for the mass. That is, complete this equation:

$$m = ?$$

1.2 Physics and Society

Vocabulary

- bias
- peer review

Science is a human endeavor. As such, it is a part of the fabric of human society. Let's take a look at some of the ways science, technology, and physics impact our everyday life.

Science in Modern Society

Modern society runs on developments in science and technology, and more breakthroughs are coming all the time. How should we use these advances for the greatest benefit of society as a whole? This is a question that goes beyond science. It involves economics, practicality, morals, and laws.

Ethics is an important part of science

A scientific discovery gives added insight into nature. It shows how a certain part of nature works. But knowing how something works isn't the same as knowing how best to use that knowledge. That is something scientists, politicians, and an informed public must decide together.

For example, the development of electrical power systems has greatly improved the quality of life for millions of people. This great benefit also comes with a downside, however, because electricity can be deadly if it is not used with proper care. Society makes decisions about how to reduce the dangers and what level of danger is acceptable. It must also consider the advantages and disadvantages of the various ways of producing electricity, such as coal-fired power plants, hydroelectric dams, and nuclear power plants, illustrated in **Figure 1.3**.

In making the decisions that affect society, people need to avoid bias. A **bias** is a preference for a particular point of view for personal rather than logical or scientific reasons. Because scientists are human too, they can be affected by bias as much as politicians, business leaders, and others. If enough of us in the general public are educated about the various aspects of modern science, however, we can see through biases and make informed decisions that benefit all of humanity.

▼ **Figure 1.3 Electric power plants** Electricity can be produced in a number of different ways. The power plants shown here use (from left to right) nuclear energy, the Sun, and water to generate electricity. Each of these methods has benefits and drawbacks.