Many people consider physics to be a difficult science that is far removed from their lives. This may be because many of the world’s most famous physicists study topics such as the structure of the universe or the incredibly small particles within an atom, often using complicated tools to observe and measure what they are studying.

But everything around you can be described by using the tools of physics. The goal of physics is to use a small number of basic concepts, equations, and assumptions to describe the physical world. These physics principles can then be used to make predictions about a broad range of phenomena. For example, the same physics principles that are used to describe the interaction between two planets can be used to describe the motion of a soccer ball moving toward a goal.

Many physicists study the laws of nature simply to satisfy their curiosity about the world we live in. Learning the laws of physics can be rewarding just for its own sake. Also, many of the inventions, appliances, tools, and buildings we live with today are made possible by the application of physics principles. Physics discoveries often turn out to have unexpected practical applications, and advances in technology can in turn lead to new physics discoveries. Figure 1.1 indicates how the areas of physics apply to building and operating a car.

**FIGURE 1.1**
The Physics of Cars: Without knowledge of many of the areas of physics, making cars would be impossible.

Exposure to science, both formal and informal, shapes students’ current views of physics. Students should be encouraged to express their perceptions and attitudes in a brainstorming session. Students need to realize that applied science, which is aimed at creating technology, interacts with basic science, which strives to develop fundamental ideas to explain natural phenomena.

Point out that physics is a very broad field of study that presents an organized way of modeling and interpreting nature. The different areas of basic science specialize in interpreting different aspects of nature (living things, materials, celestial objects, and so forth). Sometimes, the boundaries between these areas are not clear, but the fundamental ideas of physics underlie all basic and applied sciences.

**Differentiated Instruction**

As students work through the chapter, ask them to list terms or words that are used in physics and in their daily lives. For example, terms such as mechanics, optics, speed, vibration, and pendulum could be included in their lists. Encourage students to list each word’s scientific meaning, as well as the more common meaning. Remind students that this type of list will be helpful as they continue with their study of physics.
Physics is everywhere. We are surrounded by principles of physics in our everyday lives. In fact, most people know much more about physics than they realize. For example, when you buy a carton of ice cream at the store and put it in the freezer at home, you do so because from past experience you know enough about the laws of physics to know that the ice cream will melt if you leave it on the counter.

People who design, build, and operate sailboats, such as the ones shown in Figure 1.2, need a working knowledge of the principles of physics. Designers figure out the best shape for the boat’s hull so that it remains stable and floating yet quick-moving and maneuverable. This design requires knowledge of the physics of fluids. Determining the most efficient shapes for the sails and how to arrange them requires an understanding of the science of motion and its causes. Balancing loads in the construction of a sailboat requires knowledge of mechanics. Some of the same physics principles can also explain how the keel keeps the boat moving in one direction even when the wind is from a slightly different direction.

Any problem that deals with temperature, size, motion, position, shape, or color involves physics. Physicists categorize the topics they study in a number of different ways. Figure 1.3 shows some of the major areas of physics that will be described in this book.

**FIGURE 1.3**

<table>
<thead>
<tr>
<th>Name</th>
<th>Subjects</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanics</td>
<td>motion and its causes, interactions between objects</td>
<td>falling objects, friction, weight, spinning objects</td>
</tr>
<tr>
<td>Thermodynamics</td>
<td>heat and temperature</td>
<td>melting and freezing processes, engines, refrigerators</td>
</tr>
<tr>
<td>Vibrations and wave phenomena</td>
<td>specific types of repetitive motions</td>
<td>springs, pendulums, sound</td>
</tr>
<tr>
<td>Optics</td>
<td>light</td>
<td>mirrors, lenses, color, astronomy</td>
</tr>
<tr>
<td>Electromagnetism</td>
<td>electricity, magnetism, and light</td>
<td>electrical charge, circuitry, permanent magnets, electromagnets</td>
</tr>
<tr>
<td>Relativity</td>
<td>particles moving at any speed, including very high speeds</td>
<td>particle collisions, particle accelerators, nuclear energy</td>
</tr>
<tr>
<td>Quantum mechanics</td>
<td>behavior of submicroscopic particles</td>
<td>the atom and its parts</td>
</tr>
</tbody>
</table>

**Teaching Tip**

Ask students to list the careers that they are interested in pursuing. Point out how a physics background may contribute to their effectiveness in those careers. Above all, a good understanding of science makes it possible to critically examine scientific theories and make educated decisions about science-related issues facing our society.

**ENGLISH LEARNERS**

Explain that the words *mechanic* and *mechanics* can have different meanings, depending on the context. The word *mechanic* is used for a skilled person who repairs and maintains machines. The plural of *mechanic* is *mechanics*. However, the term *mechanics* is also used to mean a branch of physics that deals with objects in motion and the forces that cause and change motion.
The Scientific Method

When scientists look at the world, they see a network of rules and relationships that determine what will happen in a given situation. Everything you will study in this course was learned because someone looked out at the world and asked questions about how things work.

There is no single procedure that scientists follow in their work. However, there are certain steps common to all good scientific investigations. These steps, called the scientific method, are summarized in Figure 1.4. This simple chart is easy to understand; but, in reality, most scientific work is not so easily separated. Sometimes, exploratory experiments are performed as a part of the first step in order to generate observations that can lead to a focused question. A revised hypothesis may require more experiments.

Physics uses models that describe phenomena.

Although the physical world is very complex, physicists often use models to explain the most fundamental features of various phenomena. Physics has developed powerful models that have been very successful in describing nature. Many of the models currently used in physics are mathematical models. Simple models are usually developed first. It is often easier to study and model parts of a system or phenomenon one at a time. These simple models can then be synthesized into more-comprehensive models.

When developing a model, physicists must decide which parts of the phenomenon are relevant and which parts can be disregarded. For example, let’s say you wish to study the motion of the ball shown in Figure 1.5. Many observations can be made about the situation,
including the ball’s surroundings, size, spin, weight, color, time in the air, speed, and sound when hitting the ground. The first step toward simplifying this complicated situation is to decide what to study, that is, to define the system. Typically, a single object and the items that immediately affect it are the focus of attention. For instance, suppose you decide to study the ball’s motion in the air (before it potentially reaches any of the other players), as shown in Figure 1.6. To study this situation, you can eliminate everything except information that affects the ball’s motion.

**system** a set of particles or interacting components considered to be a distinct physical entity for the purpose of study

You can disregard characteristics of the ball that have little or no effect on its motion, such as the ball’s color. In some studies of motion, even the ball’s spin and size are disregarded, and the change in the position of the ball will be the only quantity investigated.

In effect, the physicist studies the motion of a ball by first creating a simple model of the ball and its motion. Unlike the real ball, the model object is isolated; it has no color, spin, or size, and it makes no noise on impact. Frequently, a model can be summarized with a diagram. Another way to summarize these models is to build a computer simulation or small-scale replica of the situation.

Without models to simplify matters, situations such as building a car or sailing a boat would be too complex to study. For instance, analyzing the motion of a sailboat is made easier by imagining that the push on the boat from the wind is steady and consistent. The boat is also treated as an object with a certain mass being pushed through the water. In other words, the color of the boat, the model of the boat, and the details of its shape are left out of the analysis. Furthermore, the water the boat moves through is treated as if it were a perfectly smooth-flowing liquid with no internal friction. In spite of these simplifications, the analysis can still make useful predictions of how the sailboat will move.

**FIGURE 1.6** Ask students to compare the photograph in Figure 1.6 with the photograph in Figure 1.5. Point out the details relevant to the study of the ball’s motion: the direction that the ball was thrown; the forces on the ball; the ball’s spin; the ball’s location at every instant; the ball’s shape, size, and mass; and the air surrounding the ball.

**Ask** Draw a diagram of the ball’s motion. Which details mentioned above did you ignore in your diagram for the purpose of simplification?

**Answer**: Size, spin, and air resistance normally affect the ball’s flight. However, as a first approximation, this study focuses on the trajectory of a model ball and assumes that the effects of air resistance and spin are negligible. Most diagrams will probably just show the ball and its path.

**TEACH FROM VISUALS**

Have students choose a simple system and construct a model of it. Allow different types of learners to use different modeling methods. For example, visual learners could draw a diagram, while kinesthetic learners could construct a mechanical model.
Galileo’s Thought Experiment

If heavier objects fell faster than slower ones, would two bricks of different masses tied together fall slower (b) or faster (c) than the heavy brick alone (a)? Because of this contradiction, Galileo hypothesized instead that all objects fall at the same rate, as in (d).

Models can help build hypotheses.

A scientific hypothesis is a reasonable explanation for observations—one that can be tested with additional experiments. The process of simplifying and modeling a situation can help you determine the relevant variables and identify a hypothesis for testing.

Consider the example of Galileo’s “thought experiment,” in which he modeled the behavior of falling objects in order to develop a hypothesis about how objects fell. At the time Galileo published his work on falling objects, in 1638, scientists believed that a heavy object would fall faster than a lighter object.

Galileo imagined two objects of different masses tied together and released at the same time from the same height, such as the two bricks of different masses shown in Figure 1.7. Suppose that the heavier brick falls faster than the lighter brick when they are separate, as in (a). When tied together, the heavier brick will speed up the fall of the lighter brick somewhat, and the lighter brick will slow the fall of the heavier brick somewhat. Thus, the tied bricks should fall at a rate in between that of either brick alone, as in (b).

However, the two bricks together have a greater mass than the heavier brick alone. For this reason, the tied bricks should fall faster than the heavier brick, as in (c). Galileo used this logical contradiction to refute the idea that different masses fall at different rates. He hypothesized instead that all objects fall at the same rate in the absence of air resistance, as in (d).

Models help guide experimental design.

Galileo performed many experiments to test his hypothesis. To be certain he was observing differences due to weight, he kept all other variables the same: the objects he tested had the same size (but different weights) and were measured falling from the same point.

The measuring devices at that time were not precise enough to measure the motion of objects falling in air. So, Galileo used the motion of a ball rolling down a ramp as a model of the motion of a falling ball.

**Differentiated Instruction**

**PRE-AP**

Have students research and identify scientific models that are no longer accepted by scientists. For example, models of the atom have been repeatedly revised since the concept of the atom was introduced by the Greek scientist Democritus in 460 BCE.

**Teach continued**

**GALILEO’S HYPOTHESIS**

**Purpose** Illustrate the arguments for and against Galileo’s thought experiment.

**Materials** pennies; tape; coffee filters; clear, deep container; water

**Procedure** Stack 10 pennies and tape them together. Hold one penny in one hand and hold the stack of pennies in the other hand; drop them simultaneously. Tell students to listen carefully and decide which object hits the ground first. It should be difficult to detect any difference in falling time.

Hold one coffee filter in one hand and a stack of 10 filters in the other hand; drop them simultaneously. This time, it should be easy to see that 10 filters fall faster than one. How could Galileo defend his hypothesis in the face of such evidence? He identified the role of air resistance.

Fill the clear container with water and drop the single penny and the 10-penny stack into the water simultaneously. This time, the single penny will land on the bottom last. Have students use these experiments to defend or criticize the argument that heavy bodies fall faster than lighter bodies.
The steeper the ramp, the closer the model came to representing a falling object. These ramp experiments provided data that matched the predictions Galileo made in his hypothesis.

Like Galileo’s hypothesis, any hypothesis must be tested in a controlled experiment. In an experiment to test a hypothesis, you must change one variable at a time to determine what influences the phenomenon you are observing. Galileo performed a series of experiments using balls of different weights on one ramp before determining the time they took to roll down a steeper ramp.

**The best physics models can make predictions in new situations.**

Until the invention of the air pump, it was not possible to perform direct tests of Galileo’s model by observing objects falling in the absence of air resistance. But even though it was not completely testable, Galileo’s model was used to make reasonably accurate predictions about the motion of many objects, from raindrops to boulders (even though they all experience air resistance).

Even if some experiments produce results that support a certain model, at any time another experiment may produce results that do not support the model. When this occurs, scientists repeat the experiment until they are sure that the results are not in error. If the unexpected results are confirmed, the model must be abandoned or revised. That is why the last step of the scientific method is so important. A conclusion is valid only if it can be verified by other people.

**Did YOU Know?**

In addition to conducting experiments to test their hypotheses, scientists also research the work of other scientists. The steps of this type of research include:
- identifying reliable sources
- searching the sources to find references
- checking for opposing views
- documenting sources
- presenting findings to other scientists for review and discussion

**SECTION 1 FORMATIVE ASSESSMENT**

1. Name the major areas of physics.
2. Identify the area of physics that is most relevant to each of the following situations. Explain your reasoning.
   - a. a high school football game
   - b. food preparation for the prom
   - c. playing in the school band
   - d. lightning in a thunderstorm
   - e. wearing a pair of sunglasses outside in the sun
3. What are the activities involved in the scientific method?
4. Give two examples of ways that physicists model the physical world.

**Critical Thinking**

5. Identify the area of physics involved in each of the following tests of a lightweight metal alloy proposed for use in sailboat hulls:
   - a. testing the effects of a collision on the alloy
   - b. testing the effects of extreme heat and cold on the alloy
   - c. testing whether the alloy can affect a magnetic compass needle

**Assessed and Reteach**

**Assess** Use the Formative Assessment on this page to evaluate student mastery of the section.

**Reteach** For students who need additional instruction, download the Section Study Guide.

**Response to Intervention** To reassign students’ mastery, use the Section Quiz, available to print or to take directly online at HMDScience.com.

**Misconception Alert!**

Point out that even when the results of an inquiry appear convincing, the conclusions must be formulated carefully by specifying the circumstances under which the experiment was performed and the reasoning that led to accepting or refuting the evidence. Ask students which variable was manipulated when vacuum pumps made it possible to test Galileo’s hypothesis.

**Air resistance.**

**Answers to Section Assessment**

1. mechanics, thermodynamics, vibrations and wave phenomena, optics, electromagnetism, relativity, and quantum mechanics
2. a. mechanics; because the ball is a moving, spinning object
   - b. thermodynamics; because cooking concerns changes in temperature
   - c. vibrations and wave phenomena; because music is a type of sound
   - d. electromagnetism; because lightning is a form of electricity
   - e. optics; because the lenses decrease the light intensity that reaches your eye
3. observing and collecting data, formulating and testing hypotheses, interpreting results and revising the hypothesis, stating conclusions
4. Answers could include diagrams, equations, and computer simulations.
5. a. mechanics
   - b. thermodynamics
   - c. electromagnetism