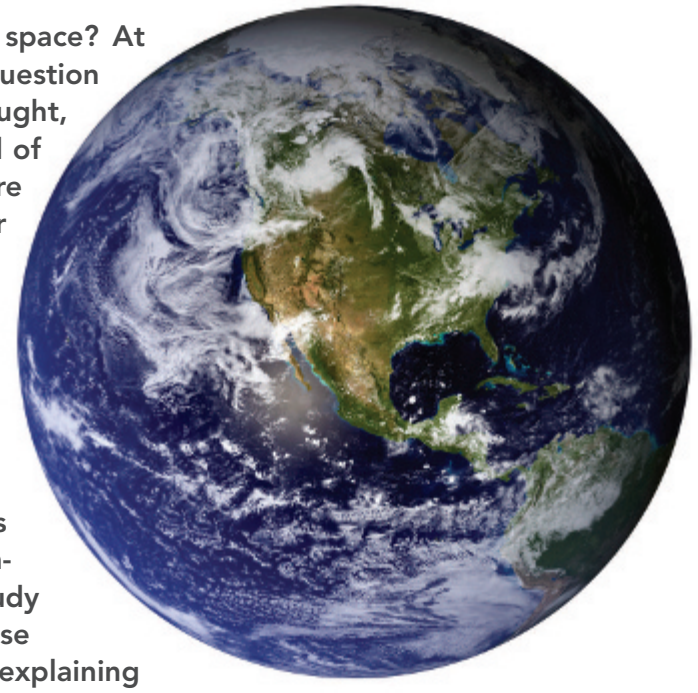
1 ABOUT SCIENCE

THE BIG IDEA Science is the study of nature's rules.



What would it be like to live in outer space? At first thought, we might think this question is for astronauts. But on second thought, we realize this question is for everybody, for all of us are in outer space. At every moment we are riding on planet Earth, which has been in outer space for billions of years, hurtling completely out of human control in orbit around the sun. Although more than 130 objects beyond our solar system have recently been found, our small life-supporting planet is special to us—it is our home.

We can't control Earth's motion, but we have learned the rules by which it moves—rules that were painstakingly discovered by investigators throughout much of human history. The study of nature's rules is what this book is about. These rules in physics are surprisingly few in number, explaining such things as why Earth is round, why its rainbows are colorful arcs, and why skies are blue and sunsets are red. Understanding nature's rules adds richness to the way we see our world.

discover!

What is the Relationship Among Art, Science, and Technology?

1. Carefully place a drop of water on a television screen or computer monitor.
2. Look at the screen through the droplet.
3. How close to the screen must you be to see individual dots without looking through the droplet?
4. Use a magnifying glass to examine a color image in a newspaper.

Analyze and Conclude

1. **Observing** How are the color images you see on television and computer monitors, in newspapers, and in Pointillist paintings produced?
2. **Predicting** How do you suppose the images on outdoor electronic displays are produced?
3. **Making Generalizations** How do art, science, and technology converge to bring us the color images that are so much a part of our daily lives?

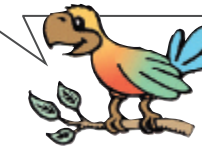
1.1 The Basic Science—Physics

Much of science today is what used to be called *natural philosophy*. Natural philosophy was the study of unanswered questions about nature. As the answers were found, they became part of what is now called science.

The study of science today branches into the study of living things and nonliving things—the life sciences and the physical sciences. The life sciences branch into areas such as biology, zoology, and botany. The physical sciences branch into areas such as geology, astronomy, chemistry, and physics.

Physics is more than a part of the physical sciences, it is the most basic of all the sciences. ☑ **Physics is about the nature of basic things such as motion, forces, energy, matter, heat, sound, light, and the composition of atoms.** Chemistry is about how matter is put together, how atoms combine to form molecules, and how the molecules combine to make up the many kinds of matter around us. Biology is still more complex and involves matter that is alive. So physics supports chemistry, which in turn supports biology. The ideas of physics are fundamental to these more complicated sciences. That's why physics is the most basic science. You can understand other sciences much better if you first understand physics. This book presents physics conceptually so that you can enjoy understanding it.

Most new discoveries occur where science fields overlap—in biochemistry and biophysics, for example. Study more than one field of science!



CONCEPT CHECK What is physics about?

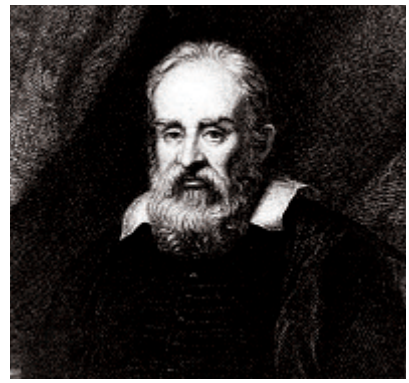
1.2 Mathematics—The Language of Science

Science was transformed in the 1600s when it was learned that nature can be analyzed, modeled, and described mathematically. When the ideas of science are expressed in mathematical terms, they are unambiguous. The equations of science provide compact expressions of relationships between concepts. Physics equations are guides to thinking! They don't have the double meanings that so often confuse the discussion of ideas expressed in common language. ☑ **When scientific findings in nature are expressed mathematically, they are easier to verify or disprove by experiment.**[1.2] The methods of mathematics and experimentation have led to enormous successes in science.

The superscript 1.2 refers to a note to the text. Notes are listed in Appendix G, which begins on page 891.

CONCEPT CHECK Why is mathematics the language of science?

FIGURE 1.1 ▶
The scientific method is often credited to **a.** Galileo Galilei and **b.** Francis Bacon.



a

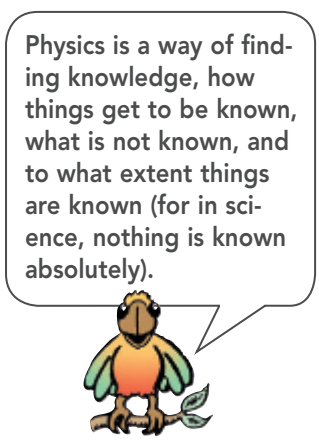
b

1.3 Scientific Methods

The Italian physicist Galileo Galilei (1564–1642) and the English philosopher Francis Bacon (1561–1626), shown in Figure 1.1, are usually credited as the founders of the scientific method. **Scientific methods** are extremely effective in gaining, organizing, and applying new knowledge. **Scientific methods generally include some, if not all, of the following:**

1. **Recognize a problem.**
2. **Make an educated guess—a hypothesis—about the answer.**
3. **Predict the consequences of the hypothesis.**
4. **Perform experiments to test predictions.**
5. **Formulate the simplest general rule that organizes the main ingredients: hypothesis, prediction, and experimental outcome.**

Although this method is popular, it is not the universal key to discoveries and advances in science. Trial and error, experimentation without guessing, and accidental discovery account for much of the progress in science. The success of science has more to do with an attitude common to scientists than with a particular method. This attitude is one of inquiry, experimentation, and humility.



CONCEPT CHECK **What are the steps of a scientific method?**

1.4 The Scientific Attitude

In science, a **fact** is a close agreement by competent observers who make a series of observations of the same phenomenon. A scientific **hypothesis** is an educated guess that is not fully accepted until demonstrated by experiment. When hypotheses about the relationship among natural quantities are tested over and over again and not contradicted, they may become **laws** or **principles.**

If a scientist finds evidence that contradicts a hypothesis, law, or principle, then the hypothesis, law, or principle must be changed or abandoned. A scientist must be prepared to change or abandon an idea. The Greek philosopher Aristotle (384–322 B.C.) claimed that an object twice as heavy as another falls twice as fast. This false idea was held to be true for nearly 2000 years because of Aristotle's authority. In modern science, however, a single verifiable experiment to the contrary outweighs any authority, regardless of reputation.

Scientists must accept their findings even when they would like them to be different. They must distinguish between what they see and what they wish to see. Scientists, like most people, have a vast capacity for fooling themselves.[1.4] People have always tended to adopt and retain general rules, ideas, and hypotheses without thoroughly questioning their validity, even after they have been shown to be false. Most often when an idea is adopted, particular attention is given to cases that seem to support it, while cases that seem to refute it are distorted, belittled, or ignored.

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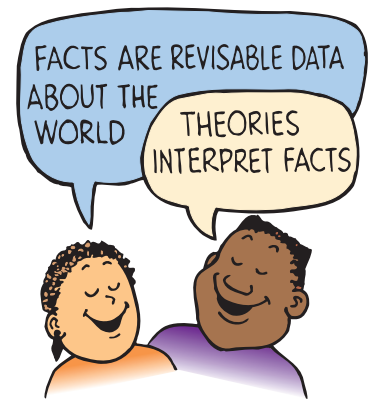


Scientific Theories Scientists use the word *theory* differently from the way it is used in everyday speech. In everyday speech, a theory is the same as a hypothesis—a supposition that has not been verified. A scientific **theory,** on the other hand, is a synthesis of a large body of information that encompasses well-tested and verified hypotheses about certain aspects of the natural world. For example, physicists speak of atomic theory; biologists speak of cell theory.

The theories of science are not fixed, but rather they evolve as they go through stages of redefinition and refinement. During the past hundred years, the theory of the atom has been refined as new evidence was gathered. Similarly, biologists have refined the cell theory.

The refinement of theories is a strength of science, not a weakness. Competent scientists must be experts at changing their minds when confronted with solid experimental evidence to the contrary of a theory, or when a conceptually simpler hypothesis forces them to a new point of view. More important than defending beliefs is improving upon them. Better hypotheses are made by those who are honest in the face of experimental evidence.

The scientific attitude accompanies a search for order, for uniformities, and for lawful relations among the events of nature. These enable us to make predictions. By better understanding nature, we can better control our destinies.

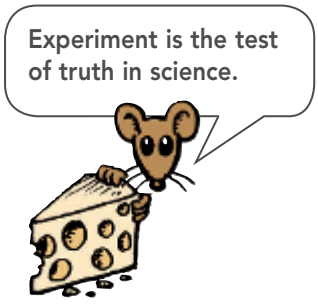
CONCEPT CHECK **When must a hypothesis, law, or principle be changed or abandoned?**

1.5 Scientific Hypotheses

FIGURE 1.2 ▲
Experiments are conducted to test scientific hypotheses.

Before a hypothesis can be classified as scientific, it must link to a general understanding of nature and conform to a cardinal rule. The rule is that the hypothesis must be testable. It is more important that there be a way of proving a hypothesis *wrong* than there be a way of proving it correct. At first this may seem strange, for usually we concern ourselves with verifying that something is true. Scientific hypotheses are different. **To determine whether a hypothesis is scientific or not, look to see if there is a test for proving it wrong.** If there is no test for its possible wrongness, then it is not scientific. Albert Einstein put it well when he stated, "No number of experiments can prove me right; a single experiment can prove me wrong."

Consider the hypothesis "The alignment of planets in the sky determines the best time for making decisions." Many people believe it, but this hypothesis is not scientific. It cannot be proven wrong, nor can it be proven right. It is *speculation.* Likewise, the hypothesis "Intelligent life exists on other planets somewhere in the universe" is not scientific. Although it can be proven correct by the verification of a single instance of intelligent life existing elsewhere in the universe, there is no way to prove it wrong if no life is ever found. If we searched the far reaches of the universe for eons and found no life, we would not prove that it doesn't exist "around the next corner." The hypothesis "Most people stop for red lights" is also outside of science, but for a different reason. Although it can easily be tested and shown to be right or wrong, the hypothesis doesn't link up to our general understanding of nature. It doesn't fit into the structure of science.



Here is a hypothesis that is scientific: "No material object can travel faster than light." Even if it were supported by a thousand other experiments, this hypothesis could be proven wrong by a single experiment. (So far, we find it to be true.) A hypothesis that has no test for its possible wrongness lies outside the domain of science.

CONCEPT CHECK **How do you know if a hypothesis is scientific?**

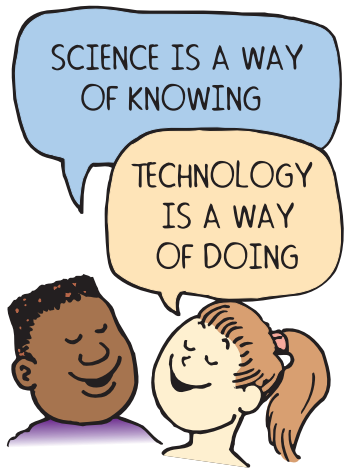
think!

Which of these is a scientific hypothesis?

a. Atoms are the smallest particles of matter.
b. The universe is surrounded by a second universe, the existence of which cannot be detected by scientists.
c. Albert Einstein was the greatest physicist of the 1900s.

Answer: 1.5

1.6 Science, Technology, and Society

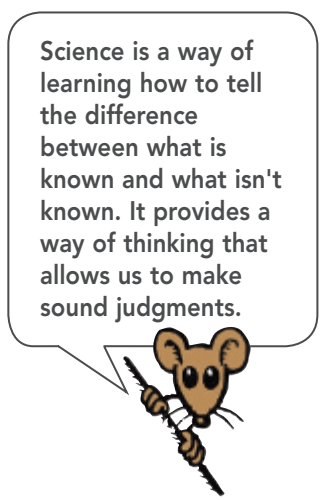


Science and technology are different. **Science is a method of answering theoretical questions; technology is a method of solving practical problems.** Science has to do with discovering facts and relationships between observable phenomena in nature and with establishing theories that organize and make sense of these facts and relationships. Technology has to do with tools, techniques, and procedures for putting the findings of science to use.

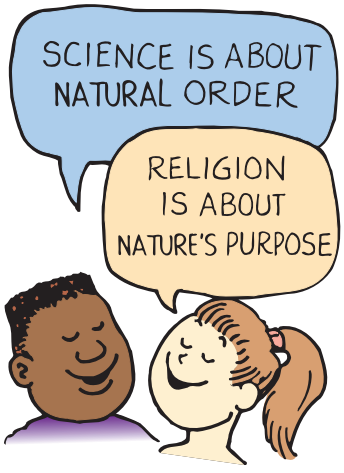
Science and technology are human enterprises, but in different ways. In deciding what problems to work on, scientists are guided by their own interests, and sometimes by a desire to help other people or to serve their nation. Most often scientists are driven primarily by curiosity, the simple urge to know. They pursue knowledge, insofar as is possible, that is free of current fashion, beliefs, and value judgments. What scientists discover may shock or anger some people, as did Darwin's theory of evolution. But science by itself does not intrude on human life—technology does. Once developed, technology can hardly be ignored. Technologists specifically set out to design, create, or build something for the use and enjoyment of humans, often for the betterment of human life. Yet some technology can have adverse side effects or create other problems that must be solved. Although technology derives from science, it has to be judged on how it affects human life.

We are all familiar with the abuses of technology. Many people blame technology itself for widespread pollution, resource depletion, and even social decay. The blame placed on technology often obscures its promise. That promise is a cleaner and healthier world. It is much wiser to combat the dangers of technology with knowledge than with ignorance. Wise applications of science and technology can lead to a better world.

Science and technology make up a larger part of our everyday lives than ever before. Humans now have much influence over nature's delicate balance. With that power comes a responsibility to maintain that balance, and to do that, we must understand nature's basic rules. Citizens must be knowledgeable about how the world works in order to deal with issues such as acid rain, global warming, and toxic wastes. The scientific way of thinking becomes vital to society as new facts are discovered and new ideas for caring for the planet are needed.



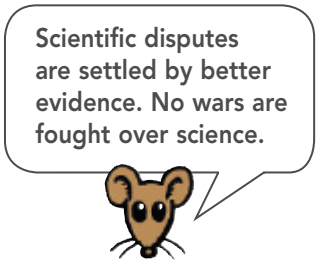
CONCEPT CHECK **What is the difference between science and technology?**



1.7 Science, Art, and Religion

The search for order and meaning in the world takes different forms; one is science, another is art, and another is religion. Although the roots of all three go back thousands of years, the traditions of science are relatively recent. More important, the domains of science, art, and religion are different, even though they overlap. **Science is mostly concerned with discovering and recording natural phenomena, the arts are concerned with the value of human interactions as they pertain to the senses, and religion is concerned with the source, purpose, and meaning of everything.**

The principal values of science and the arts are comparable. Literature describes the human experience. It allows us to learn about emotions, even if we haven't yet experienced them. The arts do not necessarily give us those experiences, but they describe them to us and suggest what may be in store for us. Similarly, science tells us what is possible in nature. Scientific knowledge helps us to predict possibilities in nature even before these possibilities have been experienced. It provides us with a way of connecting things, of seeing relationships between and among them, and of making sense of the many natural events we find around us. Though science may not answer all questions, it widens our perspective of nature. A truly educated person is knowledgeable in both the arts and science.



Science and religion are different. The domain of science is natural order; the domain of religion is nature's purpose. Religious beliefs and practices usually involve faith in and worship of a supreme being and the creation of human community—not the practices of science. In this respect, science and religion are as different as apples and oranges and do not contradict each other. The two complement rather than contradict each other.

When we study the nature of light later in this book, we will treat light first as a wave and then as a particle. To the person who knows only a little physics, waves and particles are contradictory. Light can be only one or the other, and we have to choose between them. But to the enlightened physicist, waves and particles complement each other and provide a deeper understanding of light. Similarly, people who are either uninformed or misinformed about the deeper nature of both science and religion often feel they must choose between them. But if we have an understanding of science and religion, we can embrace both without contradiction. (Of course, this doesn't apply to certain extremists who steadfastly assert that one cannot embrace both their brand of religion and science.)

think!

Which of the following involves great amounts of human passion, talent, and intelligence?

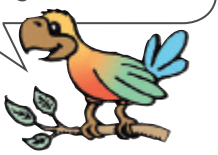
a. art **b.** literature
c. music **d.** science

Answer: 1.7

CONCEPT CHECK **How are science, art, and religion different?**

1.8 In Perspective

Doubt and uncertainty are hallmarks of science. Most physicists feel it is more interesting to live without knowing than to have answers that might be wrong.



More than 3000 years ago, enormous human effort went into the construction of great pyramids in Egypt. They were the world's greatest monuments to a vision of the universe. The Pyramids testify to human genius, endurance, and thirst for deeper understanding. A few centuries ago, the then-modern world directed its brilliance to the building of great stone and marble structures. Cathedrals, synagogues, temples, and mosques were manifestations of people's vision. Some of these structures took more than a century to build, which means that nobody witnessed both the beginning and the end of construction. Even the architects and early builders who lived to a ripe old age never saw the finished results of their labors. Entire lifetimes were spent in the shadows of construction that must have seemed without beginning or end. This enormous focus of human energy was inspired by a vision that went beyond world concerns—a vision of the cosmos. To the people of these times, the structures they erected were their "spaceships of faith"—firmly anchored but pointing to the cosmos.

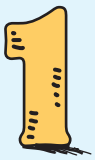
Progress in our age is much quicker than it was thousands of years ago. Today the efforts of many of our most skilled scientists, engineers, and artisans are directed toward building the spaceships that orbit Earth, and others that will voyage beyond. The time required to build these spaceships is extremely brief compared with the time spent building the stone and marble structures of the past. Many people working on today's spaceships were alive before the first jetliner carried passengers. Where will younger lives lead in a comparable time?

We are at the dawn of a major change in human growth, not unlike the stage of a chicken embryo before it fully matures. When the chicken embryo exhausts the last of its inner-egg resources and before it pokes its way out of its shell, it may seem to be at its last moments. But what seems like an end is really only a beginning. Are we like the hatching chicks ready to poke through to a whole new range of possibilities? Are our space-faring efforts the early signs of a new human era?

FIGURE 1.3 ▲
NASA astronauts may one day travel in this spaceship of the future.

Earth is our cradle and has served us well. But cradles, however comfortable, are outgrown one day. With inspiration similar to the inspiration of those who built the early cathedrals, synagogues, temples, and mosques, we aim for the cosmos. We live in a challenging and exciting time!

CONCEPT CHECK: How does progress today differ from progress thousands of years ago?



REVIEW

Concept Summary

- Physics is about the nature of basic things such as motion, forces, energy, matter, heat, sound, light, and the composition of atoms.
- When scientific findings in nature are expressed mathematically, they are easier to verify or disprove by experiment.
- Scientific methods include some, if not all, of the following: recognizing a problem, making a hypothesis, predicting, performing experiments, and formulating rules.
- If a scientist finds evidence that contradicts a hypothesis, law, or principle then the hypothesis, law, or principle must be changed or abandoned.
- To determine whether a hypothesis is scientific or not, look to see if there is a test for proving it wrong.
- Science is a method of answering theoretical questions; technology is a method of solving practical problems.
- Science is mostly concerned with discovering and recording natural phenomena, the arts are concerned with the value of human interactions as they pertain to the senses, and religion is concerned with the source, purpose, and meaning of everything.
- Progress in our age is much quicker than it was thousands of years ago.

Key Terms

scientific method *(p. 2)*
fact *(p. 2)*
hypothesis *(p. 2)*
law *(p. 2)*
principle *(p. 2)*
theory *(p. 3)*

think! Answers

1.5 Only (a) is a scientific hypothesis, because there is a test for its wrongness. The statement is not only *capable* of being proven wrong, but it *has* been proven wrong. Statement (b) has no test for possible wrongness and is therefore unscientific. Some pseudoscientists and other pretenders of knowledge will not even consider a test for the possible wrongness of their statements. Statement (c) is an assertion that has no test for possible wrongness.
If Einstein was not the greatest physicist, how would we know? It is important to note that because the name Einstein is generally held in high esteem, it is a favorite of pseudoscientists.

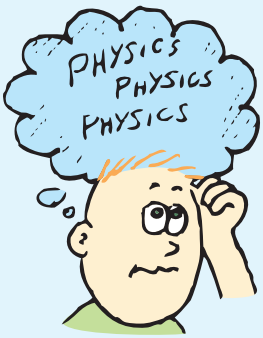
1.7 All of them! In this book, we focus on science, an enchanting human activity shared by a wide variety of people. With present-day tools and know-how, we are reaching farther and finding out more about ourselves and our environment than people in the past were ever able to do. The more we know about science, the more passionate we feel toward our surroundings. There is physics in everything we see, hear, smell, taste, and touch!

1 ASSESS

Check Concepts

Section 1.1

1. Why is physics the most basic science?



Section 1.2

2. Why is mathematics important to science?

Section 1.3

3. What are the steps of the *scientific method?*

Section 1.4

4. Is a scientific fact something that is absolute and unchanging? Defend your answer.

5. Scientific theories undergo change. Is this a strength or a weakness of science? Defend your answer.

Section 1.5

6. What does it mean to say that if a hypothesis is scientific, then there must be a means of proving it wrong?

Section 1.6

7. How do science and technology differ?

Section 1.7

8. How are science and the arts similar?

9. How do science and religion differ?

10. Why do citizens have a responsibility to have some basic understanding of nature's rules?

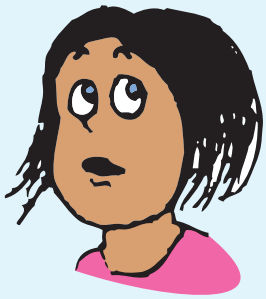
Section 1.8

11. How does the rate of change of progress differ today from the rate in previous centuries?

Think and Explain

12. Why does science tend to be a "self-correcting" way of knowing about things?

13. What is likely being misunderstood by someone who says, "But that's only a scientific theory"?



14. a. Make an argument for halting the advances of technology.
b. Make an argument for continuing advances in technology.
c. Contrast your two arguments.