1 About Science

Advances in science have brought many changes to the world. Fifty years ago, people were unfamiliar with television, jet airplanes, and how to prevent polio and simple tooth decay. Five hundred years ago, the earth was considered to be unmoving and the center of the universe. No one knew what makes the stars shine; yet today, we are preparing to travel to them—with the same energy that makes them shine.

Science is not something new. It goes back before recorded history, when people first discovered regularities and relationships in nature. One regularity was the appearance of the star patterns in the night sky. Another was the weather patterns during the year—when the rainy season started or the days grew longer. People learned to make predictions based on these regularities, and to make connections between things that at first seemed to have no relationship. More and more they learned about the workings of nature. That body of knowledge, growing all the time, is part of science. The greater part of science is the methods used to produce that body of knowledge. Science is an activity—a human activity—as well as a body of knowledge.

1.1 The Basic Science—Physics

Science is the present-day equivalent of 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. It's about the nature of basic things such as motion, forces, energy, matter, heat, sound, light, and the insides 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 more complex still and involves matter that is alive. So underneath biology is chemistry, and underneath chemistry is physics. The ideas of physics reach up to these more complicated sciences. That's why physics is the most basic science. You can understand science in general much better if you first have some understanding of physics.

1.2 Mathematics—The Language of Science

Science made its greatest headway in the sixteenth century, when it was found that nature can be analyzed and described mathematically. When the ideas of science are expressed in mathematical terms, they are unambiguous. They don't have the "double meanings" that so often confuse the discussion of ideas expressed in common language. When the findings in nature are expressed mathematically, they are easier to verify or disprove by experiment.* The methods of mathematics and experimentation led to the enormous success of science.

1.3 The Scientific Method

The Italian physicist Galileo Galilei (1564–1642) and the English philosopher Francis Bacon (1561–1626) are usually credited as being the principal founders of the **scientific method**—a method that is extremely effective in gaining, organizing, and applying new knowledge. This method is essentially as follows:

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* Although mathematics is very important to scientific mastery, it will not be the focus of attention in this book. This book focuses instead upon what should come first: the basic ideas and concepts of physics—in English. When you learn physics primarily through word descriptions that help you to visualize ideas and concepts, with only secondary emphasis on mathematical descriptions, and when you postpone to a follow-up course the practice of algebraic problem solving (which often tends to obscure the physics), you gain a better comprehension of the conceptual foundation of physics.

Fig. 1-1 Galileo (left) and Francis Bacon (right) have been credited as the founders of the scientific method.

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 three main ingredients: hypothesis, prediction, experimental outcome.

Although this cookbook method has a certain appeal, it has not always been the key to the discoveries and advances in science. In many cases, trial and error, experimentation without guessing, or just plain accidental discovery accounts 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 before the facts.

1.4 The Scientific Attitude

In science, a **fact** is generally a close agreement by competent observers of a series of observations of the same phenomena. A scientific hypothesis, on the other hand, is an educated guess that is only presumed to be factual until proven so by experiment. When hypotheses have been tested over and over again and have not been contradicted, they may become known as **laws** or **principles**.

If a scientist believes a certain hypothesis, law, or principle is true, but finds contradicting evidence, then in the scientific spirit, the hypothesis, law, or principle must be changed or abandoned. In the scientific spirit, the idea must be changed or abandoned in spite of the reputation of the person advocating it.

As an example, the greatly respected Greek philosopher Aristotle (384–322 B.C.) claimed that falling objects fall at a speed proportional to their weight. This false idea was held to be true for more than 2000 years because of Aristotle's compelling authority. In the scientific spirit, however, a single verifiable experiment to the contrary outweighs any authority, regardless of reputation or the number of followers or advocates. In modern science, argument by appeal to authority is of no value whatever.

Scientists must accept their findings and other experimental evidence even when they would like them to be different. They must strive to distinguish between what they see and what they wish to see, for scientists, like most people, have a vast capacity for fooling themselves.* People have always tended to adopt general rules, beliefs, creeds, ideas, and hypotheses without thoroughly questioning their validity and to retain them long after they have been shown to be meaningless, false, or at least questionable. The most widespread assumptions are often the least questioned. 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.

Scientists use the word *theory* in a different way from its usage in everyday speech. In everyday speech a theory is no different from 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. Physicists, for example, speak of the theory of the atom; biologists have the cell theory.

The theories of science are not fixed, but undergo change. Scientific theories evolve as they go through stages of redefinition and refinement. During the last 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. Many people feel that it is a sign of weakness to "change your mind." Yet competent scientists must be experts at changing their minds. They change their minds, however, only when confronted with solid experimental evidence to the contrary or when a conceptually simpler hypothesis forces them to a new point of view. More important than defending beliefs is improving them. Better hypotheses are made by those who are honest in the face of fact.

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* In your education it is not enough to be aware that other people may try to fool you, but mainly to be aware of your own tendency to fool yourself.

1.5 Scientific Hypotheses Must Be Testable

Before a hypothesis can be classified as scientific, it must conform to a cardinal rule. The rule is that the hypothesis must be testable. It is more important that there be a means of proving it *wrong* than that there be a means of proving it correct. At first thought this may seem strange, for we think of scientific hypotheses in terms of whether they are true or not. For most things we wonder about, we concern ourselves with ways of finding out whether they are true. Scientific hypotheses are different. In fact, if you want to distinguish 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.

Consider the hypothesis "Intelligent life exists on other planets somewhere in the universe." This hypothesis is not scientific. Reasonable or not, it is *speculation*. Although it can be proved correct by the verification of a single instance of intelligent life existing elsewhere in the universe, there is no way to prove the hypothesis 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." A hypothesis that is capable of being proved right but not capable of being proved wrong is not a scientific hypothesis. Many such statements are quite reasonable and useful, but they lie outside the domain of science.

▸ **Question**

Which of these is a scientific hypothesis?

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

▸ **Answer**

Only *a* is scientific, because there is a test for its wrongness. The statement is not only *capable* of being proved wrong, but it in fact *has* been proved 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, which 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. So we should not be surprised that the name of Einstein, like that of various religious figures, is cited often by charlatans who wish to bring respect to themselves and their points of view.

1.6 Science and Technology

Science and technology are different from each other. 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.

Another difference between science and technology has to do with its effect on human lives. Science excludes the human factor. Scientists who seek to comprehend the workings of nature cannot be influenced by their own or other people's likes or dislikes, or to popular ideas about what is correct. What scientists discover may shock or anger people—as did Darwin's theory of evolution. If a scientific finding or theory is unpleasant, we have the option of ignoring it. Technology, on the other hand, can hardly be ignored once it is developed. We do not have the option of refusing to breathe polluted air; we do not have the option of refusing to hear the sonic boom of a supersonic jetliner overhead; we do not have the option of living in a nonnuclear age. Unlike science, advances in technology *must* be measured in terms of the human factor.

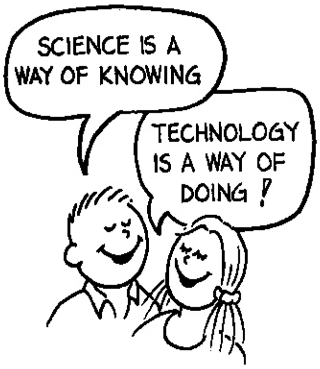

Fig. 1-2 Science complements technology.

We are all familiar with the abuses of technology. Many people blame technology itself for the widespread pollution and resource depletion and even social decay in general—so much so that the promise of technology is obscured. That promise is a cleaner and healthier world. It is much wiser to combat the dangers of technology with knowledge than ignorance. Wise applications of science and technology *can* lead to a better world.

1.7 In Perspective

More than 2000 years ago enormous human effort went into the construction of great pyramids in Egypt and in other parts of the world. It was only a few centuries ago that the most talented and most skilled artists, architects, and artisans of the world directed their genius and effort to the building of the great stone and marble structures—the cathedrals, synagogues, temples, and mosques. Some of these architectural 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 ripe old ages 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 that time, the structures they erected were their "spaceships of faith," firmly anchored but pointing to the cosmos.

Today the efforts of many of our most skilled scientists, engineers, artists, and artisans are directed to building the spaceships that already orbit the earth, and others that will voyage beyond. The time required to build these spaceships is extremely brief compared to the time spent building the stone and marble structures of the past. Many people working on today's spaceships were alive before Charles Lindbergh made the first solo airplane flight across the Atlantic Ocean. Where will younger lives lead in a comparable time?

We seem to be 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 feel it is at its last moments. But what seems like its end is really only its beginning. Are we like the hatching chicks, ready to poke through to a whole new range of possibilities? Are our spacefaring efforts the early signs of a new human era?

The earth is our cradle and has served us well. But cradles, however comfortable, are one day outgrown. With inspiration that in many ways is similar to the inspiration of those who built the early cathedrals, synagogues, temples, and mosques, we aim for the cosmos.

We live at an exciting time!

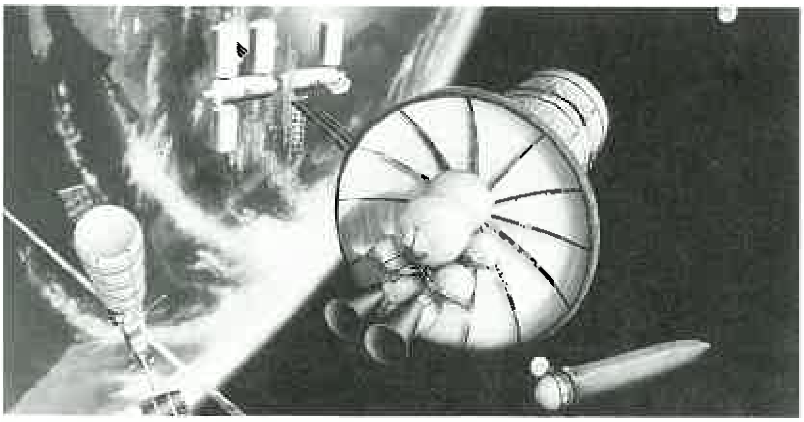

Fig. 1-3 A NASA conception of a spaceship of the future. New discoveries await the people who will venture beyond our solar system.

1 Chapter Review

Concept Summary

Science is an activity as well as a body of knowledge.

- Physics is the most basic of all the sciences.
- The use of mathematics helps make ideas in science unambiguous.

The scientific method is a procedure for answering questions about the world by testing educated guesses, or hypotheses, and formulating general rules.

- Hypotheses in science must be testable; they are changed or abandoned if they are contradicted by experimental evidence.

A theory is a body of knowledge and well-tested hypotheses about some aspect of the natural world.

- Theories are modified as new evidence is gathered.

Science deals with theoretical questions, while technology deals with practical problems.

Important Terms

fact (1.4)
hypothesis (1.3)
law (1.4)
principle (1.4)
scientific method (1.3)
theory (1.4)

Review Questions

1. Why is physics the most basic of the sciences? (1.1)
2. Why is mathematics important to science? Why is the usage of mathematics minimized in this book? (1.2)
3. What is the scientific method? (1.3)
4. Is a scientific fact something that is absolute and unchanging? Explain. (1.4)
5. Distinguish between a hypothesis and a theory. (1.4)
6. Theories in science undergo change. Is this a strength or a weakness of science? Explain. (1.4)
7. What does it mean to say that if a hypothesis is scientific then there must be a means of proving it wrong? (1.5)
8. Distinguish between science and technology. (1.6)

Think and Explain

1. Why does science tend to be a "self-correcting" way of knowing about things?
2. What is likely the misunderstanding of someone who says, "But that's *only* a scientific theory"?
3. a. Make an argument for bringing to a halt the advances of technology.
   b. Make an argument that advances in technology should continue.
   c. Contrast your two arguments.