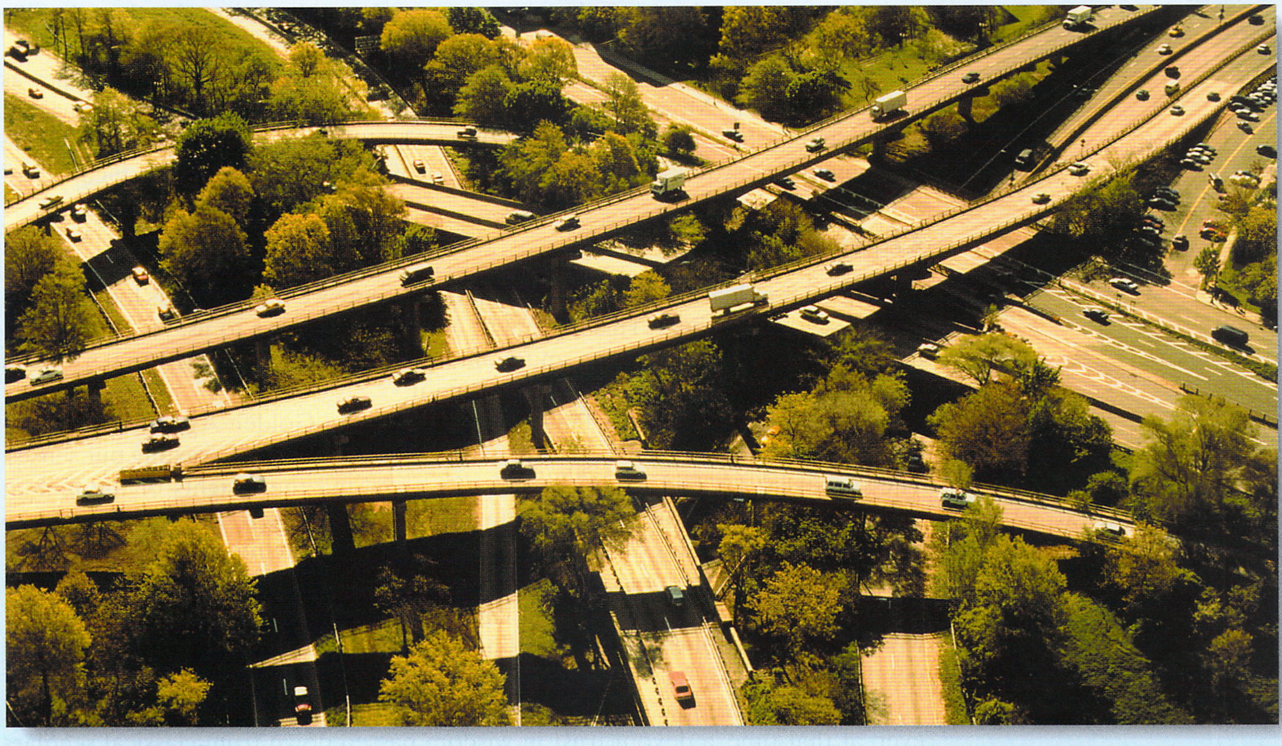
1 Science: A Way of Knowing

KEY IDEA

Science is a way of answering questions about the physical universe.



PHYSICS AROUND US . . . Making Choices

Our lives are filled with choices. What should I eat? Is it safe to cross the street? Should I bother to recycle an aluminum can or just throw it in the trash? Every day we make dozens of decisions; each choice is based, in part, on the knowledge that actions in a physical world have predictable consequences.

When you drive from home to school, for example, you have to decide which of several possible routes to take. Your choice might depend on many factors: the time of day, road construction and repair schedules, traffic reports, and perhaps even the weather. Some routes might be shorter in distance but rely on roads with lots of long traffic lights. Other routes might require driving a longer distance but at higher speeds. Over time you test many different routes, observing the time and convenience of each. In the end, you develop an excellent sense of the alternatives and choose your route accordingly.

This simple example illustrates one way we learn about the universe. First, we look at the world to see what is there and to learn how it works. Then we generalize, making rules that seem to fit what we see. And finally, we apply these general rules to new situations we've never encountered before, and we fully expect the rules to work.

There doesn't seem to be anything earth-shattering about discovering the best driving route to school. However, the same analytical procedure of observation and testing can be applied in a more formal and quantitative way when we want to understand the workings of a distant star or a living cell. In these cases, the enterprise is called science.

THE SCIENTIFIC METHOD

Science is a discipline that asks and answers questions about the working of the physical world. It is not primarily a set of facts or a catalog of answers, but rather a way of conducting an ongoing investigation of our physical surroundings. The people who conduct these investigations about our world are called **scientists.** Like any human activity, science is enormously varied and rich in subtleties. Nevertheless, a few basic steps taken together can be said to comprise the **scientific method.**

What we discuss below presents several elements that characterize science as a way of knowing. Most of the time, scientists more or less follow this scheme, but you shouldn't think of it as a rigid cookbook procedure. Many scientists have made fundamental contributions while deviating from the outline shown in Figure 1-1.

Observation

If our goal is to learn about the world, the first thing we have to do is look around us and see what's there. This statement may seem obvious to us; yet throughout much of history, learned men and women have rejected the idea that you can understand the world simply by observing it.

The Greek philosopher Plato, living during the Golden Age of Athens, argued that we cannot deduce the true nature of the universe by trusting our senses. The senses lie, he said. Only the use of reason and the insights of the human mind can lead us to true understanding. In his famous book *The Republic,* Plato compared human beings to people living in a cave, watching shadows on a wall but unable to see the objects causing the shadows. In just the same way, he argued, observing the physical world can never put us in contact with reality but will doom us to a lifetime of wrestling with shadows. Only with the eye of the mind can we break free from illusion and arrive at the truth.

During the Middle Ages in Europe, a similar frame of mind existed. However, at that time, a devout trust in wisdom passed down from classical scholars and theologians replaced human reason as the ultimate tool in the search for truth. A story (probably apocryphal) recounts a debate in an Oxford college on the question, "How many teeth does a horse have?" One learned scholar quoted the Greek scientist Aristotle on the subject; another quoted the theologian St. Augustine to put forward a different answer. Finally, a young monk at the back

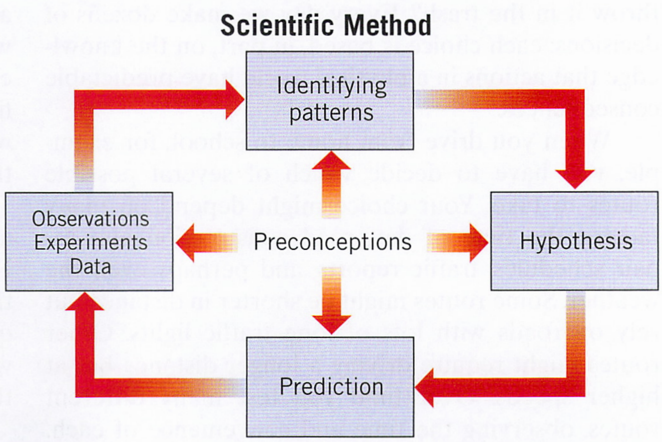


Figure 1-1. The scientific method can be represented as a cycle of collecting observations (data), identifying patterns and regularities in the data (synthesis), forming hypotheses, and making predictions, which lead to more observations.

of the hall got up and noted that since there was a horse outside, they could settle the question by looking in its mouth. At this point, the manuscript states, the assembled scholars "fell upon him, smote him hip and thigh, and cast him from the company of educated men."

As both of these examples illustrate, we can develop strategies for learning about the physical world using our reasoning powers alone or relying on accepted authority, without actually making observations. However, such approaches are not what we call the scientific method, nor do they produce the kinds of advanced technologies and knowledge we associate with modern societies. These other attempts to understand the physical world were, however, perfectly serious and were pursued by people every bit as intelligent as we are. In the next chapter, we will see how human beings gradually came to understand that observation complements pure reasoning and thus has an important role to play in learning about the universe.

In the remainder of this book, we differentiate between **observations,** in which we observe nature without manipulating it, and **experiments,** in which we manipulate some aspect of nature and observe the outcome. An astronomer, for example, might observe distant stars without changing them, while a physicist might experiment by heating materials and measuring changes in their properties.

Plato compared observing nature to watching shadows on a wall; the underlying reality is inaccessible.

Identifying Patterns and Regularities

When we observe a particular phenomenon over and over again, we begin to get a sense of how nature behaves. We start to recognize patterns in nature. Eventually, we generalize our experience into a synthesis that summarizes what we have learned about the way the world works. We may, for example, notice that whenever we drop a book, it falls. With this statement, we're incorporating the results of many observations.

Scientists often summarize the results of their observations in mathematical form, particularly if they have been making quantitative measurements. In the case of a falling book, for example, they might measure the time it takes a book to fall a certain distance, rather than just noticing that it falls. Their next step would probably be to collect their data in the form of a table (see Table 1-1). These data could also be presented in the form of a graph, in which distance is plotted against time (see Figure 1-2).

After preparing tables and graphs of their data, our scientists might notice that the longer the time something falls, the greater the distance it travels. Furthermore, the distance isn't simply proportional to the time of fall. That is, if a book falls for twice as long, it does not travel twice as far. Rather,

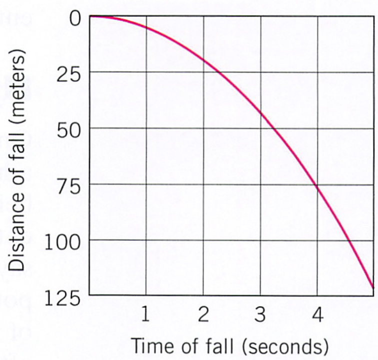


FIGURE 1-2. Measurements of a falling object can be presented visually in the form of a graph. Time of fall (on the horizontal axis) is plotted versus distance of fall (on the vertical axis).

TABLE 1-1 Measurements of a Falling Object

Time of fall (seconds)	Distance of fall (meters)
0	0
1	4.9
2	19.6
3	44.1
4	78.4

A time-lapse photograph of a falling lightbulb.

if one book falls for twice as long as another book, it travels four times as far. If it falls three times longer, it travels nine times as far, and so on. This statement can be summarized in three ways (a format that we'll use throughout this book):

1. In words:

The distance traveled by a falling object is proportional to the square of the time of the object's travel. Thus, during each tick of the clock, the distance the object falls is greater than during the previous tick.

2. In an equation with words:

$$\text{Distance} = \text{constant} \times \text{time} \times \text{time}$$
$$= \text{constant} \times (\text{time})^2$$

3. In an equation with symbols:

$$d = k \times t^2$$

The symbol k is a *constant* that defines the quantitative mathematical relationship between distance and time squared. The value of this constant has to be determined from measurements. (We'll return to the subject of constants in Chapter 2.)

Mathematics is a concise language that allows scientists to communicate their results and make very precise predictions (see Chapter 2). However, anything that can be said in an equation can also be said (although in a less concise way) in a plain English sentence. When you encounter equations in your science courses, you should always ask, "What English sentence does this equation represent?" This routine will keep the mathematics from obscuring the simple ideas that lie behind most equations.

Not every scientific idea can be or has to be stated this precisely, however. A scientist studying the formation of tornadoes, for example, might notice that certain combinations of atmospheric conditions—low pressure, high humidity, and strong vertical temperature differences, for example—always precede the formation of a tornado. The scientist might conclude that a number of criteria favor tornado formation. This conclusion can be tested, and so it is a part of scientific inquiry.

Hypothesis and Theory

Once we have summarized experimental and observational results, we can form a **hypothesis**—a tentative, educated guess—about how the world works for the behavior under study. In the case of our everyday experience with many different kinds of falling objects, we can formulate a hypothesis very easily. We can say, "When I drop a solid object, it falls." In other cases, the formation of the hypothesis may be more complicated, and the hypothesis may be stated in the form of mathematical equations. When confronted with a new phenomenon, scientists often weigh several different hypotheses at once, much as a detective in a murder mystery may consider several different suspects. It's also quite common to start with a hypothesis and then look for observations that support or disprove it. However, you must be careful that you don't let a favorite hypothesis prejudice your observations.

The word **theory** refers to a description of the world that covers a relatively large number of phenomena and has met and explained many observational and experimental tests. After observing hundreds of dropped objects, for example, we might state a theory such as "In the absence of wind resistance, all objects fall a distance proportional to the square of the time of the fall." Just as a detective announces a solution at the conclusion of a murder mystery, so do scientists reach a logical conclusion based on their observations of nature.

One word of caution: scientists don't rely on a rigorous definition when they use the words "theory" and "law." Their use often follows historical precedent, and many bodies of knowledge that are called "theories" are among the best-verified aspects of our knowledge of the world. Two examples are the theory of relativity (see Chapter 28) and the theory of evolution in biology.

Prediction and Testing

In science, every hypothesis must be tested. We test hypotheses by using them to make **predictions** about how a particular system will behave; then we observe nature to see if the system behaves as predicted. For example, if we hypothesize that all objects fall when they are dropped, then we can test this idea by dropping all sorts of objects—a lightbulb, a book, a glass of water. Each drop constitutes a test of our prediction. The more tests that give the same result, the more confidence we have that the hypothesis is correct.

So long as we restrict our tests to solids or liquids on the Earth's surface, the hypothesis is consistently confirmed. Test a helium-filled balloon, however, and we discover a clear exception to the rule. The balloon "falls" up. The original hypothesis, which worked so well for most objects, fails for certain gases. More tests would show that's not the only limitation. If you were an astronaut in the space shuttle, every time you held something out and let it go, it would neither fall nor rise. It would float in space. Evidently, our hypothesis is invalid in orbit, as well.

This example illustrates an important aspect about testing hypotheses. Tests do not necessarily prove or disprove a hypothesis; instead, they often serve to

In orbit, an object does not fall if you drop it, but continues floating. This is an example for which the simple hypothesis "When I drop a solid object, it falls" doesn't work.

define the range of situations under which the hypothesis is valid. For example, we may observe that nature behaves in a certain way only at high temperatures or only at low ones, or only at low velocities or only at high ones. Such limitations indicate that the original hypothesis doesn't cover enough ground and has to be replaced by something more general. In the example of falling objects, we will see that the hypothesis "Objects fall when dropped" has to be replaced by a more sophisticated and general set of hypotheses called Newton's laws of motion and the law of universal gravitation. These laws describe and predict the motion of dropped objects both on the Earth and in space and are, therefore, a more successful set of statements than the original hypothesis. (We discuss Newton's laws in more detail in Chapters 4 and 5.)

Testing and retesting of hypotheses under many different circumstances lies at the heart of science. Any scientific hypothesis must be subject to modification or even rejection based on new observations and experiments. The famous astronomer and popular science writer Carl Sagan once said that "the essence of science is that it is self-correcting." No scientific idea, no matter how cherished, is immune from the power of new facts. For example, the idea that the Sun moves around the Earth was considered an established fact for at least 2000 years. But later, more accurate measurements of planetary motions could not be explained by this idea, and eventually it was replaced by today's understanding that the Earth moves around the Sun.

When a hypothesis has been tested extensively and seems to apply everywhere in the universe—when we have had enough experience with it to have a lot of confidence that it is true—we generally elevate the hypothesis to a new status. We call it a **law of nature.** We will encounter many such physical laws in this book, all of them backed by countless observations and measurements. It is important, however, to remember where these laws come from. They are not written on tablets of stone, nor are they simply good ideas that someone once had. They arise from repeated and rigorous observation and testing—observations and testing that you could duplicate yourself. They represent our best understanding of how nature works.

Remember, scientists never stop questioning the validity of their hypotheses, even after we call them laws. Scientists constantly think up new, more rigorous experiments to test the limits of theories and laws. In fact, one of the central tenets of science is:

Every law of nature is subject to change based on new observations.

The Scientific Method in Operation

Together, the elements of observation, hypothesis formation, prediction, and testing make up the scientific method. In an idealized sense, you can think of the method as working as shown in Figure 1-1. In this never-ending cycle, observations lead to hypotheses, which lead to more observations.

If observations are consistent with a hypothesis, then more exacting tests may be devised. If the hypothesis fails, then the new observations may be used to modify it, after which the revised hypothesis is tested again. Scientists continue this process until they reach the limits of existing equipment, in which case they often try to develop better instruments to do even more rigorous tests. If it appears that there's just no point to going further—when decades of experiments support a given hypothesis—then scientists may eventually call the hypothesis a law of nature. But even the most thoroughly tested law of nature is subject to change if new observations warrant.

Several important points should be made about the scientific method.

1. While scientists attempt to be objective, they often observe nature with preconceptions about what they are going to find. Most experiments and observations are designed and undertaken with a specific hypothesis in mind, and most researchers have a strong hunch about whether that hypothesis is right or wrong. Given human nature and the difficulty of many state-of-the-art experiments, the history of science has many examples of discoveries that were later shown to be false, from N-rays to polywater to cold fusion. In most of these cases, researchers thought they saw the evidence that they wanted to see, but the results could not be reproduced by other people. Perhaps the most important point about the scientific method is that scientists have to believe the results of their experiments and observations, whether the results fit preconceived notions or not. Science doesn't ask that we enter the cycle of Figure 1-1 with no preconceptions or hunches, but it demands that we be ready to change those ideas if the evidence forces us to do so.

2. There is no one correct place to enter the cycle. Scientists often start their work by making extensive observations, but they can also start with a hypothesis and test it. Wherever they enter the cycle, the scientific process takes them all the way around.

3. Observations and experiments must be reported in such a way that anyone with the proper equipment can verify the results. In other words, scientific results must be *reproducible.*

4. There is no end to the cycle. Science does not provide final answers, nor is it always a search for ultimate truth. Science is a way of producing successively more detailed and exact descriptions of the physical world—descriptions that allow us to predict the behavior of that world with higher and higher levels of confidence.

5. Finally, the orderly cycle shown in Figure 1-1 provides a useful idealized framework to help us think about science, but science is not a rigid cookbook-style set of steps to follow. Science is often an intensely creative activity, undertaken by a wide variety of human beings. Scientific discovery often involves occasional bursts of intuition, sudden leaps of understanding, a joyful breaking of the rules, and all the other sorts of spontaneity we associate with human activities.

Physics in the Making

Dmitri Mendeleev and the Periodic Table

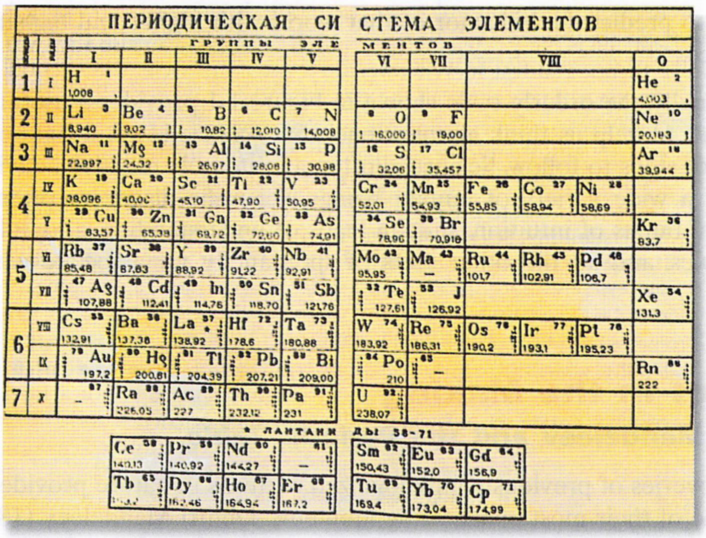
The discoveries of previously unrecognized patterns in nature provide scientists with some of their most exhilarating moments. Dmitri Mendeleev (1834–1907), a popular chemistry professor at the Technological Institute of St. Petersburg in Russia, experienced such a breakthrough in 1869 as he was tabulating data for a new chemistry textbook.

The mid-nineteenth century was a time of great excitement in physics and chemistry. Almost every year saw the discovery of new physical phenomena and one or two new chemical elements, while new apparatus and processes were greatly expanding the repertoire of laboratory and industrial scientists. In such a stimulating field, it wasn't easy to keep up to date with all the developments and summarize them in a textbook. In an effort to consolidate the current state of knowledge about the most basic chemical building blocks, Mendeleev listed various physical and chemical properties of the 63 known chemical elements (substances that could not be divided by chemical means). He arranged his list in order of increasing atomic weight and then noted the distinctive characteristics of each element.

Examining his list, Mendeleev recognized an extraordinary pattern: elements with similar physical and chemical properties appeared at regular, or *periodic,* intervals. One group of elements, including lithium, sodium, potassium, and rubidium (he called them Group I elements), were soft silvery metals that formed compounds with chlorine in a one-to-one ratio. Immediately following the Group I elements in the list were beryllium, magnesium, calcium, and barium—Group II elements that form compounds with chlorine in a one-to-two ratio—and so on.

As other similar patterns emerged from his list, Mendeleev realized that the elements could be arranged in the form of a table (Figure 1-3). Not only did this periodic table highlight previously unrecognized relationships among the elements, but it also revealed obvious gaps—places where as yet undiscovered elements must lie.

The power of Mendeleev's periodic table of the elements was demonstrated when he used it to predict the properties of several elements that were not known at the time. Within 15 years, chemists isolated the elements gallium and germanium, whose properties were strikingly close to Mendeleev's predictions. In subsequent years, Mendeleev's table provided physicists with a foundation for understanding the structure of the atom and quantum mechanics (see Chapter 22).



ПЕРИОДИЧЕСКАЯ СИСТЕМА ЭЛЕМЕНТОВ

		ГРУППЫ ЭЛЕМЕНТОВ										
		I	II	III	IV	V	VI	VII	VIII			0
1	I	H 1 1,008										He 2 4,003
2	II	Li 3 6,940	Be 4 9,02	5 B 10,82	6 C 12,010	7 N 14,008	8 O 16,000	9 F 19,00				Ne 10 20,183
3	III	Na 11 22,997	Mg 12 24,32	13 Al 26,97	14 Si 28,06	15 P 30,98	16 S 32,06	17 Cl 35,457				Ar 18 39,944
4	IV	K 19 39,096	Ca 20 40,08	Sc 21 45,10	Ti 22 47,90	V 23 50,95	Cr 24 52,01	Mn 25 54,93	Fe 26 55,85	Co 27 58,94	Ni 28 58,69	
	V	29 Cu 63,57	30 Zn 65,38	31 Ga 69,72	32 Ge 72,60	33 As 74,91	34 Se 78,96	35 Br 79,916				Kr 36 83,7
5	VI	Rb 37 85,48	Sr 38 87,63	Y 39 88,92	Zr 40 91,22	Nb 41 92,91	Mo 42 95,95	Ma 43 —	Ru 44 101,7	Rh 45 102,91	Pd 46 106,7	
	VII	47 Ag 107,88	48 Cd 112,41	49 In 114,76	50 Sn 118,70	51 Sb 121,76	52 Te 127,61	53 J 126,92				Xe 54 131,3
6	VIII	Cs 55 132,91	Ba 56 137,36	La 57 * 138,92	Hf 72 178,6	Ta 73 180,88	W 74 183,92	Re 75 186,31	Os 76 190,2	Ir 77 193,1	Pt 78 195,23	
	IX	79 Au 197,2	80 Hg 200,61	81 Tl 204,39	82 Pb 207,21	83 Bi 209,00	84 Po 210	85 —				Rn 86 222
7	X	87 —	Ra 88 226,05	Ac 89 227	Th 90 232,12	Pa 91 231	U 92 238,07					

* ЛАНТАНИДЫ 58-71

Ce 58 140,13	Pr 59 140,92	Nd 60 144,27	61 —	Sm 62 150,43	Eu 63 152,0	Gd 64 156,9
Tb 65 [illegible]	Dy 66 162,46	Ho 67 164,94	Er 68 167,2	Tu 69 169,4	Yb 70 173,04	Cp 71 174,99

FIGURE 1-3. The first published version of Dmitri Mendeleev's periodic table of the elements revealed regular patterns in the chemical behavior of known elements, as well as obvious gaps where as yet undiscovered elements must lie. Elements in the same column (which Mendeleev called Groups I, II, etc.) have similar chemical properties.

The discovery of the periodic table ranks as one of the great achievements of science. It was so important, in fact, that Mendeleev's students carried a copy of it behind his coffin in his funeral procession. ●

OTHER WAYS OF KNOWING

The central idea of science revolves around the notion that by observing and measuring, we can discover laws that describe how nature works. *Every* idea in science is subject to testing. If an idea cannot be tested, it may not be wrong, but it simply isn't part of science.

For example, a scientist can hypothesize that a particular painting was executed in the seventeenth century. She could use various chemical tests to analyze the composition of the paint, document the age of the canvas, X-ray the structure of the painting, and so on. Her statement about the age of the painting may turn out to be wrong (the painting may, for example, turn out to be a modern forgery). The key here is that the statement can be tested and is, therefore, an acceptable scientific hypothesis.

The methods of science can determine the age of a painting, but they cannot tell us if the painting is beautiful.

But some questions cannot be answered by the methods of science. No physical or chemical test can tell us whether the painting is beautiful or important or valuable, nor can any test be devised that can tell us how we are to respond to it. These questions are simply outside the realm of science. In fact, the methods of science are not the only way to answer many questions that matter in our lives. While science provides us with a way of tackling questions about the physical world, such as how it works and how we can shape it to our needs, many questions—you might argue the most important questions—lie beyond the scope of science and the scientific method. Some of these questions are deeply philosophical: What is the meaning of life? Why does the world hold so much suffering? Is there a God? Other important questions are more personal: What career should I choose? Whom should I marry? Should I have children? These questions cannot be answered by the cycle of observation, hypothesis, and testing. For answers, we turn instead to religion, philosophy, and the arts.

A symphony, a poem, and a painting are not, in the end, objects to be studied scientifically. These art forms address different human needs and they use different methods than science. The same can be said about religious faith. Strictly speaking, no conflict should exist between science and religion because they deal with different aspects of life. Conflicts arise only when zealots on either side try to push their methods into areas where they aren't applicable.

Pseudoscience

Many kinds of inquiry—extrasensory perception (ESP), unidentified flying objects (UFOs), astrology, crystal power, reincarnation, and the myriad claims of psychic phenomena you see advertised in magazines and on TV—fail the elementary test that defines science. None of these subjects, collectively labeled **pseudoscience,** is subject to reproducible testing in the sense we are using that term. No test that you can devise will convince those who believe in these notions that their ideas are wrong. Yet, as we have seen, the central property of scientific ideas is that they can be independently tested and that they may, at least in principle, be wrong. Untestable pseudoscientific ideas thus lie outside the domain of science.

The rejection of these subjects may at first glance make scientists seem close-minded and narrow, but nothing could be further from the truth. Scientists thrive on discovering the strange and remarkable in nature. That's how they make their reputations and increase human understanding. So if the physical remains of a UFO were to be discovered and made available for study or if reproducible experiments pointed to as yet unknown abilities of the human brain, scientists would jump at the chance to study them.

LOOKING DEEPER

Astrology

Astrology is a very old system of beliefs that most modern scientists would call a pseudoscience. The central belief of astrology is that the positions of objects in the sky at a given time (at the moment of a person's birth, for example) determine a person's future. Astrology was part of a complex set of omen systems developed by the Babylonians and was practiced by many famous astronomers well into modern times.

If you were in a spaceship above the Earth's atmosphere, you could see the Sun and the stars at the same time. As the Earth traveled around the Sun, you would see the backdrop of stars change. The band of background stars through which the Sun appears to move is called the zodiac (Figure 1-4). The stars of the zodiac are customarily divided into twelve constellations, called signs or houses. At any time, the Sun, the Moon, and the planets all appear in one or another of these constellations, and a diagram showing these positions is called a horoscope. The constellation in which the Sun appeared at the time of your birth is your Sun sign, or simply your sign.

Astrologers have a complex (and far from unified) system in which each combination of heavenly bodies and signs is believed to signify particular things. The Sun, for example, is thought to indicate the outgoing, expressive aspects of one's character, the Moon represents the inner-directed ones, and so on.

Scientists reject astrology for two reasons. First, there is no known way that planets and stars could exert a significant influence on a child at birth. It is true, as we learn in Chapter 5, that stars and planets exert a tiny gravitational force on the infant, but the gravitational force exerted by the delivering physician (who is much smaller but much closer) is far greater than that exerted by any celestial object.

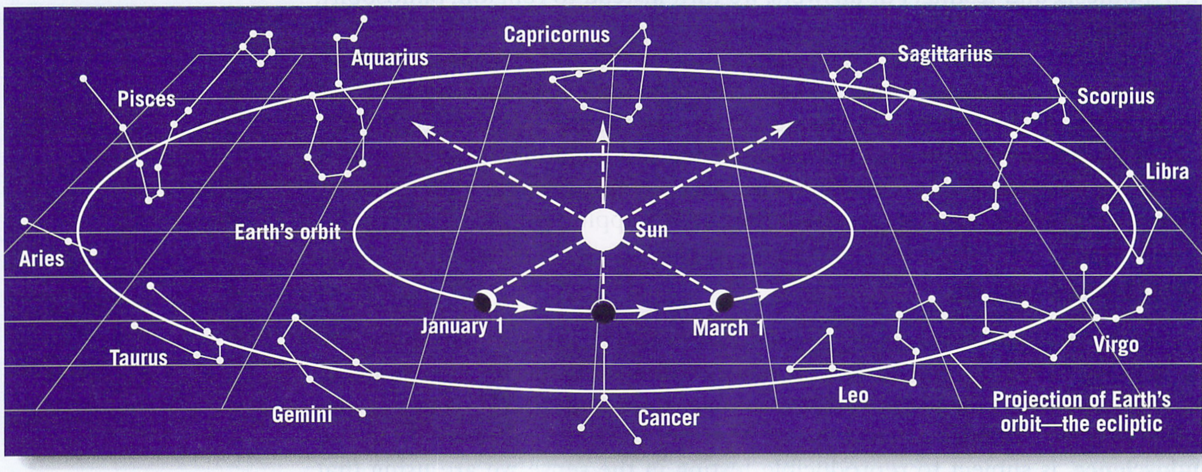


FIGURE 1-4. The stars of the zodiac form a band in the same plane as the Earth's equator.

More important, scientists reject astrology because it just doesn't work. Over the millennia, no evidence at all shows that positions of the stars can predict the future.

You can test the ideas of astrology for yourself, if you like. Try this: have a member of the class take the horoscopes from yesterday's newspaper and type them on a sheet of paper without indicating which horoscope goes with which sign. Then ask members of your class to indicate the horoscope that best matches the day they actually had. Have them write their birthday (or sign) on the paper as well.

If people just picked horoscopes at random, you could expect about 1 person in 12 to pick the horoscope corresponding to his or her sign. Are the results of your survey any better than that? What does this tell you about the predictive power of astrology?

THE STRUCTURE OF SCIENCE

Scientists investigate all sorts of natural objects and phenomena: the tiniest elementary particles, microscopic living cells, the human body, forests, the Earth, stars, and the entire cosmos. Throughout this vast sweep, the same scientific method is applied. Men and women have been carrying out this task for hundreds of years, and by now we have a pretty good idea about the way that many parts of our universe work. In the process, scientists have also developed a social structure that provides unity to the pursuit of scientific knowledge, as well as the recognition of important disciplinary differences within the larger scientific framework.

The Specialization of Science

Science is a human endeavor, and humans invariably form themselves into groups with shared interests. When modern science first started in the seventeenth century, it was possible for one person to know almost all there was to know about the physical world and the three kingdoms—animals, vegetables, and minerals. In the seventeenth century, Isaac Newton could do pioneering research in astronomy, the physics of moving objects, the behavior of light, and mathematics. Thus, for a time prior to the mid-nineteenth century, scholars who studied the workings of the physical universe formed a more or less cohesive group, who called themselves natural philosophers. However, as human understanding expanded and knowledge of nature became more detailed and technical, science began to fragment into increasingly specialized disciplines and subdisciplines.

Today, our knowledge and understanding of the world is so much more sophisticated and complex that no one person could possibly be at the frontier in such a wide variety of fields. Scientists today must choose a field—biology, chemistry, physics, and so on—and study one small part of the subject in great depth. Within each of these broad disciplines there are hundreds of different subspecialties. In physics, for example, a student may elect to study the behavior of light, the properties of materials, the nucleus of the atom, elementary particles, or the origin of the universe. The amount of information and expertise required to get to the forefront in any of these fields is so large that most students have to ignore almost everything else to learn their specialty.

Science is further divided because scientists within each subspecialty approach problems in different ways. Some scientists are *field researchers,* who go into natural settings to observe nature at work. Other scientists are *experimentalists,* who manipulate nature with controlled experiments. Still other scientists, called *theorists,* spend their time imagining how the universe might work in areas where we still don't have detailed explanations. These different kinds of scientists need to work together to make progress.

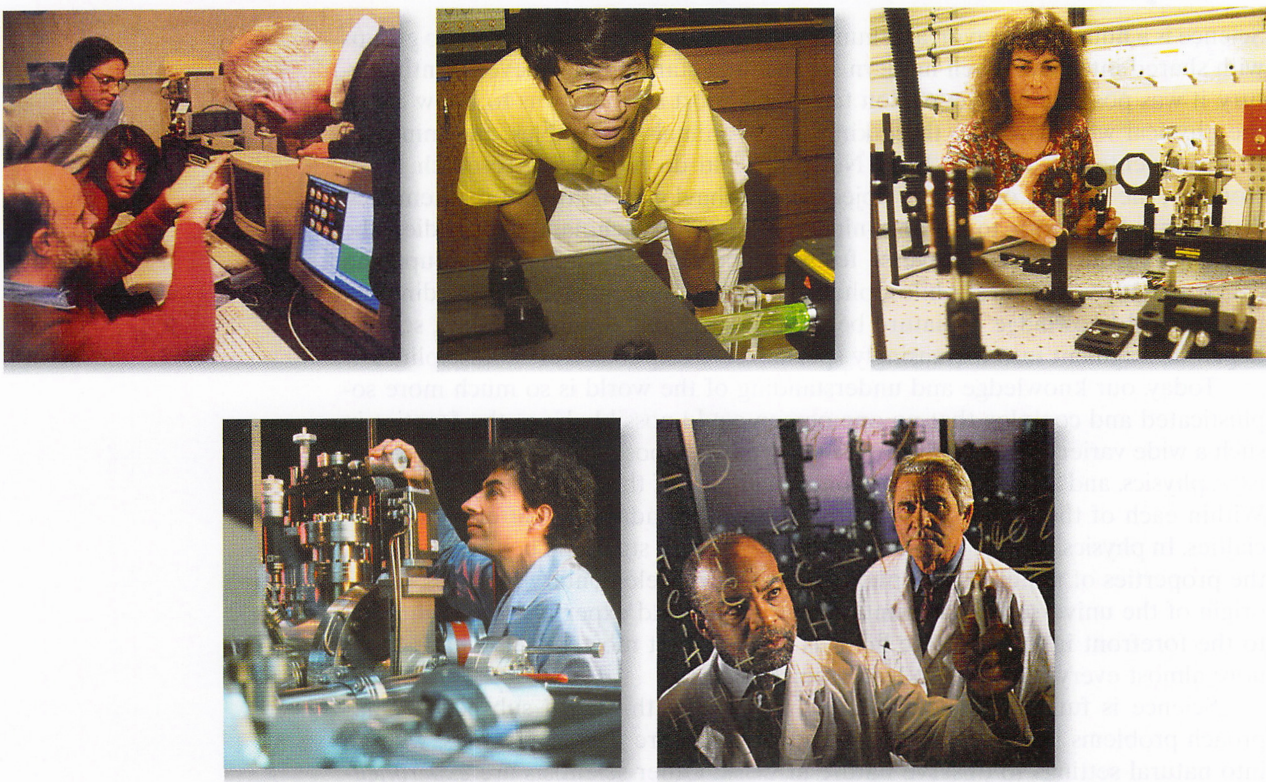
The fragmentation of science into disciplines was formalized by a peculiar aspect of the European university system. In Europe, each academic department can have only one professor. All other teachers, no matter how famous and distinguished, have less prestigious titles. As the number of outstanding scientists grew in the nineteenth century, universities were forced to create new departments to attract new professors. Several German universities, for example, supported separate departments of theoretical and experimental physics. At one time, Cambridge University in England had seven different departments of chemistry!

In North America, each academic department generally has many professors. Nevertheless, American science faculties are often divided into several departments, including physics, chemistry, astronomy, geology and biology—the branches of science.

The Branches of Science

Several branches of science are distinguished by the scope and content of the questions they address.

Physics is the search for laws that describe the most fundamental aspects of nature: matter, energy, forces, motion, heat, light, and other phenomena. All natural



Scientists come from all kinds of backgrounds but share a curiosity about the world and a desire to learn about it.

systems, including planets, stars, cells, and people, display these basic properties, so physics is the starting point for almost any study of how nature works.

Chemistry is the study of atoms in combination. Chemicals form every material object of our world, while chemical reactions initiate vital changes in our environment and our bodies. Chemistry is thus an immensely practical (and profitable) science. Most of the largest industries in the world today are chemical industries, including petroleum refining, agrochemicals, plastics, mining, and pharmaceuticals.

Astronomy is the study of stars, planets, and other objects in space. We are in an era of unprecedented astronomical discovery, thanks to human and robotic space exploration.

Geology is the study of the history, evolution, and present state of our home, planet Earth. Many geology departments also emphasize the study of other planets as a way to understand the unique character of our own world.

Biology is the study of living systems. Biologists document life at many scales, from individual microscopic molecules and cells to expansive ecosystems.

The Scope of Physics

Physics is the study of nature at its most basic level. Everything from the particles that make up atoms to the stars and galaxies we see in deep space fall within its scope. One of the most remarkable aspects of physics is that its laws apply to this wide variety of objects and systems.

Among the most basic questions to ask about any physical object are how does it move and what makes it move that way. Every object moves to some extent, whether it be the space shuttle zipping along at 17,000 miles per hour or the atoms in rocks at the summit of Mount Everest vibrating back and forth in place. Important information about an object can be found by describing its motion and trying to determine why it moves as it does. This study of motion and the causes of motion is called mechanics and is discussed in Chapters 3–8 of this book.

Energy, which enables an object to move, provides a unifying concept in mechanics. But the transfer of energy from one object to another has its own rules and limitations. The study of these rules is called thermodynamics and is presented in Chapters 9–13.

Mechanics deals with most objects as simple particles or rigid bodies in motion. It turns out that waves offer a model of motion that is just as valid as the concept of a particle moving along a line. In fact, we will see that it is not always possible to tell the difference between particle motion and wave motion. We discuss waves in Chapter 14 and present some of their most common applications in Chapter 15 on sound.

The next part of our survey of physics examines electricity and magnetism. In combination, these forces help hold atoms and molecules together, so that when you sit in a chair you remain you and don't become part of the chair. Electricity and magnetism are manifested in many familiar appliances, but they are also remarkably intertwined in the phenomenon of light. We discover the amazing world of electromagnetism in Part V of the book (Chapters 16–20), including brief presentations of electrical circuits and optics.

Once we've learned the concepts and vocabulary from all these areas of physics, we can put them together to study the structure of matter itself. What makes a material a gas, a liquid or a solid? What happens when iron rusts or wood burns? These are questions that chemists can answer, but the underlying principles of atoms in combination are part of physics. These concepts have led to today's information age of computers, the Internet, and the devices that enable them to operate; we talk about these topics in Chapters 21–25.

Delving still deeper within the atom, we enter the realm of the smallest known entities—the subatomic particles. We touch on the mind-expanding topics of nuclear physics and particle physics in Chapters 26 and 27.

Among the most astonishing discoveries of physics is the realization that the laws of nature need to be modified when applied to objects that are very small, such as atoms, or very large, such as stars, or that are moving very fast. Some of these modifications are discussed in Chapter 21 on quantum mechanics, while others are presented in Chapter 28 on special and general relativity. In the book's final chapter, we examine connections between subatomic particles and the largest known physical systems, galaxies, and the universe itself.

By the time you have finished this journey, you will have touched on many of the great truths about the physical universe that scientists have deduced over the centuries. You will discover how the different parts of our universe operate and how all the parts fit together, and you will know that there are still great unanswered questions that drive scientists today. You will understand some of the great scientific and technological challenges that face our society and, more important, you will know enough about how the world works to deal with many of the new problems that will arise in the future.

SCIENCE, TECHNOLOGY, AND SOCIETY

We can study the physical universe in many ways and for many reasons. Many scientists are driven by curiosity and the pure joy of discovering how the world works—they are interested in knowledge for its own sake. These scientists are engaged in **basic research.** They might study the behavior of distant stars, matter at extremely cold temperatures, or subatomic particles. Although discoveries made by basic researchers may have profound effects on society (for example, see the discussion in Chapter 17 of the discovery of the electric generator), that is not the primary goal of these scientists.

Other scientists approach their work with specific goals in mind. They wish to develop **technology,** in which they apply the results of science to specific commercial or industrial goals. These scientists are said to be doing **applied research,** and their ideas are often translated into practical systems by large-scale **research and development (R&D)** projects. For example, physicists have determined that some materials emit electrically charged particles (electrons) when you shine a light on them. This is an example of basic research. Later, physicists and engineers applied this concept and developed devices such as electric-eye door openers, solar panels for generating electricity, CD players, and optical bar code scanners, among many other products. Each of these products came about after years of research and development, but they all use the same basic idea of physics. For another example, see Physics and Modern Technology on page 16.

Government laboratories, colleges and universities, and private industries all support both basic and applied research; however, most large-scale R&D (as well as most applied research) is done in government laboratories and private industry (Table 1-2).

TABLE 1-2 Some Important Research Laboratories in the United States

Facility	Type	Location
Argonne National Laboratory	Govt/Univ	near Chicago, IL
Bell Laboratories	Industrial	Middletown, NJ
Brookhaven National Laboratory	Government	Upton, NY
DuPont Central Research & Development	Industrial	Wilmington, DE
Fermi National Accelerator Laboratory	Govt/Univ	Batavia, IL
IBM Watson Research Center	Industrial	Yorktown Hts, NY
Keck Observatory	University	Kamuela, HI
Los Alamos National Laboratory	Government	Los Alamos, NM
National Institutes of Health	Government	Bethesda, MD
Oak Ridge National Laboratory	Government	Oak Ridge, TN
Stanford Linear Accelerator Center	Govt/Univ	Menlo Park, CA
Texas Center for Superconductivity	University	Houston, TX
United States Geological Survey	Government	Reston, VA
Woods Hole Oceanographic Institution	University	Woods Hole, MA

Connection

Buckyballs—A Technology of the Future?

An extraordinary discovery, announced in 1990, reveals the close relationships among pure scientific research, applied research, and technology. For centuries the element carbon was known in only two basic forms—graphite, the soft black mineral used in pencils, and diamond, the hard transparent gemstone. However, in 1985 chemists at Sussex University in England and Rice University in Texas found evidence for a totally new form of carbon—one in which 60 carbon atoms bond together in a ball-shaped molecule (Figure 1-5). The distinctive linkage of the atoms, much like the geodesic domes of architect-inventor Buckminster Fuller, led scientists to dub the new material buckminsterfullerene, or buckyballs for short. Buckyballs, although completely unexpected, at first excited little attention outside a small research community because the material had no known uses and it could only be produced in minute quantities. Nevertheless, the lure of the new form of an important chemical element kept several research groups busy studying the stuff. With no obvious practical applications, these early buckyball studies were examples of basic research.

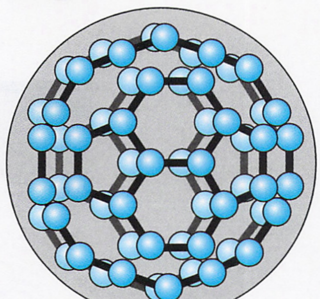
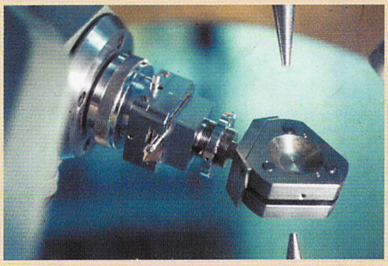


FIGURE 1-5. Buckyballs are soccer-ball-like molecules of 60 carbon atoms (red spheres) that form crystals in which these round molecules stack together like oranges at the grocery store.

A major advance came in May 1990, when a small team of German chemists discovered a way to produce and isolate large quantities of buckyball crystals in a simple and inexpensive device. With the possibility of commercial-scale production, an explosion of applied buckyball research followed. Thousands of scientists, including teams at most of the major industrial and government

Physics and Modern Technology—Diamonds

You probably know that diamonds make beautiful and expensive jewelry, and you may know that a diamond is one of the hardest substances known. But physicists have shown that diamond has other remarkable properties, including low-friction surfaces, transparency to infrared radiation, and high thermal conductivity. These properties make industrial diamonds useful in many areas of modern technology.

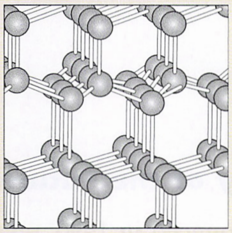


Miniature high-pressure cells use diamond anvils to squeeze samples of rock or metal without breaking, forming new kinds of materials.

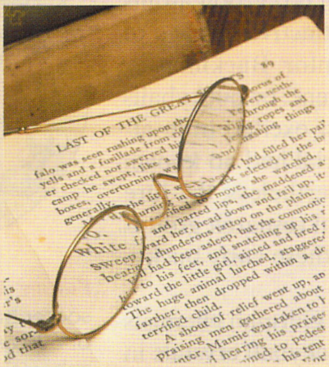
Diamond saws enable fast, focused street repair without noisy and destructive jackhammers.

Grinding wheels with diamonds embedded in the edges are used to cut stone and metal materials.

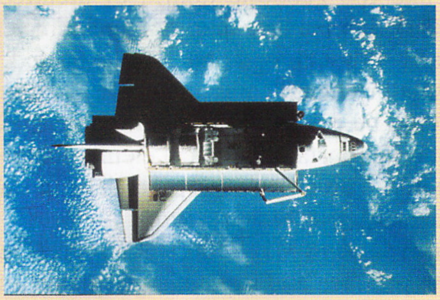
Gem-quality diamonds are beautiful forever.



The diamond structure consists of carbon atoms held together in a strong network of chemical bonds.



One-hour eyeglasses are made possible by diamond grinders and polishers linked to a computer.



The space shuttle has hinges lined with thin diamond coatings for strength and low friction. Future spacecraft may have diamond windows as well.

laboratories, jumped on the buckyball bandwagon. Hundreds of scientific articles documented an astonishing range of chemical and physical properties for the new carbon.

Among the extraordinary findings, scientists found that buckyballs and closely related materials may contribute to a new generation of versatile electronic materials, powerful lightweight magnets, atom-sized ball bearings, and super-strong building materials. With such extraordinary prospects on the horizon, buckyball investigations may soon become the domain of engineers developing new technologies—new kinds of batteries for automobiles, carbon-based girders for skyscrapers, unparalleled lubricants, and other products as yet undreamed of.

Buckyball products may soon appear at your hardware store when engineers take the results of applied scientific research and use them to design large-scale production facilities. When the discovery is big enough, the transition from small, basic research to new technologies may be rapid indeed! ●

Funding for Science

An overwhelming proportion of funding for American scientific research comes from various agencies of the federal government—your tax dollars at work (see Table 1-3 and Figure 1-6). In 2002, the United States government's total research and development budget was about $118 billion. The *National Science Foundation,* with an annual budget of almost $5 billion, supports research and education in all areas of science. Other agencies, including the Department of Energy, the Department of Defense, the Environmental Protection Agency, and the National Aeronautics and Space Administration, fund research and science education in their own particular areas of interest, while Congress may appropriate additional money for special projects.

An individual scientist seeking funding for research usually submits a grant proposal to the appropriate federal agency. Such a proposal includes an outline

TABLE 1-3 Your Tax Dollars: Federal Science Funding, 2002

Agency or Department	Funding (in millions of dollars)
Department of Agriculture	1,182
Department of Defense	50,134
Department of Energy	21,209
United States Environmental Protection Agency	592
United States Geological Survey	950
National Aeronautics and Space Administration	14,902
National Institutes of Health	23,333
National Institutes of Standards and Technology	493
National Oceanographic and Atmospheric Administration	836
National Science Foundation	4,789

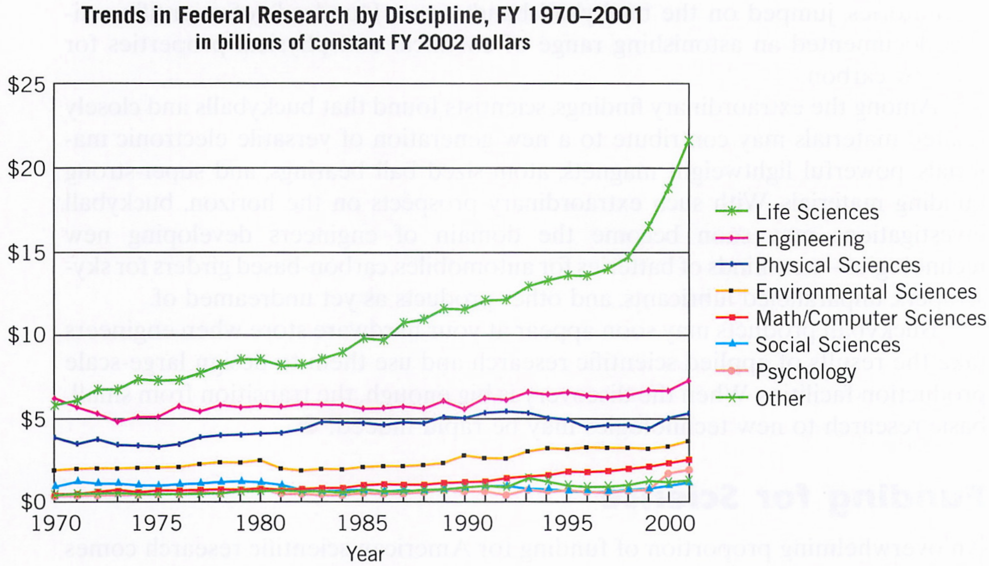


FIGURE 1-6. A graph showing the spending by the federal government on scientific research (in constant dollars), 1970–2001. (*Source:* National Science Foundation data and graph © 2002 AAAS)

of the planned research, together with a statement of why the work is important. The agency evaluating the proposals asks panels of independent scientists to rank the proposals in order of importance and funds as many as it can. Depending on the field, a proposal has anywhere from about a 10% to 40% chance of being successful. This money from federal grants buys experimental equipment and computer time, pays the salaries of researchers, and supports advanced graduate students. Without this support, science in the United States would all but come to a halt. The funding of science by the federal government is one place where the opinions and ideas of citizens, through their elected representatives, have a direct effect on the development of science.

As you might expect, scientists and politicians engage in many debates about how this research money should be spent. One constant point of contention concerns the question of basic versus applied research. How much money should we put into applied research, which can be expected to show a quick payoff, as opposed to the basic sciences, which may not have a payoff for years (if at all)?

THINKING MORE ABOUT

Science: Research Priorities

Sometimes questions of research funding get caught up in questions of public policy. For example, there have been 800,000 cases of AIDS diagnosed in the United States since 1980, primarily among male homosexuals and intravenous drug users. Over that same period, more than 5,000,000 Americans have died of cancer. Yet by 1990, the budget for AIDS research at the National Institutes of Health exceeded that for cancer.

Critics of this policy argue that research money should be spent on those diseases that affect the greatest number of people and that a vocal minority has distorted the federal policy.

Supporters argue that AIDS, an incurable and invariably fatal disease, represents a *potential* threat to many more people than cancer. They point to the tens of millions of heterosexual men and women who have died of the disease in Africa as a portent of what could happen if a cure or vaccine for the disease is not found soon.

As so often happens, there is no scientific solution to this problem. What do you think the proper course for the government ought to be? Should we spend more to combat a disease that is already killing many people or one that is relatively minor now but could potentially be even more deadly? What nonscientific arguments should be brought to bear in making decisions such as these?

Summary

Science, a way of learning about our physical universe, is undertaken by women and men called **scientists.** The **scientific method** relies on making reproducible **observations** and **experiments,** which may suggest general trends and **hypotheses,** or **theories.** Hypotheses, in turn, lead to **predictions** that can be tested with more observations and experiments. Successful hypotheses may, after extensive testing, be elevated to the status of **laws of nature,** but are always subject to further testing. Science and the scientific method differ from other ways of knowing, including religion, philosophy, and the arts, and differ from **pseudosciences.**

Science is organized around a hierarchy of fundamental principles. **Physics,** the most fundamental science, focuses on overarching concepts about forces, motion, matter, and energy—phenomena that apply to all scientific disciplines. Other scientific disciplines—**chemistry, astronomy, geology,** and **biology**—address specific aspects of the natural world. This body of scientific knowledge forms a seamless web, in which every detail fits into a larger, integrated picture of our universe.

Scientists engage in **basic research,** whose goal is solely the acquisition of knowledge, and in **applied research** and **research and development (R&D)**, which are aimed at specific problems. This process develops **technology.**

Key Terms

applied research The type of research performed by scientists with specific and practical goals in mind. This research is often translated into practical systems by large-scale research and development projects. (p. 14)

basic research The type of research performed by scientists who are interested simply in finding out how the world works, in knowledge for its own sake. (p. 14)

experiment The manipulation of some aspect of nature to observe the outcome. (p. 3)

hypothesis A tentative, educated guess, after summarizing experimental and observational results, about how the world works for the behavior under study. (p. 4)

law of nature An overarching statement of how the universe works, following repeated and rigorous observation and testing of a hypothesis or group of related hypotheses. (p. 6)

observation The act of noting nature without manipulating it. (p. 2)

physics The search for laws that describe the most fundamental aspects of nature: matter, energy, forces, motion, heat, light and other phenomena. (p. 12)

prediction The behavior of a system that will confirm or deny a hypothesis. (p. 5)

pseudoscience The types of inquiry, such as extrasensory perception (ESP), unidentified flying objects (UFOs), astrology, crystal power, reincarnation, and the myriad claims of psychic phenomena, that fail the elementary test that defines science. (p. 9)

research and development (R&D) The process of bringing new discoveries to practical use, often in industrial or governmental laboratories. (p. 14)

science A method for answering questions about the working of the physical world. (p. 2)

scientific method A cycle of collecting observations (data), identifying patterns and regularities in the data (synthesis), forming hypotheses, and making predictions, which lead to more observations. (p. 2)

scientist A person who studies questions about our world for a living. (p. 11)

technology The application of science to specific commercial or industrial goals. (p. 14)

theory A description of the world that covers a relatively large number of phenomena and has met and explained many observational and experimental tests. (p. 4)

Review

1. Describe the steps in the scientific method.
2. What is the difference between an experiment and an observation?
3. Why do scientists use equations?
4. How does a hypothesis differ from a guess?
5. What is pseudoscience? Give an example.
6. What distinguishes a theory from a natural law?
7. How does a scientist choose between competing hypotheses?
8. Must scientists always conduct their research without preconceptions?
9. What does it mean that scientific experiments must be reproducible?
10. What are some ways of knowing that are not science?
11. How is Mendeleev's development of the periodic table of the elements an example of the scientific method at work?
12. Who pays for most scientific research in the United States?
13. What are the five major branches of science?
14. What kind of experiment might a chemist perform?
15. What kind of observation might an astronomer make?
16. What is the difference between basic and applied research?
17. How do research efforts of theorists, experimentalists and field scientists differ?
18. What is the National Science Foundation?

Questions

1. Which of the following statements can be tested scientifically? Explain your reasoning.
   a. Most of the energy coming from the Sun is in the form of visible light.
   b. Unicorns exist.
   c. Shelley wrote beautiful poetry.
   d. The Earth was created over 4 billion years ago.
   e. Diamond is harder than steel.
   f. Diamond is more beautiful than ruby.
   g. A virus causes the flu.
   h. Chocolate ice cream tastes better than strawberry ice cream.
2. Ten balls have ten different weights, but they all have the same size and surface texture. Each ball is dropped from the same elevation and allowed to fall to the ground. You measure the time of fall for each ball and notice that the heavier the ball, the less time it takes to fall. Can you conclude from the results of this experiment that heavier things fall faster than lighter things? Explain your reasoning.
3. The claim is sometimes made that the cycle of the scientific method produces closer and closer approximations to reality. Is this a scientific statement? Why or why not?
4. Scientists are currently investigating whether certain microscopic organisms can clean up toxic wastes. Suppose that one scientist proposed the following experiment: "In a plastic bucket, mix toxic waste and some microscopic organisms. If the toxicity of the waste is reduced, then the microscopic organisms tested are effective at cleaning up toxic waste." Is this a good scientific experiment? Why or why not?
5. Categorize the following examples as basic research or applied research.
   a. The discovery of a new galaxy.
   b. The development of a better method to fabricate rubber tires.
   c. The breeding of a new variety of disease-resistant chicken.
   d. A study of the diet of parrots in a tropical rain forest.
   e. The identification of a new chemical element.
   f. The improvement of a method to extract the element gold from stream gravels.
6. A recent television commercial claimed that an antacid consumed "47 times its own weight in excess stomach acid." How would you test this statement in the laboratory? As a consumer, what additional questions should you ask before deciding to buy this product? Are all of these questions subject to the scientific method?
7. State whether each of the following situations is an example of an observation or an experiment and explain the reason(s) for your choice.
   a. Recording the position of the setting sun on the horizon during the year.
   b. Recording the changes in atmospheric pressure while a cold front moves through your hometown.
   c. Measuring the amount of snowfall or rain on the roof of your physical science building.
   d. Recording the boiling point for a beaker of water while you add different amounts of salt to the water.
   e. Recording the times of free fall for different objects that have been thrown off the roof of your science building.
   f. Measuring the difference between the temperature inside and outside your dormitory room window during the winter and relating this difference to the presence and absence of fog on the window.
8. One form of pseudoscience goes by the name of Ancient Astronauts. Part of this argument is that ancient monuments such as the pyramids could not have been built by Egyptian engineers but required the help of extraterrestrials. How would you go about investigating such a claim? (*Hint:* You might start by finding out what ancient Egyptian engineers knew how to do.)

Problems

1. Susan has kept careful records of driving speed versus fuel efficiency. She has noted that in traveling 10 miles per hour (mph) she averages 22 miles per gallon (mpg) of gasoline. Similarly, she gets 26 mpg at 20 mph, 29 mpg at 30 mph, 31 mpg at 40 mph, 32 mpg at 50 mph, 28 mpg at 60 mph, and 24 mpg at 65 mph. Describe and illustrate some of the ways you might present these data. What additional data would you like to obtain to improve your description?

2. Measure the height and weight of 10 friends and present these data both in a table and graphically. What trends do you observe? Why might physicians find such a table useful?

3. Follow these instructions for the next six experiments or observations. First, describe and identify in words the pattern that you observe. Then, using a graph, plot the data that will best illustrate this pattern.

a. Your friend is at a stop sign on the way to the pizza shop. You record the speedometer readings every 2 seconds as she travels to the next stop sign. The following table gives the times and speedometer readings for her car.

Time (seconds)	Speed (miles per hour)
0	0
2	10
4	20
6	30
8	40
10	50
12	50
14	50
16	50
18	35
20	20

b. The following table gives the measured times for a simple pendulum (a washer at the end of a string) to complete one full oscillation (one period), depending on the length of the string. (*Hint:* Try graphing the string length against the square of the period and see if you get a pattern.)

String length (centimeters)	Period (seconds)
5	0.45
10	0.63
15	0.78
20	0.90
25	1.00
50	1.42

c. An exercise therapist has recorded the maximum heart rate for a sample of typical human beings. A table of the maximum heart rate and age of this sample of human beings is given in the following table.

Heart rate (beats per minute)	Age (years)
200	20
195	25
190	30
180	40
170	50
155	65
140	80

d. While waiting for the gas station attendant to fill up your car's 10-gallon tank, you record the time it takes for the pump to reach every 2 gallons. A table of your findings is given next.

Volume (gallons)	Time (seconds)
0	0.0
2	2.5
4	5.0
6	7.5
8	10.0
10	12.5

e. Every day, Cowboy Joe used to set his clock to noontime by noting the time when the shadow of the corral gate was the shortest during the day. Cowboy Joe, taking a keen interest in geometry, used this information to calculate the altitude of the Sun at noon (i.e., the angle above the horizon that the Sun is at noon). Joe also noticed that the length of this noontime shadow and the altitude of the Sun changed throughout the year. The table here gives the noontime altitude of the Sun and the length of the corral gate's shadow during the year.

Date	Altitude of Sun (degrees)	Shadow of corral gate (feet)
January 22	19	29
February 20	28	19
March 21	39	12
April 21	51	8
May 20	58	6
June 21	62	5
July 21	59	6
August 21	50	8
September 21	39	12
October 24	27	19
November 22	19	29
December 21	16	35

f. The estimated world population is given in the following table.

Decade (AD)	Population (in billions)
1650	0.5
1850	1.0
1920	2.0
1990	5.5

4. Make the following predictions based on the data presented in the six tables of Problem 3 and the trends that you observed.

a. What will the speed of your friend's car be at time 22 s? 24 s? (See Problem 3a.)

b. What will the period of the simple pendulum be for a string of length 75 cm? (See Problem 3b.)
What is the string length if the period of the pendulum is 2 s? (See Problem 3b.)

c. What is the maximum heart rate for a 90-year-old woman? A 15-year-old boy? (See Problem 3c.)

d. How long will it take you to pump 15 gallons of gas using the pump in Problem 3d?

e. How long will the shadow of the corral gate be on May 1? (See Problem 3e.)
What will the altitude of the Sun be on August 1? (See Problem 3e.)

f. What will be the world population in 2010 A.D.? (See Problem 3f.)

Investigations

1. Find a science story in a newspaper or magazine. Did it originate at a scientific meeting? Which one?

2. Which is the closest major government research laboratory to your school? Which is the closest industrial laboratory? What kind of research do they perform?

3. How did your representatives in Congress vote on funding for the space station? Why did they vote that way?

4. How are animals used in scientific experimentation? What limits should scientists accept in research using animals?

5. Malaria, the deadliest infectious disease in the world, kills more than 2 million people (mostly children in poor countries) every year. The annual malaria research budget in the United States is less than $1 million—a minuscule fraction of the spending on cancer, heart disease, and AIDS. Should the United States devote more research funds to this disease, which is uncommon in North America? Why or why not?

6. Describe a program of scientific research carried out by a member of your school's faculty. How is the scientific method employed in this research?

7. Identify a current piece of legislation relating to science or technology (perhaps an environmental or energy bill). How did your representatives in Congress vote on this issue?

WWW Resources

See the *Physics Matters* home page at **www.wiley.com/college/trefil** for valuable web links.

1. **www.uwgb.edu/dutchs/CosmosNotes/cosmos3.htm** A discussion of the third episode of the PBS video series *Cosmos: A Personal Journey* by astronomer Carl Sagan, discussing the pseudoscience of astrology and some of the history linking astrology to modern science.
2. **www.periodic.lanl.gov/** The Periodic Table of the Elements. A sophisticated online periodic table of the elements created by the Los Alamos National Laboratory.
3. **mathforum.org/alejandre/workshops/buckyball.html** A webpage dedicated to buckminsterfullerenes (buckyballs), their discovery and uses (including animations).
4. **www.project2061.org/tools/sfaaol/chap1.htm** *Chapter 1: The Nature of Science* from the Project 2061 website at the American Association for the Advancement of Science (AAAS).
5. **merlot.org/** An expert-reviewed website dedicated to reviewing web resources. Click on *Science and Technology* and then *Physics* to view thousands of annotated websites discussing physics.
6. **www.sciencenews.org/** The online version of a weekly newsmagazine of science for all the latest happenings.