CHAPTER 11

Science and Philosophy

CHAPTER OBJECTIVES

In this chapter we will address the following questions:

- How Has Science Developed Historically?
- What Are the Basic Issues in Philosophy of Science?
- Is There a Specific Scientific Method?
- How Are Paradigms and Models Justified?
- Do Scientific Methods Have Limitations?
- On What Points Do Philosophy and Science Agree and Differ?
- How Does Science View the Universe and Life Processes?

It is becoming the thumb rule of science that nothing is the way we thought it was, and whatever we think we understand today will be changed to something else when looked at more closely tomorrow.[1]

The Development of Science

Scholars in many fields have pointed out that there has been more scientific progress in the last 175 years than in all previous history. Certainly the pace of scientific growth has been greatly accelerated—so much so that our age is frequently called the age of science and **technology.** The development of science is predominantly the work of Western civilization in its modern period. Other civilizations have made important contributions to human progress mainly in nonscientific fields. The early Greeks made many advances in philosophy, art, and government. When they turned their attention to science, they showed interest chiefly in pure science or in theory. Nonetheless, ancient Greeks developed basic mathematics, astronomy, and medicine. During this period, philosophy and science overlapped; little or no sharp distinction was made between them. The ancient Hebrews are known for their insights in religion and morality. The Romans were administrators, lawgivers, and practical builders. Theology was one of the main interests of the medieval period. Since the Renaissance, however, and especially during the last century, progress in the West has been focused on science and its practical applications.

Science has been called "trained and organized common sense." Its distinctive characteristic is its critical and accurate observation and description of things and events. The term *science* comes from the Latin *scire,* "to know." Today, the word *science* is used in a narrower sense to designate a quantitative, testable and objective knowledge of nature.

Pure science is objective knowledge for its own sake, without consideration for any practical application. *Applied science* is scientific knowledge put to practical use or applied within science itself (e.g., the application of mathematics to physics). *Technology* often is used to mean "applied science"; an example is the application of pure science that enables industry to manufacture computers. *Technology* also refers to inventions that work even though people have no scientific understanding of why they function (such as the early steam engines); medieval technology was technology in this sense.

The development of science is one of the greatest achievements of the human mind. Without some knowledge of the growth of science, it is difficult to understand modern history. A glance at the history of scientific accomplishments in both pure science and technology will help us to appreciate the curiosity and inventiveness of the human mind.

SCIENCE AND EARLY CIVILIZATION

Early civilization, with primitive agriculture and industrial arts, appears to have originated in or near the valleys of great rivers, such as the Nile, the Euphrates, and the Yellow River. The land was fertile and water was available for people and herds. More than two thousand years before the common era began, the Babylonians and Egyptians possessed a considerable body of knowledge. They used fixed units of measurements, such as standards of length, weight, and volume; a multiplication table; tables of squares and cubes; and a decimal system based on our ten fingers. In Egypt, the periodic rise of the waters of the Nile, resulting in lost boundary marks, led to a system of land surveying that stimulated the growth of geometry. Instruments such as set squares, levels, beam balances, and plumb lines, as well as a considerable amount of mathematical knowledge, were needed to build the pyramids. Weaving and spinning were practiced, and wheeled chariots were in use.

Both the Egyptians and the Babylonians thought the world resembled a box, of which the earth was the floor. There was a rudimentary astronomy based on observations of the regularities of the "heavenly bodies." There was a calendar containing 365 days. The days of the week were named after the sun, the moon, and the five known planets, and the months and the years were determined from the movement of the moon and the apparent movement of the sun. By the sixth century B.C.E., eclipses could be predicted. In India and China, too, progress was being made. Paper and the compass were invented in China. The system of numerals we use today came from India by way of Arabia.

GRAECO-ROMAN SCIENCE

With the Greeks, human consciousness and interest in humanity and nature expanded rapidly. The Greeks wanted to know for the sake of knowing, and the scientific as well as the philosophical spirit was born. The contribution of the Greeks was so great that many of the scientific and philosophical terms we use today originated with them. Thales (c. 624–546 B.C.E.), the first Ionian nature philosopher, who lived in the Greek colonial city of Miletus in Asia Minor, is reported to have visited Egypt and to have become acquainted with the system of land surveying in use there. Later he advanced geometry and set forth his views about the watery nature of the world. Other pre-Socratic thinkers were instrumental in advancing interest and knowledge in areas that were to become important for the development of science and philosophy.

Other achievements of classical Greece included the first detailed example of what mathematical astronomy could be and the first extended attempt at a mathematical structure of matter (Plato); proposals that the earth was spherical (Pythagoras); drawings of parallels of latitude and longitude on a map of the known world and calculations of the circumference of the globe with only a 1 percent error (Eratosthenes); development of the theory that the earth rotated on its axis and moved in orbit around the sun (Aristarchus); systematizing of the theorems of plane and solid geometry (Euclid); discovery of specific gravity (Archimedes); advancements in medicine that included outlining the nervous system, and, although this was not a universally shared view, ascertaining that the brain was the center of consciousness (Hippocrates and followers); a basic atomic theory of matter (Leucippus and Democritus); the ordering of thought by means of logic, and development of classification schemes for the various branches of knowledge (Aristotle). The idea of nature as a rational, orderly whole (*kosmos*) is of Greek origin.

However, we should not conclude that the interpretations mentioned in the preceding paragraph were unerring or dominant at the time. For example, many of Aristotle's views were more prevalent than other Greek interpretations of that era (e.g., his understanding of nature's basic elements—earth, air, fire and water). Furthermore, Ptolemy had proposed the erroneous, long-lasting view of the earth as center of the universe, with the sun, moon, and stars revolving around it.

The Romans were a practical people who excelled as administrators and builders. They had little interest in pure science or knowledge for its own sake. Their amphitheaters, aqueducts, forums, and roads reflected their concern with engineering and the practical or useful arts. For a thousand years, during the Middle Ages, Europe made only slight advances in pure science. During the earlier part of the Middle Ages, the influence of Plato's philosophy was strong, and Aristotle was known mainly for his logic. During the later part, the period of cultural flowering, Aristotle's philosophy was accepted as the great authority. Thinkers of that period looked to deductive reasoning (syllogistic logic) and divine revelation as their sources of knowledge. They thought they knew the meaning and the purpose of their own lives and of the universe. The scholastic philosophers and theologians continued the Greek concept of nature as a rational, orderly whole, a concept basic to modern science.

THE MIDDLE AGES

However, the Middle Ages in Europe was one of the most inventive periods in the history of technology. Among the achievements were the stirrup, horse collar, ox yoke, iron plow with mould board, three- and four-field system of crop rotation, windmill, Gothic arch and vault, mechanical clock, optics, and systematic utilization of natural sources of power. It would be hard to characterize medieval technology as "applied science," however, because this inventiveness consisted of efforts to control nature before scientists learned to understand it.

From the ninth to the eleventh century, Greek knowledge was translated into Arabic. Islamic civilization, which included most of the Mediterranean world, produced new scientific developments written in Arabic. Mathematics, medicine, astronomy, and optics, were among the sciences advanced by the Arabic world. Eventually, the knowledge of ancient Greece and the scientific progress of this civilization were translated into European languages. Without the Arabic resource, the scientific developments of European civilization would have been seriously retarded.

Europe enjoyed the technical heritage of the Middle Ages from the sixteenth through the eighteenth centuries, the period of the Scientific Revolution.

THE SCIENTIFIC REVOLUTION

During the Renaissance and Enlightenment periods (c. 1500–1800), Aristotle's authority and medieval theology were replaced by different methods of discovering knowledge about the world and by a new view of the universe. The Copernican Revolution, named for the Polish monk Copernicus (1473–1543) (see biography and insert, pp. 214–215), was the replacement of the belief that the earth is the stationary center of the cosmos with the theory that the sun is the center of our solar system, the earth one of the planets. Copernicus reached this conclusion by mathematical and analytical reasoning.

Francis Bacon (1561–1626) relied on the inductive method, by which facts drawn from experimentation are used to formulate hypotheses and eventually to describe scientific laws and universal principles. He proposed that inquirers must first empty their minds of preconceptions or "self-evident truths," then make observations and generalize. Bacon's simple notion of induction assumed that it is possible for a scientist to be totally neutral, free from all assumptions—a condition not possible for even the most detached investigator. Also, his assertion that direct observation was essential to science would eliminate theoretical science, in which theories are built by mathematical inferences and indirect evidence; the nature of submicroscopic particles such as quarks and gluons (see p. 229) is within theoretical science. However, Bacon's conclusions regarding the inductive method and the importance of doubting all received knowledge has had immense influence in the history of modern thought.

Descartes (1598–1650) relied on deduction and used the method of mathematics to reason to the concept of a mathematically intelligible, mechanical universe. He proposed that scientists begin with self-evident axioms and then, by logical reasoning, deduce various inferences. Descartes attempted to extend the deductive method to all fields of human knowledge. Although he did not reject the value of experimentation, he relied on the attainment of knowledge through reason. A weakness in this approach is that scientists disagree about what principles are truly self-evident. Among his achievements were the development of analytic geometry, a concept of a unified, mathematically ordered universe explainable in mathematical terms, and an independent spirit of scientific investigation.

Galileo (1564–1642) combined mathematical and experimental methods. Questioning many of Aristotle's teachings, he defended Copernicus and readily used experimentation to attack accepted beliefs about physical laws. He devised an improved telescope and also established the law of falling bodies (regardless of the size or weight of falling bodies, their acceleration is constant); he made other discoveries in astronomy and physics. At several times during his life, Galileo suffered persecution by church officials who resisted his methods and conclusions which were offensive to the medieval intellectual establishment.

Johannes Kepler (1571–1630) worked out a complex geometric hypothesis to account for

Nicolaus Copernicus

Copernicus (1473–1543) was born in Torun, Poland. He studied at the University of Kracow, and was appointed a canon of the cathedral of Frauenberg, which gave him an income for life and enabled him to study law and medicine in Italy. Although he did not take courses in astronomy, he collected books in astronomy and mathematics and is often considered the father of modern astronomy. He developed the theory that the earth revolves and moves with the other planets around the sun—the heliocentric view that was to replace the Ptolemaic view. This was a major development, but equally important was the method Copernicus had employed, which included independent mathematical reasoning. The masterpiece for which he is famous is *Concerning the Revolutions of the Celestial Spheres* (1543). The printed form reached him only a few hours before his death.

distances between the elliptical planetary orbits previously thought to be circular. He also discovered that the motions of the planets are relative to their distance from the sun. His astronomical conclusions have since been called Kepler's Laws. In addition, Kepler made contributions in optics and mathematics; his *Epitome of Copernican Astronomy* (1618–1621) became the first textbook of astronomy based on Copernican principles.

Newton (1642–1727) (see biography and excerpt, pp. 216–217) united into one all-embracing law of gravitation the explanation of the motion of all bodies in the planetary system; the universe is presented as one great unity operating according to unalterable principles. Among his important discoveries were the law of gravitation, the principles of calculus, and the compound nature of light.

The implications of Newton's research were those of the scientific revolution: opinions accepted in the past, whether philosophical, theological, or scientific, could be challenged and the issues reexamined; the universe was governed by rational, universal laws, which could be formulated as precisely as mathematical principles. The scientific revolution was not intrinsically antireligious but by implication called for a radical departure from past views of reality and from authoritarian declarations, especially on matters best researched through experimentation and observation.

Excerpt from Copernicus:

The Preface to the Books of the Revolutions to the Most Holy Lord, Pope Paul III (1543)

I may well presume, most Holy Father, that certain people, as soon as they hear that in this book *On the Revolutions of the Spheres of the Universe* I ascribe movement to the earthly globe, will cry out that, holding such views, I should at once be hissed off the stage. . . . That I allow the publication of these my studies may surprise your Holiness the less in that, having been at such travail to attain them, I had already not scrupled to commit to writing my thoughts upon the motion of the Earth. How I came to dare to conceive such motion of the Earth, contrary to the received opinion of the Mathematicians and indeed contrary to the impression of the senses, is what your Holiness will rather expect to hear. So I should like your Holiness to know that I was induced to think of a method of computing the motions of the spheres by nothing else than the knowledge that the Mathematicians are inconsistent in these investigations.

For, first, the Mathematicians are so unsure of the movements of the Sun and Moon that they cannot even explain or observe the constant length of the seasonal year. Secondly, in determining the motions of these and of the five other planets, they do not even use the same principles and hypotheses as in their proofs of seeming revolutions and motions.

Copernicus, Nicolaus, *On the Revolutions of the Heavenly Spheres,* trans. A. M. Duncan (New York: Barnes and Noble, 1976).

MODERN SCIENCE

The nineteenth century witnessed the rapid growth of science and industry. John Dalton (1766–1844) and others advanced the atomic theory, which in turn advanced all thought relative to matter and led to the particle concept for matter and energy. There was significant growth in the studies of electricity, heat, energy, light, and magnetism. Another great work of the nineteenth century was the application of scientific methods to the study of living organisms. Although the idea of evolution had been known to some Greek philosophers, it was not widely accepted before Charles Darwin (1809–1882) published the *Origin of Species* in 1859. The concept of evolution has had widespread influence on modern thought.

The twentieth century has brought unparalleled advances in many fields of science and abandonment of many interpretations that had been taken for granted during the previous centuries. The sciences of the nineteenth century, for example, took matter, space, and time as basic and fixed entities. Matter was thought to be composed of simple and indivisible atoms existing in absolute space and time. Concepts of relativity, subatomic particles, and the quantum theory have profoundly altered the older models. Explanations, subject to revision, of a cosmos in which random events occur and laws are statistically probable inferences allow scientists

Isaac Newton

Isaac Newton (1642–1727), British mathematician, physicist, and philosopher, formalized Galilean mechanics, discovered the inverse square law of universal gravitation, and made notable contributions to the theory of light. One of Newton's major works was *Optics* (1704). He was educated at the University of Cambridge, where he was a professor of mathematics from 1675 to 1707.

Philosophiae Naturalis Principia Mathematica (1687), generally known as *Principia,* is Newton's most philosophically oriented work. No one without a comprehensive knowledge of mathematics can understand it properly, which contributes to its inaccessibility. *Principia* provides an inclusive system of mechanics accounting for the motion of bodies on or near the surface of the earth and for all motion throughout the universe.

Newton claimed that his method was empirical and inductive. Furthermore, he asserted that his discovery of universal gravitation was evidence for belief in a deity.

Several seventeenth- and eighteenth-century philosophers, especially the British empiricists and Kant, were influenced by Newton. For example, much of Locke's philosophy can be seen as developing the philosophical implications of Newtonian mechanics.

to examine new information and make new interpretations.

Science is now closely tied to mathematics; scientists are more conscious of the limits of what is known and the vast areas yet to be explored. Recently, scientific inquiry has been used in the humanities and social sciences, such as psychology and economics. We will consider some modern views of the universe and life later in this chapter.

Philosophy of Science: Basic Issues

Knowledge resulting from scientific conclusions plays an important role in our understanding of the world around us. Because science to a large extent shapes our understanding of reality, philosophers are analyzing the methods and concepts of science. These studies have emerged as an area called philosophy of science.

The basic issues of philosophy of science can be grouped into two categories. The first is the analysis of the logic and the language of science. In this category philosophers have understood that the natural sciences (such as physics, chemistry, and biology) as well as the social sciences (such as psychology and sociology) offer explanations, formulate laws, and propose theories. However, concerned with the language of science, philosophers of science ask, "What constitutes a satisfactory scientific explanation, law, or theory?" They explore the criteria or standards for acceptable scientific explanations. The criteria or standards are made more explicit as

Excerpt from Newton:

Philosophiae Naturalis Principia Mathematica, Selections from the Preface (1687)

The forces of gravitation with which bodies tend to the sun and the several planets can be discovered from the celestial phenomena. . . . I wish we could derive the rest of the phenomena of nature by the same kind of reasoning from mechanical principles; for I am induced by many reasons to suspect that they all depend upon certain forces by which the particles of bodies, by causes hitherto unknown, are either mutually impelled towards each other and cohere in regular figures, or are repelled and recede from each other; which forces being unknown, philosophers have hitherto attempted the search of nature in vain.

. . . It may be that there is no body really at rest, to which the places and motions of other bodies can be referred. . . . It is indeed extremely difficult to discover and distinguish effectively the true motion of particular bodies from the apparent; because the parts of that immovable space in which these motions are performed do by no means come under the observation of our senses.

Newton, Sir Isaac, *Philosophiae Naturalis Principia Mathematica,* ed. A. Koyrè (Cambridge, Mass.: Harvard University Press, 1972).

philosophers endeavor to set forth the patterns in the process whereby scientists structure and organize their findings into theories and laws. Also, concerned with the logic of science, philosophers analyze the methods by which hypotheses are tested and theories are supported; the logical relationships between hypotheses and laws or between laws and theories are studied.

The second major category of philosophy of science is the relationship between scientific knowledge and broader concerns. For example, to what extent does science offer us a quite abstract and partial knowledge of things, accurate as it otherwise might be? Some philosophers have attempted to make use of this knowledge to answer such general questions as, "Is there anything unique about human beings, or are they just another species of animal?" Others have made use of scientific knowledge to address theological concerns about the possibility of a creator, that is, whether there is any place for a traditional God in the world portrayed by science.

As philosophers investigate science, the validity of scientific explanations and the superiority of scientific statements over intuitive, rational, and religious knowledge, become significant issues. Therefore, philosophy of science has become an important study attempting to establish greater precision about what constitutes scientific facts, scientific methodologies, and the limitations of science. Current issues in philosophy of science (related to the previous chapters on the sources, nature, and tests of knowledge) include explorations of the sources for arriving at scientific knowledge, the objectivity of such knowledge, and the tests of scientific truth.

Scientific Methods

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THREE POSSIBLE MEANINGS OF "SCIENCE"

Because the terms **science** and **scientific methods** are both used in a number of different ways, an examination of some of these different usages will help us understand the nature of the processes and the terms involved. The word *science* is used, first to denote any of the many sciences. These include physics, chemistry, astronomy, geology, and biology. Mathematics and logic are sometimes referred to as formal or abstract sciences, and disciplines such as botany and mineralogy often are called descriptive or empirical sciences. There are a great many sciences, and their fields overlap.

Second, the term *science* may be used for the entire body of systematic knowledge, including the hypotheses, theories, and laws that have been built up by the work of numerous scientists through the years. This knowledge is mainly theoretical, in contrast with the practical skills and the arts.

Third, a considerable number of people use the term *science* to designate the results of a method of obtaining knowledge that is objective and verifiable. In this sense, a documented biography is scientific.

SCIENTIFIC POSTULATES

Before we attempt to examine how scientific truth can be tested, it is important to examine the notion of *proof.* All proof must begin with certain assumptions. This is true in science, philosophy, or religion. Some ideas or facts must be accepted as **postulates**—that is, must be taken for granted. These include the fundamental laws of thought or logic, such as the principles of identity ("all A is A"), noncontradiction ("not both A and not-A"), and excluded middle ("either A or not-A"); these are commonly spoken of as self-evident. Ordinarily, we also accept the evidence of immediate experience. Anyone working in the sciences usually proceeds on the basis of some or all of the following basic assumptions, postulates, axioms, or conditions.

1. The principle of *causality* is the belief that every event has a cause and that, in identical situations, the same cause always produces the same effect.

2. The principle of *predictive uniformity* states that a group of events will show the same degree of interconnection or relationship in the future as they showed in the past or show in the present.

3. The principle of *objectivity* requires the investigator to be impartial with regard to the data. The facts must be such that they can be experienced in exactly the same way by all normal people. The aim is to eliminate all subjective and personal elements insofar as possible and to concentrate on the object being studied.

4. The principle of *empiricism* lets investigators assume that their sense impressions are reliable and that they can test truth by an appeal to the "experienced facts." Knowing is the result of observation, experience, and experiment, as opposed to authority, intuition, or reason alone.

5. The principle of *parsimony* is that, other things being equal, take the simplest explanation as the most valid one. A check on unnecessary intricacy, this principle cautions against complicated explanations. It is sometimes called **Occam's razor,** after William of Occam, a fourteenth-century English philosopher who said that "entities should not be multiplied beyond necessity."

6. The principle of *isolation,* or *segregation,* requires that the phenomenon under investigation be segregated so that it can be studied by itself. However, in so doing, the phenomenon is somewhat altered, thereby reducing the universality of the theory put forth; the results are true "under these circumstances."

7. The principle of *control* emphasizes that variables not under investigation must be held constant during experimentation. Otherwise, many factors may vary at the same time, and the experiment could not be repeated in the same way. If the conditions change while the experiment is being conducted, the results may be invalid. More important, it is not always possible to tell which variation caused the result.

8. The principle of *exact measurement* requires results to be such that they can be stated in quantitative or mathematical terms. This is the goal at least of the physical sciences, which seek verifiable objective measurements.

A scientist, E. G. Conklin, years ago raised the question of whether there can be such a thing as a "purely objective science." He reminds us that there can be "no observation without an observer, no experiment without an experimenter, no classification without a classifier."[2] In the physical or inorganic sciences, the postulates and conditions we have set forth can be met fairly adequately. We can isolate and control and measure with a high degree of success. When we come to a study of living creatures, especially humans and society, new and difficult conditions are encountered. Life on its higher levels cannot be isolated and controlled without altering the nature of that which is to be studied. Separate a person from society and you change the nature of his or her being.

Neither the scientist nor the philosopher has any secrets or methods of obtaining knowledge that are not open to people in general. Science differs from ordinary common sense in that it is more critical, more penetrating, and more controlled and exact in its observations and analyses.

Scientific method can be divided into two parts: the logical methods and the technical or technological methods. The logical methods are those of reasoning or drawing inferences. These logical processes are the same in all the sciences, in philosophy, and in all clear and accurate thinking. They include such principles of reasoning as the method of agreement, the method of difference, and the method of concomitant variation.

The technical methods are those of manipulating the phenomena under investigation. This is what many people think of as "science." These methods are many and varied. Here we include the constantly growing mass of apparatus and equipment that aids in observation and experimentation. These instruments immediately come to our attention as we enter a scientific laboratory. They extend our powers of observation and control. Without a knowledge of the field and the methods of reasoning, however, they are of little use.

A VARIETY OF SCIENTIFIC METHODS

There is no universal agreement, even among scientists, about what is meant by *scientific method*. Science has evolved from common sense, and the transition from one to the other has been gradual and continuous. A careful examination of the sciences—such as physics, astronomy, and botany—fails to reveal any single method in use. Sciences such as astronomy proceed by means of observation and mathematical calculations from these observations. Other sciences, such as physics and chemistry, emphasize controlled experimentation. In still other sciences, trial and error, statistics, and sampling are used. Thus there are scientific methods rather than *the* scientific method. The method used depends on the nature of the material or problem to be studied.

Observation. Some sciences, such as astronomy and botany, have been built up by careful and methodical observation. Observation is a matter of sense perception: we see, hear, touch, feel, or smell something. On the basis of our observations we draw conclusions regarding relations, causal sequences, and the meaning of the situation.

The *method of agreement,* one of the inductive methods, is sometimes called the *observational* method of agreement.[3] The principle involved is that "the sole invariable circumstance accompanying a phenomenon is causally connected with the phenomenon." Some years ago, for example, eight well-known leaders in the United States lumber industry became ill and died. Even though they lived in widely separated areas of the country, the fact that they all died within a short period led some people to think that there might be a common cause. On examination of the circumstances of the deaths and the events leading up to them, it was noted that not only had all the men died of amoebic dysentery but also all of them had attended the same conference of lumber dealers a few weeks before. All of them had stayed at the same hotel and had used water that was later found to be contaminated with microorganisms that cause dysentery; the sewage system was blocked. In the light of all the circumstances, the contaminated water at the hotel was identified as the cause of the untimely deaths, or "the sole invariable circumstance." There were, of course, a number of common conditions besides the use of the contaminated water. In such circumstances one needs to make a judgment of relevance based on general knowledge and past experience. In this case, the water supply was first assumed to be the cause; further investigation disclosed that this water was contaminated with organisms that caused the illness.

Trial and Error. The method of trial and error, sometimes called trial and success, or trial and chance, does not need lengthy discussion. Trial and error is used by animals as they try to solve their problems. It is a technique used by psychologists who study animals and human beings. A rat uses trial and error to get out of a maze or around some obstacle in its path. A chimpanzee tries various means to secure food that is out of reach. A person uses this method to find out how some gadget works. Trial and error can be used deliberately by scientists as they try different hypotheses and by philosophers as they test ideas and systems of thought for coherence and factual and logical consistency.

The trial-and-error method does involve reflection. Reflective thinking has been called "trial and error by ideas." In reflective thinking, the fumbling is done in the imagination. We may carry out in our imagination a number of proposals or hypotheses and conclude that some may work and others will not.

Experimentation. Active experimentation is the principal method of discovering and verifying causes. Experimentation involves *manipulation* and *control.* Although observation and trial and error have been widely used, they have their limitations. Great advances in scientific research were made possible when techniques of control were discovered and put to use. In an experiment, the observer controls the conditions relating to the subject of study. He or she then manipulates these conditions, changing one factor at a time so that the results can be correlated with the different conditions. The *method of difference,* sometimes called the *experimental* method of difference, is widely used in science: the rule is to vary only one factor or condition at a time, keeping all other factors unchanged or constant. The investigator makes a difference in only one variable to see whether it will make a difference in the result.

A simple illustration of the method of difference is the coin-and-feather experiment in physics. Why does a feather fall to the ground more slowly than does a coin? An experiment is designed to see whether the cause is the resistance of the air. A coin and a feather are dropped at the same time in the chamber of an air pump in which air is present. The coin drops quickly, whereas the feather's fall is retarded. With the other factors kept constant, the air is pumped from the chamber. The coin and the feather are dropped again. This time they reach the bottom of the chamber at the same time. It is reasonable to conclude that buoyancy slowed the fall of the feather.

Statistical Method. The term *statistics* refers to the mathematical science of the collection, analysis, and classification of numerical data as a basis for induction. Statistical methods arose in early times to help rulers and states gather information about population, births, deaths, wealth, taxes, and the like. These methods have been greatly refined, and today statistical methods are used in everyday affairs, in business and financial activities, in education, and in many of the sciences. Counting, measurement, averages, means, medians—all enable us to make our information more exact and to find order in a mass of detail. Although the use of statistics helps us to understand particular features of groups (for example, white male drivers in America between the ages of 19 and 25), we learn nothing definite about a certain individual of that group; what can be said of a general nature about a group based on statistical evidence cannot be said in the same sense of any individual in it. Statistics help us to determine the probability of events so that we can make predictions, to explain causes and effects, to describe types of phenomena, and to make comparisons. Data often are presented in tables, charts, and graphs, which make it easy to see the distribution of events.

Sampling. In sampling, we assume that the nature of some members of a class is an indication of the nature of all the members. When is a single instance likely to be an accurate representative of the whole and when is it not likely to be? When the material to be examined is known to be homogeneous throughout, a single sample will give accurate results. A random sample will suffice, because there are no varying conditions the distribution of which must be considered. Such samples often are valuable for comparison of the same material at different times or places.

As the heterogeneity of the material increases, the number of samples needed increases. If we know that the sand on a seashore is uniform, then a single sample may be sufficient. If we suspect that the sand is not uniform throughout, then we will take samples at many different places. These can be mixed, and we can "sample the sample."

When differences among items must be taken into account, as in public polls, the investigator must be careful to see that the sample is representative. We must consider whether age, gender, occupation, economic status, education, religion, politics, and other factors influence the results. In this case, the sample constructed needs to be a cross section of the population. The bacterial content of water in a pond may vary in different parts of the pond and be affected by inlet or outlet, running or stagnant areas, surface or depth, vegetation and wind direction. In this situation, a sample from each area must be examined.

The Nature and Role of Models and Paradigms

The concept of models in science is an important one. Although models usually mean nothing more than pictorial, mechanical, or physical representations of things in the physical universe, they are successful in guiding scientific practices. It is useful to think of a model as a set of rules, or an algorithm. For example, a number of computer games are based on models that provide the logic by which decisions are made in the games even though the logic may not work in the "real" world. In science, models are often mathematical. The laws of physics and the techniques of calculus, for example, can be used to construct a model that will predict how objects behave when certain forces are applied under certain conditions. Its purpose is to enable scientists to "try out" a number of experimental conditions and to test hypotheses without actually manipulating physical objects. Often models are used to represent objects that are not actually seen by scientists, such as molecules and atoms. They allow scientists to make predictions and to hypothesize and experiment with things that are otherwise unavailable, thereby helping new discoveries to come about.

Models, however, are not the only thing which guide scientific practices. True enough, they are the tools by which scientific practices are made possible and scientific progress is advanced. But there is another sense in which science is guided. The very questions that are asked, the modes of investigation that scientists are inclined to use, the way they analyze data, and the way their findings supplement a larger body of theory are all a matter of the context in which these activities take place. For philosopher of science Thomas S. Kuhn,[4] the context or background of conditions, or set of fundamental assumptions, within which science actually takes place, is called a **paradigm**. Paradigms are not necessarily explicitly recognized by a scientific community. Nevertheless, they guide the way science is actually practiced. A paradigm guiding scientific activities is like a pipe through which water flows, directing it without necessarily being apparent to the flow itself. Paradigms are not merely the pictorial tools that are meant by models, but are the very picture itself, adhered to by the community of scientists, within which the world is interpreted. On Kuhn's view, "normal" scientific investigation proceeds within the framework of a reigning paradigm just as long as there are no new discoveries to challenge it. When that happens, as it did in the case of Einstein's theory of relativity, a crisis occurs and then the question is whether to adopt a new paradigm. Two persistent philosophical questions which may be addressed to scientists are: "Does today's science agree with reality as it *is,* or is today's science a current intellectual agreement among contemporary scientists?" and "Is all scientific knowledge limited to some degree of approximation, subject to ongoing refinement and correction?"

Adherence to a paradigm or model is at heart a matter of faith, of taking particular ideas for granted, however reasonable they seem. The fact that scientists of a given historical period, or individual scientists at any time, prefer one paradigm or model over others indicates that valuing is present in the selection process. Hence, science cannot be regarded as totally value free.

A Method of Acquiring Knowledge

The methods we considered earlier in this chapter are not separate and distinct; they are interrelated and supplement one another. In fact, it is not possible to use one of them apart from all the others. In a general way, we may say that *scientific method* is a collective term designating numerous processes and steps by which the various sciences are built up. Scientific method enables scientists to test their hypotheses, to determine whether rejection or conditional acceptance and further testing should occur; it is a way that scientific knowledge is accumulated.

To avoid a false impression, we need to recognize that scientific method cannot be reduced to an absolute formula or a master plan. As noted by one physicist:

> If by scientific method we mean the sequence and rule by which scientists now and in the past have actually done their work, then two truths soon become obvious. First, as for every task, there are here not one but many methods and uncountable variants and, second, even those different methods are for the most part read into the story after it has been completed, and so exist only in a rather artificial and debatable way. The everpresent longing to discover some *one* master procedure underlying all scientific work is understandable, for such a discovery might enormously benefit all fields of scholarship; but . . . this hope had to be given up.[5]

What follows, then, are general steps present in scientific method.

1. *Recognize that a problem exists and state the problem.* Thinking ordinarily begins when there is some definite obstacle, or difficulty, or possibly when we are merely curious about something. It is crucial to state the problem clearly and correctly. Without a clear statement of the problem, an investigator cannot proceed with the development of a hypothesis and subsequent steps of the research.

At this point it is helpful to state the major assumptions or postulates directly related to the defined problem. Whatever is taken for granted as true at the outset of research influences the development of a **hypothesis** and subsequent steps of investigation. For example, if a proposed study assumes that the results of a previous research project are valid, this assumption should be stated as a postulate.

2. *The available and relevant background information is collected.* Determine what else has been done about the problem or closely related problems. This material may be readily available or require considerable research and analysis. Occasionally, this step is minimized as an investigator leaps intuitively to step 3.

3. *A hypothesis is formulated.* Science has no real rules for thinking up an hypothesis, which is a proposed solution or possible explanation

stated in general terms. Hypotheses are often the result of a leap of imagination speculating on a certain problematic issue; they may occur to the scientist during research into background information. The investigator may make educated guesses as the problem is clearly stated. The researcher selects for testing the hypothesis that appears to be most probable on the basis of available evidence. There may be no limit to the number of hypotheses that may be set forth as possible solutions to a problem, but each must undergo the same rigorous investigation.

4. *Deductions are drawn from the hypothesis.* The principles of formal logic are used to decide what results would indicate the validity of a hypothesis; that is, if a hypothesis is true, it implies that particular consequences are observable and can be tested directly. The investigator predicts a result based on the hypothesis; that is, if A and B are true, then C must be true.

5. *An appropriate research plan is developed and implemented.* Having determined in the fourth step what else will be true if the hypothesis is true, the researcher then attempts to see whether these other conditions are true or actually occur. Empirical procedures for collecting and treating data (i.e., observation and other scientific methods discussed earlier in this chapter) are planned. Once developed, the procedures should be so clear that any qualified scientist could follow them and obtain the same data.

The data resulting from implementing the research plan are collected, organized, and classified.

6. *Verification is the final stage.* An interpretation of the data (which may include conclusions, generalizations, and applications) is developed. If this explanation corresponds to the hypothesis, the investigator is able to conclude that the hypothesis is confirmed or verified. Hypotheses that stand up to further empirical testing may eventually be considered scientific laws, principles, or theories.

A hypothesis is rejected when it is used to make a prediction that is not confirmed by the observed outcome. If a hypothesis is not verified, another hypothesis may be developed and tested.

Steps similar to these six are followed in any research study that requires reflective thinking and empirical verification. Those who claim that scientific method is limited are usually thinking of the more restricted approach, in which the material is objective and the results must be stated in mathematical or quantitative terms. For example, some people working in the natural sciences object to the use of the terms *science* and *scientific method* when applied to the social sciences, such as psychology, sociology, or economics.

Limitations of Scientific Methods

In our discussion in this section we are thinking of *science* and *scientific methods* in the more restricted sense—as the terms are used by most scientists in the natural sciences, in which the methods are strictly empirical and objective and the purpose is to interpret the world quantitatively and mathematically. We are assuming that scientists are free to investigate anything with which their methods are capable of dealing. The purpose of this section is not to urge that the sciences be kept out of any particular areas of human experience; rather, it is to indicate the limitations inherent in scientific methods.

If one reads widely in the literature of the sciences, many questions arise in one's mind. For example, why are there several psychologies, each claiming to be the valid approach and to represent the truth? What are the dominant factors in human behavior and social progress? Are they geographic, hereditary, psychological, cultural, religious, or economic, to mention a few of the possible answers? The conflicting evidence and claims are bewildering.

There are principles that will help to point up some of the limitations of science. Keep these suggestions in mind when considering science and scientific methods.

1. *In scientific research, you can find only that which your methods and your instruments are*

capable of finding. You can discover only that which is discoverable with the technique you use. This seems so obvious that one wonders why it is so frequently overlooked. If you use an objective method, you find only what can be stated objectively. If you proceed on the basis of the postulates of physics and chemistry, you find only what can be stated in physical or chemical terms. If you get in touch with your friend by telephone, you hear his voice; you get what the instrument transmits, and nothing more. If you investigate an object with a pair of scales, you get its weight. There may be other interesting things about it, but you are entitled to claim as scientifically valid knowledge only what your instrument and method are capable of giving you.

A number of scientists who proceed on the basis of the postulates of the physical sciences say that they never find such things as sensations, thoughts, or acts of will. Others have told us that they cannot detect purpose or meaning in any part of the universe disclosed by powerful telescopes. But should a person expect to find thoughts, acts of will, purpose, or meaning by looking through a telescope or using any scientific method?

2. *Scientific classification gives valuable information, but no single classification includes everything in the subject being classified.* Classification is one of the fundamental bases of scientific knowledge. We do not know what a thing is until we can classify it or put it into a meaningful context. If a thing cannot be analyzed and classified, it eludes science.

The kind of classification, however, depends on our purpose in making it. Things may be classified in many different ways. Buildings may be classified according to location, type, or valuation. Ill people may be classified according to their ailments, the doctors attending them, their ages, races, economic statuses, and so on. It is especially obvious in the case of ill people that classification is a means of dealing with things by the simple device of disregarding their differences. For example, several people with many different characteristics may all be classed as having typhoid fever. Scientific classification frequently includes details of the differences by the use of subdivisions or subclasses. However, the fact remains that the original classification was based on some one common characteristic. Therefore we are justified in asserting that simple classification treats a group of people or things that have certain qualities in common as if they possessed only those qualities. Scientists are entirely justified in doing this, if they do not forget what they have done.

3. *The whole may have qualities absent in the parts.* If we analyze an object, its elements or simple units are not more real than the object or event with which we began. Scientific method is concerned with breaking objects down into their constituent elements. Some people are inclined to believe that these simple units have a reality not possessed by the complex object. This may be called the **fallacy of reduction**, or reductionism. The explanations of science add something to our knowledge; they give us new facts or point out things that we would have overlooked otherwise, but they do not take anything away from the actual world. To explain is not to explain away. To explain the colors of the sunset as electromagnetic vibrations is not to explain away the sunset, but merely to analyze it, to add to our knowledge of the nature of light and colors.

If we analyze a living organism, we may not find life in the same sense in a particular part. Yet there is life in the total organism; the whole has a quality not found in parts.

Reductionism often leads to the *nothing but* syndrome. For example, "humans are nothing but a complex of biochemical mechanisms"; a possible implication is to equate human beings with rats, which are also a complex of biochemical mechanisms. Pondering, reflection, and decision making are not characteristics of biochemical mechanisms; the function of feelings is equally irrelevant.

When we analyze things into simple units, it is a mistake to believe that these units are more "real" than the whole of which they are parts, or of the same kind of reality as the whole. The real nature of things is found as much in wholes and in qualities as in parts or elements. The world that any science gives us may be a real world, but it is neither the whole world nor the only world. No one can interpret adequately any situation without considering it as a whole, as well as knowing its parts and the relations of those parts to one another.

4. *There may be many interpretations of a thing, a person, or an event, each of which is valid in certain contexts.* Each interpretation may be illuminating from one point of view. The farmer who sees the boys stealing his apples gets extremely excited. The psychologist describes the state of the man by saying that a stimulus has called forth an emotional response. The physiologist describes the reaction as accelerated heart action. The physicist may describe it by reference to the increased velocity of the molecules in the blood. A bystander may simply remark that the man is angry. Each is describing the event properly from her or his own viewpoint.

The uncritical attempt to explain or describe everything in one language or with reference to one principle or type of interpretation is one of the more frequent misuses of the scientific methods. It may be called the **fallacy of oversimplification**. It occurs whenever all things are thought to be exhaustively treated by inclusion in one single category. Examples of hasty oversimplification include the simplistic explanations of history or of human conduct. Some explain history solely on the basis of climatic changes, others solely on the basis of economic forces, and still others on the basis of biological factors. Human conduct has been explained entirely by genetic conditions, by psychological urges, and by environmental pressures. Although all these factors are important, we may well be suspicious of attempts to explain complex events with reference to a single set of concepts. There are multiple approaches to understanding our world.

5. *When we consider anything that is in a process of development, we find the later stages as real as the earlier stages, and the latter are probably more informative about the nature of the process.* A prevalent mistake is that of regarding what is earlier in development as more real than what follows. The genetic method, which traces things back to their beginnings, is useful if it does not cause us to neglect the more advanced stages. We cannot explain later stages adequately or fully by the earlier stages. If we could see the earth as it was many millions of years ago, we would be impressed by the fact that no life was present. Later we might see life but no human beings. Of the first view, we would say that only mechanical forces were present. It would be observed still later that living organisms were present. Eventually the process produced *Homo sapiens* with self-consciousness and a degree of intelligence.

Aristotle once asked how we should study an oak tree. Where should we start? Should we start with the acorn or the young sapling, with the tree in its maturity or in its period of decay? Clearly all the processes belong to the concept "oak tree," and a mere description of its parts or a cross section of it at any one period does not describe the unity of the organism. For Aristotle, reality was a process of development from potentiality to actuality. The later stages of an evolutionary process indicated most clearly the nature of the force or forces that have been present throughout the process.

6. *The sciences are dependent on our sense organs and our views of reality.* Scientific instruments are extensions of the human senses. We can increase the range of our senses with instruments such as the telescope, microscope, and computer, but we cannot provide new ones or change the nature of our organs.

When we observe, it is always with some "interest." We have a tendency to see what we are trained to see or expect to see. After we receive the image or the sensation, we have to move on to inference or generalization. This involves the logical operation of the human mind.

Observation and theories develop hand in hand. Different observations lead to different theories, and different theories lead us to make different observations. Science depends on the human sense organs and the processes of human reason. The "standpoint of the observer", the viewer's "frame of reference," is increasingly recognized in all fields. Because science is often said to be based on observation and experimentation, we emphasize again that scientific knowledge depends also on assumptions and postulates and that these in turn rest essentially on informed faith.

7. *The sciences cannot prescribe values.* The biological and physical sciences seek to describe and predict the empirical events within their spectrum; the behavioral and social sciences attempt to describe and predict many areas of human (and nonhuman) interaction. The biological and physical scientist might describe methods by which new life forms are created; the social scientist might describe trends and consequences of population growth. Neither scientist as *scientist* has a method by which she or he can provide what *ought* to be done; the value or moral issues are beyond the scientist's methods.

A scientist can, of course, *describe* objectively the values idealized and practiced by individuals and groups of people, but what *ought to be* is a prescription beyond scientific method. Furthermore, a scientist can point out that an object is "valuable" as a tool, but whether the object has intrinsic value is a nonscientific judgment. When scientists prescribe values, they are no longer restricting themselves to scientific methods; they are practicing philosophy.

Many sciences, perhaps all of them, employ objective, quantitative, and mechanical methods because of the greater accuracy of these methods. When they are used, however, the sciences are not telling the whole story. Scientific methods are among our most useful intellectual tools, but, like the others, they can be misused.

Philosophy and Science: Agreements and Contrasts

During the last few centuries, philosophy has developed in close association with science. Many of the outstanding philosophers have made important contributions in the sciences. For example, Leibniz shared in the discovery of the differential calculus. The contributions of Alfred North Whitehead and Bertrand Russell to mathematical theory are well known to students of mathematics and advanced philosophy. Both philosophy and science use the methods of reflective thinking in their attempt to describe the facts of the world and of life. Both exhibit a critical, open-minded attitude and an impartial concern for the truth. They are interested in organized and systematized knowledge.

Science supplies philosophy with a large amount of factual and descriptive material. Indeed, the philosophy of any period is related to the scientific outlook of that period. Science exerts a check on philosophy by helping to eliminate such ideas as are incompatible with scientific knowledge, and philosophy critically examines the foundations of science.

Philosophy takes the piecemeal knowledge of the various sciences and organizes it into a more complete and integrated world view. In this connection the progress of the sciences makes philosophy necessary, because the discovery of new facts and relationships forces us to revise our notions and interpretations not only in the sciences but in most other fields. For instance, the acceptance of the concept of evolution forced us to revise our thinking in nearly all other areas. Further contributions of philosophy to science are the criticism by philosophy of the assumptions and postulates of the sciences and the critical analysis of many of the terms used.

The contrasts between philosophy and science generally represent tendencies or points of emphasis, not absolute distinctions. Whereas particular sciences deal with restricted or limited fields, philosophy attempts to deal with the whole of experience. Philosophy thus attempts to gain a more comprehensive view of experience in general. Whereas science is more descriptive in its approach, philosophy is more synthetic, dealing with the properties and qualities of nature and life as a whole. Science attempts to analyze the whole into its constituent elements; for example, the study of a virus considers its smaller divisions as well as its interrelationship with the entire auto-immune system. Whereas science tends to eliminate the personal factor and to ignore values in its drive for objectivity, philosophy assesses personality, values, and all realms of experience.

Although there are many areas in which the scientist gives us much knowledge, there are other areas into which scientists do not venture, such as religious commitment, devotion, and worship; the values, ends, and purposes and meanings of life; beauty in the arts and literature; a life view and a world view that integrate human knowledge and insights, in which the scientist, as scientist, has no method of investigation.

Scientific Views of the Universe

The purpose of considering briefly some scientific views of the universe and life is twofold. First, these views are taken seriously by those philosophers who intend to incorporate scientific information into their philosophical positions. Second, readers unfamiliar with such information may gain a sense of awe about the cosmos as well as respect for the men and women engaged in scientific pursuits. How did the universe begin? Is the universe everlasting, without beginning and end, or will it someday cease to exist? Of what is the universe made? The study of these issues is **cosmology** (*cosmos* means "universe"). Questions about the origins, destiny, and basic structure of reality have occupied many thinkers since ancient times. Religions have offered conflicting answers; philosophers have contributed various explanations, and scientists propose differing interpretations of their findings.

What is "life"? How did life begin? To what extent is life present elsewhere in the universe? The study of the origin, nature, and extent of life has no widely used name; yet biologists, chemists, physicists and other scientists study these topics with whatever methods their instruments allow.

Scientific views of the universe and life contribute significantly to contemporary metaphysics. Once a matter of speculation and belief, the study of the nature of reality relies heavily on scientific inquiry. Let us consider some representative answers to questions about the origin, nature, and extent of life.

THE ORIGIN AND DESTINY OF THE UNIVERSE

The Steady State Theory. According to the steady state theory, the universe has always existed and will continue to exist indefinitely. Although the universe is expanding at a constant rate, its density remains constant because of the creation of matter out of nothing; newly created matter fills the expanding cosmos such that the density remains stable. This theory, also called *continuous creation,* is not widely accepted by contemporary scientists.

The Big Bang Theory. According to the modern big bang theory, developed in the 1930s and 1940s, the cosmos began with a gigantic explosion. As long ago as twenty billion years, the universe burst forth from a singular state of unimaginable density and high temperatures. In the course of that event—called the big bang—space and time were created and all the matter in the universe released; today's expanding cosmos is the result of that initial explosion.

According to the essential elements of the big bang theory (which has more than one interpretation), there are two possible destinies for the universe. The first theory asserts that the cosmos is constantly expanding, although at a progressively slower rate. Such an *open* universe eventually will cool off, the stars will burn out, and space will become a giant cemetery of dead stars and other matter, with neither heat nor light.

Equally bleak is the second theory, that of a *closed* universe: the cosmos at some distant time will contract and form a fireball that resembles its origin. An 80-billion-year periodic cycle of big bangs and contractions pulsates from explosion to explosion, from evolving universe to evolving universe. This theory is frequently called the *pulsating cosmos.*

One troublesome question can be put to the proponents of the big bang theory: Why does the universe appear so uniform? Another question revolves around what happened in the first instant following the gigantic explosion. The inflationary-universe understanding of the big bang theory rests on the idea that, shortly after creation, the new universe went through a brief and extremely rapid expansion, before and after which everything expanded at a relatively slow rate. For contemporary physicists and astronomers, this inflationary theory solves some of the complex scientific problems inherent in the big bang theory.

Unanswered Questions. We have been considering a metaphysical issue, the origin and destiny of the universe; but is it not possible that several parallel universes bubble up rather than explode with one or more initial big bangs? Might such universes be connected in some way? In a scientific view assuming cause-and-effect relations, what caused the big bang? What caused the cause of the big bang? What caused the "state of unimaginable density" to exist in the first place? Why is there something rather than nothing? How fast is the universe expanding? How did the initially smooth universe become so clumpy with various galactic structures? How old is the universe? Are there dimensions to the universe besides three of space and one of time? These questions are among those facing cosmologists today.

THE NATURE OF THE UNIVERSE

The Expanse of the Cosmos. The immensity of the universe is beyond our imaginations. Our planet is a small part of the solar system. As far as we know, the solar system consists of one star (the sun), nine planets, thirty-two moons, about 50 thousand asteroids, millions of meteorites, 100 billion comets, dust specks, and an assortment of gas molecules and atoms. Yet 99.86 percent of the solar system's substance is contained in the sun. Our planet represents only .0014 percent of the substance of the solar system.

Our sun, which has a diameter of 864,000 miles (the earth has a diameter of just under 8,000 miles), is one of 100 billion suns or stars in our galaxy, the Milky Way. This galaxy stretches for about 920 quadrillion miles. About 100 billion galaxies of different shapes dot the universe.

The earth is traveling 67,000 miles per hour in its annual journey around the sun. The Milky Way galaxy speeds along at 1.3 million miles per hour, propelled farther into an expanding cosmos. Every four seconds the universe adds to itself a volume equivalent in size to the Milky Way!

Nature of Matter. Equally fascinating are the matter and energy studies that investigate the minute parts of our world. We might ask, why should a stone or a tree or a human hand be analyzed into anything different from a stone or a tree or a human hand? There are several reasons. First, particular things, such as stones, trees, human bodies, oceans, and land forms undergo alterations. Processes such as growth, decay, weathering, and erosion are always taking place. Second, physical objects undergo or are affected by inner transformations of various kinds. Under certain conditions they may pass back and forth between solid state, liquid state, and gaseous state. Third, although we can have contact or have experience with particular physical objects through our various sense organs, we cannot experience matter itself. **Matter** is the substance of which any physical object is composed.

During the sixth and fifth centuries B.C.E., certain people became curious about the nature of the world. They started a new line of thinking and investigation that, by various paths, led to our modern conceptions of matter. To trace this development in any detail would carry us too far afield and would embrace a considerable portion of the history of philosophy and science. However, early in the nineteenth century, when chemists and physicists were again turning their attention to the constitution of matter, John Dalton proposed, as Democritus had in the past, but on new knowledge, a possible explanation of certain chemical and physical actions and reactions.

Two methods of studying the nature of matter have been used side by side: that of chemical and physical analysis, with instruments and apparatus, and that of mathematical or logical speculation.

Careful and elaborate research has revolutionized our views of the material universe and ushered in the nuclear age. Many able investigators have offered both mathematical and empirical evidence in support of the view that the atom is an exceedingly complicated system—one might say it is "a little world in itself."

Quarks and Gluons. In the first half of the twentieth century, a picture of the atom as a miniature solar system developed. At the atom's center is the nucleus (like the sun), consisting of a cluster of relatively massive particles called protons and neutrons. Around the nucleus spin the electrons, one for each proton in the nucleus. As research progressed, other particles, known as elementary particles, were discovered. In 1964, quarks (considered the most basic constituent of matter) were proposed as the mathematical and possibly physical bases of the relationships among subatomic particles; experiment has also indirectly suggested their existence. Some physicists are still not sure whether quarks really exist; they might be merely inferred mathematical abstractions that help explain the behavior of the particles they supposedly constitute. (A few scientists posit a prequark structure.)

The significance of quarks was first implied by the Roman philosopher Lucretius, when he proposed that the succession of things inside other things had to end. Lucretius' argument, however, was for indivisible atoms as the "end." Some physicists believe that with the discovery of quarks, the end is at hand, that the fundamental structure of all matter has been established.

Theoretically, quarks are structureless; there is no division within them. They are at the base of all material structure. There are thought to be six types of quarks. In 1979, gluons were proposed as the embodiment of the force that holds quarks together. Although quarks and gluons are not directly observable, their existence is supported by the behavior of the particles they constitute. Gluons carry the strong nuclear force, which holds the nucleus of an atom together and is one of the four forces of nature. The other three forces are the weak nuclear force (responsible for radioactive decay), the electromagnetic force, and the gravitational force. Physicists are searching for one underlying force for all four, a unified theory of the four forces of nature, which would be as fundamental a statement of the universe's laws as scientists can currently conceive.

At the fundamental level of quarks, matter may be dematerialized; the extent to which quarks can be called material is under discussion. Also being studied is the extent to which order, predictability, chaos, and chance are characteristic of subatomic reality.

The principle of indeterminacy has been widely accepted among scientists and has influenced thinking in philosophy. Realities beyond appearances at both the macrocosmic and microcosmic levels have fascinated thinkers since ancient times through today. At either level, the issues of space, time, and relativity are considerations.

SPACE–TIME AND RELATIVITY

Space and Time. Views of space and time have changed as the horizons of human knowledge have been extended. The terms *space* and *time* each are used with two different meanings. *Perceptual* space is the space in which we live and move—for example, the distance between objects and the areas through which these objects move. Perceptual *time* is the time we experience day by day as we make and keep appointments. These experiences are parts of direct awareness or sense perception.

Conceptual space and time are the idealized space and time of mathematics. They are that to which philosophers refer when they ask whether space and time are limited or unlimited, subjective or objective. Apart from a few philosophers like Immanuel Kant, who argued that space and time were categories of the human mind or ways in which the mind perceives and organizes the world, most thinkers until recently have thought that space and time were real, separate entities, albeit entities of a special kind.

The traditional view not only described space and time as fixed and definite, but as experienced in essentially the same way by all normal people. Although motion takes place in space and time, the latter were not thought to be materially affected by the motion. Space was distinguished by the property of extension in all directions, and all the elements and units of space were of the same nature. Time was characterized by duration, and each instant or division of time was similar to every other bit of time. Until early in the twentieth century, the traditional views of space and time were not seriously questioned.

As a result of the investigations of a number of scientists in the late nineteenth century and the early decades of the twentieth, great changes were taking place in human thinking about space, time, motion, and the like. With the verification in 1919 of some of Einstein's predictions, the theory of relativity came to be almost universally accepted. Soon people were talking about space–time, the curvature of space, relative motion systems, and frames of reference.

Relativity. What is meant, in simple terms, by the notion of relativity? Consider some common human experiences. A man standing on the bridge of a wide river, looking over the railing at the water below, may get the impression that the river is standing still and that he and the bridge are moving. Many persons have had the peculiar experience of sitting in a plane at an airport and receiving the impression that the plane is moving, only to find in a moment or two that it was a nearby plane that was in motion. Again, a woman leaning over the rear of a moving boat may suddenly get the sensation that she is at rest and the water is moving. Until we can see some other "fixed" object, we cannot trust our perceptions.

The theory of relativity arose from the need for a frame of reference—a standard that scientists could use in analyzing the laws of motion. The need for such a standard is apparent when we ask ourselves "Motion with respect to what?" One central precept for relativity is that there is no "correct" place from which to view the universe; there is no "God's-eye" view of things; every observer sees the same laws of nature.

Albert Einstein (1879–1955) (see biography and excerpt, pp. 232–233), through his special and general theories of relativity, showed that absolute space and absolute time do not exist. The space–time continuum consists of four dimensions, including the three space dimensions and time on an equal footing. The presence of matter in space causes space to "curve," forming gravitational fields—a property of space itself.

In 1905 Einstein proposed a special theory of relativity (called special because it refers to a special kind of motion) based on two postulates: the *special relativity principle* and the *constancy of the speed of light.*

The *special relativity principle* is limited to the description of events as they appear to observers in a state of uniform, relative motion; it assumes that absolute speed cannot be measured, only speed relative to some other object; the motion of one object can be defined only with respect to that of a second object; no absolute meaning can be given to the statement that an object is at rest. All observers moving at constant velocities with respect to each other should find the same laws of nature operating within their frames of reference. For example, experiments done within a moving laboratory (a plane or train) are completely unaffected by the laboratory's motion, provided it continues to move in a straight line at a constant speed. In fact, no experiment carried out inside a closed laboratory can reveal the speed at which the lab is moving.

The second postulate of the special theory of relativity proposes that the *speed of light* appears to be the same to every observer; the speed of light is always the same no matter how fast the observer or light source is moving. For example, if an observer is approaching a light source at 100 miles per hour or 100,000 miles per hour, the speed of light will be 186,000 miles per second in either case. Implied in this postulate is that the maximum velocity that can be attained in every frame of reference in the universe is that of light; we can accurately describe relative motion by using the speed of light as a basis.

Among the consequences of accepting the two postulates of special relativity are length contraction, mass increase, and time dilation. As the speed of an object approaches the speed of light, its length—along the direction of motion—decreases, it becomes heavier, and time measured on its clock runs more slowly than time measured on the clock of a "still" observer; events occurring simultaneously according to one observer may happen at different times according to an observer moving past the first. Experiments carried out in particle accelerators have confirmed these postulates.

In 1915 Einstein extended his special theory to a general theory of relativity applicable to all observers not in uniform relative motion; this led to an elaborated concept of gravitation; it states that all observers, regardless of their state of motion, see the same laws of physics operating in the universe. This general theory attempts to show that the structure of space is determined by matter, thus eliminating "absolute space," and that the laws of physics are the same everywhere. This general theory treats gravity not as a force that acts directly across empty space between bodies (the Newtonian view) but as an apparent force that arises because the presence of matter in space causes space to curve, forming gravitational fields; thus, gravity becomes a property of space itself. Therefore, bodies and even rays of light follow curved paths near massive bodies, and clocks run slow where gravity is strong, and light becomes redshifted (stretched in wavelengths) when moving up through a gravitational field. These effects have also been confirmed by observation and experiment.

The implications of the special and general theories of relativity show that no frame of reference for observations of nature is more privileged than any other.

The Origin and Nature of Life

As we look around ourselves, we are impressed by the amazing variety of living things on and in the earth, the waters, and the air. The microscope discloses a further world of life. Living forms seem to occupy almost every conceivable place in nature. How do organisms differ from the inorganic processes that we have been considering? Where did life come from, and what are some of its characteristics?

Since early times, people have observed that living things tend to reproduce their kind. Does all life come from one source or are all the different kinds of life separate and distinct in origin? There have been several theories.

1. *All matter is alive,* and there is no need to make any rigid distinction between organic and inorganic matter. This view, held by a number of early Greek thinkers, was known as *hylozoism.* The discovery of viruses, filter passers, and the like, and the knowledge that living and nonliving matter are composed of the same elements, tends to make the separation seem less rigid.

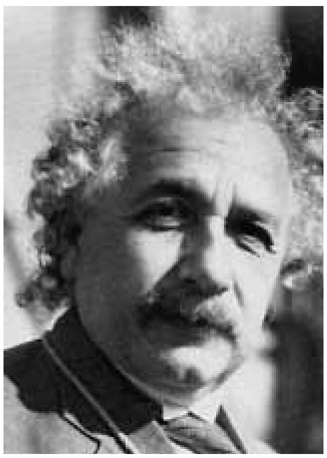
2. The notion of *spontaneous generation* appears in the writings of Lucretius in the first century B.C.E. This concept was held by many people until about 1860, when Louis Pasteur proved fairly conclusively that it was false. He compared sterilized and unsterilized liquids and demonstrated that microorganisms are carried in the dust-laden air.

3. The idea of *panspermia,* that life originated other than on earth and arrived here by space-traveling spores, and the view that chemical building blocks for life arrived from space, have been revived recently. Panspermia transfers the problem of life's origin elsewhere but does not answer the fundamental question of how life originated.

4. Based on a literal reading of biblical material, there is the belief in *direct creation* by a special act of God, which confines the entire creative process to six days of twenty-four hours each (Genesis, Chapter 1:1–2:4a, but not Genesis 2:4b*ff.*). There also have been attempts to mediate between biblical and modern scientific accounts by the use of explanations like the geological-day interpretation theory (that "day" means a geologic era). To many people, these views fail to do justice to the biblical or to the scientific accounts of creative processes.

5. *Present living forms, including humans, originated through a gradual process of develop-*

Albert Einstein



Albert Einstein (1879–1955) was a German-born Swiss–American theoretical physicist and mathematician. He studied at Zurich's Federal Institute of Technology and received his doctorate from the University of Zurich. From 1913 to 1933, he taught at the University of Berlin. Deprived of citizenship in 1933 when Hitler came to power, he came to the United States and accepted a position at the Institute of Advanced Studies, Princeton, where he spent the rest of his life.

The most important consequence of Einstein's theory of relativity for philosophical thought has been the change in concepts of time and space. He destroyed the assumption that there is an all-embracing time in which all events in the universe have their place. Einstein proved that there is no experiment capable of determining absolute motion. Because time and space are measured separately, there always remains a degree of subjectivity that not only affects human observers but all other things. Time and space are dependent on each other, forming a relationship that can be analyzed in many different ways. Time had previously been regarded as a fixed cosmic measure. Einstein introduced the idea of local time connected with the earth's motion.

His works include *Groundwork of the General Theory of Relativity* (1919), *The Meaning of Relativity* (1921), *On the Method of Theoretical Physics* (1933), and *Out of My Later Years* (1950).

ment. This does not rule out the idea of creation by God, if God is interpreted as the creative agency, although the idea of a special act of creation at one time or place would be rejected. Life seems always to arise from life. If, as the story is pressed back, the distinction between animals and plants and between living and nonliving forms tends to disappear, and if living matter was, at some time, created from the nonliving, it need not seriously affect our general outlook on life. The chief effect could be to increase our appreciation of what has been called "nonliving" matter. Philosophers and scientists today, with few exceptions, believe that the living forms on earth developed through some process of evolution.

Recently it has been suggested by some scientists that life may have evolved repeatedly during the Earth's first billion years, only to be obliterated by periodic, rare impacts by asteroids.

Human Beings and Evolution

Advances in the physical sciences, especially those connected with the new power from nuclear fission and fusion, have been spectacular. But perhaps they are no more important in the long run than advances in the life sciences, which have great implications for our understanding of humans. New knowledge in the life sciences

Excerpt from Einstein:

The World As I See It, "The Religiousness of Science" (1934)

You will hardly find one among the profounder sort of scientific minds without a peculiar religious feeling of his own. But it is different from the religion of the naive man. For the latter, God is a being from whose care one hopes to benefit and whose punishment one fears; a sublimation of a feeling similar to that of a child for its father, a being to whom one stands to some extent in a personal relation, however deeply it may be tinged with awe.

But the scientist is possessed by the sense of universal causation. The future, to him, is every whit as necessary and determined as the past. There is nothing divine about morality; it is a purely human affair. His religious feeling takes the form of a rapturous amazement at the harmony of natural law, which reveals an intelligence of such superiority that, compared with it, all the systematic thinking and acting of human beings is an utterly insignificant reflection. This feeling is the guiding principle of his life and work, insofar as he succeeds in keeping himself from the shackles of selfish desire. It is beyond question closely akin to that which has possessed the religious geniuses of all ages.

Einstein, *The World As I See It,* trans. A. Harris (New York: Philosophical Library, 1949).

gives rise to philosophical problems of primary importance, as we shall see.

ORGANIC EVOLUTION

Evolution in the biological sense, or organic evolution, is a process of growth or development of all forms of life. It means that "the present is the child of the past and the parent of the future." The theory of organic evolution posits that the plants and animals we see about us today are the descendants of ancestors that were, on the whole, somewhat simpler. These ancestors were the offspring of still simpler ancestors, reaching back for millions of years to exceedingly low forms of life or to life's beginnings. The numerous species of animals and plants have developed by natural descent, with modification, from previously existing types. In general, the theory is that life proceeds from the simple to the more complex or from the lower to higher forms. The term *higher* here means increased structural complexity and range of functions or powers. *Evolution* is the name for this process of change; a theory of evolution is an interpretation of how the process occurs. Theories of evolution attempt to identify the major factors that have produced new species. Though the fact of evolution is well established by a large body of evidence (see Evidence for Organic Evolution below), there is much debate among scientists over the theory of evolution. (We must keep in mind that a *hypothesis* is a proposal or informed guess with research yet to be completed; a *theory* is a confirmed hypothesis, an explanation of evidence gathered by means of research.)

To understand this process of change, we will examine the term **Darwinism.** In the narrow sense, Darwinism refers to a theory of organic evolution presented by Charles Darwin (1809–1882) (see biography and excerpt, pp. 236–237) and by other scientists who developed various aspects of his views. We call this narrow sense *biological Darwinism.* In the broad sense, Darwinism refers to a collection of scientific, social, theological, and philosophical thought that was historically stimulated by Darwin's theory of evolution.

Natural Selection. The most important feature of Darwin's theory, and the most important single contribution ever made to the understanding of evolution, was the idea of *natural selection.*

Darwin, extending the ideas of the Reverend Robert Malthus to all species, noted that populations increase rapidly, and if unchecked will exceed the means of support—especially food resources—available for the species. As a result of this overpopulation, a struggle for survival ensues, to be resolved by natural selection. "It may metaphorically be said that natural selection is daily and hourly scrutinizing, throughout the world, the slightest variations; rejecting those that are bad, preserving and adding up all that are good; silently and insensibly working, whenever and wherever opportunity offers, at the improvement of each organic being in relation to its organic and inorganic conditions of life."[6]

In Darwin's original theory, natural selection played both a negative and a positive role. In a species whose members were unable to adapt to changed circumstances, natural selection would lead to extinction. Where a sufficient number of members of the population were able to adapt ("survival of the fittest"), natural selection would lead to species transformation. Darwin argued that those individuals which possessed chance variations favored by the new and unpredicted environment would be selected and survive. They would tend, by the laws of heredity, to pass these novel characteristics to their offspring. As the result of many such combinations of chance variations and selections for changed environments, a modified population would result. Biologists considering this process of "descent with modification" would classify the later population as a species distinct from the ancestor one. In this way, the process of natural selection would lead to the origin of a new species.

Although Darwin, in *Origin of Species,* placed the greatest weight on evolution by natural selection, he cited two additional factors that, in conjunction with natural selection, affect the evolution of populations: sexual selection and the inheritance of characteristics acquired during the lifetime of the individual organism.

Sexual Selection. The second mechanism of evolution was described by Darwin as the "struggle of males for females." This is a special case of a more general phenomenon: selection in favor of a characteristic that will increase the tendency to produce young will occur even though it may not be favored by natural selection. All such cases Darwin calls *sexual selection.* It is clear that different sorts of characteristics can influence the probability of having offspring. Darwin regards sexual selection as especially significant in the evolution of human beings. The loss of body hair, for example, is attributed to systematic choice by our ancestors of mates who exhibited large regions of bare skin.

Inheritance of Acquired Characteristics. Because Darwin predated the clear formulation of the concept of mutation, the modern theory of the origin of genetic variation was not available to him. Consequently, he suggested that some variations are due to the action of the environment on the germ plasm and that others are due to the effects of use and disuse. For example, if an animal's skin is tanned by sunlight, this might result in changes in its germ plasm that would result in its offspring possessing pretanned skin; or, if a wolf developed its muscles by chasing rabbits, its pups might inherit larger muscles. These mechanisms, if they exist, would account for some variability. But they would also account for some evolutionary change even in the absence of natural or sexual selection. Darwin stressed the inheritance of acquired characters as an aid in explaining both variability and evolutionary change. Although now defunct, this theory had a strong influence on further progress in the study of evolution and contributed significantly to present understanding of the subject.

Darwinism and Genetics. Darwin's theory of natural selection as the chief (but not the sole) factor of evolution was criticized even by his contemporaries. Some, such as the co-founder of the theory, Alfred Russel Wallace (1823–1913), believed that natural selection alone sufficed, whereas others, such as Darwin's collaborator on animal instincts, George John Romanes (1848–1894), added additional factors, believing natural selection to be inadequate for the production of new species. A major weakness in Darwin's work was his theory of heredity, as he was unaware of the contemporaneous work of Gregor Mendel (1822–1884), who in 1865 discovered the basic laws of genetics.

The new science of genetics was based on the idea of "characters" that arose as a unit and could be transmitted whole from one generation to the next, and it rapidly replaced the outmoded concept of partial transmission of characters upon which Darwin had largely based his theory of heredity.

The study of genetics, the modern science of heredity, has increased our understanding of both life and the theory of evolution. The bearing of genetics on the theory of evolution has to do with the phenomenon of *mutations,* the abrupt, random changes in heredity observed by geneticists; to explain evolution on this basis alone is *mutationism.* When we look more closely at the random elements in evolution, we discover that it is impossible for evolution to occur entirely at random; there is more to it than accident and chance.

In the period from the mid-1930s to the mid-1940s, Mendelian genetics was reconciled with Darwinian natural selection in what is now termed the "modern synthesis." This theory (sometimes called neo-Darwinism) combined the stepwise process of genetics with the cumulative process of selection, and is widely, though not universally, accepted among biologists today. Some biologists, such as Stephen Jay Gould, have proposed alternative theories of evolution. According to Gould's theory of "punctuated equilibrium," many species do not change over long periods of time—the "equilibrium" which produces a new species in a relatively short geological period of time (5,000 to 50,000 years). Other biologists argue that evolution is not an entirely random process—that evolutionary change does have an orientation or direction. Once a certain sort of structural change has started in a given group, it tends to continue until the group becomes extinct or gives rise to a new species. Although all biologists accept evolution as a foundation fact for their science, they disagree—as is normal in science—concerning theories to explain that process.

Evidence for Organic Evolution. For about two hundred years, the evidence for evolution has been accumulating. The main fields from which the evidence has come include:

1. *Comparative anatomy.* This is a study of the structural correspondence (bones, muscles, bodily organs, and the like) that exists among the great divisions of animals.

2. *Study of vestigial remains.* In some lower animal forms, these vestigial remains—organs and glands—continue, but they have lost their function or use in later or higher forms.

3. *Embryology.* Embryology consists of a study of organisms in the early stages of development from the fertilized ovum. The embryos of the different species of animals tend to be similar in the early stages.

Charles R. Darwin

Charles R. Darwin (1809–1882) was a British naturalist whose theory of organic evolution through natural selection led to great changes in the biological sciences, philosophy, and religious thought. Educated at Edinburgh and Cambridge Universities, he joined a British expedition aboard the H.M.S. *Beagle* for a five-year study (1831–1836) of the plants, animals, fossils, and geological formations at widely separated points on the globe, mainly the coast of South America and islands in the Pacific Ocean. His *Origin of Species* (1859) and *Descent of Man* (1871) gave factual evidence for the view that species are related in ascending order and that humans came from the same group of animals as did the chimpanzee and other apes. However, he never asserted that we descended *from* the apes. Darwin's writings led to heated debates that still continue today.

4. *Blood and fluid tests of animals.* These tests tend to confirm relationships among the various species.

5. *Examination of fossils.* Fossil forms or other remains of extinct forms of animals, and of early stages of animals that exist today, have been preserved in the earth's crust.

6. *Study of geographical distribution.* The location and distribution of the plants and animals in the various parts of the world seem to be explained only on the basis of evolution.

7. *Domestication and experimentation.* By various methods of selective breeding, it is possible to do in a short time what the slower processes of unmanipulated nature might do over a long period of time.

8. *Classification.* Animals are arranged in an ascending order of complexity from unicellular organisms to humans.

What is sometimes said to be the *strongest argument for evolution* is the fact that the evidence from these various fields of research dovetails, or fits into a single pattern, thus forming one united theoretical whole.

Excerpt from Darwin:

Voyage of the Beagle, Chapter 5 (1839)

A very singular little bird, Tinochorus rumicivorus, is here common: in its habits and general appearance, it nearly equally partakes of the characters, different as they are, of the quail and snipe. The Tinochorus is found in the whole of southern South America wherever there are sterile plains, or open dry pasture land. It frequents in pairs or small flocks the most desolate places, where scarcely another living creature can exist. Upon being approached they squat close, and then are very difficult to be distinguished from the ground. When feeding they walk rather slowly, with their legs wide apart. They dust themselves in roads and sandy places, and frequent particular spots, where they may be found day after day: like partridges, they take wing in a flock. In all these respects, in the muscular gizzard adapted for vegetable food, in the arched beak and fleshy nostrils, short legs and form of foot, the Tinochorus has a close affinity with quails. But as soon as the bird is seen flying, its whole appearance changes; the long pointed wings, so different from those in the gallinaceous order, the irregular manner of flight, and plaintive cry uttered at the moment of rising, recall the idea of a snipe. The sportsmen of the *Beagle* unanimously called it the short-billed snipe. To this genus, or rather to the family of the Waders, its skeleton shows that it is really related.

C. Darwin, *Journal of Researches into the Natural History and Geology of the Countries Visited during the Voyage of H.M.S. Beagle* (New York: Heritage Press, 1957).

MISINTERPRETATIONS OF EVOLUTION

To understand clearly what evolution is, we must rid ourselves of some prevalent misconceptions.

1. *We are not descendents of the apes.* First, the theory of evolution does not mean or imply that all living forms are tending toward *Homo sapiens* or that any present species is changing into any other species. It does not mean that we "came from" the monkey or are a "made-over monkey." We have had a long ancestry, extending back through earlier species. Although apes and humans likely have common ancestors, the ape is not our ancestor. The other mammals that exist today have also had a long ancestry. Most students of evolution illustrate the relationships among living creatures by a tree with many long branches. Once a branch has been separated from the trunk, or main branch, it does not return; it goes off in a new and separate direction. Existing species are represented by the tips of the branches only. Many of the branches probably have reached "dead ends," so to speak. A few others have died and disappeared in the past.

There is no possibility of any present species of animal giving rise to animals that are in a different evolutionary line. To locate connections and relationships, it is necessary to delve into the distant past.

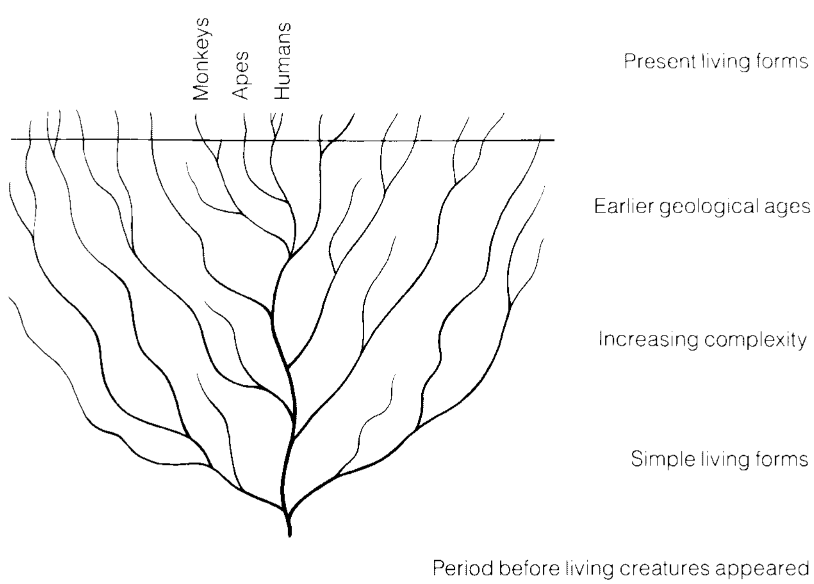
2. *The theory of evolution is not synonymous with* Darwinism. Darwinism is one explanation of how one species may have arisen from another. A few years ago, when an outstanding scientist said that he did not accept Darwinism, he was quoted, incorrectly, as stating that he did not believe in evolution. One may reject Darwin's explanation of how one species arose from another, as many do, and still accept the theory of evolution.

3. *The theory of evolution is not an explanation of the origin of life.* It is the theoretical interpretation of a process, or a description of the mechanisms by which one species was derived from another. Such interpretations may be mechanistic, vitalistic, or teleological; they may be nontheistic or theistic. Just as a knowledge of the development of the individual does not imply any single attitude toward life, so an acceptance of the theory of evolution does not in itself force on us any single philosophy of life or any one interpretation of the universe.

4. *The theory of evolution is not necessarily a denial of religion and of belief in God.* If you do not find it difficult to believe in God when you know that the individual has come to adulthood as the result of a slow process of growth, why should the knowledge that humanity has been the result of a process of development cause so much concern?

Keep in mind that the theory of evolution does not explain the origin or the nature of life and the will to live. Philosophically, natural selection leaves much unexplained. Natural selection is not the creative factor in evolution; it is a mere act of sifting or eliminating forms of life that cannot cope with the environment. Natural selection guides or selects variations, but it does not create these variations. (See earlier discussion on p. 234.)

The terms *competition,* the *struggle for existence,* and the *survival of the fittest,* used in the discussion of evolution, also need to be criticized



Simplified Genealogical Tree of Animals

and evaluated carefully. Both competition and cooperation are present in nature; competition and struggle by no means tell the whole story. The "survival of the fittest" may mean only that those who survive are able to survive in some particular environment, and this may depend on various chance factors. There are many degrees and types of adaptation as well as of fitness. In some environments, only low forms of life can survive.

Although the evidence for organic evolution appears to be conclusive, some people remain unconvinced. Historically, most of the opposition has come from a branch of religious conservatives, known as *fundamentalists,* who have defended a literal interpretation of the account of creation contained in Genesis. Early Roman Catholic opposition was modified in later pronouncements, especially by the *Papal Encyclical* of 1951. The mainstream of Protestants accepted evolution, whereas various fundamentalist groups took a stand against it in denominational conventions and state legislatures. The controversy came to its peak between 1920 and 1930, and especially during the Scopes trial in Dayton, Tennessee, in 1925.[7]

There has been a recent resurgence in this country of *creationism,* or *creation science.* It is important to distinguish this view from others that have preceded it, such as the nineteenth-century theory of *special creation,* which asserted that God in some way *directly* intervened in the order of nature to originate each new species. Darwin was extremely hostile to special creation in his *Origin of Species.* Contemporary creationists assert that they have an alternative scientific view to the theory of evolution based on the "biblical account of creation," by which they mean, of course, the account found in the first chapter of Genesis, in which all of creation lasts six days. They regard the description of the creation in Genesis as a genuine scientific alternative to the theory of evolution, and want it to be taught as such in the public schools of the United States. Recent court decisions in Arkansas and elsewhere, however, have rejected "creation science" as a disguised form of religious teaching, and have concluded that as a consequence it cannot be given "equal time" with evolution in science courses.

One response to the creationists' assertion is that their views are neither biblical nor scientific. Biblical scholars in major universities point out that there are several other accounts of creation in the Bible; for example, both the Book of Job (Job 38:7) and Proverbs (Proverbs 8:22–31) contain descriptions of creation. To call one account the "literal" one, they believe, is arbitrary and whimsical. The conclusion of those who support evolutionary theory and biblical thought is that nothing in the long history presented in the Bible on the subject of creation precludes the findings of modern science.

SOME QUESTIONS ABOUT EVOLUTION

Millions of stars in the Milky Way may have habitable planets; this magnitude is a possible truth for other galaxies as well. Whether intelligent life or simple forms of life exist elsewhere in the cosmos is not known. If intelligent beings are discovered on some distant planet, the psychological effect on humanity would be substantial; a reassessment of the place and significance of human life in the universe would be on our philosophic agenda.

As scientists look for the origins of life by means of laboratory experiments and space probes, many questions remain unanswered. Although we may discover the origin of the constituent building blocks of life, that is not the same as discovering the origin of life itself. We wonder how these building blocks came together as a living entity, that is, how they were able to reproduce themselves. How was the transition made from chemical evolution to biological evolution and natural selection?

Currently, scientists believe that the earliest signs of life on our 4.5 billion-year-old earth occurred between 3.5 to 3.8 billion years ago. "Recent life," including that of mammals, is only 70 million years old; *Homo sapiens* emerged less than 250,000 years ago. But the reasons for the rates of evolutionary change of life; how the fertilized egg becomes the developed organism, and what kinds of information are built into the human nervous system are not completely known.

Reflections

SCIENCE AS EXPLANATION AND TECHNOLOGY

Science is founded on informed faith in particular views of the universe. The precise expanse and nature of the universe as well as the origin of its natural laws are mysteries. It is possible that these mysteries will remain issues of faith or theoretical hypotheses, forever beyond direct observation and experimentation.

Contemporary scientists are far more modest in their claims of certainty than citizens anxious to invest all-knowing certitude in anything or anyone "scientific."

Schools of thought are found in the physical and social sciences, and surprising to many persons, in mathematics.[8] Not even Einstein's theory of general relativity is beyond revision; other interpretations offering more refined explanations may be developed. For any scientific explanation to be adequate, it must accommodate new data obtained by reliable scientific methods. More than one interpretation of data can be expected on most issues; high degrees of probability seem to be more attainable than certainty.

During the last century, applied science took us from the motor car to interplanetary probe, from the nucleus of the atom to the edge of the universe, from deciphering the genetic code to personal computers in homes. The interplay between basic and applied science has broadened the scope of both disciplines. In the area of technology, we have seen the ongoing development of sophisticated methods of communication, transportation, and entertainment. As a result of medical knowledge and technology, the average human life span has increased significantly, and the average American lives in better health and comfort than did any nineteenth-century monarch.

Critics of technology frequently blame both pure science and technology for the bomb, pollution, futile prolongation of life in terminally ill patients, exploitation of limited natural resources, and inaccurate bills generated by a computer. But technology is neither blameworthy nor praiseworthy; human beings and their decisions deserve the criticism. Human error causes computer error; humans invent lethal weapons. The bewildering array of options offered by science requires human competence and judgment to make well-informed and moral choices.

CONTEMPORARY PHILOSOPHY OF SCIENCE

In this chapter we have been introduced to the history of science, philosophy of science, and scientific views of the universe and life. Historians of science continue their research, as do pure and applied scientists. Philosophers of science continue to study the methods by which science is able to progress and make advances in human knowledge. The standard philosophical approach is that science—with its methods for hypothesizing, testing, and confirming hypotheses as theories, laws, and principles about our world—provides us with a steady progress in the accumulation of knowledge; this approach is being debated vigorously among philosophers of science. Dissatisfied with the standard view, some philosophers are studying the extent to which science and scientific knowledge are conditioned by the human community in which research is carried on. They are also challenging some of the basic assumptions that underlie scientific methods and scientific laws. Other issues under examination today include (a) whether scientific theories, when held to be true, give an exact analysis of a reality independent of those theories, or is it impossible to posit a reality independent of t he human minds that are aware of it? (b) the relation of science and religion: are the two types of knowledge contradictory? complementary? independent from each other? (c) the role of mathematics in science: why are the laws of nature formulated in mathematical terms; is this necessary or merely convenient? and (d) the role of major scientists—from Aristotle to Newton to Einstein to current theorists—in particle physics, cell biology, evolutionary theory, and the neurosciences.

As such, philosophy of science is in a state of turmoil. It has become difficult for philosophers to be able to agree on the criteria by which scientific knowledge can be held as certain truth. Some philosophers still hold to the view that science is steadily progressive in the accumulation of knowledge, while others are of the opinion that there are discontinuities and "leaps" in the process brought about by changes in paradigms so that the question has been raised whether we can think of Newton and Einstein, for example, as referring to the same "world."

It is fair to say that the nature of science is no longer regarded as something clear-cut and settled, as was the case before the impact of studies in the history of science brought to light the way sciences actually develop. These studies revealed that the scientific enterprise is far more complex than previous philosophical theories would lead us to believe.

Glossary Terms

COSMOLOGY The study of the origin, nature, and development of the universe as an orderly system; theories formulated from such study.

DARWINISM The Darwinian theory that the origin of species is derived by descent, with variation, from parent forms, through the natural selection of those best adapted in the struggle for existence.

FALLACY OF REDUCTION The belief that an object's simpler units have a greater reality than the larger, complex object itself.

FALLACY OF OVERSIMPLIFICATION The uncritical attempt to explain everything with one principle or type of interpretation.

HYPOTHESIS A tentative proposal or possible explanation; often an early step in scientific method; an informed guess with research yet to be completed. (See theory.)

MATTER The substance or substances of which any physical object consists or is composed.

OCCAM'S RAZOR The principle that, other things being equal, one should always take the simpler explanation as the valid one.

PARADIGM A model or an example that identifies certain scientific phenomena and guides the inquiries of scientists; the context, background of conditions, and the set of fundamental assumptions within which science takes place.

POSTULATES A postulate is a fundamental assumption used as a basis for developing a system of proofs, but not subject itself to proof within the system. Though some logicians use *axioms* and *postulates* as synonymous, for others an axiom is a self-evident truth, whereas a postulate is a presupposition or premise of a train of reasoning and not necessarily self-evident. In this latter sense, all axioms are postulates, but not all postulates are axioms. A postulate is a basic statement "taken for granted" from which other statements may be deduced.

SCIENCE (1) Used to denote any of the many sciences; (2) Knowledge of nature that is quantitative, objective, and testable; (3) The entire body of systematic knowledge built up through experimentation and having a valid theoretical base.

SCIENTIFIC METHOD The processes and steps by which the sciences obtain knowledge.

TECHNOLOGY A body of useful and practical knowledge which deals with applied science, engineering, industrial arts, and the like.

THEORY The general conclusion after evidence is gathered and anlyzed; a confirmed hypothesis; an explanation of evidence gathered by means of research.

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Chapter Review

THE DEVELOPMENT OF SCIENCE

1. The development of science is predominantly the work of Western civilization in its modern period.
2. Today the word *science* is used in a narrow sense to designate a quantitative, testable and objective knowledge of nature. Pure science is objective knowledge for its own sake, without consideration of any practical application. Applied science is scientific knowledge put to practical use as technology or applied within science itself.
3. Because of curiosity and technology, the scientific spirit was born in the Graeco-Roman period.
4. Medieval science included much inventiveness and provided the technical heritage for the period of the Scientific Revolution; Islamic Civilization was highly significant for European Civilization.
5. During the Scientific Revolution, new methods of discovering knowledge about the world and a new view of the universe replaced former interpretations.
6. During the nineteenth century, modern science advanced the atomic theory and concentrated on matter and energy. Scientific methods were applied to living organisms and Darwin's *Origin of Species* introduced the concept of evolution.

PHILOSOPHY OF SCIENCE: BASIC ISSUES

1. Philosophical examinations of science can be classified as "philosophy of science."
2. There are two major categories of philosophy of science.

SCIENTIFIC METHODS

1. The word *science* can be used to refer to any of the many sciences.
2. Scientific postulates are at the foundation of scientific inquiry.
3. The various scientific methods include observation, trial and error, experimentation, statistical analysis, and sampling.

THE NATURE AND ROLE OF MODELS AND PARADIGMS

1. Models are the pictorial, mechanical, or physical representations of things in the physical universe; paradigms are the world views or set of fundamental assumptions that identify certain scientific phenomena and within which scientific activities take place. Some philosophers view these concepts as fundamental in philosophy of science.
2. The fact that scientists of a given historical period, or individual scientists at any time, prefer one paradigm or model over others indicates that valuing is present in the selection process. Hence, science cannot be regarded as totally value free.

A METHOD OF ACQUIRING KNOWLEDGE

1. Recognize that a problem exists and state the problem.
2. Collect the available and relevant background information.
3. Formulate an hypothesis.
4. Draw deductions from the hypothesis.
5. Develop and implement an appropriate research plan.
6. Verify the hypothesis; verification is the final stage.

LIMITATIONS OF SCIENTIFIC METHODS

1. Results of scientific research are hampered by the techniques and instruments used. What we claim as factual is only as accurate as the instrument allows.
2. Classification of information is essential but no classification is all-inclusive.
3. The whole may have qualities absent in the parts. No simple unit is more real than the ob-

ject investigated. Scientific explanation is another form of interpretation; it does not give us the "pure truth."

4. There may be many interpretations of things or people illuminating equally significant points of view. Complex events need many approaches for total understanding.
5. When we consider anything in the process of development, we must consider the entire process. We cannot explain later stages adequately by earlier stages alone.
6. We tend to see what we expect to see; therefore, we are never completely "objective" in our observations.
7. Values or ethical issues are beyond scientific methods. When scientists choose to prescribe values, they have entered the realm of philosophy.

PHILOSOPHY AND SCIENCE: AGREEMENTS AND CONTRASTS

1. The contrasts between philosophy and science generally represent tendencies or points of emphasis, not absolute distinctions.

SCIENTIFIC VIEWS OF THE UNIVERSE

1. Interpretations of the origin and destiny of the universe include the steady state theory and the Big Bang theory.
2. Issues about the nature of the universe include the expanse of the cosmos and the nature of matter (including quarks and gluons).
3. Views of space, time, and relativity have undergone change in recent years.

THE ORIGIN AND NATURE OF LIFE

1. There are several theories describing the origin and nature of life.

HUMAN BEINGS AND EVOLUTION

1. Darwinism in its narrow sense refers to a theory of organic evolution presented by Charles Darwin and by other scientists who developed various aspects of his views.
2. The most important feature of Darwin's theory was the idea of natural selection.
3. The study of genetics has increased our understanding of both life and the theory of evolution.
4. There is much empirical evidence for organic evolution.
5. Misinterpretations of evolution include misconceptions about humans as descendants of the apes, Darwinism, the origin of life, and the role of evolutionary theory in religious thought.
6. The views of "creation science" can be argued to be neither Biblical nor scientific.

REFLECTIONS

1. Science is founded on informed faith in particular views of the universe.
2. Contemporary scientists are far more modest in their claims of certainty than citizens anxious to invest all-knowing certitude in anything or anyone "scientific."
3. Tentative explanations are called theories and are subject to continual study, testing, revision, and rejection.
4. Schools of thought are found in the physical and social sciences and in mathematics.
5. In the area of technology we have seen the ongoing development of sophisticated methods of communication, transportation, and entertainment.
6. Technology itself is neither blameworthy nor praiseworthy: human beings decide how technology will be employed.
7. Philosophy of science is in a state of turmoil; standard philosophical views of science are being debated vigorously.
8. It is fair to say that the nature of science is no longer regarded as something clear-cut and settled. Studies in the history of science have revealed that the scientific enterprise is far more complex than previous philosophical theories would lead us to believe.
9. As different thinkers endorse and defend different and changing philosophic conceptions of science, the controversy serves to cast light on science itself. Although there are no settled answers, there is ongoing inquiry. In this respect, philosophy of science resembles science itself.

♦ ♦

Study Questions and Projects

1. Read the following quotations, discuss their implications, and indicate why you agree or disagree with them.
   (a) "All scientific descriptions of facts are highly selective . . . , they always depend upon theories. . . . Similarly, a scientific description will depend, largely, upon our point of view, our interests, which are as a rule connected with the theory or hypothesis we wish to test; although it will also depend upon the facts described."
   (b) Warren Weaver says, "Science is what scientists do . . . and scientists are human." Scientists, he points out, differ from people in general only in their "schooling in scientific method, their knowledge of the vast successes science has had, their proud partnership in the profession that has measured the star, split the atom, and probed the cell. This inheritance is, I am bound to tell you, magnificent but dangerous."[9]
2. Evaluate the following quotations:
   (a) "Even the most 'unprejudiced' science is imbedded in philosophy—sometimes in a philosophy that is not very sound or consistent."
   (b) "If science could tell with certainty all that it is capable of telling, it would still leave our most pressing questions unanswered."
   (c) "In Western culture science . . . is the discovery of useful facts. . . . This factualness of science makes it blind to the difference between the trivial and the significant, the odious and the exquisite, the good and the bad."
   (d) "If a scientific age is to be a good civilization, it is essential that increase in knowledge be accompanied by increase in wisdom or in a sense of human values."
3. What would be your reaction if life were successfully synthesized in a laboratory? Compare your reaction to evolutionary theory with that of an earlier generation.
4. Justify the statement that there are "a variety of scientific methods" rather than one method only. Give examples.
5. Discuss briefly the methods, problems, and possible disadvantages involved in observation, experimentation, and statistical procedure and sampling.
6. Read the cover story of *Time* for December 28, 1992, entitled "What Does Science Tell Us About God?" In what ways is the magazine report related to this chapter, "Science and Philosophy?" Note points of agreement and disagreement.
7. Comment on philosophical issues present in the twelve vital challenges facing science as reported in the December 1992 edition of *Scientific American*.
8. Evaluate the following statement, in terms of the issues presented in Chapter 11:

   "We believe that the world is knowable, that there are simple rules governing the behavior of matter and the evolution of the universe. We affirm that there are external, objective, extrahistorical, socially neutral, external and universal truths and that the assemblage of these truths is what we call physical science. Natural laws can be discovered that are universal, invariable, genderless and verifiable. They may be found by men or by women or by mixed collaborations of any obscene proportions. Any intelligent alien anywhere would have come upon the same logical system as we have to explain the structure of protons and the nature of supernovae. This statement I cannot prove, this statement I cannot justify. This is my faith." (S. Glashow, "We Believe That The World Is Knowable" in the *New York Times,* October 22, 1989, p. E24.)
9. Read a weekly science section from a Tuesday's *New York Times.* What philosophical issues exist in one or more of the reports?
10. Write an essay on "Science and Values."
11. Two articles on human evolution were published in *Nature: International Weekly Journal of Science* 368, (March 31, 1994). Read Waddle's "Matrix Correlation Tests Support a Single Origin for Modern Humans" (pp. 452–454) and Bowcock et al. "High Resolution of Human Evolutionary Trees with Polymorphic Microsatellites" (pp. 455–457). Incorporating your own comments on scientific method and the

theses of the two articles, write an essay entitled "Human Evolution: Hypothesis or Theory?"

12. Read Coppens's "East Side Story: The Origin of Humankind" in *Scientific American* 270 (May 1994): 88–95. Considering Chapter 2, "Human Nature: What Is It?" and Chapter 11, "Science and Philosophy," what philosophical issues remain unresolved in the Coppens article?

Suggested Readings

Boyd, R. et al. (eds.). *The Philosophy of Science.* Cambridge, Mass.: MIT Press, 1991.

With more than forty readings, this anthology covers the most important developments in the past six decades; a thorough glossary and bibliography are included.

Brody, B. A., and Grandy, R. E. (eds.) *Readings in the Philosophy of Science.* 2nd ed. Englewood Cliffs, N.J.: Prentice Hall, 1989.

An anthology whose four parts cover theories, explanation and causality, confirmation of scientific hypotheses, and selected problems of particular sciences. The text concludes with a bibliographical essay.

Fetzer, J. H. *Philosophy of Science.* New York: Paragon, 1992.

The author provides a foundation for inquiry into the nature of science, the history of science, and the relationship between the two; he investigates the aims, methods, and explanations of empirical science.

Feyeraband, P. K. *Realism, Rationalism and Scientific Method,* Vols. I and II. Cambridge: Cambridge University Press, 1981.

By one of the most important contemporary philosophers of science, these volumes deal mainly with three ideas that the author believes have played an important role in the history of science, philosophy, and civilization: criticism, proliferation, and reality.

Hesse, M. B. *Models and Analogies in Science.* London and New York: Sheen and Ward, 1963.

A basic exploration of scientific models.

Kitcher, P. *The Advancement of Science: Science Without Legend, Objectivity Without Illusions.* New York: Oxford, 1993.

The author attempts to resurrect the notions of objectivity and progress in science by identifying both the limitations of idealized treatments of the growth of knowledge and overreactions to philosophical idealizations.

Kosso, P. *Reading the Book of Nature: An Introduction to the Philosophy of Science.* New York: Cambridge University Press, 1992.

Why should we believe what science tells us about the world? Observation data, confirmation of theories, and the explanation of phenomena are all considered at an introductory level.

Kourany, J. A., (ed.). *Scientific Knowledge: Basic Issues in the Philosophy of Science.* Belmont, Calif.: Wadsworth, 1987.

An introductory exploration of philosophy of science.

Laudan, L. *Science and Relativism.* Chicago: University of Chicago Press, 1990.

The author explores some key controversies in the philosophy of science.

Lindberg, D. C. *The Beginnings of Western Science.* Chicago: University of Chicago Press, 1992.

A full, unified account of the European scientific tradition in philosophical, religious, and institutional context from 600 B.C.E. to 1450 C.E.

Salmon, W. C. *Four Decades of Scientific Explanation.* Minneapolis, Minn.: University of Minnesota Press, 1990.

The author provides a definitive introduction to scientific explanation by recounting and analyzing the major developments during the past fifty years.

Notes

1. Lewis Thomas, "On Life In A Hell Of A Place," *Discover* (November 10, 1983): 42.
2. E. G. Conklin, *Man, Real and Ideal* (New York: Scribner's, 1943), p. 5.
3. See J. S. Mill, *A System of Logic* (London: John W. Parker, 1851), 3rd ed., Vol. I., Book 3, Chapter 8.
4. T. S. Kuhn, *The Structure of Scientific Revolutions,* 2nd ed. (Chicago: University of Chicago Press, 1970).
5. G. Holton, *Introduction to Concepts and Theories in Physical Science* (Cambridge, Mass.: Addison-Wesley, 1952), pp. 218*f.*
6. Darwin, *Origin of Species,* 6th ed. (London: J. Murray, 1872), p. 126.
7. See G. Ray, *Six Days or Forever? Tennessee vs. John Thomas Scopes* (Boston: Beacon, 1958); W. B. Gatewood, *Preachers, Pedagogues and Politicians: The Evolution Controversy in North Carolina, 1920–1927* (Chapel Hill: University of North Carolina Press, 1966). The play *Inherit the Wind,* by Jerome Lawrence and Robert E. Lee, is a popular treatment of the Scopes trial, although it does not list the dominant characters by name. More recent explorations of the issues may be found in M. Ruse, ed., *But Is It Science?: The Philosophical Question In The Creation/Evolution Controversy* (Buffalo, N.Y., Prometheus, 1988); L. B. Gilkey, *Creationism on Trial: Evolution and God at Little Rock* (San Francisco: Harper, 1985); and T. M. Berra, *Evolution and the Myth of Creationism: A Basic Guide to the Facts in the Evolution Debate* (Stanford, Calif.: Stanford University Press, 1990).
8. See "Mathematics, Philosophy of," in A. Flew, *A Dictionary of Philosophy* (New York: St. Martin's, 1979); the more advanced essay "Mathematics, Foundations of" in the *Encyclopedia of Philosophy* (New York: Macmillan, 1967); or M. Kline, *Mathematics: The Loss of Certainty* (New York: Oxford University Press, 1980).
9. "Science and the Citizen," *Bulletin of the Atomic Scientists* 13 (December 1957): 365; *Science* 126 (December 13, 1957): 1223.