PHYSICAL SCIENCE: AN INTEGRATED APPROACH

Russell A. Roy

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The cover photograph shows the space shuttle Columbia at the top of the launch tower. Liftoff was March 22, 1982.

Astronauts Jack R. Lousma, commander, and C. Gordon Fullerton, pilot, were the crew. Thanks are extended to NASA for the use of this and other photographs used throughout the textbook.

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Preface

Physical Science: An Integrated Approach is designed for use in general education physical science courses. It covers topics in scientific methodology, the history of science, physics, chemistry, astronomy, geology, and technology. The approach is non-mathematical, with a small amount of arithmetic and simple algebra being sufficient for calculations. A laboratory manual is available to accompany this text. It has exercises in conversions, scientific notation, and scientific methodology, and also includes thirteen laboratory experiments from physics, chemistry, astronomy and geology. The latter are designed for 50 minute periods and use relatively simple equipment.

At Santa Fe Community College, the text and manual are used in a one semester, four credit, general physical science course. Each section meets four times a week with three 50 minute periods devoted to lecture and one period to lab. This course has been taught at Santa Fe for ten years, and the materials have been developed over this period. Instructors from the areas of physics, chemistry, astronomy, and geology agreed on a common, "core" content along with some optional topics. No available texts were found to be satisfactory, lacking either depth or coverage, or being too long and too expensive. As we developed the curriculum, the materials were written, student tested, and revised a number of times. Preliminary editions of this text have been used at Santa Fe for four years.

The topic order results from presenting basic material first. Scientific methodology, classical physics, and basic chemistry are presented so that the concepts and vocabulary can be used to develop more complex topics. Some instructors at Santa Fe do not follow the chapter order, however, but successfully teach them out of sequence. The chemistry will be done before the physics, for example, or some topics in astronomy first. This reordering usually is done to get a good beginning for the course by allowing instructors to start with material they prefer.

There are four "Perspectives" in the text. These are shorter than the chapters and consist of optional material. They are basically "stand alone" and can be taught anywhere in the course, although they are more enriching with more appropriate placement. Perspective I is a brief treatment of celestial mechanics and can be used after Chapter One to help introduce the course, or can be done with the other astronomy material. Perspective II uses classical mechanics to analyze an automobile accident. Perspective III is a historical review of our understanding of the earth's place in the cosmos, and Perspective IV is a very brief treatment of historical geology. There is more than enough material for one semester and no instructor covers the entire text. An instructor's manual is available which discusses instructional approaches in more detail. It also includes a bank of multiple choice test items.

The author would like to thank his fellow physical science instructors for their help and advice: Jerry Bieber, Van Dubolsky, Sally Hoffman, Jean Klein, and Mike Patrick. The revised edition was typed by Betty Stevens and Anita Batey who did an excellent job.

The manuscript was reviewed by Ben de Mayo, West Georgia College, Dennis A. Likens, Tuskeegee University, Roland E. Johnson, Fayetteville State University, and Robert J. Backes, Pittsburgh State University. The author wishes to thank these individuals for many helpful comments and corrections. The revised edition is much improved.

The author would also like to thank his publisher, Chuck Grantham, and his staff, for much help and encouragement. Thanks go to my wife, Eileen, and to my children, Kevin and Katy, who have been patient and understanding on the many weekends, evenings and vacations spent with "the book."

Russell A. Roy

August 1990

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CHAPTER 1

The Nature of Science

Truth in science can be defined as the working hypothesis best suited to open the way to the next better one.
Konrad Lorenz

1.1 OVERVIEW

What is a human being? There is a biological answer to this question. Humans are *Homo sapiens*, members of the genus *Homo* and species *sapiens*. We are vertebrate animals (animals with backbones), and we are mammals since we suckle our young. Humans are in a particular subcategory of mammals called the primates, characterized by flat nails instead of claws, forward facing eyes, and large brains. A complete biological definition would allow us to distinguish between a human being and any other living thing. It is possible to be a human being without knowing any of this, of course. When we are conceived our parents provide a "genetic blueprint" that not only provides all the biological information to make a *Homo sapiens*, but also makes each of us a unique individual.

But biological information, as amazing and wonderful as it is, is not the only information that we have. After we are born, we learn language, we learn how to participate in society; we learn a great deal, more by far as human beings than any other animal. All of this nongenetic information can be called culture, and it is clear that human culture is extraordinarily rich and complex. The more we know about our human culture, the richer our individual lives will be.

In most of the world today an institution, called a school, is used to help people learn about their human culture. Of course it is possible, even necessary, to learn outside of school, but our culture has become so complex that schools are necessary. (See Figure 1-1.)

During the last few centuries, the development of science and technology has been very rapid. Science and technology have deeply influenced all other aspects of human culture, overwhelmingly in some cases. There are many obvious benefits from science, but there are also profoundly disturbing results. No one can deny the ever increasing importance of science and technology. To participate in our culture it is thus necessary to understand science and technology, at least in a general way.

Besides a general understanding of our culture, knowing about science and technology can also help us in specific ways. It is a rare individual whose career will not involve some aspects of science or technology directly. The computer is often mentioned as an example of this, but there are many others. While one doesn't have to be a scientist to get a job, it is clear that scientific and technological skills can be very useful in the work place.

A third reason to study science and technology can be inferred from news stories on television and in newspapers. Issues such as nuclear power, genetic engineering, pollution, and weather and climate modification are being hotly debated. As science and technology continue their rapid growth, tomorrow (or maybe this afternoon) will bring new issues. It is increasingly necessary for people to be politically active in resolving these issues. We all generate toxic waste. Where should it go? Should it be dumped in your neighborhood? It has to go somewhere. We all use electricity, and nuclear power plants are one way to generate electricity. (See Figure 1-2.) Should they be built? Where? Are they safe? Decisions and policies will be made which will affect us and our children. To the extent that we are informed, we can participate in this process. To be good citizens, it is proper to vote; it is even better to vote wisely.

In most countries some part of culture is taught by a teacher to twenty or thirty students in class. This is a high school English class in the United States.

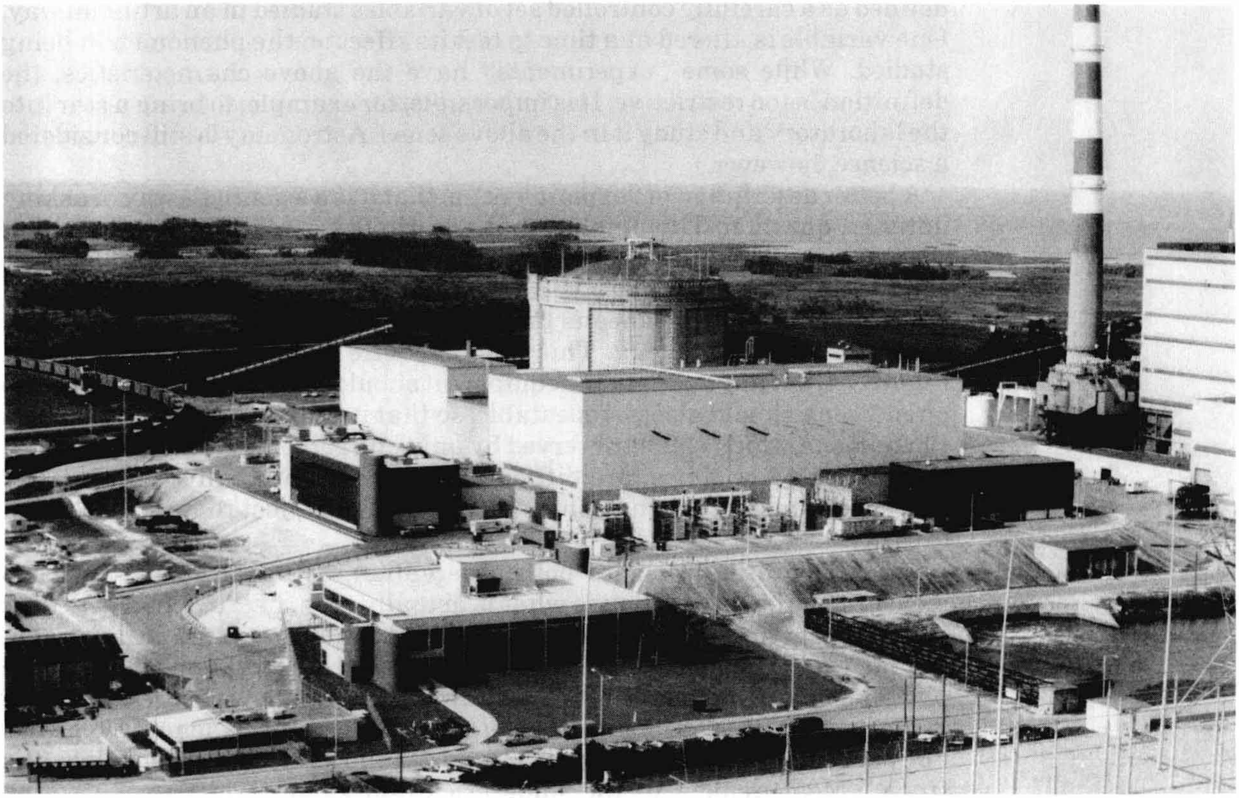
Figure 1-1

This text is about science and technology. It cannot cover everything about this topic; no book, or even hundreds of books could do that. But this text will introduce you to science and technology, show how they work, and describe some of the results that have been found, especially in the physical sciences.

1.2 GATHERING AND TESTING INFORMATION

Science is a way of gathering information about the physical universe and testing its validity. (Key words and phrases, such as *science*, have been italicized throughout this text. These words are defined in a glossary at the end of the text.) The purpose of this method is to understand the universe well enough to discover basic relationships. In the rest of this chapter we will look into how science gathers and tests information. We will also describe the physical sciences that this text will discuss.

There are several ways to collect information. Some information from the physical universe comes to us from our immediate surroundings through our physical senses. But it is hard to experience everything directly, so we rely on secondary sources of information: parents, friends, teachers, newspapers, and television, for example. A library contains a great deal of



This is a typical nuclear power plant. Compared to other industries, nuclear plants supposedly involve less risk, but there is no scientific definition of a "safe risk" and many do not find nuclear plants "safe." Others do, however, and this is an area of continuing controversy.

Figure 1-2

information and helps determine how effective a school is.(See Figure 1-3.)

Today, the amount of information available to us has become enormous. Anyone can collect all they want, either directly or indirectly. What distinguishes science from other activities is that scientific information is tested before it is accepted as "true." As philosopher Bertrand Russell put it, "It is not what the man of science believes that distinguishes him, but how and why he believes it. His beliefs are tentative, not dogmatic; they are based on evidence, not on authority."

Ordinary people accept most of their information from an "authority." We accept what we read in the newspapers, what our teachers and friends tell us; rarely are we skeptical. Many human activities are based on authority, law for example. In a criminal or civil proceeding, the outcome is determined by what statutes say and by the outcomes of earlier, similar cases. The judges, juries, and attorneys do not make up new law for the specific case but accept the authority of the preceding cases.

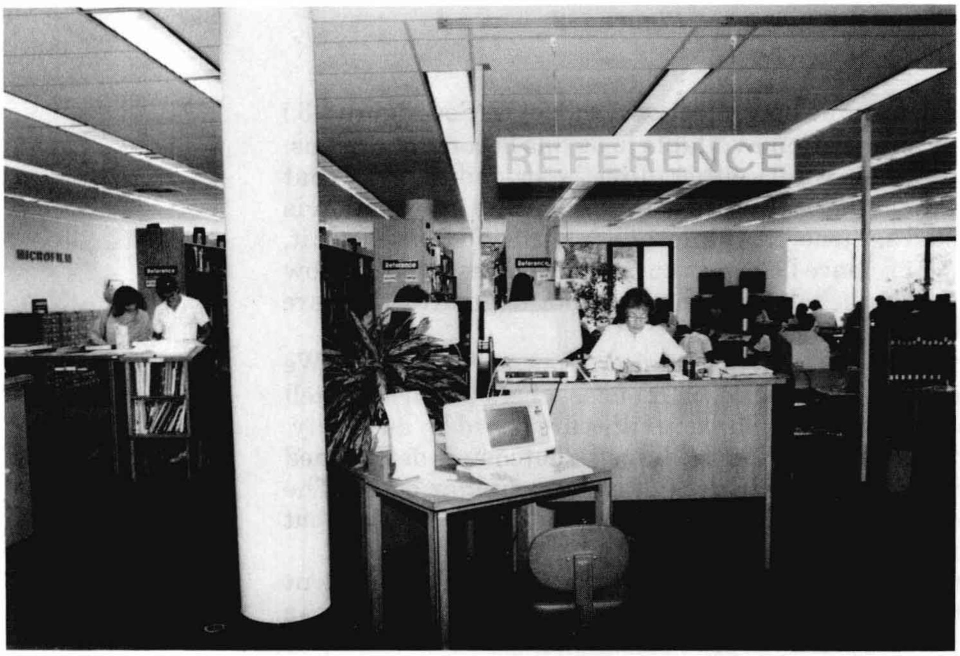
Religion is also based on authority. This might be found in a document such as the Bible or the Koran, or in a hierarchy of church officers such as the College of Cardinals or a presbytery.

Scientists do not accept information from authority. In our everyday lives we are usually not skeptical; but, when doing science, skepticism is required. No matter how carefully the information is collected, scientists check it rigorously before accepting it.

Scientists test information by experimentation. An experiment could be defined as a carefully controlled set of variables studied in an artificial way. One variable is altered at a time to test its effect on the phenomenon being studied. While some "experiments" have the above characteristics, the definition is too restrictive. It is impossible, for example, to bring a star into the laboratory and study it in the above sense. Astronomy is still considered a science, however.

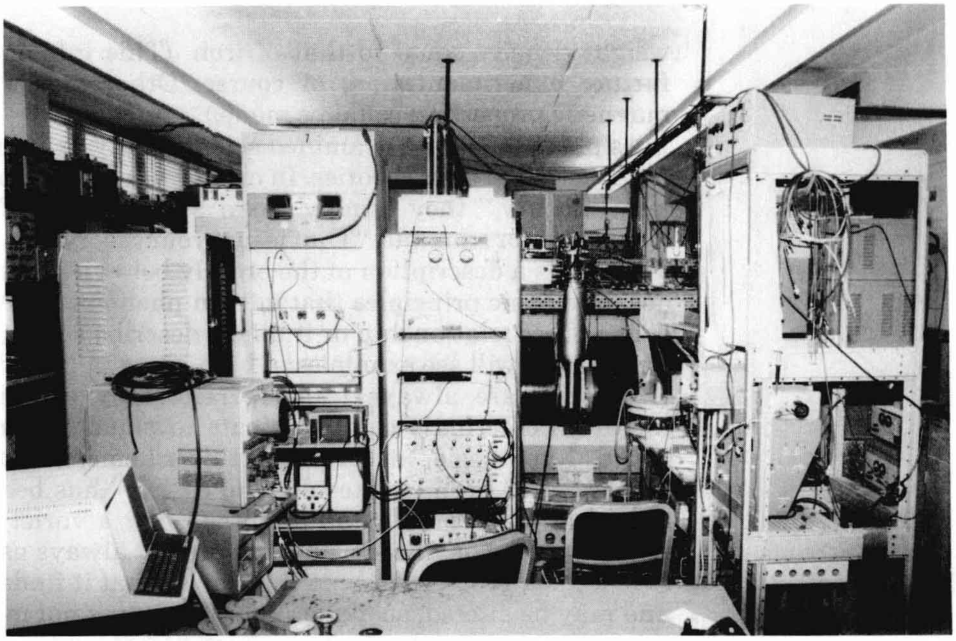
A better description of "experiment" is that it is a scientist's way of asking nature a question. This implies that experiment is really a process rather than a thing. There are several characteristics of the experimental process. First the phenomena to be studied experimentally must be observable and repeatable. Observable means that anyone, in principle, should be able to observe these phenomena. This might require complex equipment, as in Figure 1-4, but anyone with the equipment should be able to experiment. The phenomena should also be repeatable, so that it can be studied many times. Phenomena which can be observed by only one person, or which occur once or at most a few times, are difficult to study scientifically. This doesn't necessarily mean that such phenomena don't exist, just that they are hard to study.

Experimentation includes both observation, as noted above, and also measurement. Observation is what is actually seen, heard, felt, smelled, or tasted; observation is direct sensory information gathered in a careful, formal way. Because people can differ in their observation of the same phenomenon (what shade of red a shirt is, for example) scientists prefer to make quantitative observations, called *measurements*, whenever possible. For example, an observation would be "the brick feels heavier than the stone." Measurement of the same brick and stone results in "the brick weighs 6.2 lbs and the stone weighs 1.1 lbs." Measurement requires the use



A modern library is a truly wonderful source of information. First there are books, reference texts, and works of non-fiction and of fiction. There are periodicals, maps and charts, atlases, vertical files and newspapers. Today there are also computer terminals, often tied in with regional networks.

Figure 1-3



In this physics laboratory, "condensed matter" (solid state) is studied at low temperatures.

Figure 1-4

of instruments, pan balances or meter sticks, for example. When an instrument is used, a number and a unit are obtained and assigned to a particular property (weight, for instance), or a process (speed, for instance).

A prominent physicist, Lord Kelvin (1824-1907), once noted how important measurement is in science: "I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be."

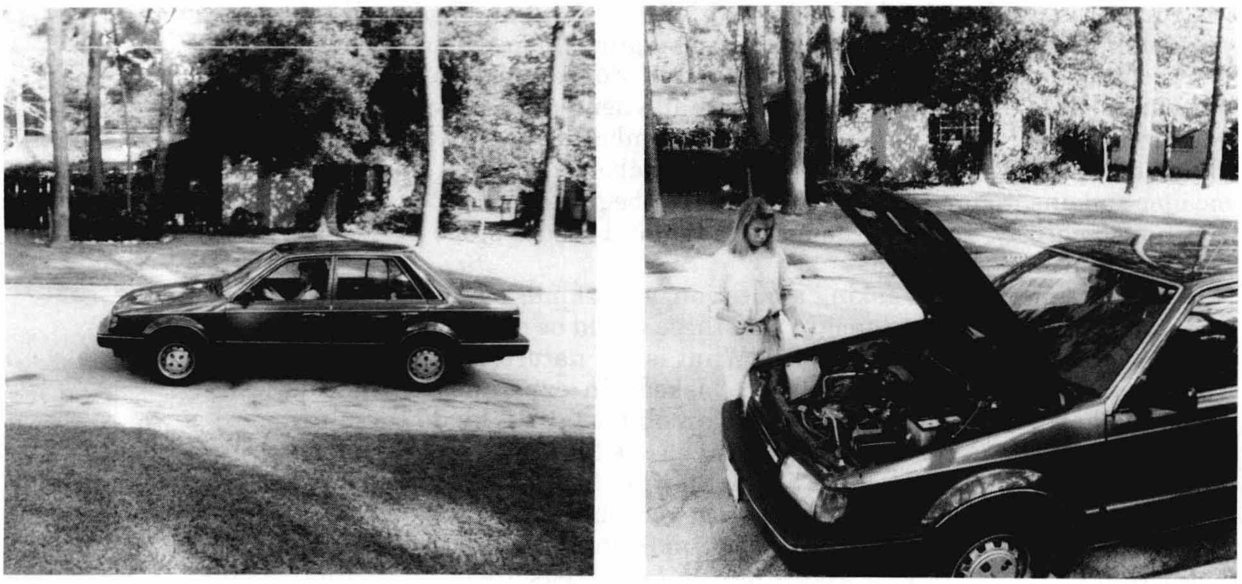
If an experiment is like asking a question, what kinds of "questions" do scientists ask? It might be thought that these would be profound questions such as: What is the purpose of life? What is the nature of the universe? These questions are too broad to be "asked" in experiments. Instead, scientists ask questions like: How does an object fall? Why do these two pieces of metal attract each other? When you ask too broad a question, you will receive only a limited answer. Scientists have found that when they ask limited questions, it is possible to reach general answers. This process, of going from specifics to results of broad applicability is called *induction*. These results are the basic relationships that scientists are trying to find.

1.3 DISCOVERING AND UNDERSTANDING RELATIONSHIPS

As experiments are done, the resulting information allows scientists to make inferences. An *inference* is an interpretation of an observation or measurement. For a simple example we might observe that a piece of some substance is solid and feels heavy. We measure the weight and the volume of the piece. Then, since the weight density of a substance equals the weight of a sample divided by its volume, we can calculate the weight density of our piece. We infer that the substance is iron because it looks like iron and has a weight density equal to that of iron. (This inference could be tested by further experimentation, of course. Other measurements, such as its magnetic properties, could be made.)

As phenomena are examined scientifically, inferences and ideas can be put together to form theories. In ordinary conversation when people use the term "theory," they usually mean an unconfirmed statement. Someone would say, for example, "That is just your theory; it is not a fact." In science, a *theory* is a description of the orderly behavior found in nature. Theories describe basic principles that govern phenomena. A principle might be a cause-effect relationship or it might describe some fundamental aspect of nature. (We will see examples of both kinds in later chapters.)

Theories are always tested carefully by experiments. Sometimes a hierarchy of terms is used to indicate how much experimental support there is. An "hypothesis," according to this scheme, is untested or little tested, a "theory" has been well tested, and a "law" has been tested enough to be universally accepted by all scientists. For a variety of reasons the three terms hypothesis, theory, and law are not always used in the above ways. Science is a process, so even the "laws" that it finds are subject to testing and may be altered, sooner or later. This does not mean, as people usually think, that a theory becomes completely discredited when it is replaced by a new theory. New theories don't often replace old theories. The new theories establish limitations to the old ones (which remain valid within those limits). New ideas extend to phenomena outside the limits until still newer ideas come along. This is the process Lorenz was referring to in the quote at the beginning of the chapter.



It is possible to drive a car successfully without knowing what is "under the hood." As we extend our knowledge, we still drive the same way, but now we can also take care of the engine.

Figure 1-5

As an analogy, consider learning about an automobile. When learning to drive, one learns about various levers and pedals, the ignition key, and the steering wheel. It is possible to "understand" the car on one level by being able to drive it. A deeper understanding would come when learning about putting gasoline, oil, and coolant in the car, as well as other maintenance tasks. Because you learned something about the car as a mechanical system, you would not discard your driving knowledge. More knowledge about the car does not disprove your original knowledge but improves it. This is basically how the scientific process works. (See Figure 1-5.)

In doing experiments and proposing theories, scientists try to be objective. How can scientists be objective? Ordinary people are rarely objective and scientists are people too. In a way, it is science that is objective rather than scientists, although most scientists try very hard to be unbiased. Science is objective because it is the result of many scientists. "Art is I; science is we," as Claude Bernard (1813-1878), a French medical scientist, put it. Experimental results, theories, and new ideas are all published and discussed. Experimental results are checked and rechecked by other scientists. Arguments, sometimes quite intense, take place as results and inferences are questioned. This process of skeptical scrutiny through more experiments is extremely rigorous. There is nothing like it in other fields. Scientists realize that if work has been done poorly, it is necessary to weed out those results. Only the best, most carefully done work should be accepted. Some of the flavor of this critical review was captured by Georg von Bekesy, Nobel Laureate in physiology:

"[One] way of dealing with errors is to have friends who are willing to spend the time necessary to carry out a critical examination of the experimental designs beforehand and the results after the experiments have been completed. An even better way is to have an enemy. An enemy is willing to devote a vast amount of time and brain power to ferreting out errors both large and small, and this without any compensation. The trouble is that really capable enemies are scarce; most of them are only ordinary. Another trouble with enemies is that they sometimes develop into friends and lose a good deal of their zeal. It was in this way that the writer lost his three best enemies." (From Georg von Bekesy, *Experiments in Hearing*, McGraw-Hill, 1960.)

Usually there is more than one theory proposed to explain the same phenomena. As these competing theories are tested and retested, the one that most scientists think best agrees with experimental results will gradually become accepted. As better experiments are done, the consensus of scientists can change, however, and the "accepted" theory will be modified or even changed drastically. At any point, the accepted theory will have withstood a great deal of testing. This doesn't mean that the theory is correct, only that it has withstood the experimental testing better than any other. Two thousand years ago, for example, people believed that the earth was the center of the universe and all other celestial objects revolved around it. (This is called the *geocentric*, "earth-centered," theory.) However, thanks to the work of men like Copernicus, Galileo and Kepler, in the early 1600s, people began to realize that the earth and the other planets revolved around the sun (a sun-centered or *heliocentric* theory). A geocentric view can still be used in procedures like celestial navigation on the earth's surface however, because the predictions work well enough for these purposes.

1.4 MISCONCEPTIONS ABOUT SCIENCE

Over the years many misconceptions about science have grown up. Learning what science does not include is part of learning about science. There is not the space here to adequately cover all these misconceptions but the following ones will be discussed:

1. Science is not creative the way the arts are.
2. Science is concerned primarily with the betterment of mankind.
3. Science is omnipotent; given enough time and money, science can solve any problem.

4. In some basic way science cannot be used to understand the fullness of reality. Scientific "truth" is always lacking in its completeness.

1. Scientific Creativity

Science has been very successful, so that many people believe that scientists have discovered a "method" that can be used in a mechanical way to get results. Galileo, who certainly was one of the first to investigate nature in a scientific way, is often credited with developing the scientific method. This "method" is usually given as a list of sequential activities:

1. Observe phenomena
2. Form a hypothesis
3. Test the hypothesis by experimentation
4. Correct the hypothesis, if necessary
5. Publish the results

These activities are related to science, of course, but doing science does not involve following a recipe, like baking biscuits does. No one would expect art to be produced by mechanically going down a list that said: 1. Get a blank canvas, 2. Put paint on the canvas, and so on. The new ideas, the discoveries, the inventions of science spring from the same source as art, music, poetry and civilization: the human mind. Scientific ideas, while they may not appeal directly to the senses as a painting or symphony does, are just as creative and just as profound. It is even possible to speak of scientific theories as having beauty; it is an intellectual beauty, to be sure, but the more one understands, in art or science, the more one appreciates.

It is unfortunate that we do not understand creativity. There are creative individuals in all fields but these individuals are usually a minority. We don't know how to make someone "creative," in science or in anything else. There have been studies that show that relatively few scientists contribute to scientific progress in a creative way. It seems that if an experiment is a scientist's way of asking nature a question, only a few scientists ask good questions. Even fewer get good answers.

2. The Goal of Science

The usefulness, or lack of it, of scientific results is of no direct concern to the scientific process. Science is a method of discovering how nature works; no value judgments are made on whether the "workings" are good or bad, useful or not. This does not mean, however, that scientists have a complete disregard for the possible outcomes of their research. For example, there are many research areas that do involve hazards, both to the scientists and to the public. One such area is the genetic research being done with microorganisms. Here scientists are studying how living organisms pass characteristics to succeeding generations. Transmission of these characteristics occurs with complex structures called genes. It is now possible, at least in a rudimentary way, for scientists to alter genes so that the offspring have different characteristics than their parents. In this way a new strain of bacteria could be produced. It is possible that a strain of bacteria so formed could be very beneficial, producing a useful drug as part of its natural metabolic processes. It is also possible that a new strain of bacteria, if it "escaped" from the lab, could cause a new and deadly disease. Clearly, such research must be done under stringent guidelines to minimize the danger.

A great deal of debate occurs concerning dangerous research and its guidelines. Many times these debates cannot be resolved satisfactorily because "safe" does not mean the same thing to everyone. Risks that some of us find acceptable, such as smoking, others find unacceptable. Most scientists argue that as long as reasonable guidelines can be found, research should be done.

There is a field closely related to science, referred to as "technology" or "applied science." While the goal of "pure" science is to learn more about the basic nature of the universe, the goal of *technology* is to make better processes and products. While it is clear that the knowledge obtained from science underlies most, if not all, the results of technology, most "benefits" of science have actually been produced by technology: better medicines, home computers, more efficient carburetors, and so forth. Many of the negative aspects of our modern lives which we associate with science are also more properly associated with technology. Many industrial processes produce pollution for example, and not everyone feels that technological progress necessarily improves the quality of life.

Although they differ in their purposes, science and technology work closely together. High technology is required in many areas of science to make the measurements and to do the experiments. Quite often a result of science will unexpectedly develop into a practical application. Einstein's work with relativity remained a piece of pure science for years. The possibility of actually obtaining "atomic" energy from nuclear mass according to Einstein's famous "$E=mc^2$" was dismissed by scientists as impractical. As Nobel laureate Ernst Rutherford observed in 1933, "Anyone who expects a source of power from transformation of these atoms is taking moonshine." Today both nuclear reactors and nuclear weapons are evidence of how important an "impractical" application can be. (Rutherford did not live to see the first atomic bomb dropped in 1945, eight years after his death.)

3. The Limits of Science

The success of science has led to another misconception besides the idea of a mechanical method. This one involves the belief that science can tackle and solve any problem, especially if given enough time and money. As scientists study appropriate phenomena (those that are observable and repeatable as noted in section 1.2), it is commonly the case that as many questions are raised as answered. As scientists learn more, it is clear that there is even more yet to be learned.

There are also a great many phenomena that cannot be studied appropriately using experimentation. Music is not a science, nor is dancing. Love is not scientific; neither is war. If something is not a science, that doesn't mean that it is useless, or not as valuable, only that it is not a science. It should be noted that while music is not a science, for example, it is possible to study certain aspects of it scientifically. This is also true of dancing, war, and just about anything else. But there are aspects of these fields that cannot be studied scientifically. There is no way to do an experiment to determine who is a better composer, Bach or Mozart. Nor is there any way to define scientifically what "better" means in this case.

We can understand more about the feelings people have for the power of science by looking at the cultural origins of science. It is not easy to study the origins of culture and of rational thought because these arose before writing. And even after people began to keep written accounts, most of these accounts have not survived. However, we can find some clues by considering a Creation Myth. A *Creation Myth* is an account of how the world and life on it came to be.

As we go back and explore the ancient myths we can see the relationship of man with nature, how this relationship gave rise to culture and gave meaning to existence. By studying myth we can see a little of what our ancestors saw, a vision that we no longer see, or at least see very differently. There are many Creation Myths, about one for every culture, in fact. Myths are obviously important to cultures, some of them lasting thousands of years, even after they are discredited as "fact." Why are myths important? What purposes do they serve? We can partially answer these questions by considering part of a Creation Myth. It is the story of Prometheus from the ancient Greeks' Creation Myth.

Prometheus

Prometheus and his brother Epimetheus were demigods who were given by Zeus, the supreme god, the job of creating man and the animals for Earth. Epimetheus began with the lower animals and became so excited that he was carried away and gave them all of the good gifts of strength, wisdom, swiftness, courage, wings and so forth. Prometheus was disturbed at this because there was nothing left to give man. He decided to make up for the lack of gifts by making man in the image of gods. Even with this, however, man was still too weak and ignorant to rule over the world as he should. Prometheus felt sorry for this poor creature and decided to help him by giving him the gift of fire. With this powerful tool, he gave people heat and light, and the ability to forge weapons and other tools.

When Zeus found out that Prometheus had given man fire, he was very angry because it was now possible that man had too much power and might rival the gods themselves. To punish man, Zeus sent the first woman, Pandora, to Earth. She was endowed with every charm but also had curiosity, which led her to open a box which the gods had given her and forbidden her to open. Inside the box were all the evils which have since plagued man. To punish Prometheus, Zeus had him chained to a rock in the Caucasus Mountains where every day for eternity a vulture would come, rip him open, and eat his liver. Every night Zeus caused the liver to grow back, and the wounds would heal.

When trying to understand a myth like this, it is important to remember that it is a product of its culture. The Greeks obviously felt that certain elements here were important. Fire clearly represents a lot of power because Zeus is quite upset when men are given its use. Fire is an important tool in a literal sense, but in the Prometheus myth, fire is used more in a symbolic sense. It represents not just a tool, but tools and weapons in general, as well as the knowledge and intelligence to use them. These are powerful gifts indeed, and it is easy to see why man could rule the world with them.

But now it is necessary to ask why Prometheus is punished so severely by Zeus, or rather why the Greeks chose to emphasize this element in the myth. Prometheus, after all, worked hard to help humanity. Why would they be so concerned with the severity of his punishment? To answer this, it is necessary to realize that powerful tools can be used for ill as well as good. The more powerful something is, the more frightening it is. The same fire that can provide us with light and heat can also burn us horribly. Thus, it is reasonable to suppose that powerful "tools," and the people who bring them, need powerful controls. It was reassuring to know that there was a god like Zeus who was powerful enough to control these frightening forces. Prometheus was certainly seen as man's benefactor, but the control was also necessary.

The Prometheus myth now seems more understandable to us, but what about its relevance? We can look at a story with myth-like elements which is much closer to us in time. Analyzing this contemporary myth will illustrate some more of the relationship between science and society. This myth is recent enough to have been made into a movie, quite a few movies, in fact. They all involve a "scientist" who unlocks the "secret of life," but in doing so creates a monster who wreaks havoc with people and property. The scientist's name is Frankenstein. The original Frankenstein appeared in the novel, *Frankenstein, or The Modern Prometheus*, by Mary Godwin Shelley. In this story and subsequent movie versions, Frankenstein is pictured as a well-intentioned, but fanatic researcher. In the movie versions, the destruction the monster causes, and also its own destruction by the outraged populace, are attributed to the unnatural activities of the scientist. (See Figure 1-6.)

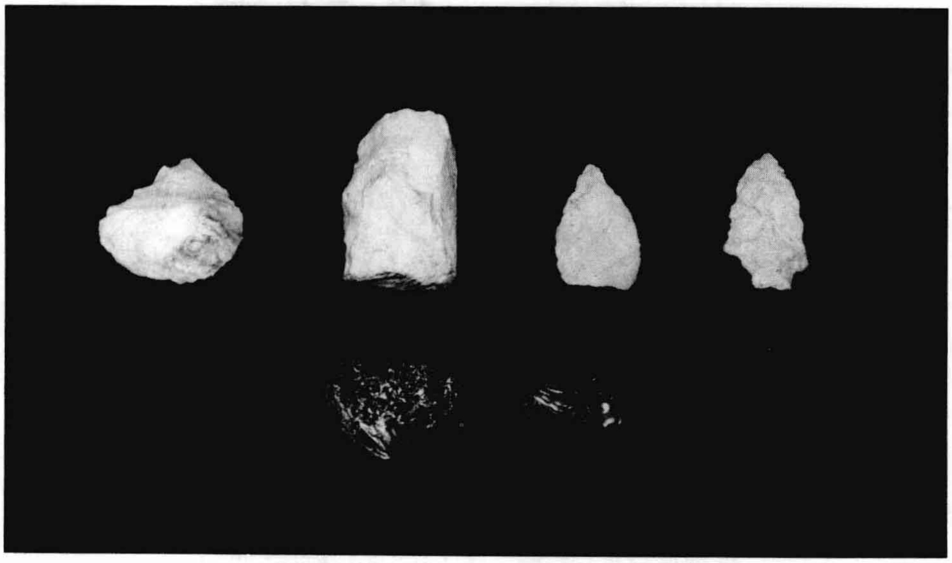
The Frankenstein "monster" has become famous through dozens of movies and television shows. Today, the monster would be right at home, at least in certain aspects of our culture.

Figure 1-6

Here we have a view of science as a powerful force, one that, according to some views anyway, needs powerful controls. "Pandora's Box" and "Frankenstein" are terms used today to describe the powerful and frightening forces unleashed by science and technology. Of course, it is not possible to completely describe science and its impact on society in terms of a "horror film" or an ancient Greek Creation Myth. What we have seen so far however, in man's relationship to nature, is that there are forces, which because of their power, are frightening and need control. At first, believing that the gods caused floods, earthquakes, plagues and other catastrophes, people used religion as a way to try to achieve some control. In some people's minds, modern science and technology have supplanted religion as the means of controlling phenomena. Scientists are not omnipotent, however; they cannot solve all of our problems any more than the rest of us can. Agricultural experts, for example, have developed new varieties of grains and other food crops that could alleviate starvation in the world. For a variety of reasons, such as civil wars, poor transportation, ignorance, and local customs, hunger and starvation are still common. Science is the best method ever found for learning about the physical universe but it does have limits. (For a further look at how knowledge becomes powerful, see "Perspective I: Celestial Patterns," after this chapter.)

4. Scientific Results

The argument is sometimes made that because experiments are artificial situations, the experiment's results cannot be applicable to "real" situations. A version of this argument is often made in biology: If a frog is studied by dissecting it and examining all the pieces carefully under a microscope, there's no way, even in theory, that such processes will tell us about the frog. Even a frog is a unique individual and the "total frog" is more than just the sum of its parts.



Technology consists of making and using tools. Stone tools like these were among the first to be made by humans. (Photo by Ray Hale)

Figure 1-7

It is true that even a frog is unique in some froggy way, but what scientists are trying to discover are the basic characteristics of frogs rather than the peculiarities of just one frog. It is true that science does not discover this kind of "uniqueness"; it is not trying to. Even though experiments are artificial situations, this simply makes it easier to discover basic principles. Once discovered, these principles and their predictions can be examined and tested again and again. When the predictions agree with what we actually observe in real situations, this is powerful evidence that, while the experiments are "artificial," the results are not.