# Chapter 1:  A Look Into the World of Science

## ENLIGHTENMENT OR DECEPTION

The advertisement reads, "Free Pizza."  But, does it really mean you will get a pizza without paying anything?  Not likely!  If you read the fine print, the ad probably means that you get the *free* pizza only after you purchase something first, like another pizza.  In other words, for a certain amount of money, you can buy two pizzas.  If that is what was meant, why didn't the advertisement say two pizzas for the regular price of one?  Does the word *free* accurately describe the offer?

Many statements in advertising are carefully designed to get your attention or mislead the potential customer.  It has become accepted practice to try to create an illusion about an item that may not accurately reflect the true nature of the product, in other words, to intentionally mislead the public to sell a product.  Using words to intentionally confuse and mislead someone is called lying.  However, since lying is such a strong word, it is often politely described as *stretching the truth*, *omitting a few of the details*, or *not being quite factual*.

Words used improperly to create an impression eventually lose their original meanings and become less useful in communication.  What does the word *free* mean?  When words are used in a careless manner, it becomes extremely difficult to understand exactly what is being said.  Understanding the exact definitions of words is a prerequisite for accurate communication.  Many arguments are brought to a quick end or become less intense when the parties involved carefully define the words they are using.  Sometimes they even discover that they agree on the issue.

Since we will be dealing with scientific information, an understanding of the methods, vocabulary, and reasoning used in science is essential.  As with any discipline, there are many words used in science that may be unfamiliar to the nonscientist.  Unfortunately, even scientists have distorted the meanings of some words through improper use.  When certain words gain a measure of prestige, they may be used to help sway the listener to a particular point of view.  For example, calling a survey a "scientific" survey (whatever that means) may cause it to carry more weight with the general public.  The word science has been used so carelessly that many people no longer clearly understand its meaning.

Because some words are not precisely defined, it is often difficult to decide if they apply to a given situation.  To illustrate, let us ask the question: What is a scientist?  Is an engineer a scientist?  Is a physician a scientist?  They are not generally considered to be scientists; however, some engineers and some physicians are scientists.  Is a student who has taken a biology course a scientist, or a student with an undergraduate degree in chemistry?  Is the holder of a doctorate degree in physics a scientist?  These, like many questions, cannot always be answered with a simple yes or no.

Our main objective is to gain an in-depth understanding of evolution.  Is evolution a theory or a fact?  As we proceed, we will discuss the meanings of several words (such as fact and theory) that are often misunderstood, but are very important to our understanding of the nature of science.  In many cases, even members of the scientific community may not agree on the proper usage of the terminology.  Our goal is to establish a mutual understanding of how these words will be used in subsequent chapters of this book.

## DATA AND ITS INTERPRETATION

An important aspect of science is the collection of information or **data** while performing experiments and making observations.  Data collection is often called the "fact" gathering phase of science.  However, the word *fact* is not precisely defined in science.  Most "facts" in science are pieces of information that scientists prefer to call data.

A certain degree of interpretation by the observer often accompanies the presentation of scientific data. Those not familiar with scientific methods can sometimes confuse the data with the conclusions based on the data. The words "scientific facts" are best avoided in preference of more accurate descriptions like *data* or *an interpretation of an observation*. To illustrate the terms we have been discussing, consider the following example.

If someone sees a limb fall from a tree during a thunderstorm, the observer might say it is a *fact* that this particular limb fell from that particular tree. However, would a person who did not see the limb fall consider it a fact? For the following discussion, let us suppose that no one actually saw the limb fall from the tree, but we find the limb lying under the tree. Would we then conclude that the limb fell from that particular tree? It is possible that the wind blew the limb from a nearby tree, or perhaps some animal carried it there from a more distant tree.

Before we conclude anything, we will need to make more observations and perform some experiments. Suppose we observe that the tree is a sugar maple tree, and we determine that the limb came from a sugar maple tree. We also search the surrounding area and are unable to discover any other sugar maple trees. After collecting this *data*, would we conclude that the limb came from that sugar maple tree? Perhaps, but it is still possible that someone carried the limb from another sugar maple tree quite a distance away, or perhaps the limb came from a nearby tree that we overlooked in our search.

Searching for something without success does not necessarily demonstrate that the thing was not there. If I search my house for my car keys and fail to locate them, I cannot be sure that they are not in the house. On the other hand, if I search my house for a lost elephant and fail to find it, I would be pretty sure that the elephant was not in the house. When we draw conclusions based on a search, we must consider the nature of the object and the nature of the search area. Were we looking for a needle in a haystack or a needle in a teacup? Perhaps we need to collect more data.

Suppose we examine the limb and the tree with a microscope and discover that the break on the limb matches a break on the tree. We even decide to analyze samples of the tree and the limb, and we find they are the same chemically. With this additional *data*, even the most ardent skeptic would probably be convinced that the limb came from the tree under which it was found. However, it is still possible that the limb was broken off an identical tree, and the break just happened to match a break on the tree to which the limb was transported. Remember, no one actually saw it fall from the tree. However, the probability that this remarkable set of coincidences actually happened is so remote that few would doubt that the limb did indeed fall from the sugar maple tree. Nevertheless, a more correct statement would be to say that, based on our *interpretation of the observations*, we conclude that the limb fell from the sugar maple tree under which it was found. Note also that we did not prove that the limb fell from the tree. We do not prove things in science! We only gather data that supports our interpretation of the observations. In casual discussions, the word "fact" is often used when either "data" or "interpretation of an observation" is a more accurate description.

The difference between scientific data and an interpretation of this data can be appreciated if we consider the statement that the Earth orbits the Sun. At the time Copernicus proposed this idea, there was no evidence that the Earth moved around the Sun. Eventually, certain observations (which will not be described here) were made that supported the idea. Although the data did not *prove* that the Earth orbits the Sun, it does support our interpretation, namely that the Earth orbits the Sun.

## THE NAMING OF IDEAS

There is much more to science than just the collection and interpretation of data. The real power of science comes from our ability to predict the outcome of certain experiments and observations even before they are performed. In order to accomplish this feat, we need a statement or formula that will tell us how to make the prediction. These statements are known by a variety of names: postulates, theories, laws, or principles.

In some science books you may even find an outline of how the naming of these ideas is supposed to evolve. After some initial investigations, a scientist will formulate an idea that is supposed to be called a **hypothesis**. When the hypothesis is supported by a large number of observations or experiments, the hypothesis is supposed to become a **theory**. If the theory makes accurate predictions over a "long" period of time and becomes universally accepted by the scientific community, the theory is supposed to become a **law** or **principle**.

Although this procedure may sound like a reasonable system, no official scientific group is commissioned to make the necessary decisions about just when these name changes are to be made. Consequently, many new ideas with little supporting evidence are called theories by their authors, and some of the most widely accepted ideas in science are still called theories. In actual fact, the scientific community does not have a definite vocabulary to differentiate between a highly successful theory and a new idea that has little supportive evidence. If scientists do not have a clear system in place, we should not be surprised to learn that statements such as the one claiming that evolution is "only a theory" can easily mislead a nonscientist.

A speculation with little supporting evidence should be called a hypothesis or simply a speculation, but these are such weak words that few people use them. Most new ideas reported in scientific journals are called theories by their author, probably because the word theory carries more weight than the words hypothesis or speculation.

Even though science has failed to provide us with a standardized vocabulary in this area, we will discuss some of the words that are commonly encountered in science. Another problem with the scientific vocabulary is that the nature of various scientific disciplines (a biological study compared to a physics experiment, for example) requires that we employ different methods. These differences tend to further confuse the naming situation. Since physics is the most fundamental science, physics examples tend to be more easily understood. Therefore, we will continue our discussion of the scientific method with some examples from physics.

## POSTULATES

Physics is a discipline that strives to fully understand the basic rules under which the various components of the Universe operate. The job of a physicist is to observe, classify, and experiment with objects in nature, and to formulate general statements that explain the behavior of these objects. The most fundamental of these general statements are known as postulates or axioms. **Postulates** are *assumptions* that can be used to accurately predict the results of experiments and observations made in the natural Universe. (As was noted above, the scientific vocabulary has not been carefully defined, and postulates are often called theories, laws, or just equations.) Postulates differ from interpretations of observations in that postulates are comprehensive statements that allow the scientist to make predictions even before the observations or experiments are performed. For example, a physicist can use the postulate of gravity to predict where a planet will be located, years before it reaches that point. (This postulate is actually an equation, commonly called the "law" of gravity.)

## THEORIES

The word *theory* is often used in association with scientific ideas. However, as we have already seen, it is a rather generic term with a highly variable meaning. The word **theory** is commonly used to describe anything from a wild speculation to an idea that is recognized by the scientific community as one of the basic foundations of science. Often *theory* and *postulate* are used interchangeably, but sometimes a more comprehensive definition is implied. When physicists refer to the *theory* of quantum mechanics, they are not just alluding to the basic postulates of quantum mechanics, but also the predictions and investigations that are associated with this area of study. In nonscientific discussions, theory is often used to imply a wild speculation, but in science, a theory is often a well-verified idea. The nonscientist should be aware of the wide range of meanings that this word encompasses. As with many scientific terms, there is no official definition for the word *theory*.

As noted, the word theory is sometimes used to describe a comprehensive area of study. The *theory* includes all the basic postulates of the theory, any predictions that the postulates imply, observational data associated with these postulates, and interpretations of that data. Examples of comprehensive theories include the theory of special relativity and the theory of quantum mechanics. Ironically, these two *theories* provide our most accurate description of the mechanical workings of the Universe!

Many of the postulates that were formulated in earlier times were called **laws**. Some postulates (or theories in the limited sense of the word) that are commonly referred to as laws include: Newton's law of gravity, the laws of thermodynamics, Ohm's law, Coulomb's law, and Newton's laws of motion. These laws are not fundamentally different from the postulates associated with various comprehensive theories such as the theory of quantum mechanics or the theory of general relativity that have been proposed in more recent times. In fact, all the laws listed above have been found to be *incorrect* under certain circumstances, and many of the newer comprehensive theories are more accurate descriptions of nature that often include one of these older laws as a special case.

The word law is no longer used for new ideas, perhaps because so many laws have been found to be incorrect, or at least limited in their application. Nonscientists often have the mistaken idea that a law is somehow more valid or factual than a "theory." However, laws are not more valid than theories, and often the reverse is true.

In 1915, Albert Einstein introduced the world to a new theory called the general theory of relativity. Today, this theory represents the most accurate description we have of the phenomena known as gravity. In fact, the postulates of Einstein's *theory* more accurately describe gravity than does Newton's *law* of gravity. Einstein's theory gives the correct answer to several gravitational problems that cannot be accurately answered using Newton's law of gravity. One of these problems was recognized soon after Newton proposed his law.

As Mercury orbited the Sun, astronomers noticed that it did not follow the exact path predicted by Newton's law. Because of its outstanding success in explaining so many other observations, people were reluctant to believe that Newton's law was not correct. Other explanations for Mercury's strange behavior were proposed. One solution to the problem required the existence of another planet near the Sun. However, astronomical searches failed to discover any objects of the size required to explain the observed deviations in Mercury's orbit. Finally, Einstein's general relativity theory explained the peculiar motion of Mercury.

If Newton's law of gravity is not correct, why do we still teach it? Unless a problem involves extremely strong gravitational forces, or other very specialized conditions, Newton's law of gravity can approximate Einstein's theory quite well. Newton's law is a special case of Einstein's theory. So you see, Newton's law is not "incorrect" in most cases, but it does have certain restrictions, and we cannot apply it to every gravitational problem as originally hoped. In addition, Newton's law has a great advantage over Einstein's theory in that it can be stated in a much simpler form and, therefore, it is easier to understand than Einstein's theory.

Finally, the mathematics used in association with Newton's law is much simpler than the mathematics required by Einstein's theory. The difference in mathematical complexity is similar to the difference between high school math and college calculus. For most problems dealing with gravity, both theories give essentially the same answer. Therefore, we merely determine under what circumstances it is permissible to apply Newton's approximation and use it only in those cases.

Because scientists have failed to carefully define these terms, the public generally believes that a scientific law is an absolute truth when in actuality, most scientific laws are not completely correct. On the other hand, the general public tends to think of theories as being more speculative, when in fact many theories provide us with our most accurate descriptions of nature. In science, most of the truly great ideas are called theories!

Although we have briefly discussed comprehensive theories, remember that the scientific community is not in uniform agreement as to the accepted usage of the word theory. Often it is used for *every* idea in science. For example, some scientists speculate that a large asteroid or comet collided with the Earth about 65 million years ago, and the resulting explosion caused the extinction of the dinosaurs. This extinction theory is similar to our tree limb example. Given enough data, we might conclude that the asteroid theory is basically correct. (There is already a great deal of evidence in support of this extinction theory.) An important difference between simple ideas and comprehensive theories is that comprehensive theories can be used to make numerous predictions about the outcomes of future studies. Many of the simple ideas in science (that are often called theories) lead to few if any predictions.

When the general public reads about a *theory* that the evolution of intelligence might be due to the complexities faced by apes in their search for a varied diet, and then a scientist tries to tell those same people that gravity is also a theory, is it any wonder that there is some confusion? With such casual usage of the word theory, is it any surprise that creationists are able to cast doubt on evolution by simply stating that it is *only a theory*? The implication being that it is not a "fact" like gravity, but some *wild speculation*. Ideas of restricted application should not be called theories. Less confusion would arise in both the scientific and nonscientific communities if such ideas were consistently referred to as hypotheses or speculations.

A hypothesis is a simple idea that a scientist proposes to explain certain observations. Most hypotheses are of the type that if enough additional data were gathered to support it, we would consider it to be a *conclusion based on the observations*. Copernicus speculated that the planets orbit the Sun. His original idea may have been a hypothesis, but we now have enough evidence in support of this hypothesis that most scientists consider it a conclusion based on the observations. Since our current theory of gravity predicts that the Earth should orbit the Sun, our observations are really evidence that supports the theory of gravity.

## THE POSTULATES OF A THEORY

The postulate formulating stage in the scientific process involves a type of reasoning known as inductive reasoning. After sufficient data has been gathered on certain objects or events, inductive reasoning is used to formulate a general postulate (or postulates) that will predict the behavior of these objects. **Inductive reasoning** is the reasoning we use to formulate a *general* statement based on *specific* observations. Simply stated, it is the reasoning of experience. We have all heard that experience is the best teacher, however, like so many old sayings this one is extremely unreliable. Conclusions based on experience are often in error!

We will look at a very simple example to illustrate the process of using inductive reasoning to formulate a postulate. Suppose we observe the dogs in our neighborhood and notice that all of them are covered with brown hair. Because of the data we have collected, we might propose a postulate, which states that all dogs have brown hair. We would very likely be accused of being a little hasty in basing our postulate on such a limited amount of data, but the above example does illustrate the inductive process, and the fallibility of inductive reasoning.

Scientific postulates must explain all of what has been observed or demonstrated in past experiments, but to be widely accepted by the scientific community, a postulate must be able to correctly predict future discoveries, or the results of future experiments. In the above example, our dog postulate would predict that all the dogs we see in the future should have brown hair. Suppose we observe more and more dogs (collect more data), and they all have brown hair. Although these data do not *prove* that our postulate is correct, they do give us more confidence in our postulate.

Notice that it is impossible to *prove* that a postulate is true in all cases. Considering our dog postulate for example, even if we were to search for years, how could we prove that we had seen every dog in the world? How could we prove that all future dogs will have brown hair, or that all the dogs that lived in the past had brown hair? A postulate is a statement that cannot be proven. However, as more of its predictions are verified, we gain more *confidence* in the postulate.

What happens if we observe something that contradicts a postulate? For example, suppose we observe a dog that is not brown. Of course this piece of data would prove that our postulate must be wrong, but there are two options open to us. We might have to throw out the postulate and start over, but it might be possible to amend the postulate to cover the observed exceptions. Perhaps the dogs that are not brown have long hair. Our new restricted postulate might state that all short-haired dogs are brown. Since the new postulate is restricted to short-haired dogs, it cannot be applied to long-haired dogs. (We might also have to carefully define what is meant by short hair.)

The distinction between a *scientific postulate* and a *conclusion based on observational evidence* can be fuzzy. A *postulate* is an assumption we make because it explains our observations, while a *conclusion based on the evidence* is something we accept as true (at least for the time being), because the evidence is so overwhelming. In the tree-limb example, one could always argue that there is not enough evidence to say that the limb came from the tree in question. Since no one saw the limb fall, some might say that they do not believe that the limb fell from that tree. However, if no amount of evidence will satisfy us, we will make little progress toward understanding the mysteries of the Universe.

Postulates such as those associated with Einstein's theory of general relativity cannot be proven correct in all circumstances. It would be impossible to accurately investigate all the gravitational problems in the Universe and prove that the postulates give the exact answer in every situation. If postulates (and, therefore, the theories to which they apply) cannot be proven, why do scientists have such a great deal of confidence in many of them? The answer is quite simple. Theories that are widely accepted by the scientific community have been used to make *many* accurate predictions about future investigations. However, there is always a *possibility* that some future prediction will be invalidate the theory or a part of the theory.

A comprehensive scientific theory creates a unified picture out of many observations, some of which may seem totally unrelated. The reason for the success of science can be traced to the ability of theories to predict the results of future experiments and observations. An understanding of a few scientific theories will enable a scientist to explain and predict the results of innumerable experiments. Millions of individual pieces of data and hundreds of thousands of problems can be unified into an understandable picture by a few comprehensive theories.

When a scientific theory has an overwhelming amount of supportive evidence, some may be tempted to say that the theory has become "fact." However, theories never become facts. As we have stated, the word "fact" is best avoided in science, and probably should be avoided in other disciplines as well.

## TESTING A THEORY

If postulates are statements that can never be proven, what determines the degree to which the scientific community accepts a theory based on these postulates? As stated above, the real test of a theory is how well it explains and predicts the results of experiments and observations.

Scientific theories contain *general* postulates that are used to make *specific* predictions. This phase in the scientific process involves the reasoning of logic that we call deductive reasoning. **Deductive reasoning** is logical reasoning that uses one or more *general* statements (called premises) to formulate a *specific* conclusion or prediction. A premise can be either a postulate or an observation.

To illustrate, let us return to our postulate that all short-haired dogs are brown. If we observe that Rover is a short-haired dog, then according to our dog postulate and our observation that Rover is a short-haired dog, we would predict that Rover must be brown. We have not proven that Rover is brown; we have only *concluded* that Rover must be brown *if our premises are correct*. If a conclusion based on deductive reasoning is found to be incorrect, one or more of the premises (either the postulate or the observation, in this example) must be incorrect. As we noted earlier, postulates may turn out to be wrong since inductive reasoning was used in their formulation.

The next stage in the scientific process is to attempt to verify the prediction. In our dog theory, for example, Rover should be examined. If Rover is not brown, of course our postulate is in trouble, and it must be discarded or modified again. However, if we can verify that Rover is brown, we will have an additional piece of data to support our theory, and our confidence in the validity of the basic postulates of the theory will be slightly increased. The most widely accepted scientific theories have made many accurate predictions, increasing our confidence in the theory.

An example of this predictive process occurred in the mid-1800s. Newton's law (postulate) of gravity stated that every other object in the Universe should attract a given object. For example, the Sun, Moon, and every other object in the Universe attract the Earth. However, after calculating the forces on Uranus due to the Sun and all the known planets, it was observed that Uranus did not follow the predicted orbit. Using only Newton's equation (postulate) of gravity, calculations showed that the deviations in the orbit of Uranus could be explained if it were being attracted by a more distant planet. The location of the mystery planet was calculated, and those computations led to the discovery of Neptune. Though the discovery of Neptune did not prove Newton's law of gravity, it gave scientists more confidence in the theory.

## FALSIFIABLE OR PREDICTIVE THEORIES

To be of any practical use to scientists, the postulates of a valid scientific theory must be stated in such a way that definite predictions can be made and verified. For example, the theory of gravity says that any two objects in the Universe will attract each other with a certain force - not most of the time, or if they feel like it at the moment, but absolutely always. Every time someone tests the theory of gravity, the results must always fit precisely with the predictions of the theory (assuming the experiment was performed carefully). Just one indisputable experiment that does not fit the predictions of a theory is all it takes to invalidate the theory. We should point out, however, that if data from an experiment does not seem to fit a widely accepted theory, the theory is not immediately canned. Usually, it is the data or its interpretation that is eventually shown to be in error, not the theory.

Since a scientific theory must make definite predictions, the possibility that one of these predictions will turn out to be incorrect always exists. If even one *well verified* prediction is found to be wrong, we must conclude that the theory is false. Theories that make *definite* predictions are vulnerable to falsification and are said to be **falsifiable**.

Being falsifiable means that it must be *conceivably* possible to prove a theory false. Notice that although it is not possible to prove that a theory is absolutely correct, it must be conceivably possible to prove that a theory is false. Of course, a theory found to be false would no longer be an accepted theory. We sometimes say that scientific theories must be testable. Testable not only means that a theory must make accurate predictions, but it also implies that certain observations could disprove the theory. In our dog theory, simply locating a short-haired dog that is not brown would disprove the theory. Therefore, our dog theory makes definite predictions and is said to be *falsifiable*.

Theories with postulates that could never be proven incorrect are of no value in science. As a simple example of such a theory, I might claim that a family of elves lives in my house. These elves come out at night and play with various items, but they are very careful to replace everything when they finish. They hide whenever anyone comes near, which is why it is impossible to detect their presence. No one has ever seen them, and no one ever will because they are very clever. If you devise a plan to photograph them, or catch them, or detect their presence in any way, they will find you out and foil your plans. As you can see, the postulates of this theory have been carefully stated so that it is impossible to prove them incorrect. I do not wish to enter into a discussion about the validity of the elf theory, but merely wish to state that it is not a scientific theory. A theory such as this one extends beyond the realm of science.

Religions are generally based on nonfalsifiable postulates that cannot be studied scientifically. For example, the idea (postulate) that some prayers are answered is not falsifiable. Apparently all prayers are not answered, and there is no way of predicting exactly which prayers will be answered. Since the statement that some prayers are answered does not make *definite* predictions, this idea is not falsifiable. Although the prayer idea is not falsifiable, it may still be true that some prayers are answered. However, it is not a scientific postulate and cannot be studied by traditional scientific methods.

## HISTORICAL NARRATIVES

When making scientific investigations, reproducing the exact event of interest is not always possible. Suppose you are interested in how a particular vase shattered as it fell from a table. When it hit the floor the pieces flew in all directions and scattered around the room. You can mark the position of each piece, weigh it, note its orientation, and make other measurements that might be relevant to the collision. You can study the data from this event, but you cannot repeat the experiment. You might even make some interesting discoveries by studying the data from the collision. For example, the number of pieces as a function of their weight might be interesting, or a plot of the number of pieces as a function of their distance from the impact point might present an interesting pattern. However, you cannot repeat the original collision. Many investigations in science are constrained by the realization that certain events took place that cannot be exactly repeated. The evidence for such events must be measured, analyzed, and conclusions must be drawn without the luxury of repeating the experiments. These nonrepeatable events are historical in nature.

Historians tell us that many Europeans became aware of the New World after a man named Christopher Columbus sailed to America in the year 1492. Is this statement a conclusion based on the evidence, a portion of a historical account, or something else? There is a great deal of evidence to support this statement about Columbus, but it is not a conclusion in quite the same sense as the statement that says the Earth orbits the Sun. At any given time, a scientist can make the measurements (collect the data), which can be *interpreted* as evidence that the Earth orbits the Sun. The evidence that Columbus sailed to America, however, is of a different nature. One can look up old papers and make inquiries that might lead one to *conclude* that Columbus did sail to America, but there are no experiments that can be carried out today to demonstrate that Columbus sailed to America in 1492. Perhaps all the papers were forged. The Columbus expedition could have been a well-orchestrated hoax (although someone must have told Europe about America). Assuming the Columbus event did take place, it cannot be repeated. We must be satisfied with studies based on the data that remains.

By their very nature, historical events cannot be verified by the same methods used to verify other predictions. Since historical events have already taken place and cannot be repeated, historical accounts merely attempt to create a consistent picture from the available data. In science, that generic word “theory” is often called to action when referring to historical accounts. We will call these theories **historical narratives** to differentiate them from nonhistorical scientific theories, such as the theory of general relativity or the theory of electricity and magnetism.

Nonhistorical scientific theories attempt to explain the results of scientific experiments, and historical narratives attempt to construct a self-consistent picture that agrees with all the evidence. In certain areas of science we encounter various historical narratives. These narratives include the Big Bang that describes the formation and early evolution of the Universe, continental drift as it attempts to reconstruct the shapes and locations of the continents in ages past, and organic evolution that attempts to reconstruct the family trees of various organisms. The tree-limb illustration that we used earlier was an example of a historical narrative.

Since these narratives describe events in times past, they often contain many details. To ascertain one of the details of the narrative, sufficient evidence must be available to allow one to draw a conclusion. Reaching this conclusion is similar to reasoning used in a court of law. Insufficient evidence requires that no conclusions can be reached about that particular detail. For example, the current data is insufficient to determine who invented the wheel or when it was invented.

If enough details are known, historical narratives can be used to make certain predictions, just as is done with nonhistorical scientific theories. For example, if Columbus did open up the Americas to Europe in 1492, we would not expect to find evidence of English firearms in North America before 1492. We would not expect to find evidence of horses in the Americas before the voyage of Columbus, and we would not expect to find evidence that Europeans knew of American turkeys, corn, or tobacco prior to 1492.

Like the Columbus story, a major portion of evolution is a historical narrative. The general idea of evolution is that the first life forms were very simple, but the descendants of these early forms changed in various ways, and some groups evolved into very different looking organisms. Present day organisms are the modified ancestors of earlier life forms. Darwin called this idea *descent with modification*. Studies in the field of evolution attempt to discover just what changes have occurred, when they took place, and if these new pieces of information are consistent with the other details of the emerging evolutionary narrative.

In terms of its predictive ability, the evolution narrative is one of the most valuable "theories" in all of science. The theories of quantum mechanics and special relativity are probably the most essential of all the physical theories, and evolution performs a similar role in biology. Even fragmented knowledge of the evolution narrative allows one to make numerous predictions and greatly increases one's understanding of the living world.

For example, evolutionary evidence leads us to conclude that humans evolved from an ape-like ancestor less than three million years ago. Since other evidence suggests that dinosaurs became extinct about 65 million years ago, we can predict that no evidence of humans associating with dinosaurs will ever be found. In addition, if humans and chimpanzees evolved from a common ancestor only five to eight million years ago, we would predict that their body chemistry should be very similar, much more similar than the body chemistry of a human and a dog for example. Some of these chemical tests have been performed, and as we will see in Chapter 10, the results are consistent with our expectations.

If a jury weighs the evidence and finds a defendant guilty, the crime cannot be repeated to check the verdict. (Note, however, that many laboratory experiments may have been performed on the evidence during its examination.) Likewise, when scientists weigh the evidence and conclude that mammals evolved from reptiles, we cannot repeat history to check the conclusion. The events have already happened, and we cannot repeat the experiment. We can only study the evidence and try to assemble the pieces into a consistent picture. There are, however, important differences between a legal trial and the scientific investigation of evolution. The scientific evidence is always available to scientists for examination, and the search for new evidence continues in a never-ending process. Although conclusions are drawn along the way, the jury of scientists is always deliberating. Some additional piece of evidence may show that a conclusion is incorrect. A *scientific trial* is always in session.

The details of evolutionary changes are quite numerous and involved, and many questions have not been confidently answered at this time. For example, what specific group of reptiles gave rise to the birds? Did mollusks evolve from segmented worm-like ancestors, from a type of flatworm, or from some other group of organisms? Many relationships are not known at present, but many have been painstakingly pieced together from the fossil record and molecular studies. Evolution, like any viable branch of science, is an ongoing study.

Our scientific journey will be to explore some of the evidence that has been used to reconstruct the evolutionary history of life. As with any historical narrative, the story is not complete. Many of its gaps must await new discoveries before we are able to fill in the details, and many gaps may never be filled since some evidence may have been destroyed.

## OCKHAM'S RAZOR

Given any body of evidence, it is possible to formulate more than one postulate to explain the data. For example, in our illustration of the tree limb, it is possible that the tree limb was carried a great distance and laid under the sugar maple tree. Perhaps life forms from another world brought the limb from their home planet and left it under the tree. If there is a choice, a scientist will pick the *simplest* explanation that fully describes the observations. The principle of picking the simplest explanation or theory is known as **Ockham's Razor** (or Occam's Razor).

Ockham's Razor explains why most scientists remain skeptical that some UFO's are space ships from other worlds. Even if there are life forms on other planets scattered throughout the Universe, the energy and time required to travel even from a nearby star would make the trip extremely difficult and, therefore, highly improbable. Because a visit by beings from another world would be such an extremely incredible accomplishment, (certainly one of the most remarkable events in recorded history), the evidence for such a visit would have to be absolutely beyond reproach in order to gain acceptance.

A few ambiguous pieces of evidence are not sufficient to be interpreted as a visit by creatures from another world. Invoking Ockham's Razor, we interpret most UFO sightings as lights, meteors, airplanes, or other common phenomenon. Some sightings must remain just what the name says, unidentified flying objects. Even though we may not be able to explain all UFO sightings, there is not enough evidence to jump to the remarkable conclusion that they are the space ships of visitors from another world.

Newton's law of gravity carried with it the implication that the Earth must orbit the Sun. However, if you choose to believe that the Earth is fixed in space and does not move, the theory could be modified to accommodate this belief. All that is really needed is a footnote, which says that the Earth is special (for some unknown reason) and acts differently than all the other objects in the Universe. The fixed Earth theory would be more complicated than Newton's law of gravity, and Ockham's Razor requires us to pick the simpler theory.

Einstein's formulation of his general theory of relativity also illustrates the use of Ockham's Razor. When Einstein first proposed his theory, it was used to calculate the large-scale structure of the Universe. To the surprise of Einstein, the only possible solutions to his equations required that the Universe be either expanding or contracting. A stable solution was not possible. Instead of making the bold prediction that one day observations would show that the Universe is either expanding or contracting (we now know that it is expanding), Einstein added another term (called the cosmological constant) to his equations that permitted a static solution. Einstein later called the addition of this term his greatest blunder. With the discovery that the Universe is expanding, Einstein's extra term was no longer necessary. Although keeping a small cosmological constant could have satisfied the observations, Ockham's Razor required that it be removed.

## FIXING THE RULES

Science encompasses many widely varying areas of study. From physics to biology, the theories of science must be consistent with each other. An observation in biology cannot contradict one of the theories of physics. Likewise, one theory in physics cannot contradict another. In the past, great strides in science have sometimes taken place because of the discovery of an inconsistency. James Clerk Maxwell, one of the truly great minds in science, discovered that the four laws of electricity and magnetism were not consistent with each other. Maxwell was able to correct this inconsistency, by modifying a law known as Ampere's law (another *law* that was wrong). He was then able to write four consistent equations that contained all the information needed to describe the electric and magnetic properties of matter. These four equations (known as Maxwell's equations) are the basic postulates of the theory of electricity and magnetism.

However, Maxwell's equations were not consistent with the equations that Newton used to describe the motion of objects under the influence of various forces. (These equations were included in Newton's laws of motion.) When an observer watches the motion of an object (an airplane for example), Newton's equations of motion are used to describe the position, speed, and acceleration of the airplane. If a second observer, who is moving relative to the first observer, watches the same airplane, the second observer uses a similar set of equations to describe the motion he sees. Notice that among other things, the two observers will not measure the same speed for the airplane, since the observers are moving relative to each other. For example, an observer moving *toward* the airplane will measure a faster speed for the plane than an observer who is moving *away* from the airplane.

The equations used by the two moving observers are related to each other by another set of equations that we call *transformation equations*. They are called transformation equations because they *transform* the equations of one observer into the equations of the other observer. Scientists noticed that the equations that transformed Newton's equations of motion were not the same as the transformation equations that were used for Maxwell's equations. This inconsistency guided Einstein in the formulation of his special theory of relativity. Einstein discovered that Maxwell's equations were correct, and that Newton's *laws* of motion were wrong. However, Newton's laws of motion are still being taught, because Einstein's equations reduce to those of Newton when the speeds involved are small compared to the speed of light. Therefore, Newton's equations give an answer that is accurate enough for most of the problems encountered in everyday life. This example is another case in which the *theory* of Einstein is more accurate than the *laws* of Newton.

Evolution has come under attack in recent years, and some claim that evolution violates the second law of thermodynamics. If there were a real conflict, one of the two would have to be altered or discarded. The origin of this claimed violation seems to be a failure by some to fully comprehend the conditions under which the second law of thermodynamics applies. Fortunately, neither has to be discarded because when applied *correctly* to evolution, the second law is not violated.

In one of its simplified forms, the second law of thermodynamics states that natural processes tend to move an *isolated* system toward a state of greater disorder. The physical quantity that measures the *disorder* of a system is called the **entropy**. The second law of thermodynamics says that the entropy (or disorder) of a closed system must *increase* with time (or at best stay the same). While this statement is technically correct, our everyday use of the word disorder may not have the precise definition needed in this situation. Whether the entropy of a system (not necessarily isolated) increases or decreases with time is not always immediately obvious. The second law can most accurately be expressed in mathematical terms, and manipulating mathematical equations leaves less room for errors than does the juggling of logical-sounding phrases.

An accurate way of determining if the entropy of an object or set of objects is increasing or decreasing is to observe if energy is being absorbed (an increase in entropy) or if energy is emitted (a decrease in entropy). The entropy of an object will decrease if it is cooling off, and the entropy will increase if it is heating up.

We believe stars are made from giant clouds of hydrogen gas. However, a cloud of hydrogen gas is in a more disordered state (higher entropy) than a star like the Sun. The Sun is a spherical mass of gas with the hottest material on the inside and the cooler gases on the outside. In fact, the entropy of a star continually *decreases* with time. (The Sun is emitting energy so its entropy must be decreasing.) If the entropy of a star continually *decreases*, how could a star exist? Doesn't a star have to obey the second law of thermodynamics that says the entropy of a closed system must *increase*? The answer to this apparent paradox is easily answered if we consider the entire Universe.

The Sun is a more ordered system than the cloud of hydrogen gas out of which it was formed, but the Sun is not an *isolated* system. Since the Sun's formation about five billion years ago, it has emitted a great deal of radiation (light) out into the Universe. If we calculate the change in entropy of the entire Universe, which has been changed by the radiation from the Sun, we find that the entropy of the *whole* system has indeed *increased*. Therefore, the entropy of the Sun or any star can decrease with time, as long as the entropy of the *entire* Universe increases. This example illustrates the kinds of errors that can easily result when we try to summarize a rather sophisticated theory, like the second law of thermodynamics, with a short sentence.

The argument against evolution is very similar to the example given above. Evolution is a process that seems to produce more complex organisms as time passes. Thus, evolution requires that systems evolve to a more ordered state. The misunderstanding about the second law may stem from a failure to understand the definition of an *isolated* system. Neither the Sun nor the Earth is an isolated system, and evolution does not take place on an isolated Earth. The Sun obviously plays an important role in many events (like evolution) that take place on the Earth.

We must realize that what a physical law does not say is just as important as what it does say. As we saw in the above example of the Sun, the second law does not in any way prohibit one part of an isolated system from becoming more ordered at the expense of another part of the system. As plants and animals grow, they become more ordered. This process does not violate the second law, because the entire system is left in a more disordered state. For example, imagine starting with a baby animal and a highly ordered chunk of food (sugar for example). The animal eats the food and uses it to produce some ordered growth in its own body. However, in the process, much of the food is wasted and is given off as very disordered material and heat. Although the animal has become more ordered, the final products are more disordered than the original configuration.

Using water, carbon dioxide, and the highly ordered light energy from the Sun, plants produce ordered sugar and give off some very disordered energy. Although the sugar is more ordered than the water and carbon dioxide, if we consider the entire system, the net result is an overall *increase* in disorder.

As a drop of water freezes, it gives off energy that increases the disorder of the surrounding environment. The freezing water, however, becomes a more ordered system. This freezing process is not prohibited by the second law of thermodynamics, nor is the formation of increasingly complex molecules at the expense of the Sun's ordered energy. Evolution, which involves going from a less ordered state to a more ordered state, is a process where only one small part of a larger system becomes more ordered. Therefore, this process does not violate the second law of thermodynamics.

The entire Universe is indeed becoming more and more disordered with time, but there are *smaller pockets* within the Universe that are becoming more ordered. These smaller pockets of increased order are what allow stars to shine, water to freeze, and plants and animals to grow. The second law of thermodynamics also permits the small localized pockets of increased order that allow evolution to proceed.

Not only must all scientific theories and ideas be consistent with one another, they are also assumed to be universal in their application. Unless evidence is presented to the contrary, we will continue to assume that the rules do not change with time or from place to place within the Universe. As we look at distant stars and galaxies, we find that their behavior can be explained using the same physical theories that operate here on Earth. We have no reason to believe that gravity or electric charges behave differently at other locations in the Universe. Indeed, we see stars orbiting other stars, in obvious submission to the law of gravity. The light we see today coming from the most distant galaxies, left these objects billions of years ago, and yet that light appears to have been produced by the same kinds of atoms that we find here on Earth. We, therefore, assume that the rules by which nature operates do not change with time or location. This assumption does not mean that the Universe is static. Objects change continually, but we have no evidence to suggest that there have been changes in the laws that determine the behavior of these objects.

Before we leave our discussion of science and scientific theories, we should point out an important point about the reliability of our present scientific theories. We have gone out of our way to describe how these theories could be proven wrong and how they may have to be modified as we discover new information. However, we know the major theories of science are substantially correct since they are able to describe nature amazingly well. Even Einstein's ideas, as revolutionary as they were, did not cause us to throw out Newton's work. As we stated earlier, Newton's laws are still used in most everyday situations.

## EVOLUTION

The idea of evolution was originally introduced as an interpretation of certain observations from the fields of paleontology (the study of fossils) and biology, especially the geographical distribution of different plant and animal species. Today, evolution incorporates information from many other disciplines as well.

Many scientists discussed evolutionary changes in organisms before Darwin's time, but Charles Darwin and Alfred Wallace formulated the first reasonable explanation of the evolutionary process. Their idea was that a process known as natural selection brought about evolution. Darwin's book (<u>On the Origin of Species by Means of Natural Selection</u>) was originally published in 1859. Years before, Jean Baptiste de Lamarck had proposed that evolution occurred because organisms have some inner urge to become more complex. Lamarck apparently believed that the "Supreme Creator of all life" instilled this inner power in the organism.

Lamarck is often credited with the idea that acquired characteristics are inherited, although this idea was widely held by many others of his time. The inheritance of acquired characteristics means that characteristics changed by the environment can be inherited by the offspring. For example, if an individual uses a given set of muscles until the muscles become enlarged, the offspring of this individual may inherit a slightly enlarged set of muscles. Since there seems to be little evidence to support it, Lamarck's idea is not held in high esteem by the scientific community.

Darwin formulated the idea of **natural selection** by observing organisms in nature. He noticed that the individuals in a given population of organisms displayed a great deal of variation, for example, variations in size, color, and physical abilities such as speed and strength. Interestingly, when Darwin proposed the process of natural selection, he did not know that genes controlled the variations of a trait. Darwin also realized that all organisms produce more offspring than could possibly survive to the age of reproduction.

Although the number of organisms in a population fluctuates somewhat, the average number must be stable over relatively long periods of time. If a population were not stable, either their numbers would decrease and the population would become extinct or their numbers would increase and eventually exhaust their food supply. Populations are stable if each mating pair produces an *average* of two offspring that survive to reproduce. Since a single female can produce large numbers of offspring in her lifetime, most offspring must die before they are able to reproduce. In recent times the number of humans has grown explosively because the average couple has produced more than two surviving offspring.

Darwin reasoned that those individuals who are best suited to the environment would have a better chance of surviving to the reproductive age. Those individuals will be the ones that produce young and, therefore, pass their traits on to the next generation.

For example, animals that eat the leaves of certain tall trees might have an advantage if they were taller and could more easily reach the highest leaves. This advantage might be especially important during times when food is scarce, and other animals had eaten most of the lower leaves. The taller animals of the group would have a better chance of surviving and passing their genes for height on to the next generation. Over the years, we might expect this population to evolve into very tall animals. A scenario similar to this simplified one could explain the evolution of the giraffe. Although our scenario may sound reasonable, such stories are speculative in that they attempt to explain *why* things happen, whereas science primarily attempts to describe *how* things happen.

As we explained, there is an important difference between scientific data and a scientific theory. If you drop a rock and watch it fall to the ground, you have collected a piece of data for your scientific journal. If you carefully observe the path taken by a rifle bullet after it leaves the barrel of a gun, you have more *data* for your journal. However, if we wish to explain *how* the rock and the bullet behave, we use the theory of gravity. Do theories exist that can explain the operation of evolution?

When we discuss evolution, or what some scientists carelessly refer to as the "fact" of evolution, we are referring to the changes in life forms that have occurred through time. Did some type of evolutionary process produce the life forms we see today? In other words, do the life forms living today share a common ancestor from the past? For example, do birds and reptiles share a common ancestor from the distant past? Since we did not directly observe a population of reptiles evolve into a population of birds, some might say that we cannot answer this question. However, the data in support of evolution is so overwhelming that the vast majority of scientists have little doubt that evolution did take place. (Remember the tree-limb example above.) The fossil record provides ample evidence to support the conclusion that life forms have changed substantially through time. This conclusion based on the observational data is the general theme of the historical narrative of evolution.

Some scientists define the "theories" of evolution as the processes that have been proposed to explain the observed changes. The most widely accepted "theory" for the mechanism of evolution is the process of natural selection formulated by Charles Darwin.

Natural selection is not a broad general statement that can be used to make definite predictions, but simply a set of conclusions based on observations. However, just as Copernicus suggested that the Earth orbited the Sun before the relevant observations were made, Darwin suggested the idea of natural selection before much observational evidence had been collected to support the idea. (That foresight is what separates Newton, Einstein, and Darwin from the rest of us who are much better at hindsight.)

We have learned a great deal about biology since Darwin's time, and our knowledge of natural selection has increased as well. In terms of our current knowledge, natural selection can be summarized as follows:

1. Individual members of a given population display a great deal of variation, and genes control many of these differences.

2. All organisms produce more offspring than could possibly survive to the age of reproduction.

3. Those individuals that are *best suited* to the environment will have a better chance of producing offspring and passing their *advantageous* traits (genes) on to the next generation.

Statements 1 and 2 are simply conclusions based on observations that were made even before the time of Darwin. However, an analysis of statement 3 has led some to believe there is a problem with natural selection. It has been pointed out that "advantageous traits" are defined to be traits that are more likely to be passed on to the next generation. Statement 3, therefore, appears to be a repetitious statement or a tautology. (An example of a tautology is the statement that says all bachelors are single.)

The important part of statement 3, however, is that it says some traits are *more likely* than certain other traits to be passed on to the next generation. In other words, Darwin saw evolution as a directed process rather than a purely random process. If evolution were purely random, then all traits would have the *same* probability of being passed to the next generation. Darwin decided to place the label "advantageous" on those traits that were more likely to be passed to the next generation. For example, in the arctic, where the ground is often covered with snow, the trait of white hair might be passed to the next generation of animals preferentially over the trait of black hair. No matter what name you give to these traits, if they are more often passed to the next generation, the population will change over time. The population will evolve! Eventually, all the individuals in the population will have white hair, and the genes for black hair will disappear from the population.

Since Darwin proposed his idea, many examples supporting this type of differential selection have been documented. For example, a species of moth known as the peppered moth lives in the woods of England. This moth generally has white wings flecked with darker spots, but a few are dark gray to black in color. The lighter varieties blend in well with the tree trunks on which the moths are often found, making them difficult to spot by their natural predators. During the industrial revolution, however, coal soot from the factories darkened the tree trunks around the industrial cities. The lighter moths became easier to see than the darker varieties and the birds that preyed on these moths ate more of the lighter moths. Soon the lighter colored moths decreased sharply in numbers, and the darker varieties became more common. The population of moths changed in response to the environment. On the sooty tree trunks, the darker coloration was apparently an "advantageous" characteristic, and natural selection soon made it the dominant form. If the factories had continued polluting the air, the "white" genes might have eventually been eliminated from the population.

House sparrows were introduced into North America in 1844. Unfortunately, they have now spread over the entire continent and have become a nuisance. However, differences in widely separated populations are already apparent. In the southwest, the house sparrows are paler in color and smaller in size than the sparrows living in more northern locations. We are observing the first stages of evolution in these localized populations.

A group of finches on the Galapagos Islands has been studied extensively, and it has been documented that certain bill sizes (which are apparently "advantageous") have a higher probability of being passed on to the next generation. During several drought years it was observed that the relative numbers of seed producing plants changed. As the size of the available seeds changed, the survival rates of the birds with different size bills changed also. When most of the available seeds are large, those birds with the larger bills have more reproductive success. The population evolved as the environmental conditions changed. A permanent change in the weather would eventually produce a permanent change in the bill size of finches.

Evolution of many other groups of organisms has been well documented. In just a few decades, codling moths, that once attacked only apples, have evolved races that feed on plums and walnuts. Many insects have evolved varieties that are resistant to certain insecticides, and strains of bacteria have become resistant to certain drugs. On Faeroe Island, the house mouse has changed since it was established on the island about 250 years ago.

It should be noted that natural selection only explains *how* populations evolve, but we are often tempted to explain *why* the changes occurred. In other words, we often attempt to figure out why a certain trait is advantageous. It seems fairly obvious that the dark peppered moths have an advantage because they are harder to see against the soot-covered trees. However, trying to figure out why a certain group of reptiles evolved feathers is much more speculative. We may be able to determine *how* it happened, but trying to explain *why* is much more difficult and uncertain. Many lively discussions involve the why questions.

The above examples of evolution are so well documented that even hard-core creationists accept them as examples of evolution. However, they do not believe that many small changes similar to the ones we have observed can accumulate to the point where one population evolves into a different species. The word **microevolution** has been coined to describe those small changes that have not yet produced new species, while evolution above the species level is called **macroevolution**. Microevolution has been observed, but macroevolution above the species level has not been directly observed. (Actually, a condition called polyploidy can produce a new species of plant in just one generation. This condition will be discussed in Chapter 10.)

Many people have little trouble visualizing how a population of moths can change color over the years in response to industrial pollution, but they have a hard time visualizing how many of these small changes can produce a new species or a new family of organisms. They find it difficult to imagine how thousands of little changes could eventually transform one group of mammals into dogs and an identical group of mammals into cows. Indeed, it would be very hard to visualize how these changes could have occurred if new genes were not introduced into the population from time to time. These new genes are produced by mutations, and we will discuss some of the ways mutations arise in Chapter 5. Using a little math it can easily be shown that if just two or three mutations were injected into each of two populations every generation, the two populations would be as different as dogs and cows in less than 100 million years. This number of mutations is consistent with the number observed. We will come back to this topic in Chapter 10.

Evolution says that all the organisms we see today evolved from life forms of the past. Darwin described this idea as *descent with modification*. A group of today's organisms will be changed from its ancestors. We would expect a population of zebras living today to be significantly different from its ancestral population of say 500,000 years ago. Today's population could be so different that we might classify them as a different species.

It should be noted that we are using the word *population*, not *individual*. The word evolution is used to describe the changes that occur over time to a given *population* of organisms. As it matures, a single organism may change significantly during its own lifetime, but these are not the changes of evolution. Populations evolve, individuals mature.

## EVOLUTION: JUST PROBABILITIES

The **gene pool** of a population of organisms is the collection of *all* the genes possessed by the members of the population. As the members of the population mate, have offspring, and die, the gene pool changes. A population will evolve if its gene pool changes over time. The evolution of a population of organisms is really just a problem based on statistical probabilities. Is it possible for you to flip a normal penny and have it come up heads every time? Although theoretically possible, it is highly unlikely that the penny would never come up tails, just as it is highly unlikely that a population could remain unchanged through time.

Mutations introduce new genetic variations into a population, and natural selection is the driving force that causes a population to evolve in a certain direction. However, even if natural selection were not operating, a population that reproduces sexually would have to evolve due to the random nature of sexual reproduction. If new genetic variations were not continually created by mutations, every population of organisms would eventually become homogeneous.

Consider some population of organisms (for example polar bears). When a pair of these organisms has babies, each offspring receives half of his or her chromosomes from each parent. (Many genes are linked together on structures called chromosomes.) The genetic composition of each offspring is a purely random process. Since it is highly unlikely that the parents pass on *all* of their chromosomes to their offspring, some of their chromosomes (and the genes on them) are lost when the parents die. In each generation, chromosomes are lost until no more can be lost and the population becomes homogeneous. At that point, all the individuals would have identical genes except for those differences on the chromosomes that determine the sex of the organism. This process of homogenization *must* occur because of the random nature of egg and sperm formation, the random nature of fertilization, and the fact that *all* the chromosomes (and their genes) in one generation are generally not passed to the next generation.

The only thing that keeps this homogenization from occurring is the introduction of new genetic material through mutations. These mutations introduce new variations into the population. Therefore, the genetic makeup of the population (its gene pool) changes with time. In other words, the population evolves. The observation that populations of organisms are not homogeneous is strong evidence that new mutations are being continually introduced into the populations and that the populations are evolving. Notice that a population would evolve even without the introduction of mutations, but the evolution would be towards homogeneity.

Evolution is like a dice game where each organism brings its own dice. (The dice are the genes of the organisms.) If some individual can run faster, or is more camouflaged, or can see better, or has some other trait that gives them an advantage over the other members of the population, it is like that individual is playing with loaded dice (or have advantageous genes). It is more likely to be a winner, and being a winner means it is more likely to survive and reproduce, thus passing the loaded dice on to its offspring and the next generation. An organism that does not have loaded dice (no advantageous genes) is more likely to lose the game (it will not have offspring), and the unloaded dice will be lost. This is how the gene pool changes and the population evolves.

The difference between microevolution and macroevolution is one of degree. In a few years or a few hundred years a population evolves a little bit, but in a few thousand years or a few tens of thousands of years, a population evolves so much that we might call it a new species. Macroevolution is not easily observed simply because it takes a longer time to happen than the time over which we have been making careful observations.

The word evolution is often incorrectly interpreted to mean that the organisms of today are improved versions of their ancestors. This idea is very misleading. While many organisms living today look and behave very much like their ancestors, others have changed a great deal in appearance. The rate at which a group of organisms changes in appearance is certainly not the same for every group of organisms.

Life forms that look very similar to their ancestors are often referred to as **primitive**, but this word is in many ways an unfortunate choice. *Less specialized* would be a better description. As used here, the word *primitive* is not meant to imply that the organism is in any way less suited for its mode of life than we are for ours. Many populations of organisms become well adapted to their own little niche and subsequently undergo few *obvious* changes.

The word **advanced** is often used for organisms or parts of organisms that have changed a great deal from their ancestors. Again, this word should not be interpreted as meaning better, but just different. Terms like *greatly modified* or *more specialized* would be more accurate descriptions than *advanced*. Horses have more *advanced* feet (more highly evolved) than do primates such as humans. Our hands and feet have the same number of bones as did the earliest mammals, but the bones in the foot of the horse have been greatly modified from the *primitive* condition of early mammals. The dinosaurs were more *advanced* than the *primitive* bacteria. However, the dinosaurs are extinct while many bacteria are doing quite well.

## HOW, WHY, AND WHO

As we said earlier, often we are unable to determine *why* things happen, but asking the *why* questions and discussing the various possibilities generates excitement. For example, why are most mammals color blind? Why did certain reptiles evolve into birds? As one might imagine, a great deal of disagreement as to the causes of the observed changes exists. Upon hearing these arguments, the general public may be left with the impression that scientists are disagreeing on whether evolution actually took place, when they are merely arguing about which mechanisms were more important, or just how quickly these changes were brought about.

As we discuss topics related to evolution in the subsequent chapters of this book, we will present evidence that demonstrates evolution has happened, and we will also describe the mechanisms believed to be responsible for the observed changes. Remember, while the evidence that evolution actually happened is overwhelming, the reasons why certain changes occurred are often very speculative.

Because of its rather complex nature, we will incorporate the historical narrative of evolution, the important evolutionary principles (such as natural selection), and the speculations about why the changes occurred into an integrated summary and call it the **evolutionary theory**. Most scientists undoubtedly have this type of comprehensive picture in mind when they speak of the "theory" of evolution.

In terms of contributing to our understanding of what we observe in the natural world, all other concepts become insignificant when compared to evolution. Simply stated, evolution makes sense out of our observations in the fields of biology, biochemistry, and paleontology. Studying biology without a through understanding of evolution would be like studying chemistry without an understanding of the periodic table of the elements, or like studying the motions of the planets without comprehending Newton's law of gravity and the laws of motion.

As we observe a leaf floating to the ground, we can describe its path in terms of gravity and air resistance. The blowing breeze can be described in terms of the air masses set into motion by the Sun's energy and the rotation of the Earth. We can explain how the leaf is no longer needed by the tree and is shed as the tree becomes dormant during the winter months. But if someone asks *why* the leaf falls, we cannot really answer that question. A physicist might reply that it is due to gravity. But why was gravity made to work the way it does? The physicist might go on to explain about the gravitational interaction and mumble something about the Earth and the leaf exchanging gravitons, but he is still only describing *how* gravity behaves, not *why* the rules of gravity exist. We do not know why there is gravity or why atoms seem to be composed of positive nuclei and negative electrons - we can only describe *how* they work.

As stated earlier, science tries to answer *how* questions, but not *why* questions. However, if we try to classify all questions into the "how" group and the "why" group, we will soon encounter difficulties. For example, what do we know about mammal vision? We know that there are light receptors in the eye that respond to the light energy entering the eye. These receptors send signals to the brain, and the brain interprets the signals as vision. From experimentation we know that the black-and-white receptors in the eye (called rods) are more sensitive to light than the color receptors (called cones). In addition, we observe that most mammals are active in the morning, night, and evening hours when the light is less intense and colors are more subdued. It seems reasonable to conclude, therefore, that rod vision (black-and-white) would be more useful than color vision under these circumstances. Are we only able to determine *how* mammals see, or do we have some idea as to *why* their vision is dominated by rods? In other words, do we know *why* most mammals are color blind?

Although this book is not intended to be a creation versus evolution book, another important aspect of science should be pointed out. Science can explain *how* things operate, and sometimes perhaps it can explain *why* things happen the way they do, but it certainly does not presume to know if someone created the rules that all objects are forced to obey, or *who* that someone is. Who made the Universe, the Sun, the Earth, the plants, and the animals (including humans)? As scientists we cannot answer that *who* question. Most religious people believe that there is a God who created the life of this Earth, and that He also formulated the law of gravity and all the other physical principles that we and all other objects in the Universe are compelled to obey. No scientist can argue scientifically that they are wrong. We cannot scientifically disprove the existence of God. As we have seen, these beliefs lie outside the realm of scientific investigation. Remember, religions are based on no falsifiable ideas and cannot be investigated by the methods of science.

Does evolution conflict with the idea of creation by God? The answer to this question depends on your exact view of creation. If God made the living creatures of the world, then as scientists we can only determine *how* He did it. The preponderance of the evidence points to evolution as the method used to create the vast array of creatures that now inhabit the Earth. Contrary to popular belief, evolution does not dispute the existence of God as the creator of all things; it merely attempts to describe *how* the creation was accomplished.

In some religions, there have been interpretations of dogma or scriptures that conflict with evolution. For example, evolution may conflict with some interpretations of the book of Genesis in the Bible, namely that the Universe, the Earth, and all the living organisms were created in just six consecutive 24-hour days. Others, however, claim that the Hebrew word, which is translated as "day", can also mean a long period of time. No matter how one interprets these passages, an overwhelming amount of scientific evidence points to a very old Earth and Universe. If the Earth and Universe is not billions of years old, then God has added apparent age to the Universe to deceive us. Why would God create humans with a curious mind and then deliberately try to deceive those who dare inquire into the secrets of the Universe?

As we will see, the evidence indicates that the various life forms were not all created at the same time. The earliest organisms that we have discovered were one-celled organisms, and increasingly complex forms appeared over hundreds of millions of years. If the Earth and all its living organisms were created in just six consecutive 24-hour days, then why does all the evidence indicate that these spectacular changes occurred over millions of years? Surely we do not live in a Universe created by a dishonest God. In science, we assume that the evidence was actually created by events that happened in the past and that some supreme being did not create the evidence to appear as though something happened when it actually did not. A devious God could have created us a few seconds ago with a programmed memory of things that never actually took place.

In addition to the six consecutive 24-hour days, there are many passages in the Bible that apparently cannot be taken literally. For example Psalm 93:1 says, "... Indeed the world is firmly established, it will not be moved." This phrase was once believed to be proof that the Earth did not orbit the Sun.

Ecclesiastes 3:14 says, "I know that everything that God does will remain forever, there is nothing to add to it and there is nothing to take from it, for God has so worked that men should fear him." This statement was once used to support the belief that animals could not become extinct since God made them. We now know that many creatures have become extinct. Sadly, humans are now devastating vast areas of the world and causing the extinction of many of the unique and wonderful creatures that inhabit this planet we call Earth. Humans are the only animals capable of comprehending the concept of God, and yet many seem to have little reverence for the creation attributed to Him.

Some have claimed that evolution makes God unnecessary. However, one might just as easily support the claim that discovering the details of evolution elevates the image of God, and increases our appreciation and reverence for His work. Instead of picturing God in a playroom making various animals out of clay, He becomes the great designer who formulated the rules, knowing full well what would be produced and how it would happen. In this context, evolution is the wonderful story of the creation of God's creatures.

Recently, creationists have been advocating an idea they like to call *intelligent design*. The idea is that when one studies nature, many complicated concepts and intricate patterns are revealed. Indeed, many of the details are so complicated that we do not understand them at this time. Many diseases have not been cured, many other problems have not been solved, and our understanding of some scientific topics is very rudimentary. Intelligent design proponents believe that the complexity of nature speaks of an intelligent designer who is God. They usually do not state that the designer is God, but who else could it be?

It is possible that an intelligent designer formulated the principles that rule the Universe, but the introduction of an intelligent designer does not replace or even augment our understanding of gravity, electricity and magnetism, chemical bonding, evolution, or any other scientific idea. It does not make it easier for us to find cures for diseases such as AIDS, cancer, and Alzheimer's disease, or guide us in our search for the basic laws that govern the Universe. In addition, the introduction of an intelligent designer is a not a falsifiable theory, so the idea cannot be disproved. It is, therefore, outside the realm of science. If an intelligent designer designed the Universe, then the mission of the scientific community is to discover the details of that design and to study the creation process used to implement that design.

Just as it appears that the laws of physics were used to form the stars and planets, a preponderance of the evidence points to evolution as the process that was used to shape the living world. The idea that life forms were created by evolution may seem hard to believe. However, many ideas in biology are even more unbelievable. It is certainly an even more amazing idea to think that a person who is made of hundreds of trillions of cells could have been created from a single cell formed by the union of an egg and sperm. Yet biologists tell us that is exactly how many life forms are created. The amazing process of reproduction perpetuates life, and the evidence tells us that evolution is the process by which new diverse life forms are created.

## SOME INTERESTING QUESTIONS

The greatest value of evolution is that it provides an explanation for many of the mysteries of the living world. There are many questions that defy understanding until they are examined in the context of evolution. We will investigate much of the evidence in support of evolution later, but at this time it might be interesting to consider just a sampling of the fascinating questions that can be understood in terms of evolution.

Fossils are found in layers of sedimentary rock, and there is a very definite pattern to the layering. For example, dinosaur bones are never found in rock layers that contain the bones of elephants, horses, humans, or any of the other large mammals whose bones are so common in younger layers. How was this pattern created? We conclude that dinosaurs lived before the large mammals evolved. After the dinosaurs became extinct, the larger mammals evolved and when these mammals died, some of their bones were trapped in layers of sediment on *top* of the dinosaur bones, not alongside them.

Sharks shed their teeth and millions of fossil shark teeth have been found in certain fossil bearing layers. However, none are found with the trilobite layers of the earlier time period we call the Cambrian. This is no mystery if we realize that sharks evolved millions of years later, after these trilobites had become extinct. In Chapter 7 we will study some of the details of the fossil layering.

Many of the life forms found on islands are unique. How did these life forms originate? Most islands have been isolated for millions of years. If some type of plant or animal happened to reach the island and was able to become established, its descendants would have evolved into new species as they adapted to their new environment. If there are several islands in the group or different environments on one of the larger islands, several closely related species will evolve. A few of the animals confined to specific islands include: a family of Hawaiian birds called honeycreepers, the Darwin finches of the Galapagos Islands, the extinct dodo of Mauritius, the kiwis and extinct moans of New Zealand, insectivorous mammals called solenodons of Cuba and Hispaniola, the lemurs of Madagascar, and the extinct Tasmanian wolf of Tasmania. In Chapter 9 many of these animals will be discussed in more detail.

Baleen whales do not have teeth, but they have long plates of flexible material called baleen that hangs down from their upper jaws. Baleen is used to filter out food (small plants and animals) from the ocean water. The fetus of a baleen whale develops a full set of teeth that never erupt through the gums and are completely absorbed before birth. How does evolution explain these teeth? The fossil record shows us that the ancestors of all types of whales had teeth, and this toothed ancestry is still displayed in the embryonic development of the baleen whale's young.

The bones of a bat wing and a porpoise flipper are more similar to the bones in the human hand than they are to the bones of a bird wing and fish fin respectively. How did this happen? Although all these structures have a certain degree of similarity, the bat and porpoise are more closely related to humans than they are to either birds or fish. That is to say, bats, porpoises, and humans share a more recent common ancestor than they do with birds or fish. Even though bird wings and bat wings are used for the same function, their bones are less similar than are the bones in a bat wing and a human hand. Likewise, the dolphin flipper and the fish fin are both used for swimming, and yet the bones of the flipper more closely resemble those of the human hand. In fact, regardless of its mode of life, any given mammal will share more anatomical similarities with another mammal than it will with a non mammal. These and other similarities tell us that mammals evolved from a common ancestor with these features, which is why we classify them as mammals.

How does evolution explain the panda's thumb? The so-called "thumb" is a modified wrist bone (the radial sesamoid), but it does serve the purpose of aiding the panda as it feeds on bamboo leaves. Evolution does not always lead to the best solution of a problem. Indeed, evolution often does not lead to any solution at all, as evidenced by the numbers of species that have become extinct throughout history. Note how many of the uniquely adapted island animals have become extinct since the introduction of foreign species in more recent times. Some of the introduced species are obviously better suited to life on the islands than are many of the native species.

Boa constrictors have rudiments of hind legs, a pelvis, and two lungs. How are these structures explained? Although all snakes have two lungs, in most snakes one lung is greatly reduced in size to make the body more streamlined. Again, in terms of evolution we know that snakes evolved from walking lizards that possessed two lungs, four legs, and a pelvis. The boa constrictor is a "primitive" snake that is not as highly evolved as other snakes. Their leg bones and pelvic bones have not been completely lost.

Male bees and wasps are unable to sting. How do we explain this observation? In the context of evolution, the answer is quite simple. The stinger evolved from a modified egg-laying device that was used by the more "primitive" ancestors of bees and wasps to insert eggs into plants. Since males do not lay eggs, they did not have this egg-laying device and, therefore, did not evolve a stinger.

How do we explain the observation that each chromosome replicates itself prior to meiosis? (This replication appears to be an unnecessary complication.) Meiosis is the process by which eggs and sperms are formed in higher forms of life. Meiosis is a more complicated process than is necessary to perform the desired result. The complexity of meiosis can be understood if we view meiosis as a slight modification of simple cell division, a process we call mitosis. Meiosis evolved from mitosis. (See Chapter 6)

Evolution is a process of change. Change is observed in many parts of the Universe. The Earth changes, the stars change, life forms change, and even the Universe as a whole has evolved over time. Before life could form and prosper on Earth, the proper conditions had to be prepared. Numerous important events contributed to the establishment of these conditions, many of which occurred long before the first organisms appeared in Earth's early seas. A few important events that we would like to investigate occurred in the first few minutes after the formation of the Universe itself. Our investigation will begin there.