Evidence of Evolution 28

The female dinosaur digs and prods the muddy earth, making a circular nest of mud. After she has laid a single egg, she hovers nearby, guarding the egg from predators. The egg hatches, but something is wrong, and the baby dies. The tiny body and its broken eggshell sink into the watery earth. Eighty million years later, paleontologists discover the nesting site and the skeleton. In this chapter, you will find out how clues in the earth provide evidence of the evolution of living things.

Guide for Reading

Key words: geologic evolution, organic evolution, fossil, spontaneous generation, heterotroph hypothesis

Questions to think about:

What information do fossils provide about geologic and organic evolution?

What is the most current hypothesis of the origin of life?

28–1 Evidence from the Past

Section Objectives:

- *Describe* at least five processes by which fossils may be formed.
- *Explain* how sedimentary rocks are formed and why fossils are often found in these rocks.
- *Define* the terms *relative dating* and *absolute dating.*
- *Explain* how radioactive dating can determine the age of rocks.

Laboratory Investigation: *Examine* and *compare* a variety of fossil samples (p. 594).

Evolution is the central and unifying theme of biology. In its most general sense, the term *evolution* means a gradual change over time. Since its formation about 4.5 billion years ago, the earth itself has changed continuously. This slow change is known as **geologic evolution.** Many species also have changed since they first appeared on the earth. This process is known as **organic evolution.** How did life begin and how has it evolved into the species living today? In this chapter, you will learn about the scientific evidence for organic evolution and the theories of how life began on earth.

▲ **Figure 28–1**
A Living Fossil. This coelacanth represents a group of lobe-finned fishes that had been thought to be extinct.

Fossils

The study of fossils provides the strongest evidence of organic evolution. A **fossil** is any trace or remains of an organism that has been preserved by natural processes. By studying fossils, scientists can compare the remains of ancient organisms with organisms living today to see whether or not organic evolution has occurred.

▲ **Figure 28–2**
A Fly Fossil Preserved in Amber. This fly became trapped in sticky resin. The resin hardened into amber, preserving the insect.

When an organism dies, it usually decays without leaving any remains. Special circumstances are required for a fossil to form. In the majority of fossils, the soft tissues of the organism have decayed, and only the hard parts, such as bones or shells, have been preserved. In some fossils, however, an entire organism has been preserved with almost no decay.

Fossils in Amber and Ice The soft tissues of animals usually decay because of the activities of bacteria and fungi. In some circumstances, such as anaerobic conditions or extreme cold, decay does not occur, and entire organisms are preserved.

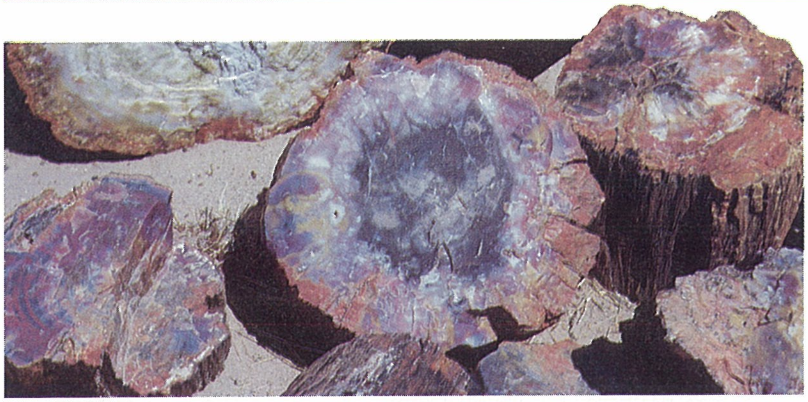
As you can see in Figure 28–2, entire insect remains can be preserved in amber. *Amber* is a hard, yellow, transparent material formed by the hardening of resin, a sticky substance produced by trees. Insects often become trapped and embedded in the resin, which then hardens into amber.

In the cold Arctic regions, entire animal remains have been preserved in ice for thousands of years. As you can see in Figure 28–3, the remains of extinct woolly mammoths can be so well preserved by the cold that their flesh, skin, and hair are present.

Fossil Bones and Petrifaction Under some conditions, the hard, mineral parts of animals, such as shells, bones, and teeth, can be preserved for millions of years. Dinosaur bones, some more than 100 million years old, have been found all over the world. Usually only teeth, parts of the skeleton, or skull fragments are preserved. It is uncommon to find a complete fossil skeleton.

Many animal skeletons have been preserved in pools of tar in which the animals were trapped. The La Brea tar pits in Los Angeles, California, contain thousands of fossils. Although most of

Figure 28–3
A Woolly Mammoth. This completely preserved body of a woolly mammoth was uncovered in the Soviet Union by a bulldozer overturning frozen ground. ▶



◀ **Figure 28–4**
Petrified Tree Trunks.

these animals lived less than 25 000 years ago, they include many extinct species, such as the saber-toothed tiger and the woolly mammoth.

In some cases, a dead organism lies in a body of water that contains a high mineral content. Gradually, the original substances of the organism dissolve and are replaced by minerals from the water. In this process, which is called **petrifaction** (peh truh FAK shun), the remains of the organism are turned to stone. Whole trees, estimated to be 150 million years old, have been preserved as stone fossils in the Petrified Forest in Arizona. See Figure 28–4. Many fossil bones actually are petrified replicas of the original bones.

Molds, Casts, and Imprints By far the greatest number of fossils form on the bottoms of lakes and seas. A dead organism slowly sinks into the sandy or muddy bottom of a lake or ocean. As additional particles of sand or mud accumulate on the bottom, the organism becomes buried. The sand or mud later hardens into rock. Meanwhile, the remains of the organism decay, but its shape is preserved in the rock as a hollow form called a **mold.** Sometimes, a mold becomes filled with minerals, which in turn harden to form rock. The hardened minerals form a **cast,** or a copy of the external form of the original organism.

Impressions made in mud, such as animal footprints, may remain when the mud hardens into rock. The impression is called an **imprint.** Among the largest known imprints are the dinosaur footprints shown in Figure 28–5. Many imprints also have been left by thin structures, such as leaves.

Calculating the Age of Fossils

Most fossils have been found in a kind of rock that is called **sedimentary** (sed uh MEN tuhr ee) **rock.** Most sedimentary rocks form on the bottoms of shallow seas or on ocean bottoms near the shorelines of continents. As a river flows over land, it wears away, or erodes, fine particles of rock. These particles are called *sediments.* When the river waters enter the sea, the sediments slowly settle to the bottom. Gradually, sediments build up on the sea bottom. Various chemical processes, combined with the pressure exerted by the weight of the sediments, slowly harden the material into rock.

Figure 28–5
Dinosaur Footprints. The size of a dinosaur can be estimated relative to the size of its imprints. ▼

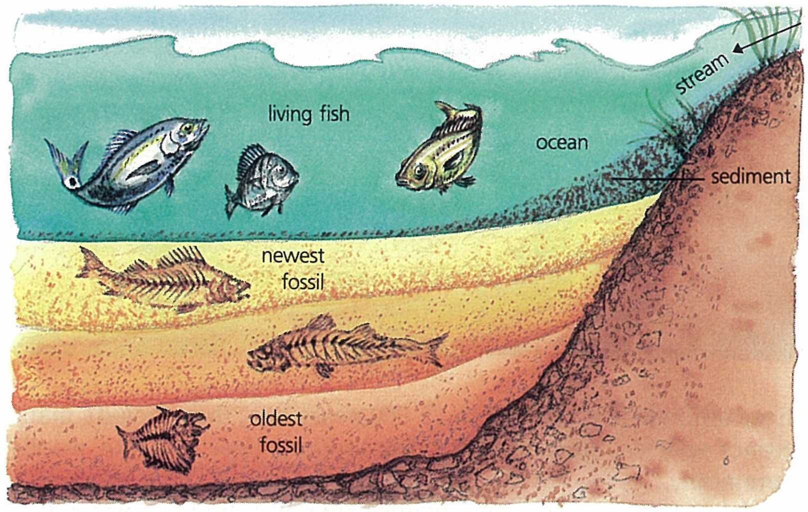


Figure 28–6

Deposition of Sediments. Streams flowing into a body of water carry fine rock particles called sediments. These sediments settle to the bottom and may gradually build up to a great thickness. The bodies of dead organisms that settle to the bottom may become fossils embedded in the sediments. The oldest fossils will be in the lowest layers, the youngest in the upper layers. ▶

The formation of sedimentary rock may continue for millions of years at any location. Because the size and mineral composition of the sediments will change from time to time, sedimentary rock acquires a layered structure. The oldest layers, those laid down first, are at the bottom. The youngest, or most recent, are at the top. The layers in between are arranged in a time sequence from older to younger. See Figure 28–6.

Critical Thinking in Biology

Identifying Assumptions

People often make assumptions without even knowing it. For example, you may assume that a woman and a boy walking together are mother and son.

Whenever you assume something, you accept it as true without proof or examination. Actions and differences of opinion are often based on assumptions that people have made. For this reason, it is important to learn how to identify assumptions.

1. A paleontologist used 16 fossil bones to reconstruct an extinct *Iguanodon,* a genus of dinosaurs. The reconstruction is shown on the right. Along with the bones, the paleontologist found an unusual bony spike about four inches long. If you were the paleontologist, where would you place the bony spike?

2. Think about why you placed the bony spike where you did. What assumptions did you make?

3. How valid do you think your assumptions were? Explain.

4. Think About It Describe the thought process you used as you answered question 2.

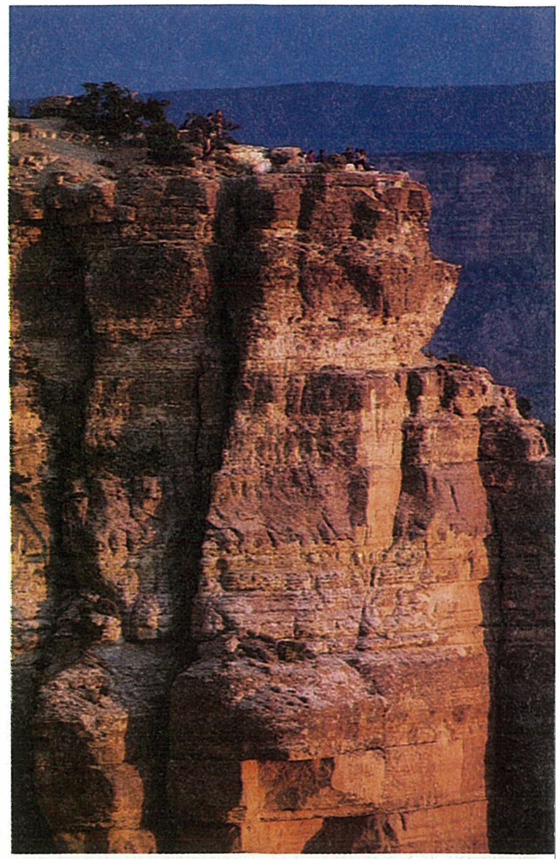
Relative Dating Over millions of years, the shifting of the earth's crust has raised some regions that once were under the seas. This shifting has caused some sedimentary layers to be exposed on the side of mountains or plateaus. Sometimes, a river has cut its way through the layers of sedimentary rock. The Grand Canyon, shown in Figure 28–7, is an example of this. If the exposed sedimentary layers have not been greatly disturbed by the motions of the earth's crust, they remain in their original sequence. The oldest are at the bottom, and the youngest are at the top. If these sedimentary layers contain fossils, scientists use the layers to determine when certain organisms existed in relation to others. Any method of determining the order in which events occurred is called **relative dating.** Fossils in the lower layers represent organisms that lived at an earlier time than the fossils in upper layers. This history of life is usually called the **fossil record.**

Absolute Dating Relative dating does not give the actual age of a rock or a fossil in years. Any method that determines how long ago an event occurred is called **absolute dating.** Many methods of absolute dating have been tried, but most scientists consider radioactive dating the most accurate and reliable method.

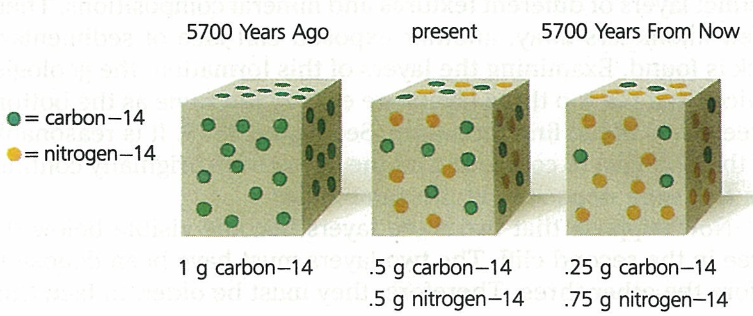
The technique of **radioactive dating** is based on the knowledge that certain elements have unstable isotopes. As you read in Chapter 3, the nuclei of these unstable isotopes tend to break down, or decay, changing to different isotopes. During this process, called *radioactive decay,* energy is given off in the form of radiation.

The rate at which a radioactive isotope decays is fixed and unchangeable. The time required for half the atoms of an isotope to decay is called the *half-life* of that isotope. For example, the half-life of carbon-14, which occurs naturally in all organisms, is 5700 years. If a fossil contains carbon-14 and was formed 5700 years ago, only half the original amount of carbon-14 would be left in the fossil today. The other half would have changed to carbon-14's decay product, nitrogen-14. See Figure 28–8. By comparing the ratio of carbon-14 to nitrogen-14, scientists can calculate a fossil's age. This method does not work for fossils older than about 50 000 years because most of the carbon-14 has decayed.

Other isotopes, such as uranium-238 or potassium-40, can be used to date older fossils or rocks in which fossils are embedded. Only *igneous* (IG nee us) rocks—formed when molten material in the crust cooled and hardened—can be dated using radioactive



▲ **Figure 28–7**
Sedimentary Rock. The layers of this rock formation in the Grand Canyon were formed from sediments deposited under water. Shifts in the earth's crust then raised the rock layers without disturbing their order. Each layer is older than those above it.



◄ **Figure 28–8**
Half-Life of Carbon-14. The half-life of carbon-14 is 5700 years.

dating methods. These methods do not work with sedimentary rocks because they give the age of the sediments, which existed long before becoming rocks. However, the absolute age of sedimentary rocks can be estimated by the age of igneous rocks that formed above, below, or within them. In this way, scientists can determine the age of fossils found in sedimentary layers.

28-1 Section Review

1. What is a fossil?
2. Name six types of fossils.
3. In what kind of rock are most fossils found?
4. What is the fossil record?

Critical Thinking

5. If you could search for fossils under the ocean floor, where would you look? (*Predicting*)

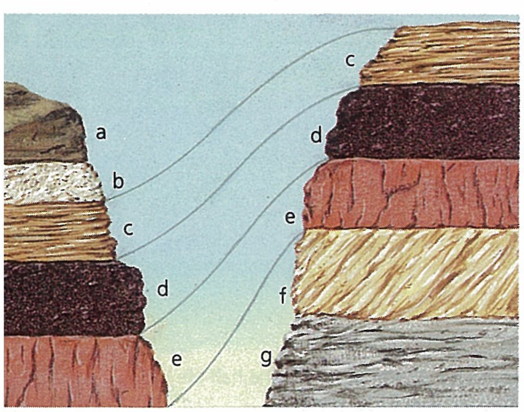
28-2 Interpreting the Fossil Record

Section Objectives:

- *Define* the terms *correlation* and *index fossil.*
- *Explain* what is meant by the geologic time scale.
- *State* two important conclusions that can be drawn from the fossil record regarding the course of changes in living things over geologic time.
- *Explain* the importance of extinctions.

Fossils supply many clues about the organisms from which they were formed. By examining fossils and the fossil record, scientists have been able to piece together a history of life.

Figure 28–9
Correlation of Separate Rock Formations. Layers C, D, and E on the left have the same composition and thickness as layers C, D, and E on the right. Comparable layers on the left and the right were probably laid down at the same time. Layers F and G on the right are therefore older than layers A and B on the left. ▼



Correlation

Suppose a geologist finds a cliff made of sedimentary rock with five distinct layers of different textures and mineral compositions. Then, a few kilometers away, another exposed cliff face of sedimentary rock is found. Examining the layers of this formation, the geologist notices that the top three layers are exactly the same as the bottom three layers of the first formation. See Figure 28–9. It is reasonable for the geologist to conclude that the layers were originally continuous and were deposited at the same time.

Now suppose that two more layers become visible below the three in the second cliff. The two layers must have been deposited before the other three. Therefore, they must be older. In fact, they must be older than the bottom three layers of the first cliff. By this process of matching, or **correlation,** scientists can show that certain rock layers in one place are older than certain rock layers in another place. It also follows that the fossils in the older layers are older than fossils in the younger layers.

Correlation of sedimentary rock allows scientists to establish the relative dating of rocks and fossils in different places. Correlation by the comparison of rock layers can produce a fairly extended relative dating of the rocks and fossils in a region. But, the method cannot be used where there are no nearby rocks that are similar. Furthermore, scientists cannot provide a correlation between rocks in a particular region and rocks in another section of the continent or another part of the world.

A study of fossils from many regions has shown that certain types of organisms seem to have appeared, flourished for a time over wide regions of the earth, and then disappeared. Rock layers that have fossils of these organisms must have been formed when

Careers *in Action*

Paleontologist

Dinosaur bones, petrified trees, insects embedded in amber: to a paleontologist, these are clues to the past. A paleontologist is a scientist who studies the traces left behind by once living organisms. These traces, called fossils, are found in many places. In fact, deciding where to look for fossils is a large part of the paleontologist's job.

Once a fossil site has been found, work in the field can be long and hard. Sometimes, the paleontologist must separate fragments of bone from the rock in which they are embedded. In the laboratory, paleontologists analyze the fossils and other clues to piece together the likely structure of an organism that may have become extinct long ago.

Paleontologists work for universities, museums, and oil companies. Most paleontologists specialize in certain types of organisms, such as plants, vertebrates, or invertebrates.

Problem Solving Imagine you are a paleontologist studying the evolution of reptiles. You are about to go on an expedition to look for fossils.

1. Why might it be best to look for fossils in areas that have large formations of sedimentary rock?
2. You find a fossil of what may be the leg of a reptile. You are not sure that it is from the type of reptile that you are studying. You know the age during which your reptile lived. How would you determine if the fossil was from the reptile that you are interested in?
3. Suppose the reptile lived between 150 and 200 million years ago. In what eras and epochs might it have lived?
4. A colleague finds an imprint of a primitive flower in the same stratum of rock that held your fossil. Does this finding then change your answer to question 3? Explain.

■ **Help Wanted:**
Paleontologist. Bachelor's degree in biology required; doctoral degree required for research. Contact: American Geological Institute, 4220 King St., Alexandria, VA 22302.

Figure 28–10
Trilobite Fossils. These two fossilized trilobites were found in Morocco. Trilobites were distant relatives of insects. ▶

these organisms were in existence. Using the fossils, it becomes possible to match the relative ages of sedimentary rocks in different parts of the world. Fossils that permit the relative dating of rocks within a narrow time span are called **index fossils.** *Trilobites* are good examples of index fossils. See Figure 28–10. Some species of these shelled marine animals only lived between 500 and 600 million years ago. Scientists know, therefore, that sedimentary rock layers containing trilobite fossils must be between 500 and 600 million years old. Index fossils have enabled scientists to find a continuous fossil sequence from the time of the first fossils up to the recent past.

Through a correlation of absolute and relative dating of rocks, geologists have been able to construct a timetable of the earth's history. This timetable is known as the **geologic time scale.** In this time scale, the earth's history is divided into several major divisions called *eras.* Each era is further subdivided into *periods* and *epochs.* Figure 28–11 shows the main subdivisions of the geologic time scale, along with a brief summary of the various types of organisms that appeared, flourished, or disappeared during each time interval.

Patterns of Evolution

When the entire fossil record is studied, some important patterns can readily be seen. One obvious pattern is that the earliest organisms were all relatively simple. As time passed, organisms slowly became more and more complex. As you read in Chapter 5, eukaryotic cells came into existence after the simpler prokaryotic cells. Similarly, multicellular organisms appeared after single-celled organisms, and terrestrial plants and animals arrived later than aquatic species.

Scientists also have observed that the move from simpler species to more complex ones seems to have occurred over thousands or millions of years. Changes in the structure of the horse, for example, have been traced from the first appearance of a horselike mammal through various stages to what is now known as

Figure 28–11 **The Geologic Time Scale.** ▶

The Geologic Time Scale

Era	Age	Period (or Epoch)		Millions of Years Ago	Plant Life	Animal Life
Cenozoic	Age of Humans	Quaternary	Recent epoch	.01	herbs dominant	modern humans and modern animals
Cenozoic	Age of Humans	Quaternary	Pleistocene epoch	2.5	trees decrease; herbs increase	early humans; large mammals become extinct
Cenozoic	Age of Mammals	Tertiary Period	Pliocene epoch	12	grasses increase; herbs appear	mammals abundant; earliest humans appear
Cenozoic	Age of Mammals	Tertiary Period	Miocene epoch	26	forests decrease; grasses develop	mammals increase; prehumans appear
Cenozoic	Age of Mammals	Tertiary Period	Oligocene epoch	37	worldwide tropical forests	modern mammals appear
Cenozoic	Age of Mammals	Tertiary Period	Eocene epoch	53	angiosperms increase	early mammals at peak
Cenozoic	Age of Mammals	Tertiary Period	Paleocene epoch	65	modern angiosperms appear	early placental mammals appear; modern birds
Mesozoic	Age of Reptiles	Cretaceous period		136	conifers decrease; flowering plants increase	large reptiles (dinosaurs) at peak, then disappear; small marsupials; toothed birds; modern fishes
Mesozoic	Age of Reptiles	Jurassic period		190	conifers, cycads dominant; flowering plants appear	large reptiles spread; first birds; modern sharks and bony fishes; many bivalves
Mesozoic	Age of Reptiles	Triassic period		225	conifers increase; cycads appear	reptiles increase, first mammals; bony fishes
Paleozoic	Age of Amphibians	Permian period		280	seed ferns disappear	amphibians decline; reptiles increase; modern insects
Paleozoic	Age of Amphibians	Carboniferous period		345	tropical coal forests; seed ferns, conifers	amphibians dominant; reptiles appear; rise of insects
Paleozoic	Age of Fishes	Devonian period		395	first forests; horsetails, ferns	early fishes spread; amphibians appear; many mollusks, crabs
Paleozoic	Age of Invertebrates	Silurian period		430	first land plants	scorpions and spiders (first air-breathers on land)
Paleozoic	Age of Invertebrates	Ordovician period		500	algae dominant	first vertebrates; worms; some mollusks and echinoderms
Paleozoic	Age of Invertebrates	Cambrian period		570	algae, fungi; first plant spores	most invertebrate phyla; trilobites dominant
Precambrian				?	probably bacteria, fungi	a few fossils; sponge spicules; soft-bodied invertebrates

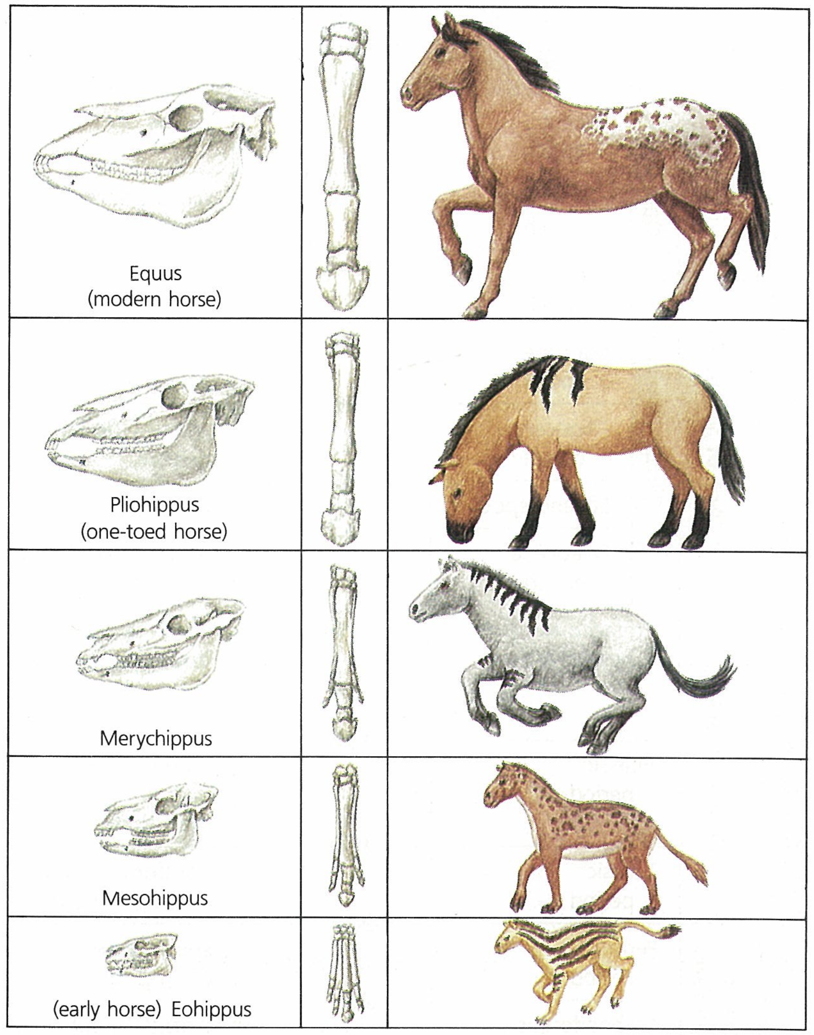


Figure 28–12

Evolution of the Horse. The fossil record provides information on the changes in the structure of the horse over time. During its evolution the horse has increased in size and the number of toes has decreased from four to just one. ▶

a horse. See Figure 28–12. These changes occur over millions of years in the species, not in any one individual. Other sequences of this kind in the fossil record indicate that later species developed from earlier ones through a series of gradual changes passed on from generation to generation. There are also many interruptions in the fossil record. Species that have not been found in the fossil record are called missing links, or *transitional forms.* Because unusual conditions are needed to form a fossil, it is not surprising that there are gaps in the fossil record. As you have read, most often, the remains of organisms simply decay without leaving behind any traces. Despite its incompleteness, the fossil record is still considered the strongest evidence of organic evolution.

A study of the fossil record also reveals that many fossils come from species no longer living today. In fact, it has been estimated that, of all the species that ever lived, less than 1 percent exist today. When the last individual of a species has died, the species is said to be **extinct.**

Another type of evidence for evolutionary relationships is the presence of **vestigial** (ves TIHJ ee ul) **structures** in modern animals. These structures are remnants of structures that were functional in an ancestral form. In modern organisms, vestigial structures are reduced in size and serve little or no function. In the human body, there are more than 100 vestigial structures, including the coccyx, or "tailbone," the appendix, the wisdom teeth, and the muscles that move the nose and ears. The human coccyx is an evolutionary remnant of an ancestral, reptilian tail, and the appendix is the remnant of a large digestive sac. Both whales and pythons have vestigial hind leg bones embedded in the flesh of the body wall. Apparently, whales and snakes evolved from four-legged ancestors.

Embryological Similarities

Comparison of the embryological development of different species can provide additional evidence of evolutionary relationships. Embryos of closely related species show similar patterns of development. Figure 28–14 illustrates various stages in the development of four different vertebrates. In these vertebrates, there are

Figure 28–14
Patterns of Development of Four Vertebrate Embryos. Similarities in the early stages of embryonic development suggest a common ancestor for these vertebrates. ▼

many similarities during the early stages of embryological development. For example, all the embryos have gill slits, two-chambered hearts, and tails. These similarities support the idea that these four organisms have a common evolutionary origin. As development continues, the embryos of each species begin to resemble the adults of their own species. The more closely related the animals, the longer they continue to resemble each other during the stages of development.

Biochemical Similarities

Scientists have discovered that the closer the phylogenetic relationships between organisms based on morphology and anatomy, the more alike the structure of their DNA and protein molecules. For example, the sequences of amino acids in the hemoglobin of closely related species are almost identical.

The degree of evolutionary relationship between different types of organisms also can be estimated with the Nuttall test, which is based on antigen-antibody reactions. (See Chapter 10.) For example, if human blood serum is injected into a rabbit, the rabbit produces antibodies against the proteins in the human blood. If serum from this sensitized rabbit is then mixed with human blood serum, a cloudy precipitate forms, showing an antigen-antibody reaction. The amount of the precipitate can be measured. If serums from a chimpanzee, a baboon, and a pig are then tested individually with serum from the sensitized rabbit, the amount of precipitate formed will be different in each case. The amount of precipitate is an indication of the similarity in protein structure between each of these animals and humans. The greater the amount of precipitate, the greater the similarity in protein structure, and the more closely the animal in question is related to humans.

28-3 Section Review

1. Name three different types of evidence, other than the evidence supplied by the fossil record, that support the theory of organic evolution.
2. Define *homologous structures.*
3. Name two analogous structures.
4. What biochemical similarity is revealed by the Nuttall test?

Critical Thinking

5. Look at Figure 28-14. How do you know that the evolutionary relationship between humans and chickens is closer than the evolutionary relationship between humans and fishes? (*Comparing and Contrasting*)

28-4 The Origins of Life—Early Hypotheses

Section Objectives:

- *Describe* the evidence for spontaneous generation.
- *Explain* how Redi used controlled experiments to disprove the widely accepted hypothesis of the spontaneous generation of maggots.
- *Explain* how Spallanzani's and then Pasteur's experiments finally disproved the hypothesis of the spontaneous generation of microorganisms.

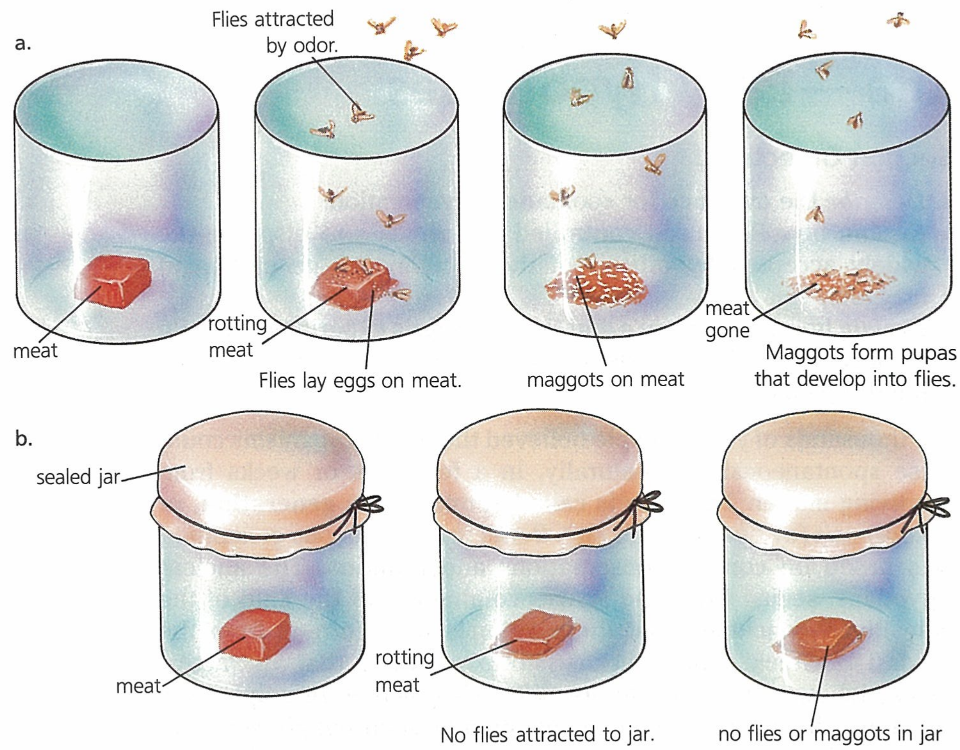
For thousands of years, people believed that living organisms could arise spontaneously, or naturally, in a few days or weeks from nonliving matter. This idea is called **spontaneous generation,** or *abiogenesis* (ay by oh JEN uh sis). Belief in spontaneous generation was based on common observations and intuition. The ancient Egyptians, seeing frogs and snakes coming out of the mud of the Nile River, concluded that these animals were formed from the mud. The Greek philosopher Aristotle reasoned that an "active principle" was responsible for life. This active principle was thought to be present in mud. Some other popular beliefs were that fleas and lice arose from sweat, mice from garbage, and flies from decaying meat.

Early Experiments

In the early 1600s, a Belgian physician named Jan Baptista van Helmont performed an experiment that seemed to support the idea of spontaneous generation. He placed wheat grains in a sweaty shirt. After 21 days, the wheat was gone, and mice were present. Van Helmont reasoned that human sweat was the active principle that changed wheat grains into mice. Even though this was an uncontrolled experiment, his experimental "proof" gained wide acceptance among the scientists of his time.

Then, in the mid-1600s, the Italian physician Francesco Redi struck the first blow against the popular idea of spontaneous generation. It was well known that whenever meat was left exposed to the air, maggots soon appeared on it. Most people were convinced that the maggots developed by spontaneous generation from the decaying meat.

Redi decided to test this idea scientifically. He began by placing many different kinds of meat in open containers. Maggots soon appeared on the meat. See Figure 28-15a. He watched the maggots consume the decaying meat, and he continued to observe them even after the meat was gone. He discovered that the maggots formed pupas, which then developed into flies of various kinds. Redi apparently was the first person to see that maggots developed into flies.

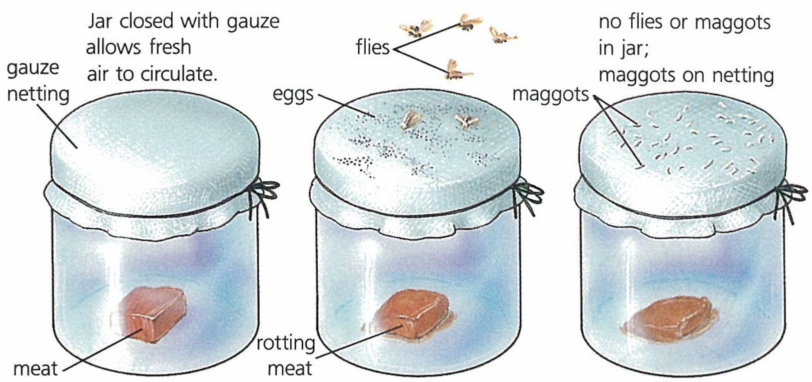


▲ **Figure 28–15**
Redi's First Experiment. This experiment showed that meat had to be exposed to the environment to develop maggots.

Redi hypothesized that the maggots developed from eggs laid on the meat by the flies. To test his hypothesis, he placed some pieces of meat in open jars, and he placed other pieces of the same meat in tightly sealed jars. Redi observed that flies entered the open jars and that maggots appeared on the meat. He further observed that no maggots appeared on the meat in the closed jars. See Figure 28–15b.

This experiment proved only that the meat had to be exposed to open air in order to develop maggots. It did not prove that the flies were the source of the maggots. Many scientists of the time claimed that fresh air was necessary for spontaneous generation. By sealing the jars, they argued, Redi had prevented the needed air from reaching the meat.

In order to answer this objection and convince the doubters, Redi performed another set of experiments. In these experiments the containers were covered by fine gauze, as shown in Figure 28–16. The gauze allowed the free circulation of air into the containers but kept the flies out of the containers. Redi observed that the flies attempted to reach the meat by landing on the gauze. The flies also deposited eggs on the gauze, which soon developed into maggots. Still, no maggots appeared inside the jars. Redi had proven conclusively that maggots did not arise spontaneously from decaying meat.



◄ **Figure 28–16**
Redi's Second Experiment. Redi's second experiment showed that maggots arise in decaying meat from eggs laid by flies.

Spontaneous Generation of Microorganisms

At about the time that Redi was performing his experiments, Anton van Leeuwenhoek (LAY ven huke) made the startling discovery of microorganisms in a drop of water. Soon, it was found that when hay or soil was placed in sterile water, millions of microorganisms appeared within a few hours. Here, surely, was a clear-cut case of spontaneous generation! The controversy that Redi had almost put to rest flared up again and raged for the next 200 years.

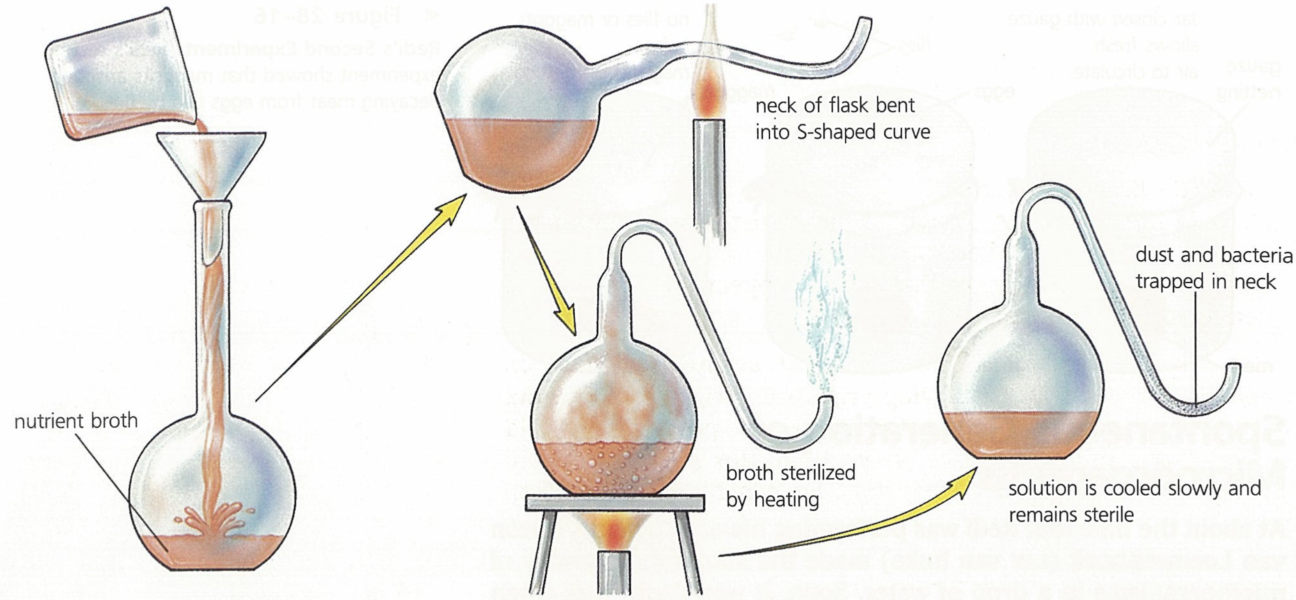
In 1745, John Needham, an English scientist, performed some experiments that reinforced the belief in the spontaneous generation of microorganisms. He boiled flasks of chicken, lamb, and corn broth for a few minutes to kill any microorganisms in them. Then, he sealed the flasks. After several days he opened and examined the flasks and found them full of microorganisms. He repeated the experiment several times and always obtained the same results. Needham and other biologists concluded that the microorganisms developed by spontaneous generation.

About 20 years after Needham did his work, Lorenzo Spallanzani, an Italian scientist, challenged Needham's conclusions. Like Needham, Spallanzani set up flasks of chicken, lamb, and corn broth. However, he boiled the contents of the flasks for a much longer time. No living organisms appeared in the flasks.

Spallanzani claimed that Needham found organisms in his heated flasks because he had not heated them long enough to kill all the organisms originally present. Needham argued that Spallanzani had heated his flasks so long that he had destroyed the "vital principle" in the air that was needed to bring about the generation of new organisms. The debate remained unsettled for almost another 100 years.

Disproving Spontaneous Generation

In 1860, the French chemist Louis Pasteur set out to disprove the theory of spontaneous generation. Pasteur thought that microorganisms and their spores were present in the air and that they became active and reproduced when they entered the nutrient



▲ **Figure 28–17**
Pasteur's Experiment. This experiment showed that microorganisms that developed in a nutrient broth came from spores and microorganisms in the air.

broth. He hypothesized that the presence of air alone could not produce microorganisms in the broth. To test this hypothesis, Pasteur filled flasks with nutrient broth. He then heated the necks of the flasks and drew them out into a long S shape, leaving the ends open. See Figure 28–17. The contents of the flasks were then sterilized by boiling. Fresh air could reach the broth, but microorganisms and their spores were trapped in the long necks of the flasks. As long as the flasks were not disturbed, the contents remained sterile. Microorganisms grew in the flasks only when the flasks were tipped and some of the broth ran into the neck and became contaminated. Pasteur's experiment finally put an end to the idea of spontaneous generation.

28-4 Section Review

1. What is spontaneous generation?
2. What did van Leeuwenhoek discover?
3. Why did Pasteur alter the shape of his flasks in his experiments with spontaneous generation?

Critical Thinking

4. What assumption did Redi make in his first experiment that forced him to conduct his second experiment? (*Identifying Assumptions*)

28-5 The Origins of Life—Modern Hypothesis

Section Objectives:

- *Define* the term *biogenesis.*
- *Describe* the conditions thought to have existed on the primitive earth according to the heterotroph hypothesis.
- *Describe* any experiments that would appear to support the heterotroph hypothesis.

Today, as you read in Chapter 5, most scientists believe in **biogenesis,** the theory that living organisms originate only from other living organisms. But, this theory has one problem: How did the first living things originate on earth? In this section, you will learn about the conditions under which life may have originated on earth.

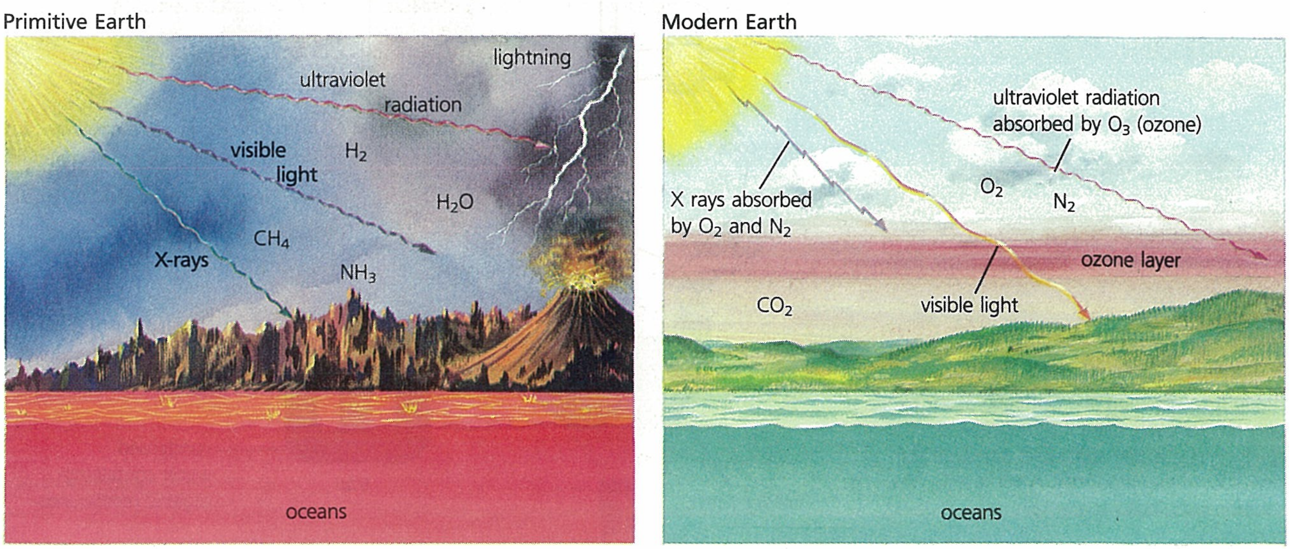
The Heterotroph Hypothesis

The most widely accepted hypothesis of the origin of life is called the **heterotroph hypothesis.** This hypothesis was formulated by a small group of scientists in the 1920s and 1930s. The scientist most often credited with development of the heterotroph hypothesis was the Russian biochemist A. I. Oparin.

Primitive Conditions on the Earth Oparin's heterotroph hypothesis assumes that physical and chemical conditions on the earth billions of years ago were very different from those today. See Figure 28–18. For example, the earth's atmosphere now consists almost entirely of nitrogen (N_2) and oxygen (O_2), with a small amount of carbon dioxide (CO_2). Chemists and geologists have evidence showing that the earth's primitive atmosphere consisted of

Figure 28–18

Early Conditions on the Earth Compared with Modern Conditions. On the primitive earth, the composition of the atmosphere was different from the modern atmosphere. In addition, the temperature was higher, and there were more sources of energy for producing chemical change. ▼



hydrogen (H_2), water vapor (H_2O), ammonia (NH_3), and methane (CH_4). There also is evidence that early temperatures were much higher on the early earth than they are at present. The oceans, when they first formed, were probably not much below the boiling point of water. The oceans of this period have been described as a "hot, thin soup," in which chemical reactions were likely to occur more rapidly than in the cooler waters of the modern earth.

Natural Synthesis of Organic Compounds Under the primitive conditions just described, simple compounds in the atmosphere and in the oceans could have reacted to form more complex organic compounds. The synthesis of organic compounds from inorganic raw materials requires energy. Many sources of energy are thought to have been present on the primitive earth. There was heat given off by the earth itself; radiation from the decay of radioactive elements in the earth's crust; electrical energy from lightning; and ultraviolet light, visible light, and X rays from the sun. Under these conditions, there would have been enough energy available for the breakdown and formation of chemical bonds. The first nucleotides, amino acids, and sugars could have been formed during this period. There have been experimental results that support this hypothesis.

In 1953, Stanley Miller, working with Harold Urey at the University of Chicago, designed an experiment simulating the conditions of the primitive earth. The specially designed experimental apparatus contained four gases—hydrogen, water vapor, ammonia, and methane. See Figure 28–19. Boiling water in the apparatus forced these gases to circulate past sparking electrodes.

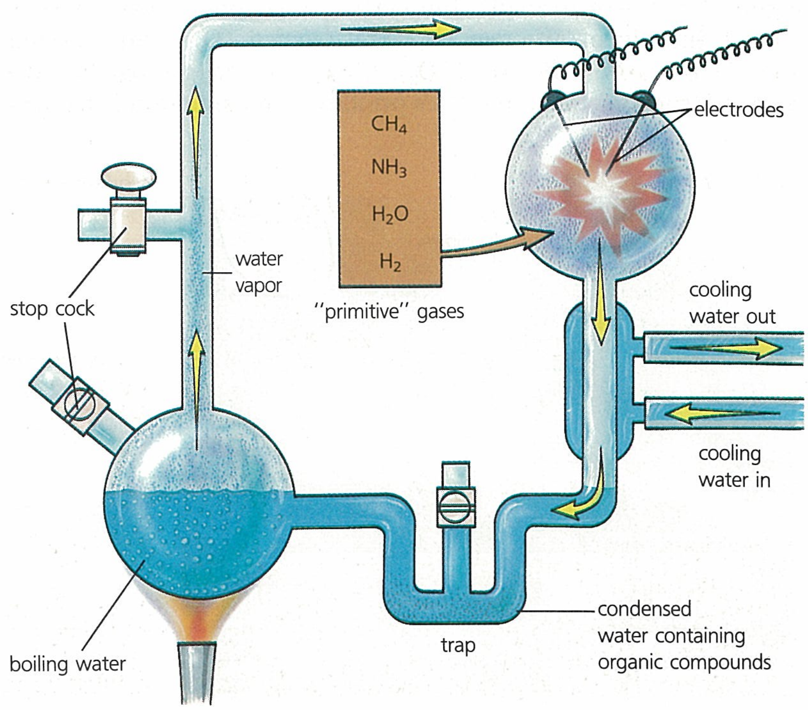


Figure 28–19
Miller's Experiment Simulating Early Conditions on the Earth. A mixture of gases thought to resemble the primitive atmosphere was continuously passed through an electric spark. Water in the apparatus dissolved the new substances produced. After a time, the solution was found to contain many organic compounds. ▶