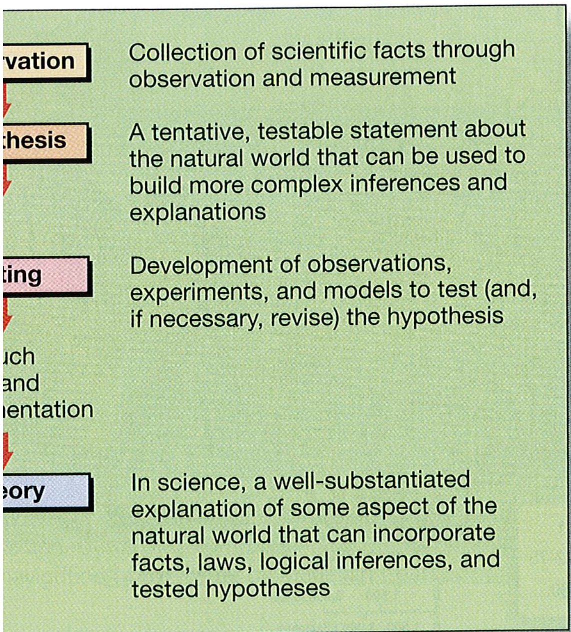


The scientific method. A flow diagram showing eps in the scientific method, along with definitions actuality, the process of science is often less nducted than is implied in this figure.

The overall goal of science is to discover underlying patterns in the natural world and then to use this knowledge to make predictions about what should or should not be expected to happen given a certain set of circumstances. Scientists develop explanations about the causes and effects of various natural phenomena (such as why Earth has seasons or what the structure of matter is). This work is based on an assumption that all natural phenomena are controlled by understandable physical processes and the same physical processes operating today have been operating throughout time. Consequently, science has demonstrated remarkable power in allowing scientists to describe the natural world accurately, to identify the underlying causes of natural phenomena, and to better predict future events that rely on natural processes.

Science supports the explanation of the natural world that best explains all available observations. Scientific inquiry is formalized into what is called the **scientific method**, which is used to formulate scientific theories (**Figure 1.11**).

Observations

The scientific method begins with *observations*, which are occurrences we can measure with our senses. They are things we can manipulate, see, touch, hear, taste, or smell, often by experimenting with them directly or by using sophisticated tools (such as a microscope or telescope) to sense them. If an observation is repeatedly confirmed—that is, made so many times that it is assumed to be completely valid—then it can be called a *scientific fact*.

Hypothesis

As observations are being made, the human mind attempts to sort out the observations in a way that reveals some underlying order or pattern in the objects or phenomena being observed. This sorting process—which involves a lot of trial and error—seems to be driven by a fundamental human urge to make sense of our world. This is how **hypotheses** (*hypo* = under, *thesis* = an arranging) are made. A hypothesis is sometimes labeled as an informed or educated guess, but it is more than that. A hypothesis is a tentative, testable statement about the general nature of the phenomena observed. In other words, a hypothesis is an initial idea of how or why things happen in nature.

Suppose we want to understand why whales *breach* (that is, why whales sometimes leap entirely out of water). After scientists observe breaching many times, they can organize their observations into a hypothesis. For instance, one hypothesis is that a breaching whale is trying to dislodge parasites from its body. Scientists often have multiple working hypotheses (for example, whales may use breaching to communicate with other whales). If a hypothesis cannot be tested, it is not scientifically useful, no matter how interesting it might seem.

Testing

Hypotheses are used to predict certain occurrences that lead to further research and the refinement of those hypotheses. For instance, the hypothesis that a breaching whale is trying to dislodge its parasites suggests that breaching whales have more parasites than whales that don't breach. Analyzing the number of parasites on breaching versus nonbreaching whales would either support that hypothesis or cause it to be recycled and modified. If observations clearly suggest that the hypothesis is incorrect (that is, the hypothesis is *falsified*), then it must be dropped, and other alternative explanations of the facts must be considered.

In science, the validity of any explanation is determined by its coherence with observations in the natural world and its ability to predict further observations. Only after much testing and experimentation—usually done by many experimenters using a wide variety of repeatable tests—does a hypothesis gain validity where it can be advanced to the next step.

Theory

If a hypothesis has been strengthened by additional observations and if it is successful in predicting additional phenomena, then it can be advanced to what is called a **theory** (*theoria* = a looking at). A theory is a well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws (descriptive generalizations about the behavior of an aspect of the natural world), logical inferences, and tested hypotheses. A theory is not a guess or a hunch. Rather, it is an understanding that develops from extensive observation, experimentation, and creative reflection.

In science, theories are formalized only after many years of testing and verifying predictions. Thus, scientific theories have been rigorously scrutinized to the point where most scientists agree that they are the best explanation of certain observable facts. Examples of prominent, well-accepted theories that are held with a very high degree of confidence include biology's theory of evolution (which is discussed later in this chapter) and geology's theory of plate tectonics (which is covered in the next chapter).

Theories and the Truth

We've seen how the scientific method is used to develop theories, but does science ever arrive at the undisputed "truth"? Science never reaches an absolute truth because we can never be certain that we have all the observations, especially considering that new technology will be available in the future to examine phenomena in different ways. New observations are always possible, so the nature of scientific truth is subject to change. Therefore, it is more accurate to say that science arrives at that which is *probably* true, based on the available observations.

It is not a downfall of science that scientific ideas are modified as more observations are collected. In fact, the opposite is true. Science is a process that depends on reexamining ideas as new observations are made. Thus, science progresses when new observations yield new hypotheses and modification of theories. As a result, science is littered with hypotheses that have been abandoned in favor of later explanations that fit new observations. One of the best known is the idea that Earth was at the center of the universe, a proposal that was supported by the apparent daily motion of the Sun, Moon, and stars around Earth.

The statements of science should never be accepted as the "final truth." Over time, however, they generally form a sequence of increasingly more accurate statements. Theories are the endpoints in science and do not turn into facts through accumulation of evidence. Nevertheless, the data can become so convincing that the accuracy of a theory is no longer questioned. For instance, the *heliocentric* (*helios* = sun, *centric* = center) *theory* of our solar system states that Earth revolves around the Sun rather than vice versa. Such concepts are supported by such abundant observational and experimental evidence that they are no longer questioned in science.

Is there really such a formal method to science as the scientific method suggests? Actually, the work of scientists is much less formal and is not always done in a clearly logical and systematic manner. Like detectives analyzing a crime scene, scientists use ingenuity and serendipity, visualize models, and sometimes follow hunches in order to unravel the mysteries of nature.

Finally, a key component of verifying scientific ideas is through the peer review process. Once scientists make a discovery, their aim is to get the word out to the scientific community about their results. This is typically done via a published paper, but a draft of the manuscript is first checked by other experts to see if the work has been conducted according to scientific standards and the conclusions are valid. Normally, corrections are suggested and the paper is revised before it is published. This process is a strength of the scientific community and helps weed out inaccurate or poorly formed ideas.

STUDENTS SOMETIMES ASK

How can I accept a scientific idea if it's just a theory?

When most
word "the
day life, it usuall
or a guess (such
common "conspiracy theory"), but the word
different meaning in science. In science, a th
guess or a hunch. It's a well-substantiated, w
well-documented explanation for observatio
natural world. It's a powerful tool that ties to
facts about something, providing an explana
the observations and can even be used to m
In science, theory is the ultimate goal; it's the
explanation of how things work.

There is also a misconception that in scien
theory is proven, it becomes a *law*. That's no
In science, we collect facts, or observations,
describe them, and we use a theory to explai
example, the *law of gravity* is a description o
then there is the *theory of gravitational attra*
explains why the force occurs. Theories don't
moted" to a law by an abundance of proof, a
never becomes a law. This doesn't mean that
unsure of theories; in fact, theories are as clo
as anything in science can be. So, don't disco
idea because it's "just a theory."

ESSENTIAL CONCEPT 1.3

Science supports the explanation of the natu
that best explains all available observations.
observations can modify existing theories, sc
developing.

CONCEPT CHECK 1.3

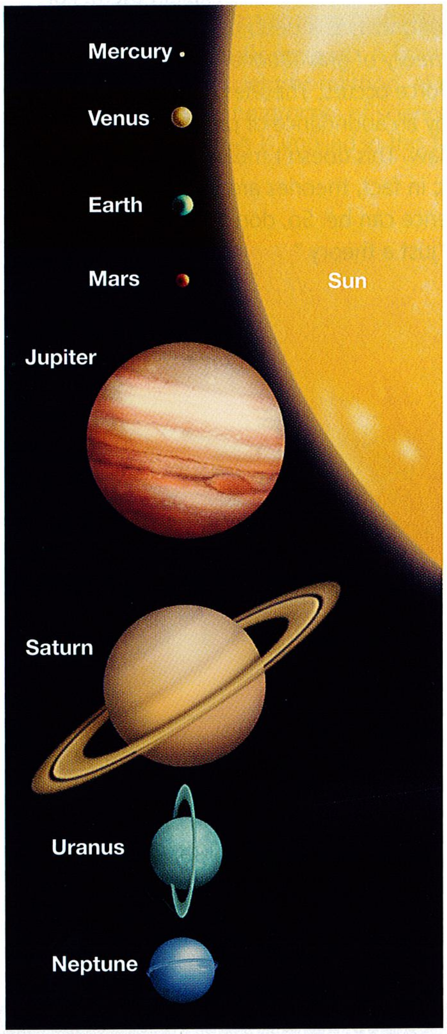
1. Outline the steps involved in the scientific method.
2. Briefly comment on the phrase "scientific certainty." Is it an oxymoron (a combination of contradictory words), or are scientific theories considered to be the absolute truth?
3. Can a theory ever be so well established that it becomes a fact? Explain.

1.4 How Were Earth and the Solar System Formed?

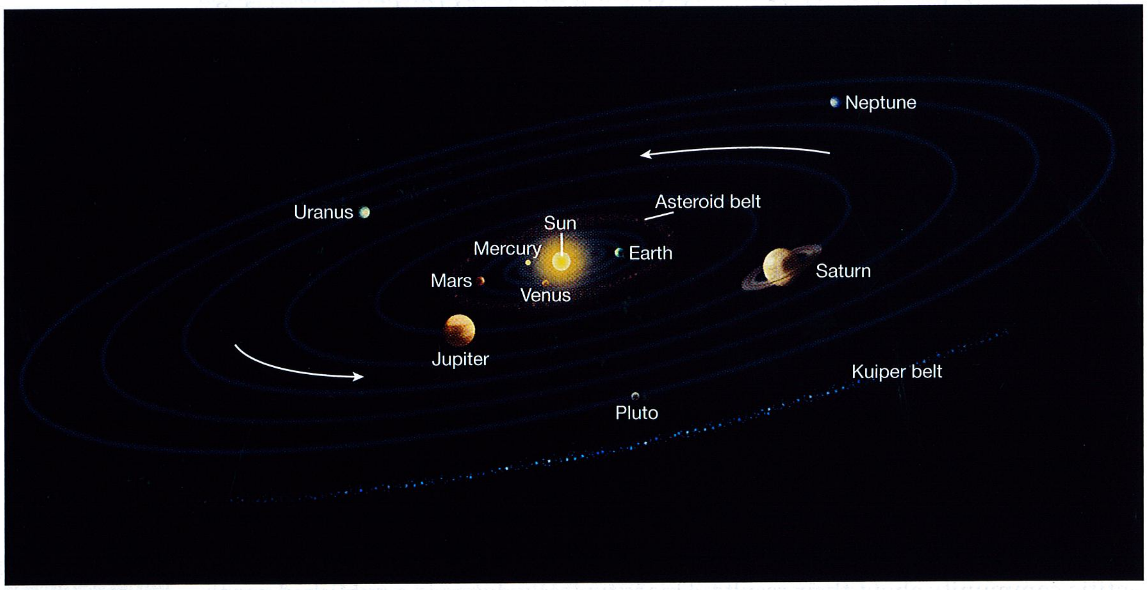
Earth is the third of eight major planets[6] in our **solar system** that revolve around the Sun (Figure 1.12). Evidence suggests that the Sun and the rest of the solar system formed about 5 billion years ago from a huge cloud of gas and space dust called a **nebula** (*nebula* = a cloud). Astronomers base this hypothesis on the orderly nature of our solar system and the consistent age of meteorites (pieces of the early solar system). Using sophisticated telescopes, astronomers have also been able to observe distant nebula in various stages of formation (Figure 1.13). In addition, more than 300 planets have been discovered outside our solar system—including one that is about the size of Earth—by detecting the telltale wobble of distant stars.

The Nebular Hypothesis

According to the **nebular hypothesis** (Figure 1.14), all bodies in the solar system formed from an enormous cloud composed mostly of hydrogen and helium, with only a small percentage of heavier elements. As this huge accumulation of gas and dust revolved around its center, the Sun began to form as magnetic fields and turbulence worked with the force of gravity to concentrate particles. In its early stages, the diameter of the Sun may have equaled or exceeded the diameter of our entire planetary system today.



(a) Features and relative sizes of the Sun and the eight major planets of the solar system.



(b) Orbits and relative positions of various features of the solar system.

Figure 1.12 The solar system. Schematic views of the solar system, which includes the Sun and eight major planets.

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[6]Pluto, which used to be considered the ninth planet in our solar system, was reclassified by the International Astronomical Union as a "dwarf planet" in 2006, along with other similar bodies.

As the nebular matter that formed the Sun contracted, small amounts of it were left behind in eddies, which are similar to small whirlpools in a stream. The material in these eddies was the beginning of the **protoplanets** (*proto* = original, *planetes* = wanderer) and their orbiting satellites, which later consolidated into the present planets and their moons.

Protoearth

Protoearth looked very different from Earth today. Its size was larger than today's Earth, and there were neither oceans nor any life on the planet. In addition, the structure of the deep Protoearth is thought to have been *homogenous* (*homo* = alike, *genous* = producing), which means that it had a uniform composition throughout. The structure of Protoearth changed, however, when its heavier constituents migrated toward the center to form a heavy core.

During this early stage of formation, many meteorites from space bombarded Protoearth (Figure 1.15). In fact, a leading theory states that the Moon was born in the aftermath of a titanic collision between a Mars-size planet named *Theia* and Protoearth. While most of Theia was swallowed up and incorporated into the magma ocean it created on impact, the collision also flung a small world's worth of vaporized and molten rock into orbit. Over time, this debris coalesced into a sphere and created Earth's orbiting companion, the Moon.

During this early formation of the protoplanets and their satellites, the Sun condensed into such a hot, concentrated mass that forces within its interior began releasing energy through a process known as a **fusion** (*fusus* = melted) **reaction**. A fusion reaction occurs when temperatures reach tens of millions of degrees and hydrogen **atoms** (*a* = not, *tomos* = cut) combine to form helium atoms, releasing large amounts of energy.[7] Not only does the Sun emit light, it also emits *ionized* (electrically charged) particles that make up the *solar wind*. During the early stages

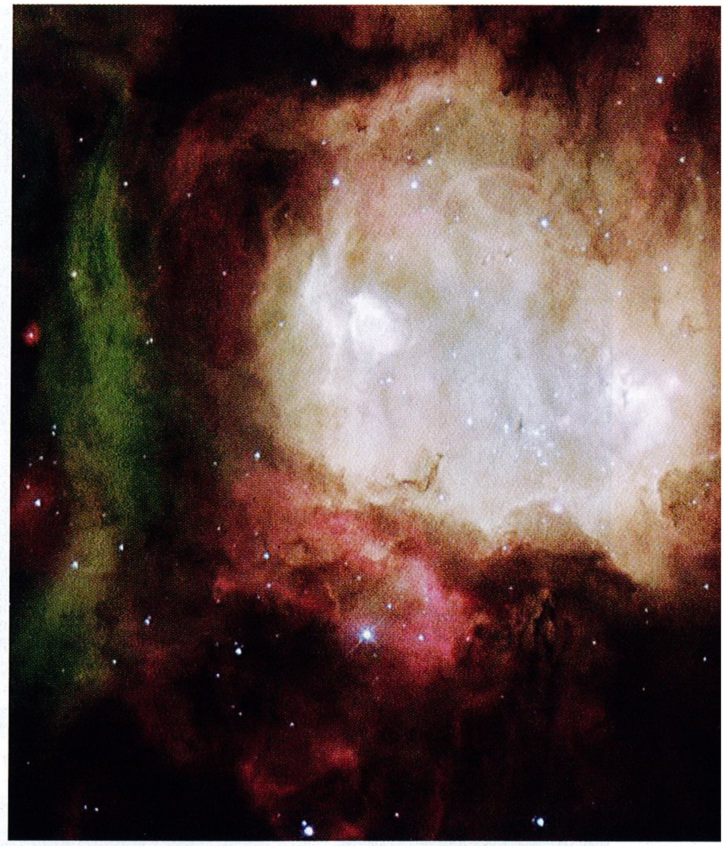


Figure 1.13 The Ghost Head Nebula. NASA's Hubble Space Telescope Ghost Head Nebula (NGC 2080), which is a site of active star formati

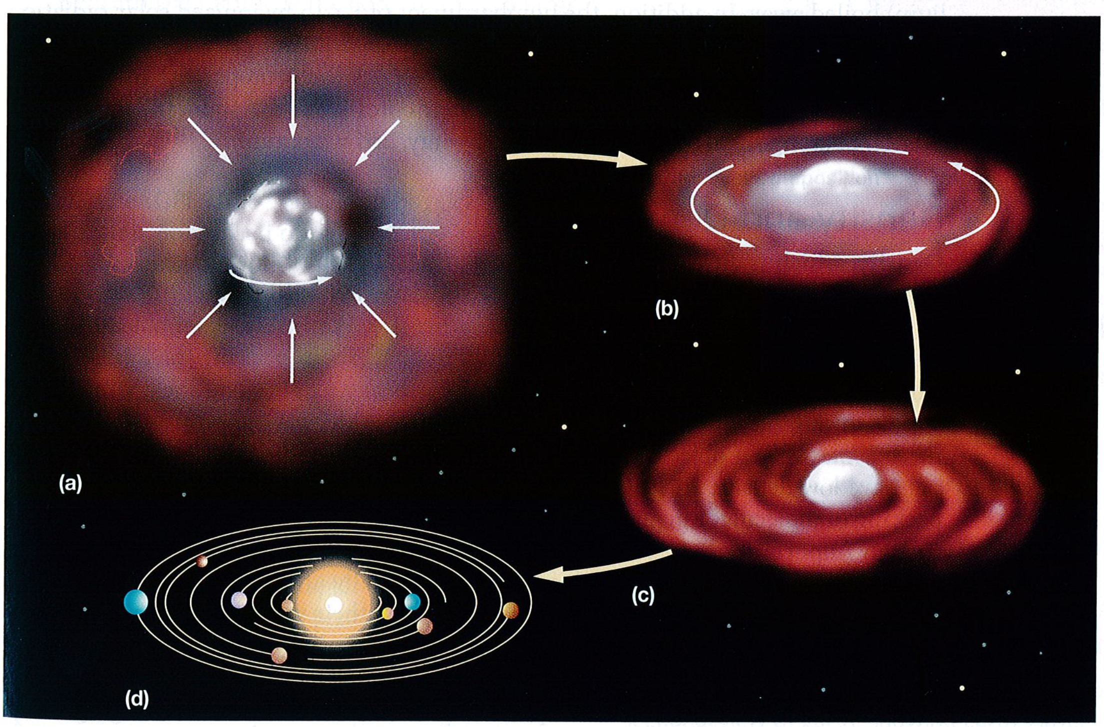


Figure 1.14 The nebular hypothesi system formation. (a) A huge clou and gases (a nebula) contracts. **(b)** material is gravitationally swept tov producing the Sun, while the remai into a disk. **(c)** Small eddies are crea circular motion. **(d)** In time, most o debris forms the planets and their r

W
The Nebular
Solar Syste

[7]Fusion in stars also combines higher elements to form even higher elements, such as carbon. As a result, all matter—even the matter that comprises our bodies—originated as stardust long ago.

An artist's
of what
d like early
pment.

of formation of the solar system, this solar wind blew away the nebular gas that remained from the formation of the planets and their satellites.

Meanwhile, the protoplanets closest to the Sun (including Earth) were heated so intensely by solar radiation that their initial atmospheres (mostly hydrogen and helium) boiled away. In addition, the bombardment of Earth by ionized solar radiation (which causes atoms to release particles) and the subsequent heat given off by protoplanets caused them to drastically shrink in size. As the protoplanets continued to contract, heat was produced deep within their cores from the spontaneous disintegration of atoms, called *radioactivity* (*radio* = ray, *acti* = to cause).

Density and Density Stratification

Density, which is an extremely important physical property of matter, is defined as mass per unit volume. In common terms, an easy way to think about density is that it is a measure of *how heavy something is for its size.* For instance, an object that has a low density is light for its size (like a dry sponge, foam packing, or a surfboard). Conversely, an object that has a high density is heavy for its size (like cement, most metals, or a large container full of water). Note that density has nothing to do with the *thickness* of an object; some objects (like a stack of foam packing) can be thick but have low density. In reality, density is related to molecular packing, with higher packing of molecules into a certain space resulting in higher density. Density is an extremely important concept that will be discussed in many other chapters in this book. For example, the density of Earth's layers dramatically affects their positions within Earth (Chapter 2), the density of air masses affects their properties (Chapter 6), and the density of water masses influences their position and movement (Chapter 7).

The release of internal heat was so intense that Earth's surface became molten. Once Earth became a ball of hot liquid rock, the elements were able to segregate according to their densities in a process called **density stratification** (*strati* = a layer, *fication* = making), which occurs because of *gravitational separation*. The highest-density materials (primarily iron and nickel) concentrated in the core, whereas progressively lower-density components (primarily rocky material) formed concentric spheres around the core. If you've ever noticed how oil-and-vinegar salad dressing settles out into a lower-density top layer (the oil) and a higher-density bottom layer (the vinegar), then you've seen how density stratification causes separate layers to form.

Earth's Internal Structure

As a result of density stratification, Earth became a layered sphere based on density, with the highest-density material found near the center of Earth and the lowest-density material located near the surface. Let's examine Earth's internal structure and the characteristics of its layers.

CHEMICAL COMPOSITION VERSUS PHYSICAL PROPERTIES The cross-sectional view of Earth in Figure 1.16 shows that Earth's inner structure can be subdivided according to its chemical composition (the chemical makeup of Earth materials) or its physical properties (how the rocks respond to increased temperature and pressure at depth).

CHEMICAL COMPOSITION Based on chemical composition, Earth consists of three layers: the **crust**, the **mantle**, and the **core** (Figure 1.16). If Earth were reduced to the size of an apple, then the crust would be its thin skin. It extends from the surface to an average depth of about 30 kilometers (20 miles). The crust is composed of relatively low-density rock, consisting mostly of various *silicate minerals* (common rock-forming minerals with silicon and oxygen). There are two types of crust—oceanic and continental—which will be discussed in the next section.

Immediately below the crust is the mantle. It occupies the largest volume of the three layers and extends to a depth of about 2885 kilometers (1800 miles). The mantle is composed of relatively high-density iron and magnesium silicate rock.

Beneath the mantle is the core. It forms a large mass from 2885 kilometers (1800 miles) to the center of Earth at 6371 kilometers (3960 miles). The core is composed of even higher-density metal (mostly iron and nickel).

PHYSICAL PROPERTIES Based on physical properties, Earth is composed of five layers (Figure 1.16): the **inner core**, the **outer core**, the **mesosphere** (*mesos* = middle, *sphere* = ball), the **asthenosphere** (*asthenos* = weak, *sphere* = ball), and the **lithosphere** (*lithos* = rock, *sphere* = ball).

The lithosphere is Earth's cool, rigid, outermost layer. It extends from the surface to an average depth of about 100 kilometers (62 miles) and includes the crust plus the topmost portion of the mantle. The lithosphere is *brittle* (*brytten* = to shatter), meaning that it will fracture when force is applied to it. As will be discussed in Chapter 2, "Plate Tectonics and the Ocean Floor," the plates involved in plate tectonic motion are the plates of the lithosphere.

Beneath the lithosphere is the asthenosphere. The asthenosphere is *plastic* (*plasticus* = molded), meaning that it will flow when a gradual force is applied to it. It extends from about

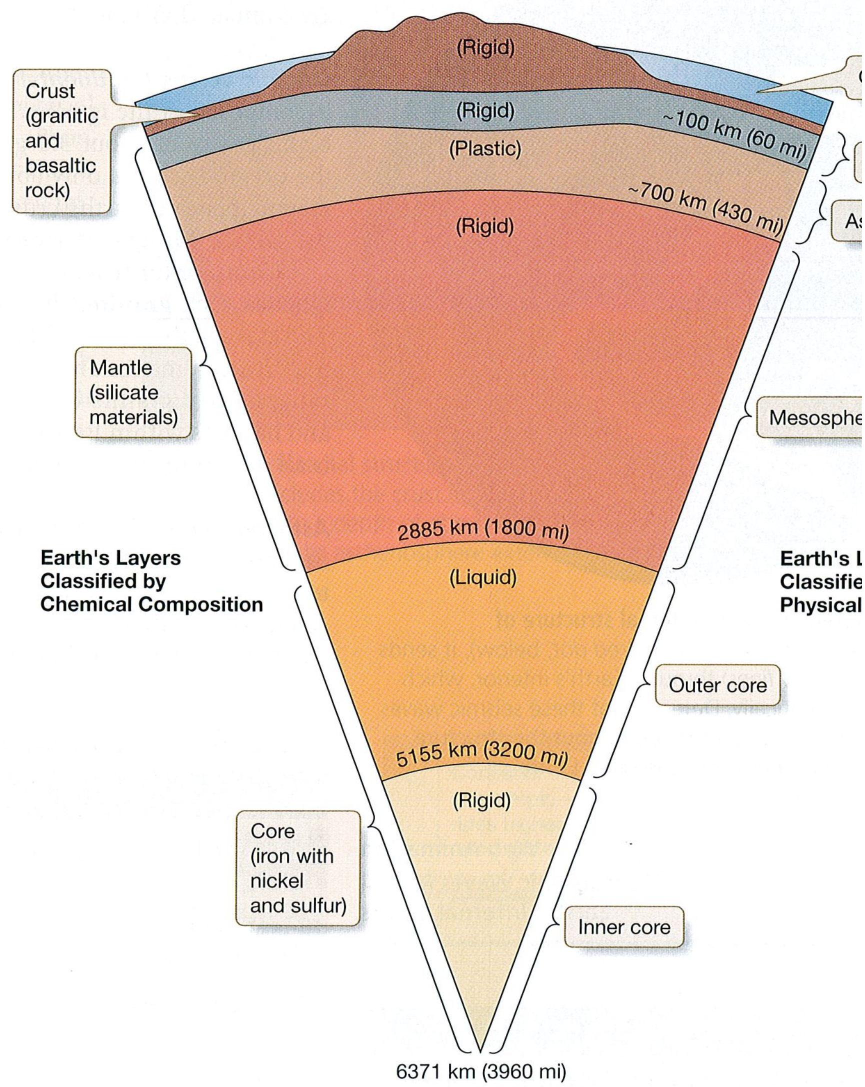
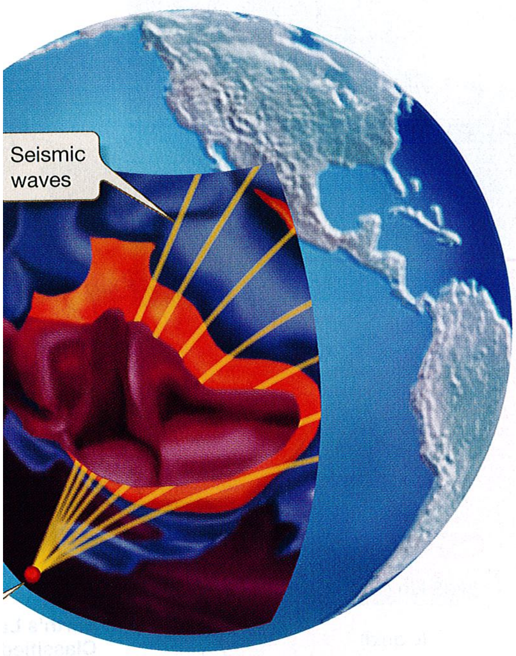


Figure 1.16 Comparison of Earth's chemical composition and physical properties. A sectional view of Earth, showing Earth's layers classified by chemical composition a side of the diagram. For comparison, Earth's layers classified by physical properties along the right side of the diagram.

'S SOMETIMES ASK . . .

know
nternal
Earth?

You might suspect that the internal structure of Earth has been sampled directly. However, humans have never
neath the crust! The internal structure of
mined by using indirect observations. Every
n earthquake, waves of energy (called *seismic*
ate Earth's interior. Seismic waves change their
bent and reflected as they move through
different properties. An extensive network of
ations around the world detects and records
he data are analyzed and used to determine
of Earth's interior (**Figure 1.17**).



Determining the internal structure of
n an earthquake occurs (*red dot*, below), it sends
s (*yellow lines*) through Earth's interior, which
grammatically. Detection of these seismic waves
globe reveals information about the structure,
, and properties of the deep Earth.

Web Animation
How Seismic Waves Reveal Earth's Internal Layers

IAL CONCEPT 1.4

fferences in composition and physical proper-
ate layers such as the brittle lithosphere and the
nosphere, which is capable of flowing slowly

100 kilometers (62 miles) to 700 kilometers (430 miles) below the surface, which is the base of the upper mantle. At these depths, it is hot enough to partially melt portions of most rocks.

Beneath the asthenosphere is the mesosphere. The mesosphere extends to a depth of about 2885 kilometers (1800 miles), which corresponds to the middle and lower mantle. Although the asthenosphere deforms plastically, the mesosphere is rigid, most likely due to the increased pressure at these depths.

Beneath the mesosphere is the core. The core consists of the outer core, which is liquid and capable of flowing, and the inner core, which is rigid and does not flow. Again, the increased pressure at the center of Earth keeps the inner core from flowing.

NEAR THE SURFACE The top portion of **Figure 1.18** shows an enlargement of Earth's layers closest to the surface.

Lithosphere The lithosphere is a relatively cool, rigid shell that includes all the crust and the topmost part of the mantle. In essence, the topmost part of the mantle is attached to the crust and the two act as a single unit, approximately 100 kilometers (62 miles) thick. The expanded view in Figure 1.18 shows that the crust portion of the lithosphere is further subdivided into oceanic crust and continental crust, which are compared in **Table 1.1**.

Oceanic versus Continental Crust **Oceanic crust** underlies the ocean basins and is composed of the igneous rock **basalt**, which is dark colored and has a relatively high density of about 3.0 grams per cubic centimeter.[8] The average thickness of the oceanic crust is only about 8 kilometers (5 miles). Basalt originates as molten magma beneath Earth's crust (typically from the mantle), some of which comes to the surface during underwater sea floor eruptions.

Continental crust is composed mostly of the lower-density and lighter-colored igneous rock **granite**.[9] It has a density of about 2.7 grams per cubic centimeter. The average thickness of the continental crust is about 35 kilometers (22 miles) but may reach a maximum of 60 kilometers (37 miles) beneath the highest mountain ranges. Most granite originates beneath the surface as molten magma that cools and hardens within Earth's crust. No matter which type of crust is at the surface, it is all part of the lithosphere.

Asthenosphere The asthenosphere is a relatively hot, plastic region beneath the lithosphere. It extends from the base of the lithosphere to a depth of about 700 kilometers (430 miles) and is entirely contained within the upper mantle. The asthenosphere can deform without fracturing if a force is applied slowly. This means that it has the ability to flow but has high **viscosity** (*viscosus* = sticky). Viscosity is a measure of a

TABLE 1.1 COMPARING OCEANIC AND CONTINENTAL CRUST

	Oceanic crust	Continental crust
Main rock type	Basalt (dark-colored igneous rock)	Granite (light-colored igneous rock)
Density (grams per cubic centimeter)	3.0	2.7
Average thickness	8 kilometers (5 miles)	35 kilometers (22 miles)

[8]Water has a density of 1.0 grams per cubic centimeter. Thus, basalt with a density of 3.0 grams per cubic centimeter is three times denser than water.

[9]At the surface, continental crust is often covered by a relatively thin layer of surface sediments. Below these, granite can be found.

substance's resistance to flow.[10] Studies indicate that the high-viscosity asthenosphere is flowing slowly through time; this has important implications for the movement of lithospheric plates.

ISOSTATIC ADJUSTMENT **Isostatic** (*iso* = equal, *stasis* = standing) **adjustment**—the vertical movement of crust—is the result of the buoyancy of Earth's lithosphere as it floats on the denser, plasticlike asthenosphere below. Figure 1.19, which shows a container ship floating in water, provides an example of isostatic adjustment. It shows that an empty ship floats high in the water. Once the ship is loaded with cargo, though, the ship undergoes isostatic adjustment and floats lower in the water (but hopefully won't sink!). When the cargo is unloaded, the ship isostatically adjusts itself and floats higher again.

Similarly, both continental and oceanic crust float on the denser mantle beneath. Oceanic crust is denser than continental crust, however, so oceanic crust floats lower in the mantle because of isostatic adjustment. Oceanic crust is also thin, which creates low areas for the oceans to occupy. Areas where the continental crust is thickest (such as large mountain ranges on the continents) float higher than continental crust of normal thickness, also because of isostatic adjustment. These mountains are similar to the top of a floating iceberg—they float high because there is a very thick mass of crustal material beneath them, plunged deeper into the asthenosphere. Thus, tall mountain ranges on Earth are composed of a great thickness of crustal material that in essence keeps them buoyed up.

Areas that are exposed to an increased or decreased load experience isostatic adjustment. For instance, during the most recent ice age (which occurred during the Pleistocene Epoch between about 1.8 million and 10,000 years ago), massive ice sheets alternately covered and exposed northern regions such as Scandinavia and northern Canada. The additional weight of ice several kilometers thick caused these areas to isostatically adjust themselves lower in the mantle. Since the end of the most recent ice age, the reduced load on these areas caused by the melting of ice caused these areas to rise and experience **isostatic rebound**, which continues today. The rate at which isostatic rebound occurs gives scientists important information about the properties of the upper mantle.

Further, isostatic adjustment provides additional evidence for the movement of Earth's tectonic plates. Because continents isostatically adjust themselves by moving *vertically*, they must not be firmly fixed in one position on Earth. As a result, the plates that contain these continents should certainly be able to move *horizontally* across Earth's surface. This remarkable idea will be explored in more detail in the next chapter.

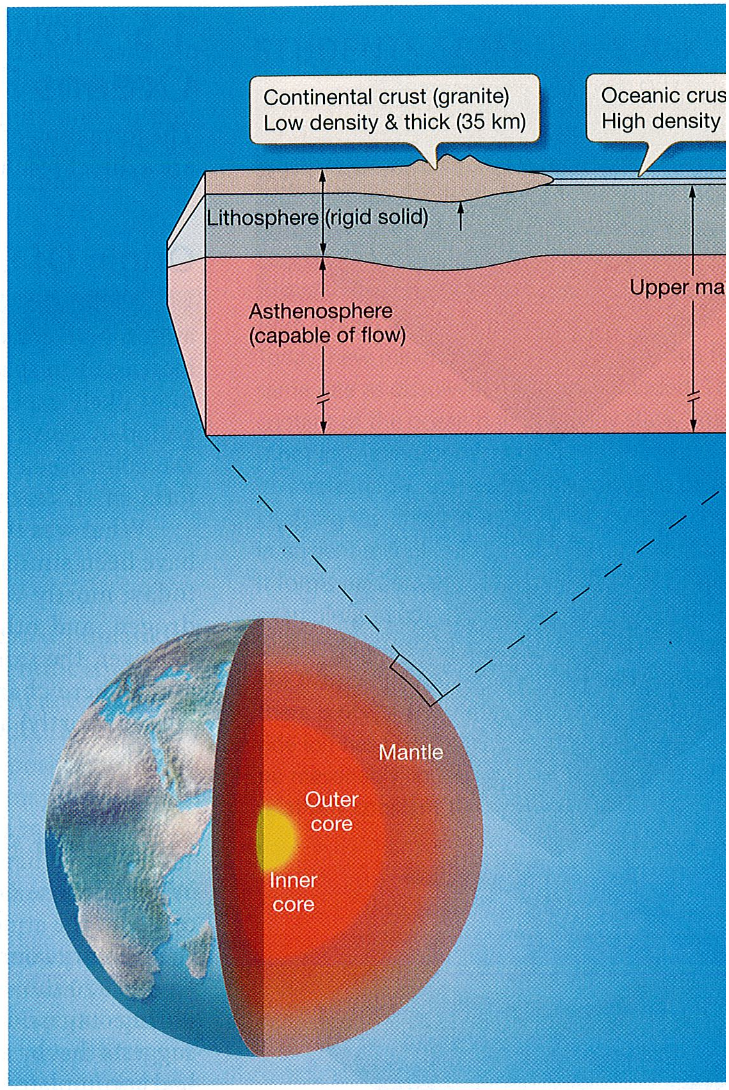


Figure 1.18 Internal structure of Earth. Enlargement (*top*) shows that lithosphere includes the crust (either continental or oceanic) plus the t of the mantle to a depth of about 100 kilometers (60 miles). Beneath sphere, the plastic asthenosphere extends to a depth of 700 kilomete

CONCEPT CHECK 1.4

1. Discuss the origin of the solar system using the nebular hypothesis.
2. How was Protoearth different from Earth today?
3. What is density stratification, and how did it change Protoearth?
4. What are some differences between the lithosphere and the asthenosphere?

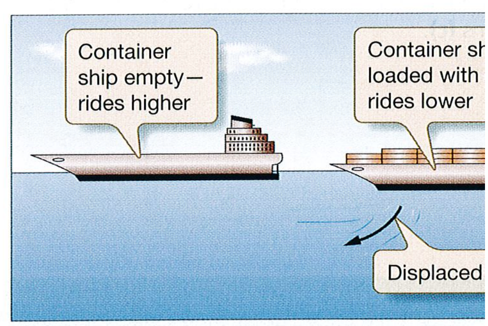
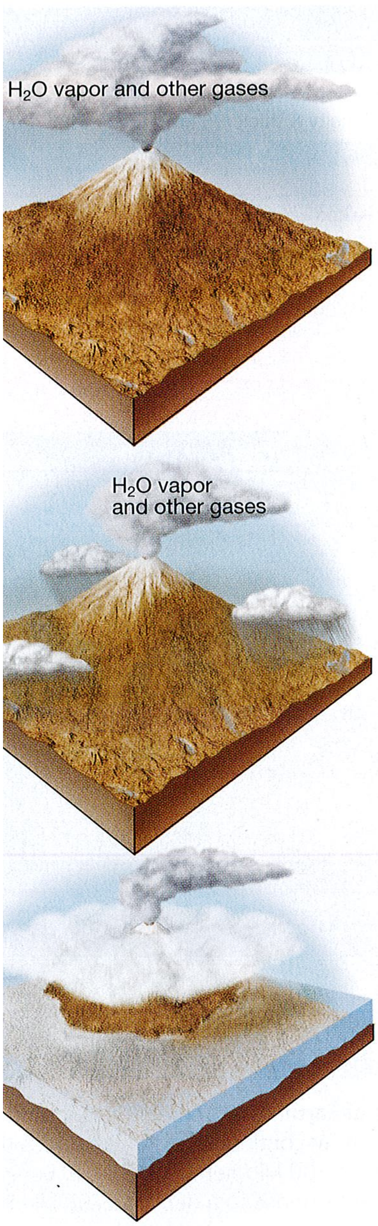


Figure 1.19 A container ship experiences isostat ment. A ship will ride higher in water when it is will ride lower in water when it is loaded with ca ing the principle of isostatic adjustment.

[10]Substances that have high viscosity (a high resistance to flow) include toothpaste, honey, tar, and Silly Putty; a common substance that has low viscosity is water. Note that a substance's viscosity often changes with temperature. For instance, as honey is heated, it flows more easily.



ıation of Earth's oceans. Early in Earth's
ıd volcanic activity released large amounts
$_2$O vapor) and smaller quantities of other
ɔoled, the water vapor **(a)** condensed into
l to Earth's surface, where it accumulated to
(c).

CONCEPT 1.5

ıad no oceans. The oceans (and atmo-
n inside Earth as a result of outgassing
by at least 4 billion years ago.

1.5 How Were Earth's Atmosphere and Oceans Formed?

The formation of Earth's atmosphere is related to the formation of the oceans; both are a direct result of density stratification.

Origin Of Earth's Atmosphere

Where did the atmosphere come from? As previously mentioned, Earth's initial atmosphere consisted of leftover gases from the nebula, but those particles were blown out to space by the Sun's solar wind. After that, a second atmosphere was most likely expelled from inside Earth by a process called **outgassing**. During the period of density stratification, the lowest-density material contained within Earth was composed of various gases. These gases rose to the surface and were expelled to form Earth's early atmosphere.

What was the composition of these atmospheric gases? They are believed to have been similar to the gases emitted from volcanoes, geysers, and hot springs today: mostly water vapor (steam), with small amounts of carbon dioxide, hydrogen, and other gases. The composition of this early atmosphere was not, however, the same composition as today's atmosphere. The composition of the atmosphere changed over time because of the influence of life (as will be discussed shortly) and possibly because of changes in the mixing of material in the mantle.

Origin Of Earth's Oceans

Where did the oceans come from? Similarly, their origin is linked directly to the origin of the atmosphere. Because outgassing releases mostly water vapor, this was the primary source of water on Earth, including supplying the oceans with water. **Figure 1.20** shows that as Earth cooled, the water vapor released to the atmosphere during outgassing condensed, fell to Earth, and accumulated in low areas. Evidence suggests that by at least 4 billion years ago, most of the water vapor from outgassing had accumulated to form the first permanent oceans on Earth.

Recent research, however, suggests that not all water came from inside Earth. Comets, being about half water, were once widely held to be the source of Earth's oceans. During Earth's early development, space debris left over from the origin of the solar system bombarded the young planet, and there could have been plenty of water supplied to Earth. However, spectral analyses of the chemical composition of three comets—Halley, Hyakutake, and Hale-Bopp—during near-Earth passes they made in 1986, 1996, and 1997, respectively, revealed a crucial chemical difference between the hydrogen in comet ice and that in Earth's water. If similar comets supplied large quantities of water to Earth, much of Earth's water would still exhibit the telltale type of hydrogen identified in these comets. Recently, however, comets that originated from the outer solar system's Kuiper belt have been analyzed, and their water in the form of ice contains nearly the correct type of hydrogen that is found in Earth's water. It now appears that these comets could have contributed water to an early Earth and points to an emerging picture of a complex and dynamic evolution of the early solar system. Still, it seems likely that most of Earth's water was derived from outgassing.

THE DEVELOPMENT OF OCEAN SALINITY The relentless rainfall that landed on Earth's rocky surface dissolved many elements and compounds and carried them into the newly forming oceans. Even though Earth's oceans have existed since early in the formation of the planet, its chemical composition must have changed. This is because the high carbon dioxide and sulfur dioxide content in the early atmosphere would have created a very acidic rain, capable of dissolving greater amounts of minerals in the crust than occurs today. In addition, volcanic gases such as chlorine became dissolved in the atmosphere. As rain fell and washed to the ocean, it carried some of these dissolved compounds, which accumulated in the newly forming oceans.[11] Eventually, a balance between inputs and outputs was reached, producing an ocean with a chemical composition similar to today's oceans. Further aspects of the oceans' salinity are explored in Chapter 5, "Water and Seawater."

CONCEPT CHECK 1.5

1. Describe the origin of Earth's oceans.
2. Describe the origin of Earth's atmosphere. How is its origin related to the origin of Earth's oceans?
3. Have the oceans always been salty? Why or why not?

1.6 Did Life Begin in the Oceans?

The fundamental question of how life began on Earth has puzzled humankind since ancient times and has recently received a great amount of scientific study. The evidence required to understand our planet's prebiotic environment and the events that led to first living systems is scant and difficult to decipher. Still, the inventory of current views on life's origin reveals a broad assortment of opposing positions. One recent hypothesis is that the organic building blocks of life may have arrived embedded in meteors, comets, or cosmic dust. Alternatively, life may have originated around hydrothermal vents—hot springs—on the deep-ocean floor. Yet another idea is that life originated in certain minerals that acted as chemical catalysts within rocks deep below Earth's surface.

According to the fossil record on Earth, the earliest-known life-forms were primitive bacteria that lived in sea floor rocks about 3.5 billion years ago. Unfortunately, Earth's geologic record for these early times is so sparse and the rocks are so deformed by Earth processes that the rocks no longer reveal life's precursor molecules. In addition, there is no direct evidence of Earth's environmental conditions (such as its temperature, ocean acidity, or the exact composition of the atmosphere) at the time of life's origin. Still, it is clear that the basic building blocks for the development of life were available from materials already present on the early Earth. And the oceans were the most likely place for these materials to interact and produce life.

The Importance Of Oxygen to Life

Oxygen, which comprises almost 21% of Earth's present atmosphere, is essential to human life for two reasons. First, our bodies need oxygen to "burn" (*oxidize*) food, releasing energy to our cells. Second, oxygen in the upper atmosphere in the form of *ozone* (*ozone* = to smell[12]) protects the surface of Earth from most of the Sun's harmful ultraviolet radiation (which is why the atmospheric ozone hole over Antarctica has generated such concern).

Evidence suggests that Earth's early atmosphere (the product of outgassing) was different from Earth's initial hydrogen–helium atmosphere and different from the mostly nitrogen–oxygen atmosphere of today. The early atmosphere probably contained large percentages of water vapor and carbon dioxide and smaller percentages

[11] Note that some of these dissolved components were removed or modified by chemical reactions between ocean water and rocks on the sea floor.

[12] Ozone gets its name because of its pungent, irritating odor.

STUDENTS SOMETIMES ASK .

Have the oceans always been salty? Are the oceans growing more or less salty through time?

It is likely that the always been salt wherever water co tact with the rock crust, some of the dissolve. This is th salts in the ocean from stream runoff or dissolving directly from Today, new minerals are forming on the sea fl same rate as dissolved materials are added. Th content of the ocean is in a "steady state," me is not increasing or decreasing.

Interestingly, these questions can also be a studying the proportion of water vapor to chl in ancient marine rocks. Chloride ion is impor it forms part of the most common salts in the example, sodium chloride, potassium chloride sium chloride). Also, chloride ion is produced like the water vapor that formed the oceans. there is no indication that the ratio of water v ride ion has fluctuated throughout geologic t be reasonably concluded that the oceans' sali relatively constant through time.

of hydrogen, methane, and ammonia but very little free oxygen (oxygen that is not chemically bound to other atoms). Why was there so little free oxygen in the early atmosphere? Oxygen may well have been outgassed, but oxygen and iron have a strong affinity for each other.[13] As a result, iron in Earth's early crust would have reacted with the outgassed oxygen immediately, removing it from the atmosphere.

Without oxygen in Earth's early atmosphere, moreover, there would have been no ozone layer to block most of the Sun's ultraviolet radiation. The lack of a protective ozone layer may, in fact, have played a crucial role in several of life's most important developmental milestones.

Stanley Miller's Experiment

In 1952, **Stanley Miller** (**Figure 1.21b**)—then a 22-year-old graduate student of chemist Harold Urey at the University of Chicago—conducted a laboratory experiment that had profound implications about the development of life on Earth. In Miller's experiment, he exposed a mixture of carbon dioxide, methane, ammonia, hydrogen, and water (the components of the early atmosphere and ocean) to ultraviolet light (from the Sun) and an electrical spark (to imitate lightning) (**Figure 1.21a**). By the end of the first day, the mixture turned pink and after a week it was a deep, muddy brown, indicating the formation of a large assortment of organic molecules, including amino acids—which are the basic components of life—and other biologically significant compounds.

Miller's now-famous laboratory experiment of a simulated primitive Earth in a bottle—which has been duplicated and confirmed numerous times since—demonstrated that vast amounts of organic molecules could have been produced in Earth's early oceans, often called a "prebiotic soup." This prebiotic soup, perhaps spiced by extraterrestrial molecules aboard comets, meteorites, or interplanetary dust, was fueled by raw materials from volcanoes, certain minerals in sea floor rocks, and undersea hydrothermal vents. On early Earth, the mixture was energized by lightning, cosmic rays, and the planet's own internal heat, and it is thought to have created life's precursor molecules about 4 billion years ago.

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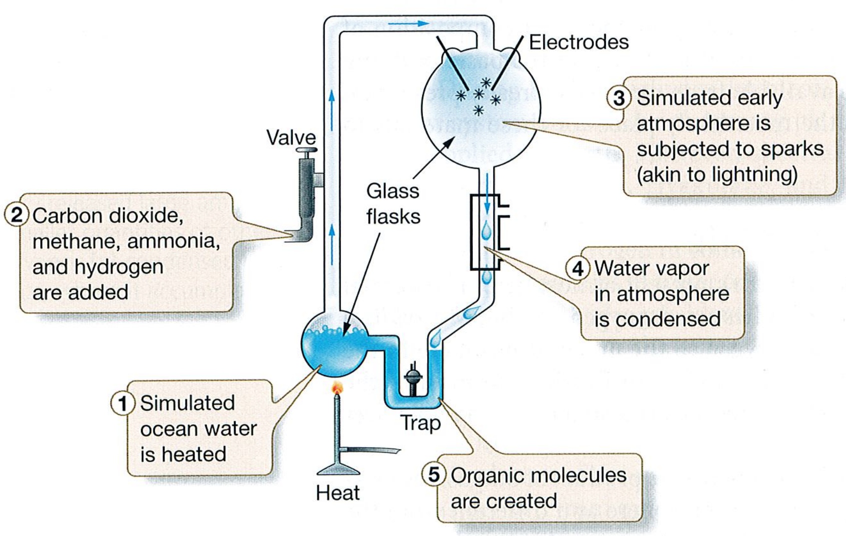
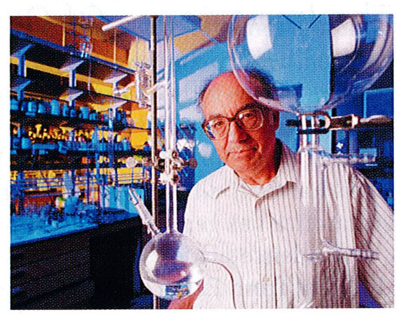


(a) Laboratory apparatus used by Stanley Miller to simulate the conditions of the early atmosphere and the oceans. The experiment produced various organic molecules and suggests that the basic components of life were created in a "prebiotic soup" in the oceans.



(b) Stanley Miller in 1999, with his famous apparatus in the foreground.

[13]As an example of the strong affinity of iron and oxygen, consider how common rust—a compound of iron and oxygen—is on Earth's surface.

Exactly how these simple organic compounds in the prebiotic soup assembled themselves into more complex molecules—such as proteins and DNA—and then into the first living entities remains one of the most tantalizing questions in science. Recent research suggests that with the vast array of organic compounds available in the prebiotic soup, several kinds of chemical reactions led to increasingly elaborate molecular structures. In fact, research suggests that small, simple molecules could have acted as templates, or "molecular midwifes," in helping the building blocks of life's genetic material form long chains and thus may have assisted in the formation of longer, more elaborate molecular complexes. Among these complexes, some began to carry out functions associated with the basic molecules of life. As the products of one generation became the building blocks for another, even more complex molecules, or polymers, emerged over many generations that could store and transfer information. Such genetic polymers ultimately became encapsulated within cell-like membranes that were also present in Earth's primitive broth. The resulting cell-like complexes thereby housed self-replicating molecules capable of multiplying—and hence evolving—genetic information. Many specialists consider this emergence of genetic replication to be the true origin of life.

ESSENTIAL CONCEPT 1.6

Organic molecules were produced in a simu Earth's early atmosphere and ocean, sugges most likely originated in the oceans.

Evolution and Natural Selection

Every living organism that inhabits Earth today is the result of **evolution** by the process of **natural selection** that has been occurring since life first existed on Earth. The theory of evolution states that groups of organisms adapt and change with the passage of time, causing descendants to differ morphologically and physiologically from their ancestors (Diving Deeper 1.2). Certain advantageous traits are naturally selected and passed from one generation to the next. Evolution is the process by which various **species** (*species* = a kind) have been able to inhabit increasingly numerous environments on Earth.

As we shall see, when species adapt to Earth's various environments, they can also modify the environments in which they live. This modification can be localized or nearly global in scale. For example, when plants emerged from the oceans and inhabited the land, they changed Earth from a harsh and bleak landscape as barren as that of the Moon to one that is green and lush.

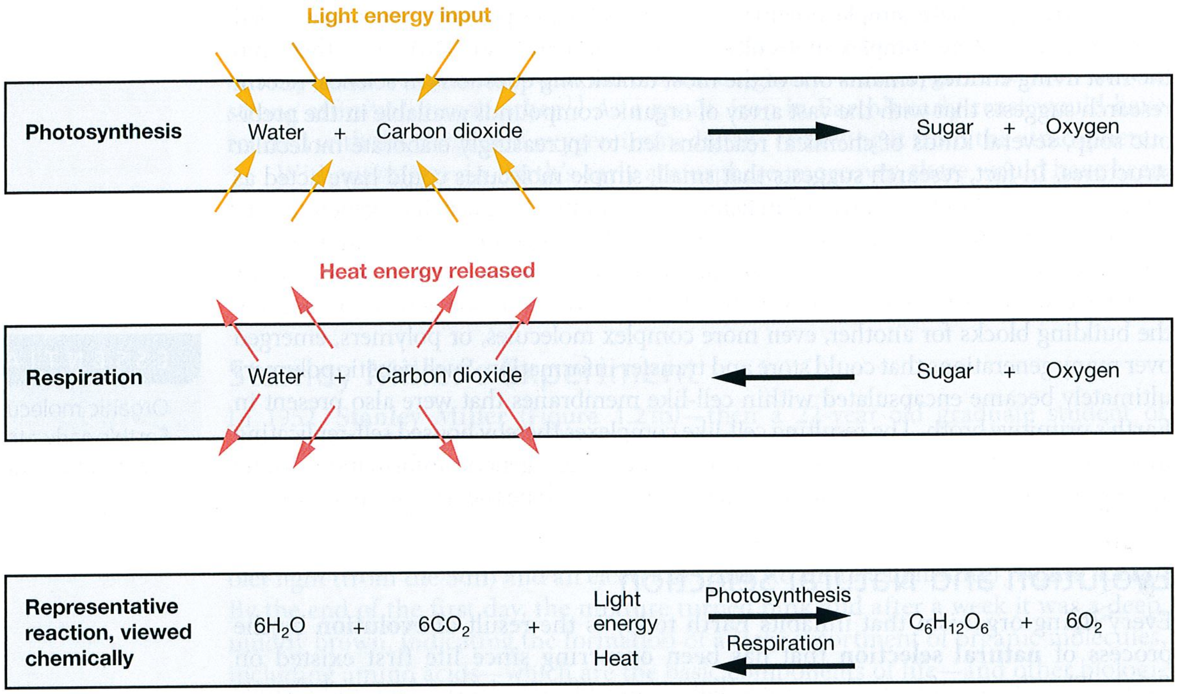
Plants and Animals Evolve

The very earliest forms of life were probably **heterotrophs** (*hetero* = different, *tropho* = nourishment). Heterotrophs require an external food supply, which was abundantly available in the form of nonliving organic matter in the ocean around them. **Autotrophs** (*auto* = self, *tropho* = nourishment), which can manufacture their own food supply, evolved later. The first autotrophs were probably similar to present-day **anaerobic** (*an* = without, *aero* = air) bacteria, which live without atmospheric oxygen. They may have been able to derive energy from inorganic compounds at deep-water hydrothermal vents using a process called **chemosynthesis** (*chemo* = chemistry, *syn* = with, *thesis* = an arranging).[14] In fact, the recent detection of microbes deep within the ocean crust as well as the discovery of 3.2-billion-year-old microfossils of bacteria from deep-water marine rocks support the idea of life's origin on the deep-ocean floor in the absence of light.

PHOTOSYNTHESIS AND RESPIRATION Eventually, more complex single-celled autotrophs evolved. They developed a green pigment called **chlorophyll** (*chloro* = green, *phyll* = leaf), which captures the Sun's energy through cellular **photosynthesis** (*photo* = light, *syn* = with, *thesis* = an arranging). In photosynthesis (Figure 1.22, *top*), plant cells capture light energy and store it as sugars. In cellular **respiration** (*respirare* = to breathe) (Figure 1.22, *middle*), sugars are oxidized with oxygen,

[14]More details about chemosynthesis are discussed in Chapter 15, "Animals of the Benthic Environment."

hotosynthesis (*top*), ddle), and representative ed chemically (*bottom*). photosynthesis, which is by plants, is represented anel. The second panel on, which is done by processes are shown he third panel.



releasing stored energy that is used as a source of energy by the organism that consumes the plant to carry on various life processes.

Not only are photosynthesis and respiration chemically opposite processes, they are also complementary because the products of photosynthesis (sugars and oxygen) are used during respiration and the products of respiration (water and carbon dioxide) are used in photosynthesis (Figure 1.22, *bottom*). Thus, autotrophs (algae and plants) and heterotrophs (most bacteria and animals) have developed a mutual need for each other.

The oldest fossilized remains of organisms are primitive photosynthetic bacteria recovered from rocks formed on the sea floor about 3.5 billion years ago. However, the oldest rocks containing iron oxide (rust)—an indicator of an oxygen-rich atmosphere—did not appear until about 2.4 billion years ago. Thus, photosynthetic organisms needed about a billion years to develop and begin producing abundant free oxygen in the atmosphere. At the same time, when a large amount of oxygen-rich (ferric) iron sank to the base of the mantle, it may have been heated by the core, risen as a plume to the ocean floor, and begun releasing large amounts of oxygen through outgassing about 2.5 billion years ago.

THE GREAT OXIDATION EVENT/OXYGEN CRISIS Based on the chemical makeup of certain rocks, Earth's atmosphere became oxygen rich about 2.45 billion years ago—called the *great oxidation event*—and fundamentally changed Earth's ability to support life. Particularly for anaerobic bacteria, which had grown successfully in an oxygen-free world, all this oxygen was nothing short of a catastrophe! This is because the increased atmospheric oxygen caused the ozone concentration in the upper atmosphere to build up, thereby shielding Earth's surface from ultraviolet radiation—and effectively eliminating anaerobic bacteria's food supply of organic molecules. (Recall that Stanley Miller's experiment created organic molecules but needed ultraviolet light.) In addition, oxygen (particularly in the presence of light) is highly reactive with organic matter. When anaerobic bacteria are exposed to oxygen and light, they are killed instantaneously. By 1.8 billion years ago, the atmosphere's oxygen content had increased to such a high level that it began causing the extinction of many anaerobic organisms. Nonetheless, descendants of such bacteria survive on Earth today in isolated microenvironments that are dark and free of oxygen, such as deep in soil or rocks, in landfills, and inside other organisms.

AL CONCEPT 1.6B

as evolved over time and changed Earth's For example, abundant photosynthetic ated today's oxygen-rich atmosphere.

Although oxygen is very reactive with organic matter and can even be toxic, it also yields nearly 20 times more energy than anaerobic respiration—a fact that some organisms exploited. For example, blue-green algae, which are also known as *cyanobacteria* (*kuanos* = dark blue), adapted to and thrived in this new oxygen-rich environment. In doing so, they altered the composition of the atmosphere.

CHANGES TO EARTH'S ATMOSPHERE Remarkably, the development and successful evolution of photosynthetic organisms are greatly responsible for the world as we know it today (**Figure 1.23**). By the trillions, these microscopic organisms transformed the planet by capturing the energy of the Sun to make food and releasing oxygen as a waste product. By this process, these organisms reduced the high amount of carbon dioxide in the early atmosphere and gradually replaced it with free oxygen. This created a third and final atmosphere on Earth: one that is oxygen rich (about 21% today). Little by little, these tiny organisms turned the atmosphere into breathable air, opening the way to the diversity of life that followed.

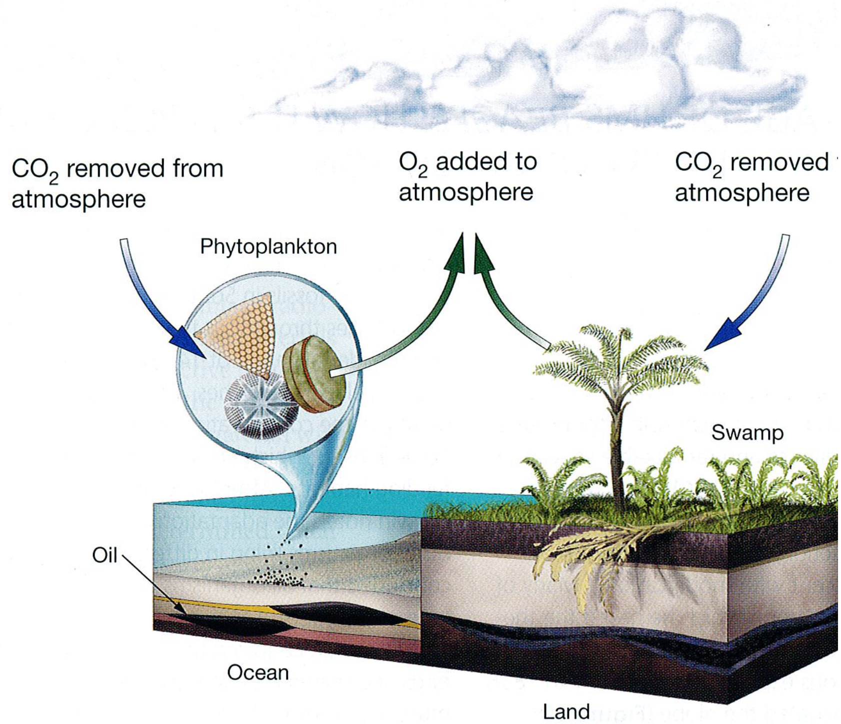


Figure 1.23 The effect of plants on Earth's environment. As microscopic photos (*inset*) became established in the ocean, Earth's atmosphere was enriched in oxy depleted of carbon dioxide. As organisms died and accumulated on the ocean fl their remains were converted to oil and gas. The same process occurred on land, producing coal.

The graph in **Figure 1.24** shows how the concentration of atmospheric oxygen has varied during the past 600 million years. When atmospheric oxygen concentrations are high, organisms thrive, and rapid speciation occurs. At such times in the past, insects grew to gargantuan proportions, reptiles took to the air, and the forerunners of mammals developed a warm-blooded metabolism. More oxygen was dissolved in the oceans, too, and so marine biodiversity increased. At other times when atmospheric oxygen concentrations fell precipitously, biodiversity was smothered. In fact, some of the planet's worst mass extinctions are associated with sudden drops in atmospheric oxygen.

The remains of ancient plants and animals buried in oxygen-free environments have become the oil, natural gas, and coal deposits of today. These deposits, which are called *fossil fuels*, provide more than 90% of the energy humans consume to power modern society. In essence, humans depend not only on the food energy stored in today's plants but also on the energy stored in plants during the geologic past—in the form of fossil fuels.

Because of increased burning of fossil fuels for home heating, industry, power generation, and transportation during the industrial age, the atmospheric concentration of carbon dioxide and other gases that help warm the atmosphere has increased, too. Scientists predict that these human emissions will increase global warming and cause serious environmental problems in the not-too-distant future. This phenomenon is referred to as the atmosphere's *enhanced greenhouse effect* and is discussed in Chapter 16, "The Oceans and Climate Change."

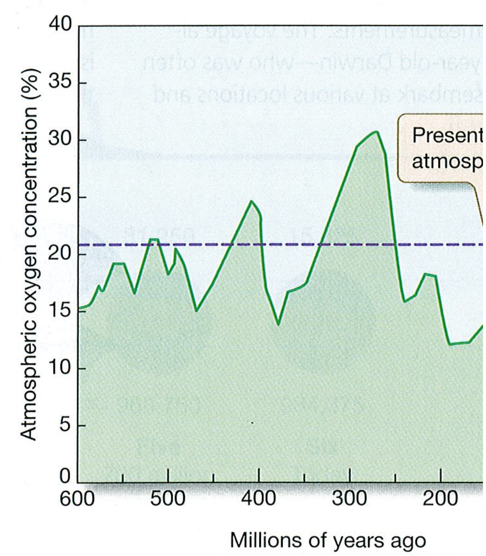


Figure 1.24 Atmospheric oxygen concentrati showing how the concentration of oxygen in has varied during the past 600 million years. T level is about 21%. Low oxygen levels are clos with major extinction events, whereas high o associated with rapid speciation, including spe

CONCEPT CHECK 1.6

1. How does the presence of oxygen in our atmosphere help reduce the amount of ultraviolet radiation that reaches Earth's surface?
2. What was Stanley Miller's experiment, and what did it help demonstrate?
3. Earth has had three atmospheres (initial, early, and present). Describe the composition and origin of each one.

Diving Deeper 1.2 Historical Feature

/OYAGE OF HMS *BEAGLE*: HOW IT SHAPED CHARLES DARWIN'S THINKING JT THE THEORY OF EVOLUTION

ȷ in biology makes sense except in of evolution."

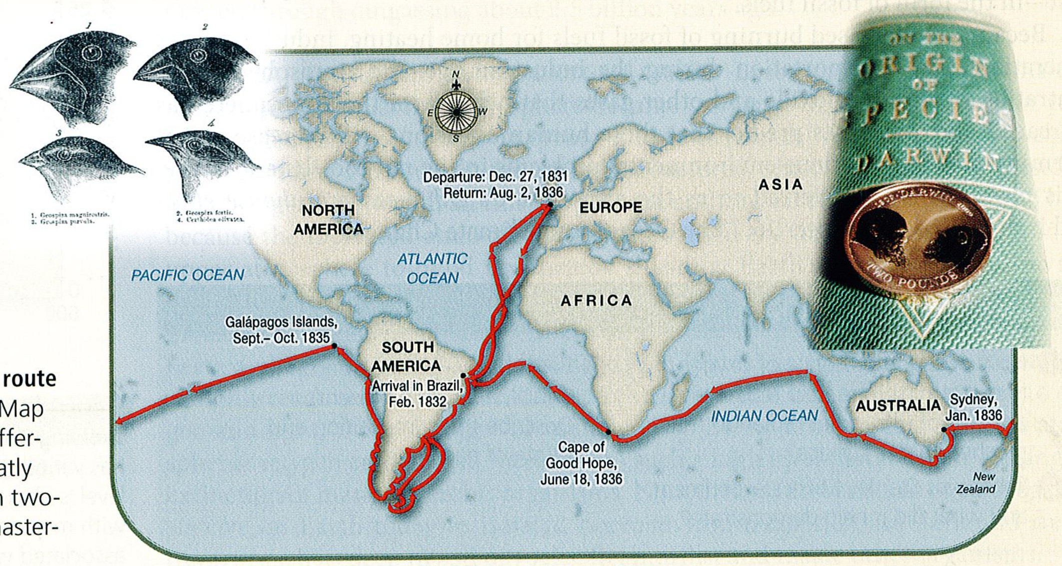
—Geneticist Theodosius Dobzhansky (1973)

ɔ explain how biologic processes oper- in nature were responsible for produc- ıany diverse and remarkable species on ꞓ English naturalist **Charles Darwin** 82) proposed the *theory of evolution* l selection, which he referred to as ı descent with modification." Many of vations upon which he based the the- made aboard the vessel HMS *Beagle* famous expedition from 1831 to 1836 mnavigated the globe (**Figure 1D**). vin became interested in natural history ꞩ student days at Cambridge University, was studying to become a minister. ɔf the influence of John Henslow, a pro- botany, he was selected to serve as an ıturalist on the HMS *Beagle*. The *Beagle* n Devonport, England, on December 27, der the command of Captain Robert ıe major objective of the voyage was ete a survey of the coast of Patagonia a) and Tierra del Fuego and to make etric measurements. The voyage al- ꞓ 22-year-old Darwin—who was often to disembark at various locations and study local plants and animals. What particularly influenced his thinking about evolution were the discovery of fossils in South America, the different tortoises throughout the Galápagos Islands, and the identification of 14 closely related species of Galápagos finches. These finches differ greatly in the configuration of their beaks (Figure 1D, *left inset*), which are suited to their diverse feeding habitats. After his return to England, Darwin noted the adaptations of finches and other organisms living in different habitats and concluded that all organisms change slowly over time as products of their environment.

Darwin recognized the similarities between birds and mammals and reasoned that they must have evolved from reptiles. Patiently making observations over many years, he also noted the similar skeletal framework of species such as bats, horses, giraffes, elephants, porpoises, and humans, which led him to establish relationships between various groups. Darwin suggested that the differences between species were the result of adaptation over time to different environments and modes of existence.

In 1858, Darwin hastily published a summary of his ideas about natural selection because fellow naturalist *Alfred Russel Wallace*, working half a world away cataloguing species in what is now Indonesia, had independently discovered the same idea. A year later, Darwin published his remarkable masterwork *On the Origin of Species by Means of Natural Selection* (Figure 1D, *right inset*), in which he provided extensive and compelling evidence that all living beings—including humans—have evolved from a common ancestor. At the time, Darwin's ideas were highly controversial because they stood in stark conflict with what most people believed about the origin of humans. Darwin also produced important publications on subjects as diverse as barnacle biology, carnivorous plants, and the formation of coral reefs.

Over 150 years later, Darwin's theory of evolution is so well established by evidence and reproducible experiment that it is considered a landmark influence in the scientific understanding of the underlying biologic processes operating in nature. Discoveries made since Darwin's time—including genetics and the structure of DNA—confirm how the process of evolution works. In fact, most of Darwin's ideas have been so thoroughly accepted by scientists that they are now the underpinnings of the modern study of biology. That's why the name *Darwin* is synonymous with evolution. In 2009, to commemorate Darwin's birth and his accomplishments, the Church of England even issued this formal apology to Darwin: *"The Church of England owes you an apology for misunderstanding you and, by getting our first reaction wrong, encouraging others to misunderstand you still."*



D **Charles Darwin: Galápagos finches, route ИS *Beagle*, and the *Origin of Species*.** Map the route of the HMS *Beagle*, beak differ- Galápagos finches (*left inset*) that greatly ɛd Charles Darwin, and the new British two- ɔin commemorating Darwin and his master- *the Origin of Species* (*right inset*).

1.7 How Old Is Earth?

How can Earth scientists tell how old a rock is? It can be a difficult task to tell if a rock is thousands, millions, or even billions of years old—unless the rock contains telltale fossils. Fortunately, Earth scientists can determine how old most rocks are by using the radioactive materials contained within rocks. In essence, this technique involves reading a rock's internal "rock clock."

Radiometric Age Dating

Most rocks on Earth (as well as those from outer space) contain small amounts of radioactive materials such as uranium, thorium, and potassium. These radioactive materials spontaneously break apart or decay into atoms of other elements. Radioactive materials have a characteristic **half-life**, which is the time required for one-half of the atoms in a sample to decay to other atoms. The older the rock is, the more radioactive material will have been converted to decay product. Analytical instruments can accurately measure the amount of radioactive material and the amount of resulting decay product in rocks. By comparing these two quantities, the age of the rock can thus be determined. Such dating is referred to as **radiometric** (*radio* = radioactivity, *metri* = measure) **age dating** and is an extremely powerful tool for determining the age of rocks.

Figure 1.25 shows an example of how radiometric age dating works. It shows how uranium 235 decays into lead 207 at a rate where one-half of the atoms turn into lead every 704 million years. By counting the number of each type of atom in a rock sample, one can tell how long it has been decaying (as long as the sample does not gain or lose atoms). Using uranium and other radioactive elements and applying this same technique, hundreds of thousands of rock samples have been age dated from around the world.

The Geologic Time Scale

The ages of rocks on Earth are shown in the **geologic time scale** (Figure 1.26; see Web Diving Deeper 1.2), which lists the names of the geologic time periods as well as important advances in the development of life-forms on Earth. Initially, the divisions between geologic periods were based on major extinction episodes as recorded in the fossil record. As radiometric age dates became available, they were also included on the geologic time scale. The oldest-known rocks on Earth, for example, are about 4.3 billion years old, and the oldest-known crystals within rocks have been dated at up to 4.4 billion years old.[15] In all, the time scale indicates that Earth is 4.6 billion years old, but few rocks survived its molten youth, a time when Earth was being bombarded by meteorites.

ESSENTIAL CONCEPT 1.7

Earth scientists can accurately determine the
rocks by analyzing their radioactive compone
which indicate that Earth is 4.6 billion years

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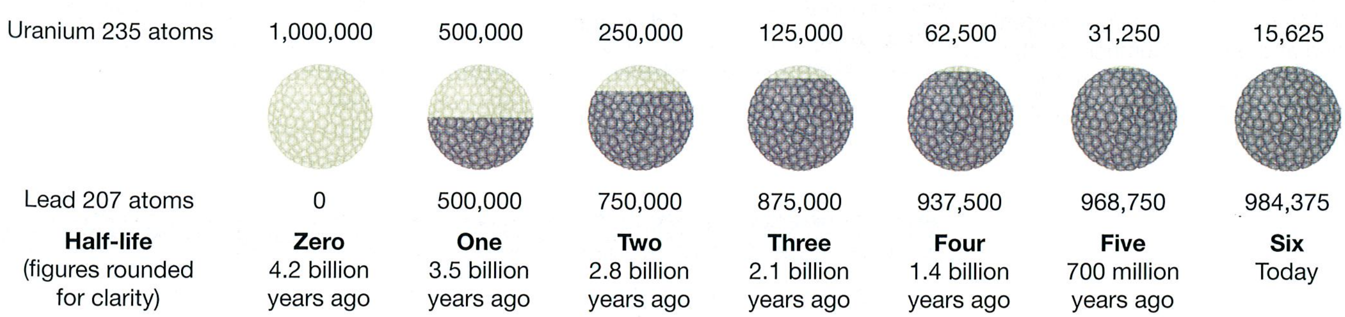
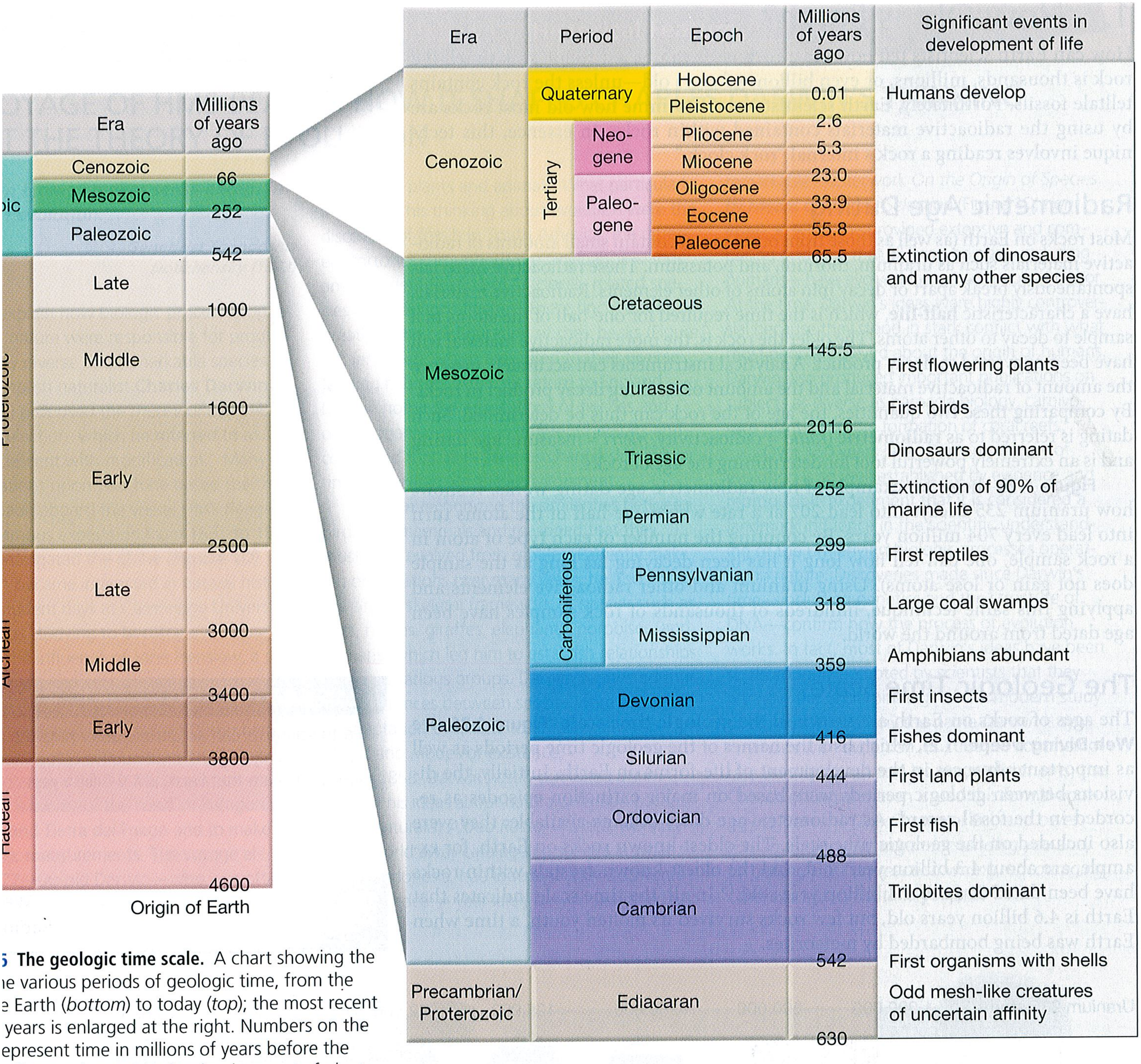


Figure 1.25 **Radiometric age dating.** During one half-life, half of all radioactive uranium 235 atoms decay into lead 207. With each successive half-life, half of the remaining radioactive uranium atoms convert to lead. By counting the number of each type of atom in a rock sample, the rock's age can be determined.

[15] Recent research suggests that crystals this old imply that significant continental crust must have formed on Earth early on, perhaps by nearly 4.5 billion years ago.



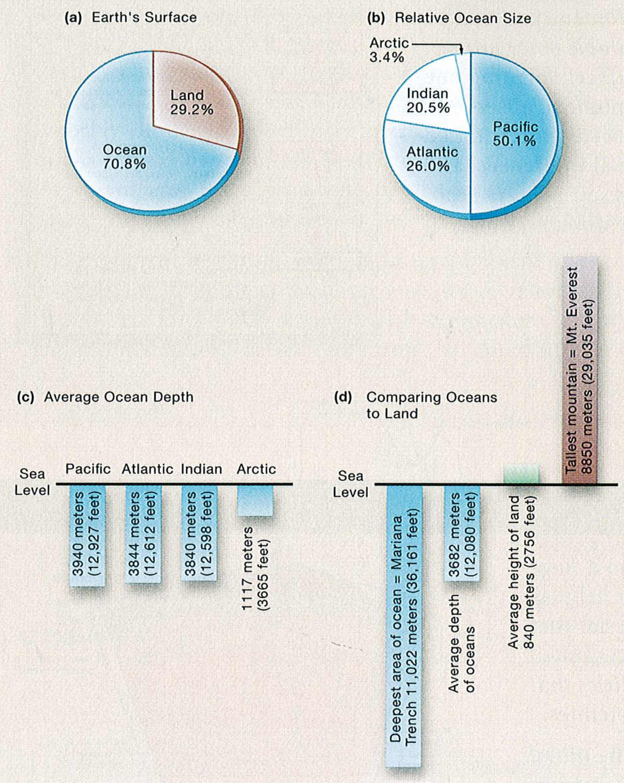
5 **The geologic time scale.** A chart showing the
ie various periods of geologic time, from the
e Earth (*bottom*) to today (*top*); the most recent
years is enlarged at the right. Numbers on the
epresent time in millions of years before the
nificant advances in the development of plants
s on Earth are also shown.

CONCEPT CHECK 1.7

1. Describe how the half-life of radioactive materials can be used to determine the age of a rock through radiometric age dating.
2. What is the age of Earth? Describe the major events that demark the boundaries between these time periods: (a) Precambrian/Proterozoic; (b) Paleozoic/Mesozoic; (c) Mesozoic/Cenozoic.

Essential Concepts Review

1.1 How many oceans exist on Earth?



- *Water covers 70.8% of Earth's surface.* The world ocean is a *single in body of water,* which is large in size and volume. It can be divic *principal oceans* (the Pacific, Atlantic, Indian, and Arctic Oceans) ditional ocean (the Southern Ocean, or Antarctic Ocean). Even t is a technical distinction between a sea and an ocean, the two ter interchangeably. In comparing the oceans to the continents, it is a *the average land surface does not rise very far above sea level* and *not a mountain on Earth that is as tall as the ocean is deep.*

Study Resources
Online Study Guide Quizzes, Web Diving Deeper 1.1 and 1.3

Critical Thinking Question

NASA has discovered a new planet that has an ocean. Using today's t how would you propose studying that ocean, all that's in it, and the se neath it? Assume an unlimited budget.

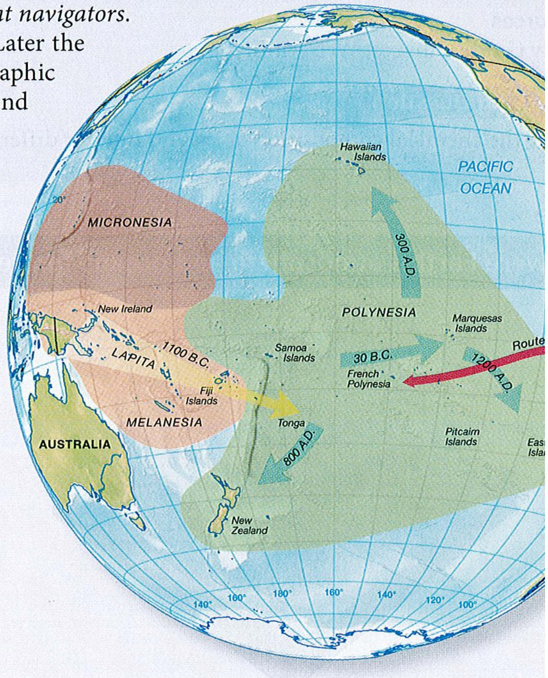
1.2 How was early exploration of the oceans achieved?

- In the Pacific, *people who populated the Pacific Islands may have been the first great navigators.* In the Western world, the *Phoenicians* were making remarkable voyages as well. Later the *Greeks, Romans,* and *Arabs* made significant contributions and advanced oceanographic knowledge. During the Middle Ages, the *Vikings* colonized Iceland and Greenland and made voyages to North America.
- The *Age of Discovery* in Europe renewed the Western world's interest in exploring the unknown. It began with the voyage of *Christopher Columbus* in 1492 and ended in 1522 with the first circumnavigation of Earth by a voyage initiated by *Ferdinand Magellan. Captain James Cook* was one of the first to explore the ocean for scientific purposes.

Study Resources
Online Study Guide Quizzes

Critical Thinking Question

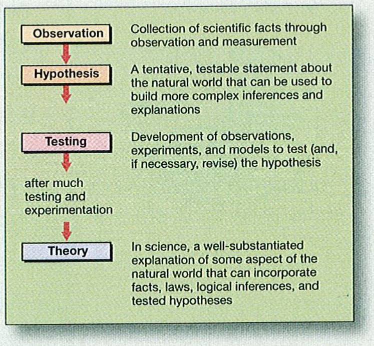
Throughout history, what navigation techniques have enabled sailors to navigate in the open ocean far from land?



al Concepts Review (cont.)

s the nature of scientific inquiry?

ific method is used to understand the occurrence of physical events or phenomena and can be cience supports the explanation of the natural world that best explains all available observations. ne scientific method include making *observations* and establishing *scientific facts*; forming one ypotheses (a tentative, testable statement about the general nature of the phenomena observed); *testing* and *modification of hypotheses*; and, finally, developing a *theory* (a well-substantiated on of some aspect of the natural world that can incorporate facts, laws, logical inferences, and potheses). Science never arrives at the absolute "truth"; rather, *science arrives at what is prob-* based on the available observations and can *continually change because of new observations.*



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/ Guide Quizzes

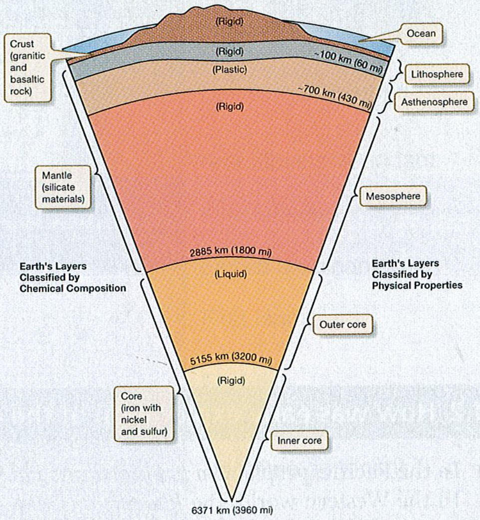
nking Question

lifference between a fact and a theory? Can either (or both) be revised?

vere Earth and the solar system formed?

system, consisting of *the Sun and eight major planets*, probably formed from a *huge as and space dust* called a *nebula*. According to the *nebular hypothesis*, the nebular ntracted to form the Sun, and the planets were formed from eddies of material that The Sun, composed of hydrogen and helium, was massive enough and concentrated emit *large amounts of energy* from fusion. The Sun also emitted *ionized particles that y any nebular gas* that remained from the formation of the planets and their satellites.

ı, more massive and larger than Earth today, *was molten and homogenous*. The *initial re*, composed mostly of hydrogen and helium, *was later driven off into space* by intense ation. Protoearth began a period of rearrangement called *density stratification* and *layered internal structure based on density*, resulting in the development of the *crust*, nd *core*. Studies of Earth's internal structure indicate that brittle plates of the *lithosphere* ; on a plastic, high-viscosity *asthenosphere*. Near the surface, the lithosphere is com- *ontinental* and *oceanic crust*. Continental crust consists mostly of granite and oceanic sists mostly of basalt. *Continental crust is lower in density, lighter in color, and thicker nic crust*. Both types float isostatically on the denser mantle below.



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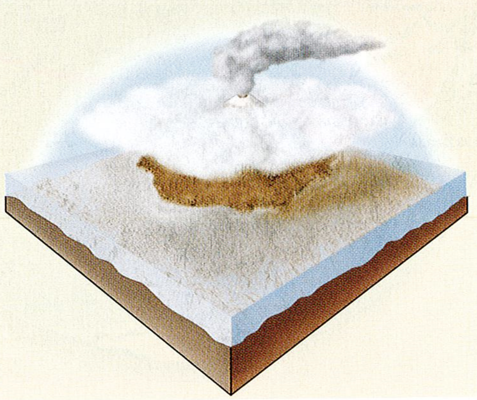
/ Guide Quizzes, Web Animations

nking Question

v the chemical composition of Earth's interior differs from its physical properties. Include specific examples.

vere Earth's atmosphere and oceans formed?



- *Outgassing produced an early atmosphere* rich in water vapor and carbon dioxide. Once Earth's surface cooled sufficiently, the *water vapor condensed and accumulated to give Earth its oceans. Rainfall on the surface dissolved compounds that*, when carried to the ocean, *made it salty.*

Study Resources

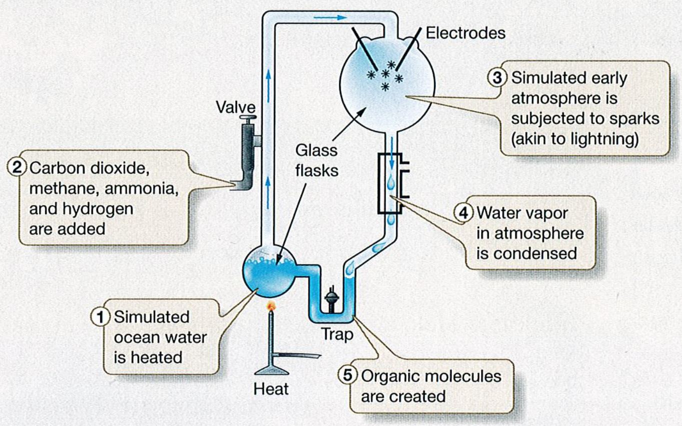
Online Study Guide Quizzes

Critical Thinking Question

Compare the two ways in which Earth was supplied with enough water to have an ocean. Which is likely to have contributed most of the water on Earth?

1.6 Did life begin in the oceans?

- *Life is thought to have begun in the oceans. Stanley Miller's experiment* showed that ultraviolet radiation from the Sun and hydrogen, carbon dioxide, methane, ammonia, and inorganic molecules from the oceans may have combined to produce *organic molecules such as amino acids.* Certain combinations of these molecules eventually produced *heterotrophic organisms* (which cannot make their own food) that were probably similar to present-day anaerobic bacteria. Eventually, *autotrophs evolved* that had the ability to make their own food through *chemosynthesis.* Later, some cells developed *chlorophyll,* which made *photosynthesis* possible and led to the *development of plants.*
- *Photosynthetic organisms altered the environment* by extracting carbon dioxide from the atmosphere and also by releasing free oxygen, thereby creating today's *oxygen-rich atmosphere.* Eventually, both *plants and animals evolved* into forms that could survive on land.



Study Resources
Online Study Guide Quizzes

Critical Thinking Question
Discuss why the great oxidation event is also called the oxygen crisis.

1.7 How old is Earth?

- *Radiometric age dating* is used to determine the ag Information from extinctions of organisms and rocks comprises the *geologic time scale,* which ind has experienced a long history of changes since *its years ago.*

Era	Period		Epoch	Millions of years ago	Signi deve
Cenozoic	Quaternary		Holocene	0.01	Humans
			Pleistocene	2.6	
	Tertiary	Neogene	Pliocene	5.3	
			Miocene	23.0	
		Paleogene	Oligocene	33.9	
			Eocene	55.8	
			Paleocene	65.5	Extinctio and many
Mesozoic	Cretaceous			145.5	First flow
	Jurassic			201.6	First birds
	Triassic			252	Dinosaur
					Extinctio marine lif
	Permian				

Study Resources
Online Study Guide Quizzes, Web Diving Deeper 1.2,

Critical Thinking Question
Construct a representation of the geologic time scale, u priate quantity of any substance (other than dollar bills which are used as examples in Web Diving Deeper 1.2). indicate some of the major changes that have occurred its origin.