CHAPTER 26

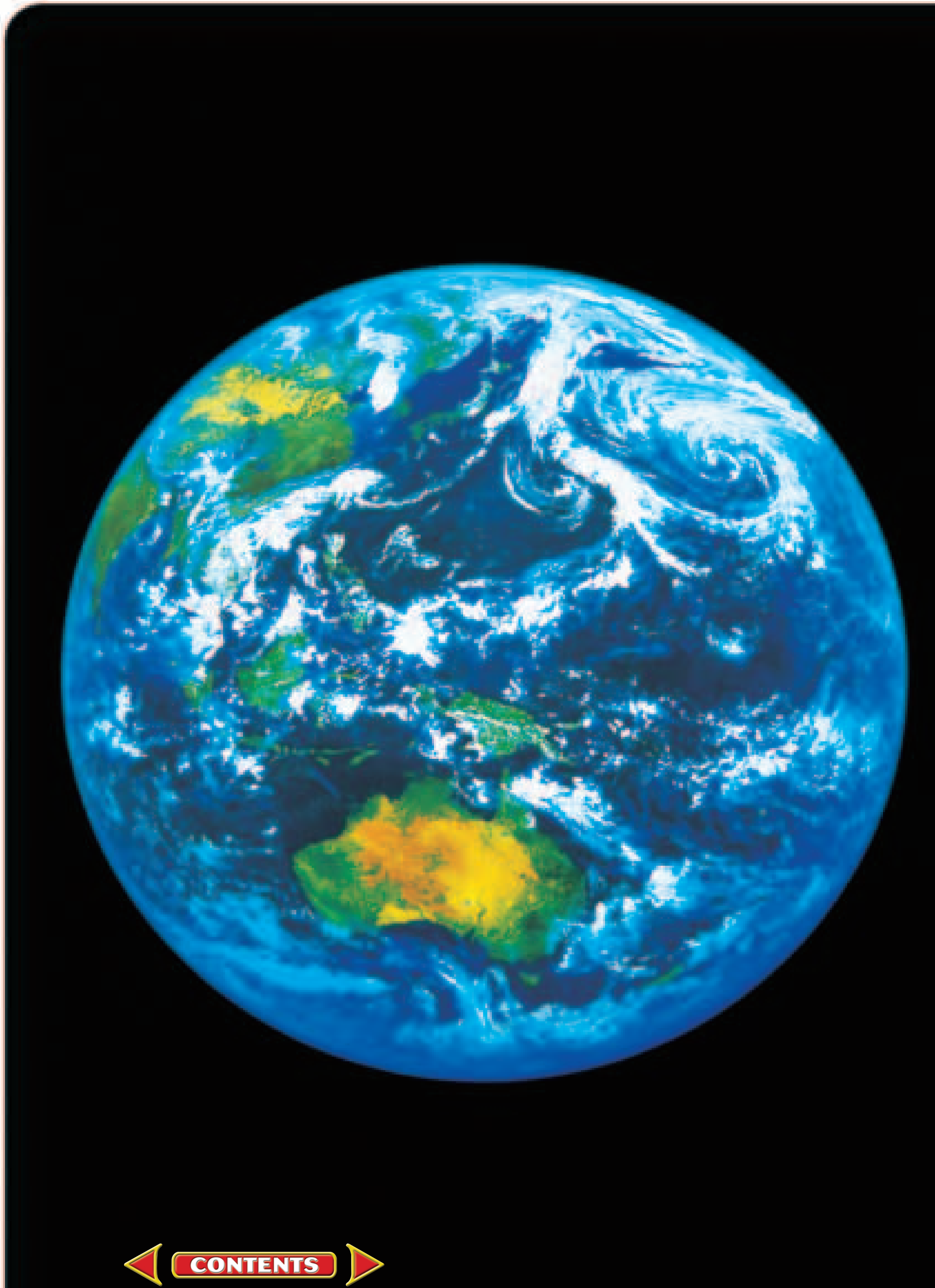
Chemistry in the Environment

What You'll Learn

- You will apply the concepts you have learned to a study of the chemistry of Earth's environment.
- You will explore the ways in which human activities affect the chemical nature of the environment.

Why It's Important

A knowledge of chemistry will help you develop a deeper appreciation for the environment and an increased awareness of the effect of human activities on Earth's air, land, and water.



This satellite photo of Earth shows some of our planet's unique features: features that allow it to sustain life.

Chemistry Online

Visit the Chemistry Web site at **chemistrymc.com** to find links about chemistry in the environment.

DISCOVERY LAB

Clarification of Water

Municipal water-treatment plants sometimes have to remove mud from the water after rainwater washes dirt into reservoirs. One way to do this is to use chemicals that cause the mud particles to clump together and settle to the bottom of the treatment tank, a process called sedimentation.

Safety Precautions

Lime is an irritant. It is harmful if inhaled or swallowed.

Materials

soil
600-mL beaker
400-mL beakers (2)
spoons (3)
powdered lime (CaO)
funnel
filter paper (2)
250-mL beakers (2)
ring stand with ring
stirring rod

Procedure

1. Place two spoonfuls of soil into a 600-mL beaker. Add water and stir until the water is muddy.
2. Divide the muddy water into two equal samples in two 400-mL beakers. Label the beakers Lime and Control.
3. Slowly sprinkle a spoonful of powdered lime (CaO) over the surface of the muddy water in the beaker labeled Lime. Do not add lime to the control beaker. Allow both beakers to remain undisturbed. Observe the beakers every five minutes until 15 minutes have elapsed. Record your observations.
4. Filter the treated water through a funnel that contains a paper filter. Collect the filtrate in a 250-mL beaker. Observe whether or not the water samples become clearer after filtration.
5. Repeat step 4 for the control, using a clean filter and beaker.

Analysis

How long did it take for the treated water to begin to clear? How did the addition of lime speed up the process of sedimentation? Did the paper filter help the water become clearer?

Section 26.1 Earth's Atmosphere

Objectives

- **Describe** the structure and composition of Earth's atmosphere.
- **Identify** common chemical reactions in the atmosphere.
- **Analyze** how human activities affect the atmosphere.

Vocabulary

atmosphere
troposphere
stratosphere

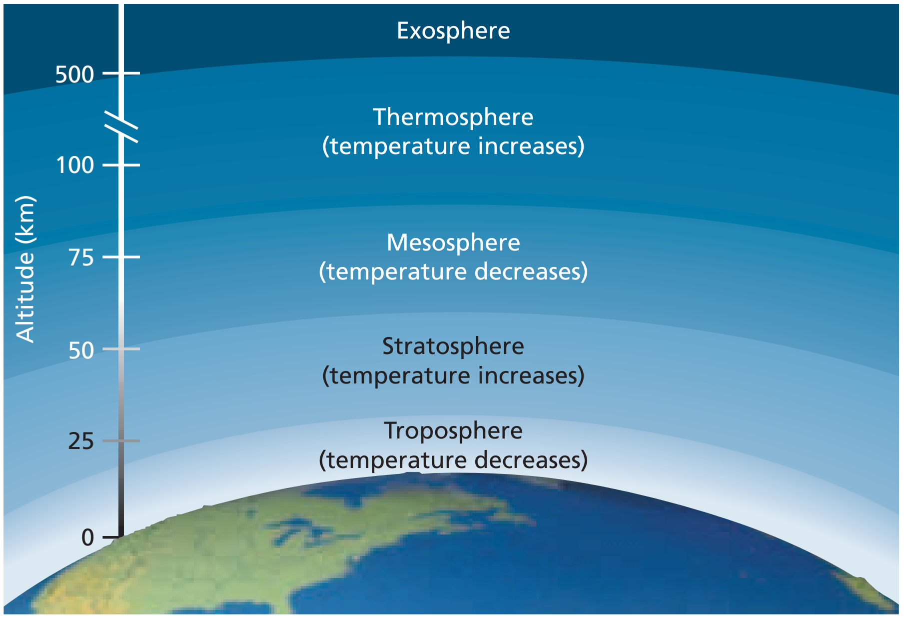
To the best of our knowledge, Earth is the only planet capable of supporting life as we know it. One glance at the photo on the opposite page helps explain why. See those wispy clouds? They are part of a protective envelope, the **atmosphere**, that blankets Earth and plays a key role in maintaining life.

A Balanced Atmosphere

Take a deep breath. You've just inhaled part of Earth's atmosphere. The atmosphere extends from Earth's surface to hundreds of kilometers into space. A largely gaseous zone, the atmosphere contains the air we breathe, the clouds overhead, and the all-important substances that protect Earth and its inhabitants from the Sun's most powerful radiation. Chemical reactions that occur in the atmosphere help maintain a balance among the different atmospheric gases, but human activities, such as burning fossil fuels, can change this balance.

Figure 26-1

Earth's atmosphere has five layers that vary in composition, temperature, altitude, and pressure. Which layer would you expect to have the greatest pressure?



Structure of Earth's Atmosphere

Earth's atmosphere is divided into five layers based on altitude and temperature variation. The lowest layer—the **troposphere**—extends from Earth's surface to a height of approximately 15 km, as shown in **Figure 26-1**. Temperatures in the troposphere generally decrease with increasing altitude, reaching a minimum of $-58°C$ at 12 km. Rain, snow, wind, and other weather phenomena occur in this layer. We live our entire lives within the troposphere. Only astronauts in spacecraft go beyond its reach.

Above the troposphere, temperatures increase with altitude, reaching a maximum of nearly 2°C at about 50 km. This region of the atmosphere is called the **stratosphere**. The stratosphere contains a layer of ozone, a gas that helps shield Earth's surface from the Sun's harmful ultraviolet radiation. Ozone protects Earth by absorbing solar radiation, which raises the temperature of the stratosphere in the process. You read about the ozone layer in Chapter 1 as you began your study of chemistry.

Beyond the stratosphere lie the mesosphere and the thermosphere. Temperatures in the mesosphere decrease with altitude because there is little ozone in the air to absorb solar radiation. The thermosphere is a region of rapidly increasing temperatures. This is because the relatively few gas molecules in this region have extremely high kinetic energies. At an altitude of about 200 km, temperatures can reach 1000°C.

The outermost layer of the atmosphere is the exosphere. Extending from about 500 km outward, the exosphere marks the transition from Earth's atmosphere to outer space. There is no clear boundary between the two, however. There are simply fewer and fewer molecules of gas at increasingly higher altitudes. Eventually, there are so few molecules that, for all practical purposes, Earth's atmosphere has ended.

Table 26-1

Composition of Dry Air Near Sea Level	
Component	**Percent**
Nitrogen	78
Oxygen	20.9
Argon	0.934
Carbon dioxide	0.033
Neon	0.00182
Helium	0.00052
Methane	0.00015
Krypton	0.00011
Hydrogen	0.00005
Nitrous oxide	0.00005
Xenon	0.000009

Composition of Earth's Atmosphere

Just as the temperature of the atmosphere varies by altitude, so does its composition. Roughly 75% of the mass of all atmospheric gases is found in the troposphere. Nitrogen and oxygen make up the vast majority of these gases. However, there are a number of minor components. The percent composition of dry air near sea level is summarized in **Table 26-1**.

Figure 26-2

When sunlight strikes dust particles in the atmosphere, it is scattered in all directions. The blue portion of the light is scattered away from your eyes, leaving the reds, oranges, and yellows you see here.

In addition to gases, the troposphere contains solids in the form of dust, salts, and ice. Dust—tiny particles from Earth's surface, ash, soot, and plant pollen—enters the atmosphere when it is lifted from Earth's surface and carried by wind. The dust particles can cause sunsets to show spectacular colors, as you can see in **Figure 26-2**. Salts are picked up from ocean spray. Ice is present in the form of snowflakes and hailstones. The troposphere also contains liquids, the most common of which is water in the form of droplets found in clouds. Water is the only substance that exists as a solid, liquid, and gas in Earth's atmosphere.

Because Earth has a strong gravitational field, most gases are held relatively close to the surface of the planet. Only lighter gases such as helium and hydrogen rise to the exosphere. These light gases, consisting of molecules that have absorbed radiation from the Sun, move so rapidly that they are able to escape Earth's gravitational field. Thus, there's a small but constant seepage of gases into outer space.

Chemistry in the Outer Atmosphere

Earth is constantly being bombarded with radiation and high-energy particles from outer space. The short-wavelength, high-energy ultraviolet (UV) radiation is the most damaging to living things. Because this radiation is capable of breaking the bonds in DNA molecules, it can cause cancer and genetic mutations. How can we exist here? Life as we know it is possible primarily because two processes, which occur in the thermosphere and the exosphere, shield us from most of this radiation.

Photodissociation Photodissociation is a process in which high-energy ultraviolet solar radiation is absorbed by molecules, causing their chemical bonds to break. In the upper atmosphere, the photodissociation of oxygen absorbs much of the high-energy UV radiation and produces atomic oxygen.

$$O_2(g) + \text{high-energy UV} \longrightarrow 2O(g)$$

The amount of atomic oxygen in the atmosphere increases with increasing altitude. Why is this true? Because so much of the UV radiation that enters the atmosphere is absorbed in the photodissociation of oxygen, most of the oxygen above 150 km is in the form of atomic oxygen. Below this altitude, the percentage of atomic oxygen decreases, and most of the oxygen in the troposphere is in the form of O_2 molecules.

Photoionization The second process that absorbs high-energy solar radiation is photoionization, which occurs when a molecule or atom absorbs sufficient energy to remove an electron. Molecular nitrogen and oxygen, as well as atomic oxygen, undergo photoionization in the upper atmosphere. Note that a positively charged particle is produced for every negatively charged electron in the atmosphere, so neutrality of charge is maintained.

$$N_2 + \text{high-energy UV} \longrightarrow N_2^{+} + e^{-}$$

$$O_2 + \text{high-energy UV} \longrightarrow O_2^{+} + e^{-}$$

$$O + \text{high-energy UV} \longrightarrow O^{+} + e^{-}$$

Ultraviolet radiation with the very highest energy is absorbed during photodissociation and photoionization in the upper atmosphere. Because most of this harmful radiation does not reach Earth's surface, life can exist.

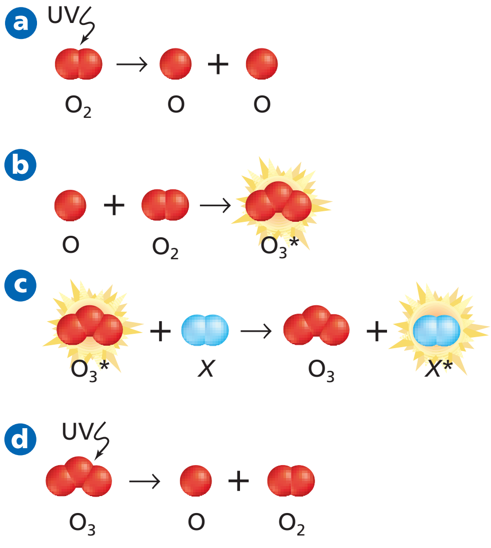
Chemistry in the Stratosphere

In addition to light gases, the upper atmosphere—more specifically, the stratosphere—contains a substance called ozone. In Chapter 1, you learned about the ozone layer and how it contributes to shielding Earth's surface from ultraviolet radiation. Now let's examine the chemical reactions that lead to the formation of ozone in the stratosphere.

Formation of ozone Although the UV radiation with the very highest energy has been absorbed by photoionization reactions in the outer atmosphere, much of the UV radiation that has sufficient energy to cause photodissociation still reaches the stratosphere. In the stratosphere, these ultraviolet waves are absorbed by O_2 molecules, which are more plentiful here than in the upper atmosphere. The O_2 molecules are split into two atoms of oxygen. These highly reactive atoms immediately collide with other O_2 molecules, forming ozone (O_3). The O_3 molecule that forms is highly unstable because its bonds contain excess energy that was gained from the UV radiation. To achieve stability, the energized O_3 molecule must lose this excess energy by colliding with another atom or molecule, denoted in **Figure 26-3** as molecule *X*, and transferring energy to it. Usually, N_2 or O_2 molecules are most abundant and serve as energy-absorbing molecules for the reaction.

Figure 26-3

Ozone molecules are formed in the stratosphere. Refer to **Table C-1** in Appendix C for a key to atom color conventions.



a An oxygen molecule forms two oxygen atoms by photodissociation.

b An oxygen atom combines with an oxygen molecule to form an energized ozone molecule (O_3*).

c The energized ozone molecule collides with molecule *X*. Excess energy is transferred to *X*, producing ozone and an energized *X* molecule (*X**).

d The oxygen molecule that forms when ozone photodissociates is available to start the ozone cycle anew.

The formation of O_3 and the transfer of excess energy to molecule X are summarized below. Remember that X is most often N_2 or O_2. An asterisk on a molecule indicates that the molecule is energized.

$$O(g) + O_2(g) \rightarrow O_3{}^*(g)$$
$$O_3{}^*(g) + X(g) \rightarrow O_3(g) + X^*(g)$$

The ozone molecule does not last long after being formed. Ozone can absorb high-energy solar radiation and photodissociate back to O_2 and O, thus starting the ozone cycle anew. If high-energy radiation were not absorbed by ozone and oxygen molecules, it would penetrate the troposphere and possibly damage or kill living things.

Thinning of the ozone layer As you read in earlier chapters, F. Sherwood Rowland and Mario Molina have proposed that chlorofluorocarbons (CFCs) are responsible for the thinning of the ozone layer that has been observed in the stratosphere. CFCs such as Freon-11 ($CFCl_3$) and Freon-12 (CF_2Cl_2), shown in **Figure 26-4**, have been used as coolants in refrigerators and air conditioners and as propellants in spray cans. They also have been used as foaming agents in the manufacture of some plastics. CFCs are highly stable molecules in the troposphere. After release, they eventually diffuse into the stratosphere, where they become unstable in the presence of the high-energy radiation found at this altitude. The CFCs absorb high-energy UV radiation, causing photodissociation in which the carbon-chlorine bonds in the molecules are broken.

$$CF_2Cl_2(g) + \text{high-energy UV} \rightarrow CF_2Cl(g) + Cl(g)$$

The atomic chlorine formed from this reaction reacts with stratospheric ozone to form chlorine monoxide (ClO) and O_2.

$$Cl(g) + O_3(g) \rightarrow ClO(g) + O_2(g)$$

The chlorine monoxide then combines with free oxygen atoms to regenerate free chlorine atoms and oxygen molecules.

$$ClO(g) + O(g) \rightarrow Cl(g) + O_2(g)$$

Because Cl atoms speed up the depletion of ozone and are first used and then re-formed, they function as a catalyst. The net result of these reactions is the conversion of ozone into O_2.

$$O_3(g) + O(g) \rightarrow 2O_2(g)$$

Each Cl atom remains in the stratosphere for about two years before it is destroyed in other reactions. During this time, it is capable of catalyzing the breakdown of about 100 000 molecules of ozone.

Careers Using Chemistry

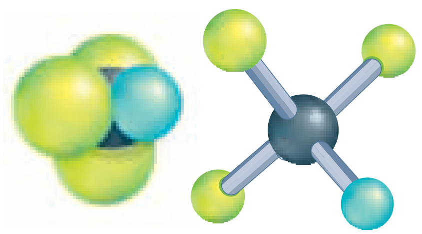
Environmental Health Inspector

Are you concerned about the quality of the air you breathe, the water you drink, and the food you eat? If so, you might become an environmental health inspector.

Also called sanitarians, many environmental health inspectors work for local, state, and federal governments. They analyze air, water, and food to identify possible contaminants. They might inspect dairies, restaurants, hospitals, processing plants, and industries. When they find contaminants, they look for the source, stop the pollution, and require the polluter to clean it up.

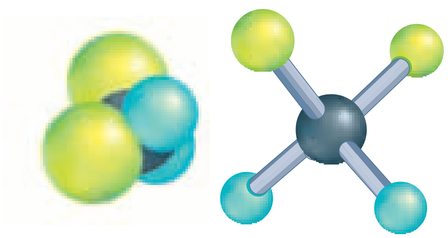
Try at Home LAB

See page 964 in Appendix E for
Modeling Ozone Depletion



$CFCl_3$

Freon-11



CF_2Cl_2

Freon-12

Figure 26-4

Freon-11 and Freon-12 are very stable compounds due to the strength of the C—F and C—Cl bonds. Because these bonds are so strong, Freon molecules are not easily broken down in the troposphere. In the stratosphere, however, high-energy radiation causes the bonds to break.

CONTENTS

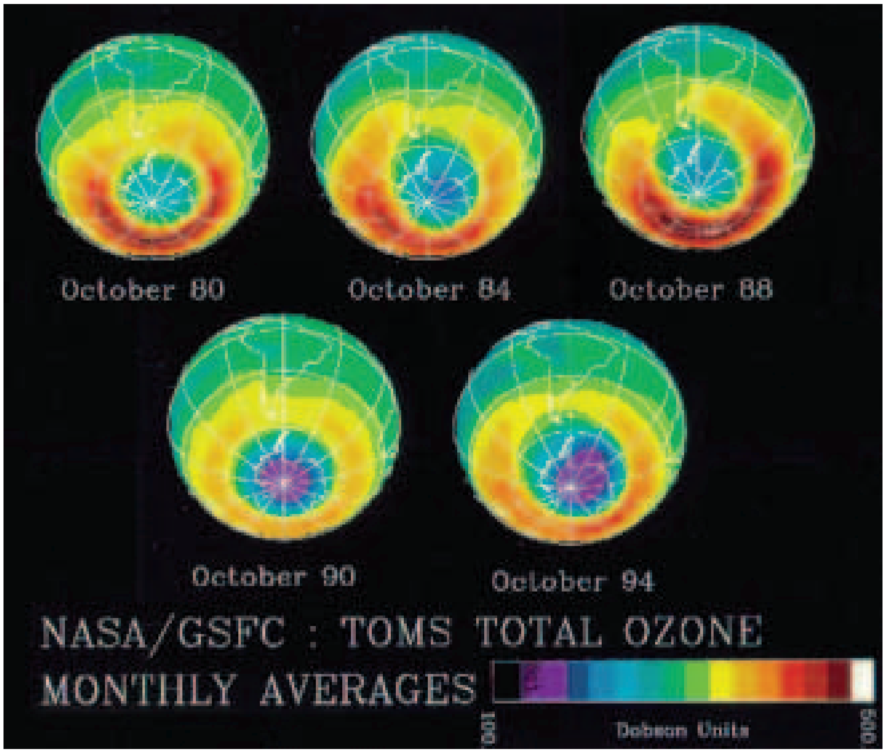


Figure 26-5

Ozone distribution in the southern hemisphere was mapped by a NASA satellite from 1980 to 1994. Observe the area of lowest ozone concentration (purple) over Antarctica. How has it changed?

An estimated several million tons of CFCs have diffused into the stratosphere. A significant change in the loss of ozone was first observed in the mid-1980s, when researchers began tracking an annual thinning of the ozone layer over the South Pole during certain months of the year. **Figure 26-5** shows satellite photos of the progressive thinning of the ozone layer over Antarctica. Scientists have recently found a similar but smaller area of thinning over the North Pole.

Because CFCs appear to play a role in the process of ozone destruction, many countries have stopped manufacturing and using these compounds. It will take many years, however, before the concentration of ozone in the stratosphere returns to its former levels. Why is this true?

Chemistry in the Troposphere

The composition of the troposphere varies from area to area, mostly as a result of human activities. Some compounds that may be present in only minute quantities in the air above a remote rain forest area may be present in much higher quantities over a large city. If you live in a city, you may have noticed that the air occasionally appears hazy, as it does in **Figure 26-6**. The haze that you see is a form of air pollution more commonly known as smog.

Photochemical smog In large cities such as Los Angeles, Denver, and Mexico City, a hazy, brown blanket of smog is created when sunlight reacts with pollutants in the air. Because the smog forms with the aid of light, it is called photochemical smog. The smog-producing pollutants enter the

Figure 26-6

Smog reduces visibility, irritates the eyes, and damages vegetation. This smog was photographed over New York City.

Figure 26-7

The combustion of petroleum in automobiles is a major source of smog. Sunlight acts on the exhaust gases of automobiles, factories, power plants, and homes to produce smog.

troposphere when fossil fuels such as coal, natural gas, and gasoline are burned. **Figure 26-7** shows one of the major sources of smog.

The burning of fossil fuels in internal combustion engines causes nitrogen and oxygen to react, forming nitrogen oxides such as NO and NO_2.

$$N_2(g) + O_2(g) \longrightarrow 2NO(g)$$

$$2NO(g) + O_2(g) \longrightarrow 2NO_2(g)$$

The NO_2, in turn, photodissociates in the presence of high-energy UV that penetrates through the upper atmosphere to form atomic oxygen, which combines with O_2 to form ozone.

$$NO_2(g) + \text{high-energy UV} \longrightarrow NO(g) + O(g)$$

$$O(g) + O_2(g) \longrightarrow O_3(g)$$

In the troposphere, ozone can irritate your eyes and lungs and increase your susceptibility to asthma and pneumonia.

Photochemical smog also contains unburned hydrocarbons and carbon monoxide, both of which come from the exhaust of automobile engines. These pollutants can be reduced or eliminated from the atmosphere in a variety of ways. Cleaner running engines and catalytic converters greatly reduce NO and hydrocarbon levels. Strict federal tailpipe emission standards are encouraging automobile manufacturers to develop new cars that are powered by electricity or alternative fuels such as natural gas.

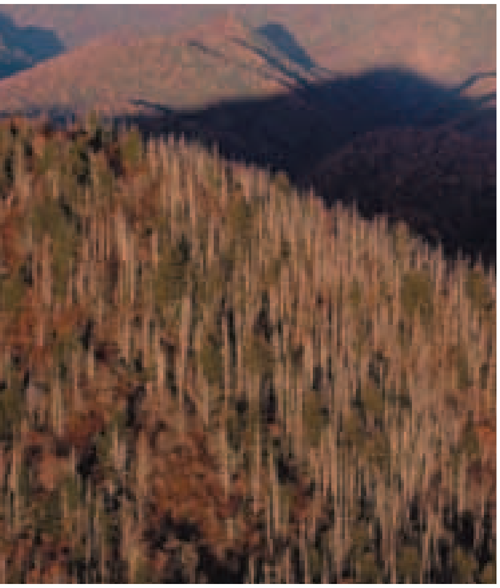
Acid rain Sulfur-containing compounds are normally present in small quantities in the troposphere. However, human activities have greatly increased the concentration of these compounds in the air. Sulfur dioxide (SO_2) is the most harmful of the sulfur-containing compounds.

Most of the sulfur dioxide in the troposphere is produced when coal and oil that contain high concentrations of sulfur are burned in power plants. The sulfur dioxide that forms is oxidized to sulfur trioxide (SO_3) when it combines with either O_2 or O_3 in the atmosphere. When SO_3 reacts with moisture in the air, sulfuric acid is formed.

$$SO_3(g) + H_2O(l) \longrightarrow H_2SO_4(aq)$$

Earth Science CONNECTION

Not all soils and bodies of water are equally affected by acid rain. Soils that contain calcium carbonate from limestone and lakes that are surrounded by and lie on top of calcium carbonate-rich soils are protected from much of the acid rain damage. The hydrogen ion in acid rain combines with the dissolved carbonate ions from the limestone to produce hydrogen carbonate ions. The hydrogen carbonate/carbonate solution in the water and soil serves as a buffer, absorbing additional hydrogen ions from acid rain and maintaining a stable pH. Areas that contain silicate rocks and soil are affected to a greater degree by acid rain. Southern Michigan and the Adirondack Mountain region of northern New York are especially susceptible to acid rain damage because of the large percentage of silicate rocks found there.



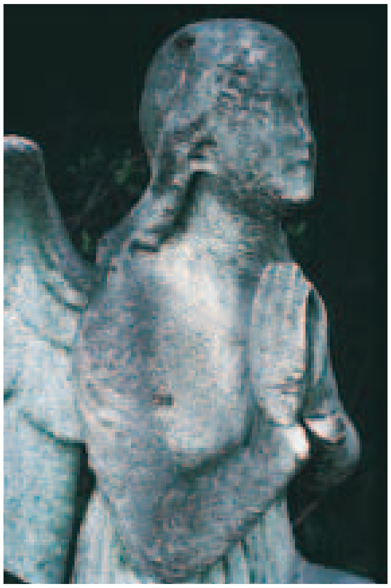


Figure 26-8

Acid-rain damage to buildings, statues, and trees amounts to billions of dollars a year.

Acidic air pollution is created also when nitrogen oxides from car exhausts combine with atmospheric moisture to form nitric acid. In either case, when this acidic moisture falls to Earth as rain or snow, it is known as acid rain. You can model the formation of acid rain in the **miniLAB** on this page.

Acid rain increases the acidity of some types of soil, resulting in the removal of essential nutrients from the soil. The loss of nutrients adversely affects the area's vegetation, leaving trees and other plants with less resistance to disease, insects, and bad weather. Acid rain also increases the acidity of streams, rivers, and lakes, which can kill or harm aquatic life. As **Figure 26-8** shows, damage to trees and to outdoor surfaces can be extensive. The acid in precipitation reacts with $CaCO_3$, the major component of marble and limestone. What products are produced by this reaction?

miniLAB

Acid Rain in a Bag

Making a Model Acid precipitation often falls to Earth hundreds of kilometers away from where the pollutant gases enter the atmosphere because the gases diffuse through the air and are carried by the wind. In this lab, you will model the formation of acid rain to observe how the damage caused by acid varies with the distance from the source of pollution. You also will observe another factor that affects the amount of damage caused by acid rain.

Materials plastic petri dish bottom; 1-gallon zipper-close, plastic bag; white paper; droppers; 0.04% bromocresol green indicator; 0.5M KNO_2; 1.0M H_2SO_4; clock or watch

Procedure

1. Place 25 drops of 0.04% bromocresol green indicator of varying sizes in the bottom half of a plastic petri dish so that they are about 1 cm apart. Be sure that there are both large and small drops at any given distance from the center. Leave the center of the petri dish empty.
2. Place a zipper-close plastic bag on a piece of white paper.
3. Carefully slide the petri dish containing the drops of indicator inside the plastic bag.
4. In the center of the petri dish, place one large drop of 0.5M KNO_2. To this KNO_2 drop, add two drops of 1.0M H_2SO_4. **CAUTION:** *KNO_2 and H_2SO_4 are skin irritants.* Carefully seal the bag. Observe whether the mixing of these two chemicals produces any bubbles of gas. This is the pollution source.
5. Observe and compare the color changes that take place in the drops of indicator of different sizes and distances from the pollution source. Record your observations every 15 seconds.
6. To clean up, carefully remove the petri dish from the bag, rinse it with water, then dry it.

Analysis

1. As the gas reacts with water in the drops, two acids form, $2NO_2 + H_2O \longrightarrow HNO_3 + HNO_2$. What are these acids?
2. Did the small or large drops change color first? Why?
3. Did the distance of the indicator drops from the pollution source have an effect on how quickly the reaction occurred? Explain.
4. State two hypotheses that will explain your observations, and incorporate the answers from questions 2 and 3 in your hypotheses.
5. Based on your hypotheses in question 4, what can you infer about the damage done to plants by acid fog as compared with acid rain?

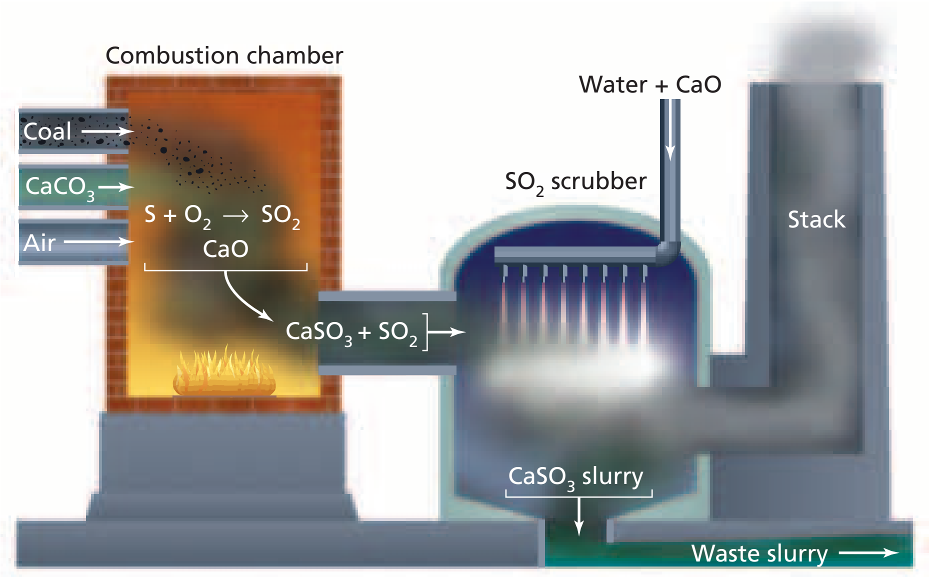


Figure 26-9

Follow the process as this power plant removes the sulfur from coal to reduce air pollution. Where is the sulfur found at the end of the process?

As human dependence on fossil fuels has increased, so has the acidity of rain. About 200 years ago, rain had a pH between 6 and 7.6, almost neutral. Today, it is common in many regions for rain to have a pH between 4 and 4.5, or even lower. In fact, the pH of rain in Wheeling, West Virginia, has been measured at 1.8, midway between the acidity of lemon juice and that of stomach acid. What do you think might account for this extreme acidity?

Given the damaging effects of acid rain, measures have been taken to reduce SO_2 emissions into the environment. High-sulfur coal may be washed before it is burned in power plants, or the SO_2 that is produced when coal burns may be removed during the burning process. This removal is accomplished by adding powdered limestone ($CaCO_3$) to the combustion chamber along with the coal, as shown in **Figure 26-9**. The limestone is decomposed to lime (CaO) and carbon dioxide.

$$CaCO_3(s) \longrightarrow CaO(s) + CO_2(g)$$

The lime then reacts with SO_2 to form calcium sulfite.

$$CaO(s) + SO_2(g) \longrightarrow CaSO_3(s)$$

About half of the SO_2 from coal is removed by adding solid limestone powder to the combustion material. The rest of the SO_2 must be removed by "scrubbing" the reaction gas with a shower of CaO and water. In this step, the remaining SO_2 is converted into solid $CaSO_3$, which precipitates as a watery slurry. Most of the sulfur is removed from the coal-burning process.

Section 26.1 Assessment

1. Compare and contrast the major layers of the atmosphere in terms of temperature, altitude, and composition.
2. Write the equations for the chemical reactions that lead to the formation of ozone in the stratosphere.
3. What is the source of the sulfur that contributes to the formation of acid rain?
4. **Thinking Critically** Hydrogen is the most abundant element in the universe. Why is it so rare in Earth's atmosphere?
5. **Applying Concepts** Explain why the following statement is true: Ozone in the troposphere is considered a pollutant, but ozone in the stratosphere is essential for life on Earth.

Section 26.2

Earth's Water

Objectives

- **Trace** the cycle of water in the environment.
- **Identify** the chemical composition of seawater.
- **Describe** methods of desalination, and **relate** the shortage of freshwater in some regions to the development of desalination techniques.
- **Outline** the steps of a water-treatment process.

Vocabulary

hydrosphere
salinity
desalination

Look back at the photo of Earth in the chapter opener. The blue oceans clearly illustrate the abundance of water on Earth. Water is a rare substance on other planets. On Earth, however, water is found as a solid, liquid, and gas throughout the environment. You have read that the presence of an atmosphere is critical for the existence of living things on Earth. Because living things cannot exist without water, it, too, is essential for life.

The Hydrosphere

Water is the most abundant substance in the human body and the most common substance on Earth, covering approximately 72% of the surface of this planet. All the water found in and on Earth's surface and in the atmosphere is collectively referred to as the **hydrosphere**. More than 97% of this surface water is located in the oceans. Another 2.1% is frozen in glaciers and polar ice caps. That leaves a meager 0.6% available as liquid freshwater.

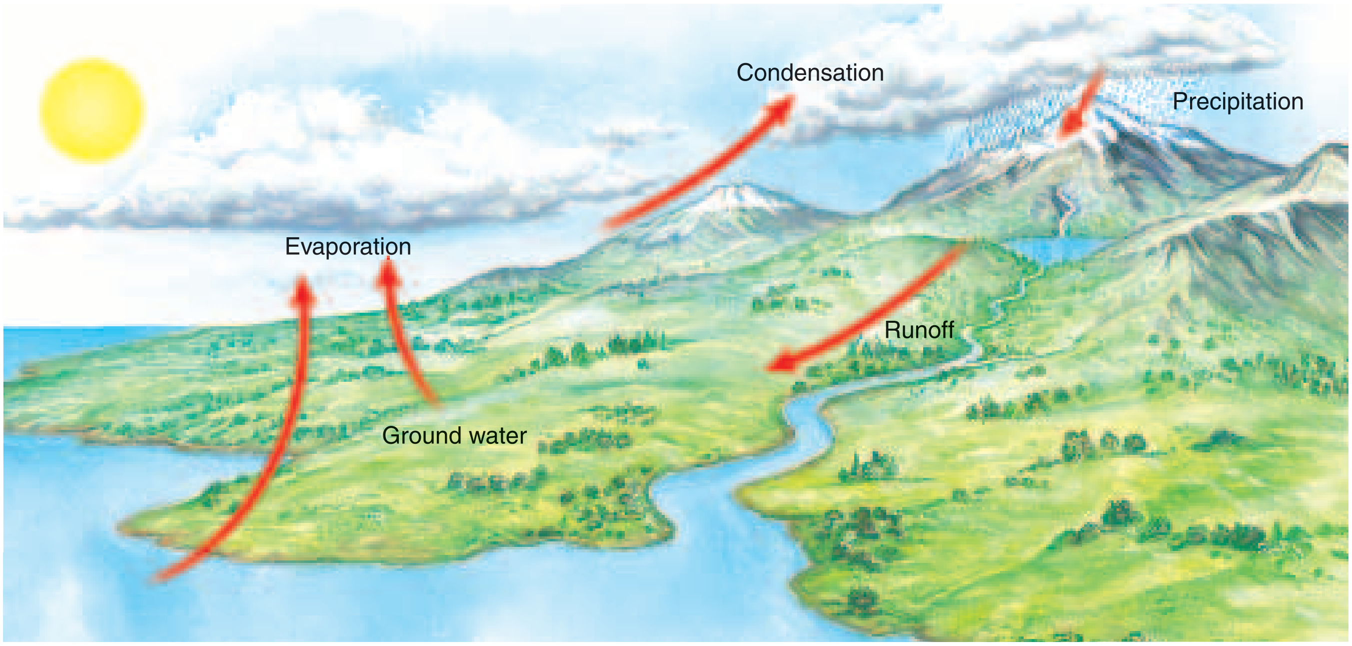
The Water Cycle

Both seawater and freshwater move through Earth's atmosphere, its surface, and below its surface in a process known as the water cycle. You may also see the water cycle referred to as the hydrologic cycle. In this cycle, water continually moves through the environment by the processes of evaporation, condensation, and precipitation. The Sun provides the energy for these processes. Follow **Figure 26-10** as you read about the water cycle.

Solar radiation causes liquid water to evaporate into a gaseous state. The resulting water vapor rises in the atmosphere and cools. As it cools, the water vapor again becomes a liquid when it condenses on dust particles in the air, forming clouds. Clouds are made of millions of tiny water droplets that collide with each other to form larger drops. When the drops grow so large that they can no longer stay suspended in the clouds, they fall to Earth in the form of precipitation—rain, snow, sleet, or hail.

Figure 26-10

The water cycle, powered by the Sun, circulates water through the atmosphere, Earth's surface, and below its surface.



Most of the falling precipitation soaks into the ground and becomes part of groundwater, the underground water that collects in small spaces between soil and rock particles. If the soil becomes saturated with water, the excess water flows along Earth's surface and into lakes and streams. This is called runoff.

Look again at **Figure 26-10**. As you can see, water cycles through the atmosphere, on Earth's surface, and under the surface. Can atmospheric processes affect the hydrosphere? The answer is most definitely yes. Processes that take place in the atmosphere, such as the formation of acid rain, can have a direct impact on the hydrosphere. The interrelatedness of the components of the environment is an important concept to keep in mind as you explore Earth's water, beginning with the vast and mighty seas.

Earth's Oceans

If you've ever swallowed a gulp of seawater, you know that it tastes quite different from tap water. Seawater contains dissolved salts, which give the water a salty taste. Where do the salts come from? Rivers and groundwater dissolve elements such as calcium, magnesium, and sodium from rocks and minerals. Flowing rivers then transport these elements to the oceans. Erupting volcanoes add sulfur and chlorine to the oceans as well.

Salinity is a measure of the mass of salts dissolved in seawater. It is usually measured in grams of salt per kilogram of seawater. The average salinity of ocean water is about 35 g per kg, so ocean water contains about 3.5% dissolved salts. Most of these salts dissociate in water and are present in the form of ions. **Table 26-2** lists the ions in seawater. Note that chlorine and sodium are the most abundant ions in seawater. Although Earth's oceans are vast, the proportions and quantities of dissolved salts are nearly constant in all areas. Indeed, they have stayed almost the same for hundreds of millions of years. Why is this so? As rivers, volcanoes, and atmospheric processes add new substances to seawater, elements are removed from the oceans by biological processes and sedimentation. Thus, the oceans are considered to be in a steady state with respect to salinity.

Table 26-2

Ionic Composition of Seawater

Dissolved ion	Percent in seawater
Chloride (Cl^-)	55.04
Sodium (Na^+)	30.61
Sulfate (SO_4^{2-})	7.68
Magnesium (Mg^{2+})	3.69
Calcium (Ca^{2+})	1.16
Potassium (K^+)	1.10
Hydrogen carbonate (HCO_3^-)	0.41
Bromide (Br^-)	0.19
All others	0.12

Desalination

In some areas of the world, such as the Middle East, freshwater is scarce. Can the people in these areas drink the much more abundant ocean water? Because seawater has a high salinity, it can't be consumed by living organisms. If humans are to use ocean water for drinking and for irrigation of crops, the salts must first be removed. The removal of salts from seawater to make it usable by living things is called **desalination**.

Dissolved salts can be removed from seawater by distillation, a simple process in which the seawater is boiled to evaporate the volatile water. Pure water vapor is collected and condensed, leaving the nonvolatile salts behind. This process is quite energy intensive and is not practical for a large-scale operation. It is rarely used commercially.

You learned in Chapter 15 that osmosis is the flow of solvent molecules through a semipermeable membrane from a region of higher solvent concentration to a region of lower solvent concentration. If a high-enough pressure is applied to the system, osmosis can be reversed; that is, the solvent can be forced to flow from low to high concentrations of solvent. This process is called reverse osmosis. In a modern desalination plant, seawater is forced under pressure into cylinders containing hollow, semipermeable fibers. A cylinder holds more than three million fibers, each of which has the diameter of a human hair. The water molecules pass inward through the walls of the fibers, and the salts are held back. Desalinated water flows through the inside of the fibers and is collected.

Biology CONNECTION

What happens if you drink seawater? The ions in the water enter your blood from the digestive tract. Your kidneys can't remove the ions fast enough, so the ion concentration remains high in the blood. Water moves out of your cells by osmosis, causing dehydration. The cells shrivel and begin to malfunction. Meanwhile, your body begins to swell as the volume of blood and the fluid surrounding cells increases due to the additional water. Dehydration causes the thirst center of your brain to signal your kidneys to stop making urine, so the ions aren't removed from your body.

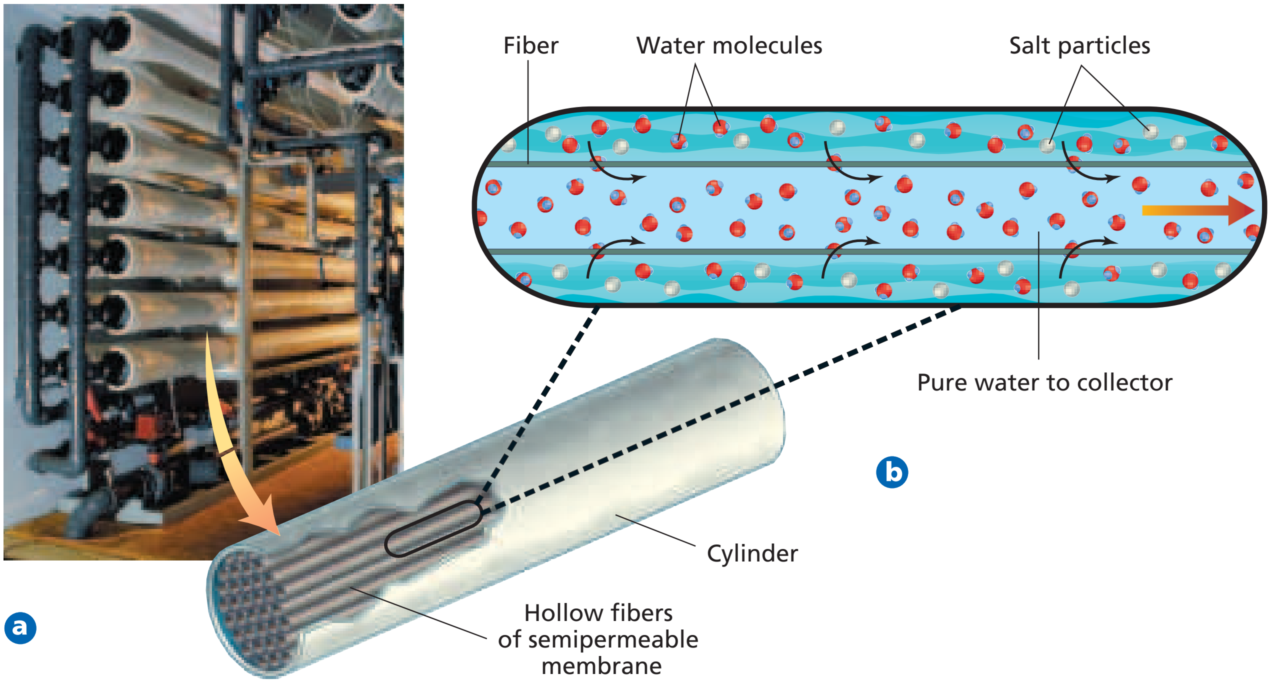


Figure 26-11

a This room in a desalination plant houses thousands of cylinders.
b Each cylinder contains millions of tiny fibers across which reverse osmosis takes place. Maintaining the high pressure necessary for this process makes it very energy intensive.

Figure 26-11 shows how seawater can be desalinated under pressure by reverse osmosis. The largest desalination plant in the world is located in Jubail, Saudi Arabia, where it produces 50% of the country's drinking water by the reverse osmosis of seawater from the Persian Gulf. Smaller desalination plants are in operation in Israel, California, and Florida.

Earth's Freshwater

How much water do you use in a day? The answer may surprise you. An average person needs to drink about 1.5 L per day for survival. But this is only a small fraction of the total amount of water used for daily activities. In the United States, about 7 L of water per person per day is used for cooking and drinking; about 120 L for bathing, laundering, and housecleaning; 80 L for flushing toilets; and 80 L for watering yards. Massive quantities of water are also used in agriculture and industry to produce food and other products. **Figure 26-12** shows the major consumers of water in the United States by daily percentage.

Recall that only 0.6% of the hydrosphere is made up of liquid freshwater. Almost all of this freshwater is found as groundwater and other underground sources. Very small amounts (0.01%) come also from surface water such as

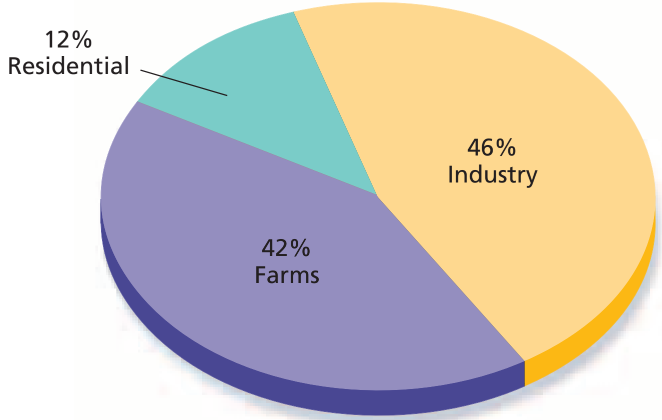


Figure 26-12

Industry and farming use most of the freshwater in the United States. Residential use accounts for about 12%.

Figure 26-13

Algae often experience a population explosion when fertilizer is carried into lakes and ponds. When the algae die and decay, oxygen in the pond is depleted, and fish may die as a result.

lakes and rivers, and the atmosphere provides a tiny amount (0.001%) as water vapor. Freshwater, essential for life on Earth, is our most precious resource. Unfortunately, human activities can affect the quality of freshwater.

Human Impact on the Hydrosphere

A freshwater stream may look sparkling and clean, but it's probably not safe for drinking. Many rivers and lakes in the United States are polluted. Bacteria and viruses enter water supplies through contamination by sewage and industrial wastes. Wastes from landfills and mines leak into groundwater reservoirs. Pesticides, herbicides, and fertilizers are picked up by rainwater and carried into streams. Streams flow into rivers, and rivers empty into oceans. In addition, coastal cities pump waste directly into the oceans. For this reason, much of the oceans' pollution is found along the coasts of continents.

A major cause of freshwater pollution, however, is caused by legal, everyday activities. Water is polluted when we flush toilets, wash hands, brush teeth, and water lawns. The main culprits are nitrogen and phosphorus—two elements found in household detergents, soaps, and fertilizers. Nitrogen and phosphorus are difficult to remove from sewage and wastewater. They contribute to water pollution by causing certain algae and bacteria to reproduce rapidly in the water. The result is an algal bloom, shown in **Figure 26-13**. When the algae die, they decompose, a process that consumes oxygen. The result is the depletion of oxygen in the water. Without sufficient oxygen, fish and other aquatic organisms cannot survive.

Chemistry Online

Topic: Wastes
To learn more about wastes, visit the Chemistry Web site at **chemistrymc.com**

Activity: Imagine you are part of a team building a self-contained space station. List different biological and industrial wastes the society will produce. Suggest strategies and technologies to cope with those wastes.

Municipal Water and Sewage Treatment

As you have learned, the water that most people use for their daily activities comes from lakes, rivers, reservoirs, and underground sources. Because it has been exposed to a variety of contaminants, it must be purified at a water treatment plant before it can be used.

The treatment of water in municipal treatment plants usually involves five steps: coarse filtration, sedimentation, sand filtration, aeration, and sterilization. The water is first passed through a screen to remove large solids. It then enters large settling tanks where sand and other medium-sized particles settle out. Often, CaO (powdered lime) and $Al_2(SO_4)_3$ (alum) are added to coagulate small particles and bacteria. These clumps of particles settle out of solution during a sedimentation step, as you saw in the **DISCOVERY LAB**. After settling, the water is filtered through a bed of sand. The filtered water is then sprayed into the air in a process called aeration. During aeration, oxygen combines with many of the harmful dissolved organic substances in the water, oxidizing them to harmless compounds.

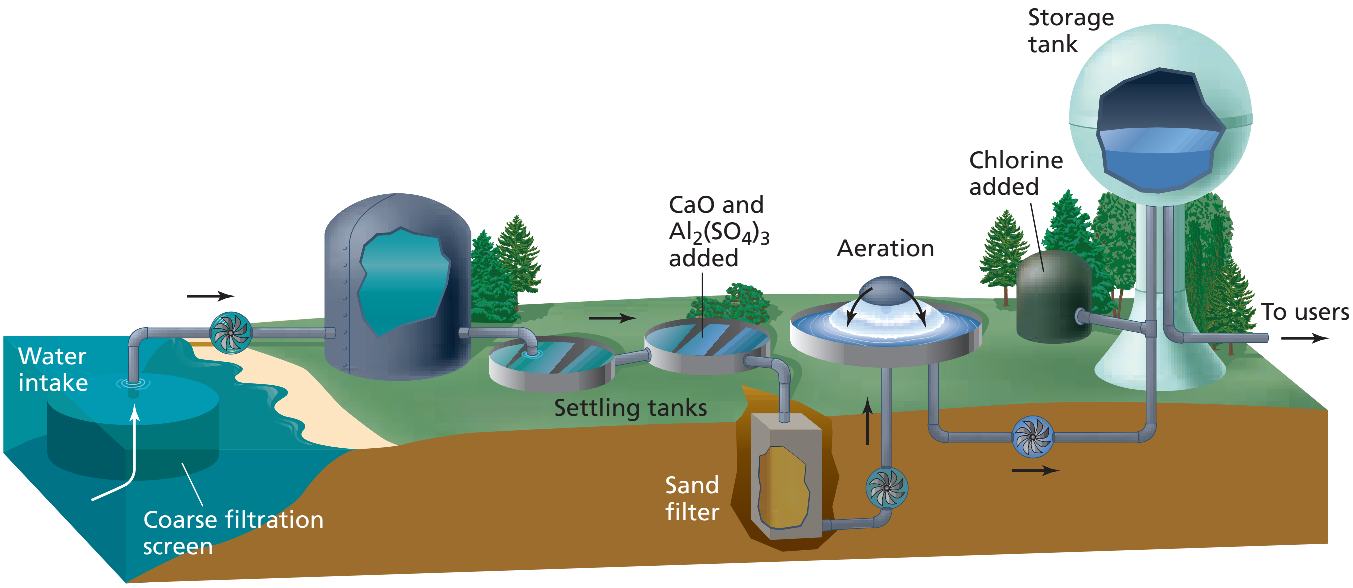


Figure 26-14

Most public water systems use these steps to treat water for human consumption.

The final step in water treatment, sterilization, is accomplished by treating the water with substances that kill bacteria. The most commonly used substance is liquefied chlorine gas. Chlorine reacts with water to form hypochlorous acid (HClO), which destroys any remaining microorganisms in the water.

$$Cl_2(aq) + H_2O(l) \longrightarrow HClO(aq) + H^+(aq) + Cl^-(aq)$$

Figure 26-14 summarizes the flow of water through a water treatment plant.

In addition to water treatment plants, cities and towns also have sewage treatment plants to maintain clean water supplies. The steps involved in sewage treatment are similar to those used to treat water. The incoming sewage is filtered to remove debris and larger suspended solids. Then, as in conventional water treatment, the sewage is passed into large settling tanks where suspended solids settle out. During aeration, the sewage water comes into contact with large amounts of air, and the increased oxygen levels promote the rapid growth of bacteria needed to biodegrade the wastes. After treatment, about 90% of solids and dissolved biodegradable wastes have been removed.

A final treatment removes many inorganic pollutants, such as the toxic heavy metals Cd^{2+} and Pb^{2+}. This treatment is usually expensive, but an increasing percentage of wastewater treatment facilities are taking this extra step to ensure that toxic substances do not enter water supplies. Before release into the environment, the processed water is treated with Cl_2 to kill any remaining bacteria.

Section 26.2 Assessment

6. Use the water cycle to explain how the hydrosphere and atmosphere are interrelated.

7. Sequence the five steps involved in municipal water treatment.

8. Explain why much of the water that comes out of your faucet is "recycled" water.

9. **Thinking Critically** Why does desalination by reverse osmosis require the use of high pressure?

10. **Making and Using Graphs** Use the data in **Table 26-2, Ionic Composition of Seawater,** to make a bar graph showing the percentages of the most abundant ions in seawater.

Section 26.3 Earth's Crust

Objectives

- **Identify** Earth's major regions.
- **List** the major elements in Earth's crust.
- **Describe** the composition of minerals.

Vocabulary

lithosphere

Earth is a large, dynamic planet that has existed, according to best estimates, for approximately 4.6 billion years. When Earth was newly formed, it was a huge molten mass. As this mass cooled, it differentiated into regions of varying composition and density. These regions, or layers, include a dense central core, a thick mantle, and a thin crust. The core is further divided into a small, solid inner core and a larger, liquid outer core. **Figure 26-15** shows Earth's layers.

Gravity caused more-dense elements to sink beneath less-dense elements in molten Earth. Hence, the core is composed mostly of iron and small amounts of nickel. In contrast to the dense core, the less-dense outer region at first consisted mostly of rock as oxygen combined with silicon, aluminum, magnesium, and small amounts of iron. This lighter outer region later separated into the mantle and the crust as Earth cooled further. Many light elements such as hydrogen escaped Earth's gravitational force and are now found mostly in space.

Earth's crust makes up about one percent of Earth's mass. Oceanic crust lies beneath Earth's oceans. Continental crust is the part of the crust beneath landmasses.

The Lithosphere

You have already studied the liquid outer part of Earth—the hydrosphere—and the gaseous atmosphere. Each of these parts has a distinct composition and environmental chemistry, as you have learned.

The solid crust and the upper mantle make up the region called the **lithosphere.** Oxygen is the most abundant element in the lithosphere. Unlike the hydrosphere and the atmosphere, the lithosphere contains a large variety of other elements, including deposits of alkali, alkaline earth, and transition metal elements. **Table 26-3** lists the most abundant elements in the continental crust portion of the lithosphere. With the exception of gold, platinum, and a few other rare metals that are found free in nature, most metallic elements occur as compounds in minerals. A mineral is a solid, inorganic compound found in nature. Minerals have distinct crystalline structures and chemical compositions. Most are combinations of metals and nonmetals.

Table 26-3

Abundance of Elements in the Continental Crust

Element	Percent by mass
Oxygen	45.2
Silicon	27.2
Aluminum	8.2
Iron	5.8
Calcium	5.1
Magnesium	2.8
Sodium	2.3
Potassium	1.7
Other elements (Ti, H, Mn, Cu, Pb, Zn, Sn, etc.)	1.7

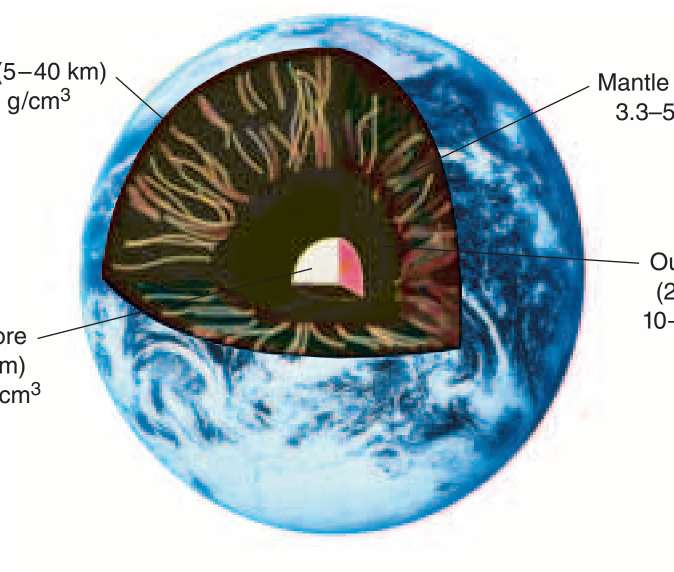


Figure 26-15

Earth's layers include a small inner core and large outer core of high density, a thick mantle of medium density, and a very thin crust of low density.

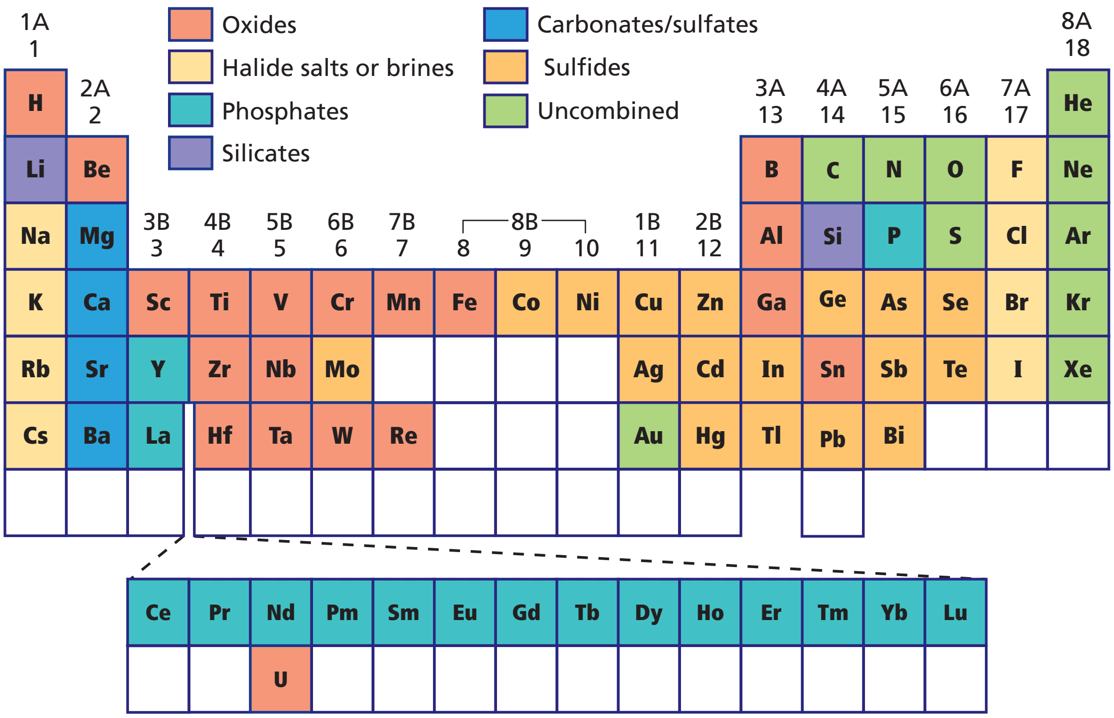
Table 26-4

Some Common Oxide, Sulfide, and Carbonate Minerals		
Oxides	**Sulfides**	**Carbonates**
SnO_2 (cassiterite)	$CuFeS_2$ (chalcopyrite)	$MgCO_3$ (magnesite)
TiO_2 (rutile)	PbS (galena)	$CaCO_3$ (calcite)
Al_2O_3 (bauxite)	HgS (cinnabar)	$SrCO_3$ (strontianite)
Fe_3O_4 (magnetite)	FeS_2 (pyrite)	$BaCO_3$ (witherite)
$FeCr_2O_4$ (chromite)	ZnS (sphalerite)	
$FeTiO_3$ (ilmenite)		
MnO_2 (pyrolusite)		
Fe_2O_3 (hematite)		

Many industrially important metals are found in the form of oxides, sulfides, or carbonates. Recall that oxides are compounds of metals combined with oxygen, sulfides are compounds of metals combined with sulfur, and carbonates are compounds of metals combined with both carbon and oxygen. **Table 26-4** lists some oxide, sulfide, and carbonate minerals and their common names. The oxides are formed largely from transition metals on the left side of the periodic table because these elements have lower electronegativities and tend to lose bonding electrons when they combine with the oxide ion. The elements on the right side of the table and in some of the other groups have higher electronegativities and tend to form bonds with sulfur that are more covalent in character. The alkaline earth metals (2A) are usually found as carbonates in the marble and limestone of mountain ranges. Thus, periodic properties govern the state of combination in which elements are found in nature. **Figure 26-16** shows the major mineral sources for most of the elements. Magnesium and calcium carbonates cause water to become hard. The **How It Works** feature at the end of the chapter shows how hard water can be softened.

Figure 26-16

This periodic table shows the mineral sources for most elements.



a Mercury is extracted from cinnabar and used in instruments that measure blood pressure and temperature.

b Bauxite is the major ore of aluminum, a metal with many uses.

c Galena is a major ore of lead. The material that holds a stained glass window together contains lead.

d Iron can be extracted from many ores, including hematite. Because iron is so strong, it is used as the framework for large buildings.

Figure 26-17

Metals are extracted from their ores and used for many purposes.

The metals in a mineral cannot always be extracted from the mineral in an economically feasible way. Sometimes, the concentration of the mineral in the surrounding rock is too low for the mineral to be mined at a reasonable cost. The cost of energy needed to mine, extract, or purify the metal also may be too high. If the metal can be extracted and purified from a mineral at a reasonable profit, the mineral is called an ore. Several ores and the metals extracted from them are shown in **Figure 26-17**.

Section 26.3 Assessment

11. Name and describe Earth's major regions.

12. Why does the composition of Earth's crust differ so greatly from that of its core?

13. What is a mineral? List some common minerals that exist as metallic oxides, as carbonates, and as sulfides.

14. **Thinking Critically** Nitrogen makes up 0.002% of Earth's lithosphere but 78% of the atmosphere. How can you explain this difference?

15. **Applying Concepts** What is an ore? Under what conditions would a mineral not be an ore?

chemistrymc.com/self_check_quiz

CONTENTS

Section 26.4

Cycles in the Environment

Objectives

- **Trace** the pathways of carbon and nitrogen through the environment.
- **Compare** and **contrast** the greenhouse effect and global warming.

Vocabulary

greenhouse effect
global warming
nitrogen fixation

Did you know that the atoms of carbon, nitrogen, and other elements in your body are far older than you? In fact, they've been around since before life began on Earth. The amount of matter on Earth never changes. As a result, it must be recycled constantly. You learned about the water cycle earlier in the chapter. A number of elements cycle through the environment in similar, distinct pathways.

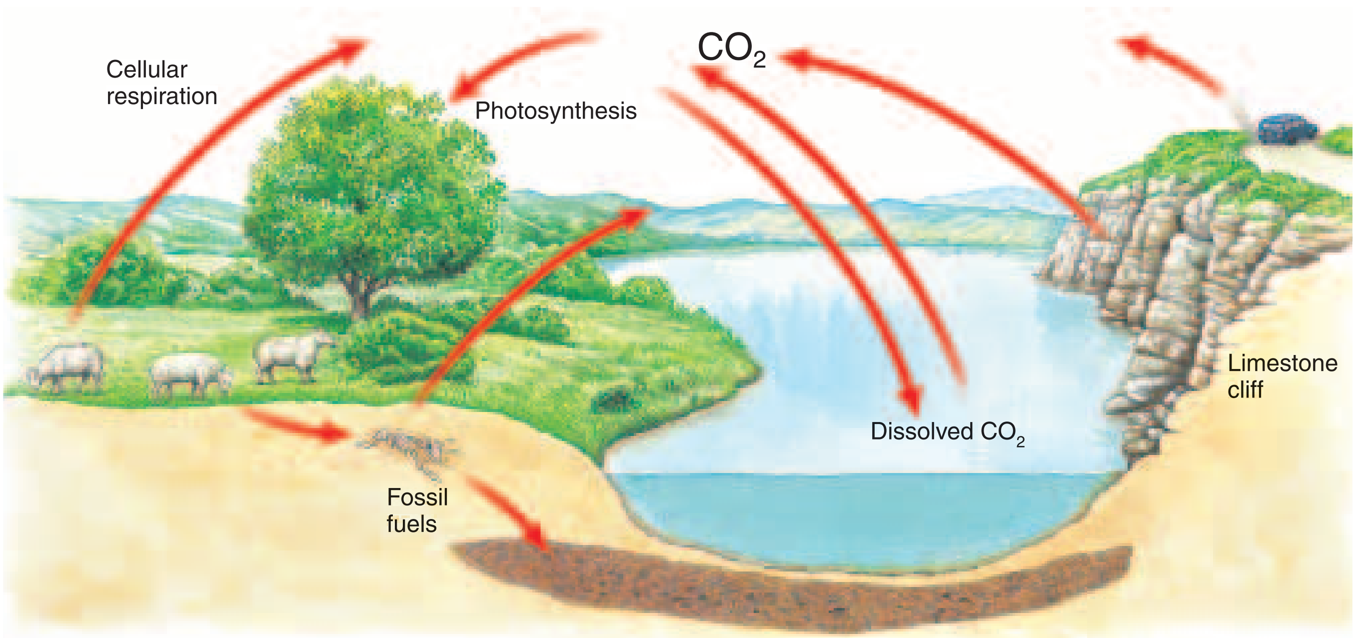
The Carbon Cycle

Carbon dioxide (CO_2) constitutes only about 0.03% of Earth's atmosphere. However, it plays a vital role in maintaining life on Earth. There is a fine balance in nature between the processes that produce carbon dioxide and those that consume it. You have learned that green plants, algae, and some bacteria remove carbon dioxide from the atmosphere during photosynthesis. Do you recall what products are formed during this process? Photosynthesis produces carbon-containing carbohydrates, which animals ingest when they eat plants and other animals. Both plants and animals convert the carbohydrates to CO_2, which is released into the atmosphere as a waste product of cellular respiration. Once in the atmosphere, the CO_2 can be used again by plants.

Figure 26-18 shows the carbon cycle. Carbon dioxide in the atmosphere is in equilibrium with an enormous quantity that is dissolved in oceans, lakes, and streams. Some of this dissolved CO_2 was once in the form of calcium carbonate ($CaCO_3$), the main component of the shells of ancient marine animals. The shells were eventually converted into limestone, which represents a large store of carbon on Earth. When the limestone was exposed to the atmosphere by receding seas, it weathered under the action of rain and surface water, producing carbon dioxide. Some of this CO_2 was released into the atmosphere. This process continues today.

Figure 26-18

Carbon cycles in and out of the environment through many pathways.



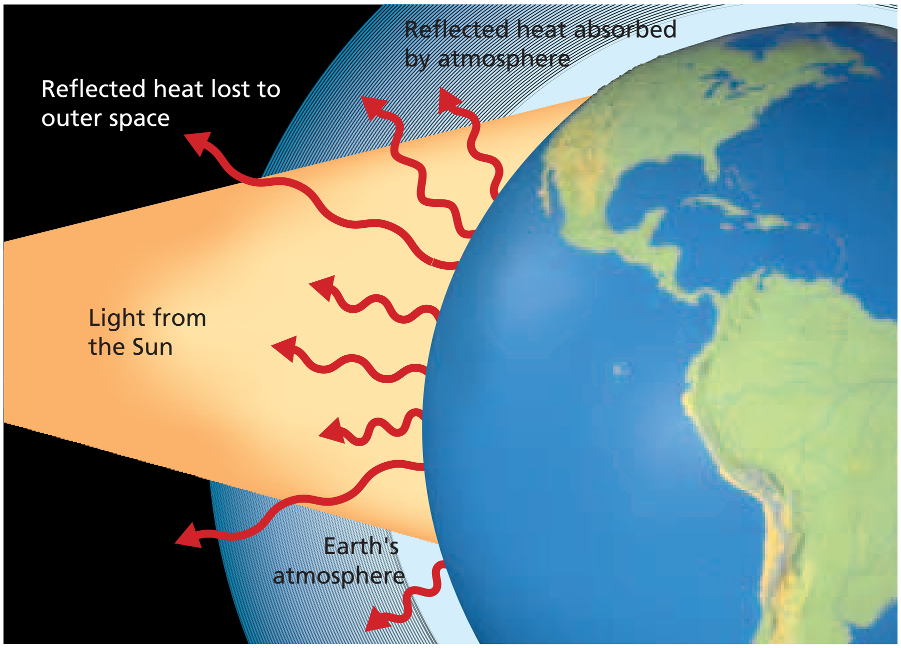


Figure 26-19

About 25% of the sunlight that strikes Earth's atmosphere is reflected back into space. Most of the remaining 75% is absorbed by atmospheric gases and Earth in the form of heat.

Carbon dioxide also enters the atmosphere when plants and animals decompose. Recall from Chapter 22 that the remains of ancient plants and animals were converted under pressure to fossil fuels. When fossil fuels are burned, the carbon is converted to CO_2. As you'll learn, the burning of fossil fuels and other human activities may be disrupting the balance of the carbon cycle.

Upsetting the balance To understand the effect of human activities on the carbon cycle, it is first necessary to explore a phenomenon known as the greenhouse effect. The **greenhouse effect** is the natural warming of Earth's surface that occurs when certain gases in the atmosphere absorb some of the solar energy that is converted to heat and reflected from Earth's surface. As **Figure 26-19** shows, the process works much like a greenhouse. Sunlight reaches Earth and is converted to heat, but the heat can't easily escape through the "greenhouse gases" to travel back into space. Instead, the heat is absorbed by molecules of greenhouse gases and transferred to the atmosphere, where it warms Earth's surface. Without the greenhouse effect, the surface of our planet would be too cold to sustain life as we know it.

Carbon dioxide is a major greenhouse gas. Most CO_2 occurs naturally. But, when we burn fossil fuels, huge quantities of CO_2—more than 5 billion metric tons a year—are added to the atmosphere. Moreover, the amount of CO_2 that is removed from the atmosphere by photosynthesis is being reduced by the continued destruction of vast forested areas, particularly rain forests. As a result of these activities, the level of atmospheric CO_2 has been increasing slowly over the past 200 years. **Diagram a** in the **problem-solving LAB** on the next page shows that the rate of increase is accelerating.

Increases in greenhouse gases such as CO_2 lead to corresponding increases in the greenhouse effect. Some scientists have predicted that these increases will cause global temperatures to rise, a condition known as **global warming**.

Scientists don't agree on the causes or the consequences of global warming, but they do know that average global temperatures are increasing slightly—about 0.5°C over the past 100 years. At present levels of fossil-fuel consumption, some scientists predict that global temperatures could increase by as much as 0.3°C each decade during the twenty-first century. Although this may seem like a small amount, it may result in the largest increase in global temperatures since the end of the last ice age.

While scientists continue to study and debate the issue of global warming, most concede that it has the potential to change Earth's climate and that tampering with the climate could be dangerous. Thus, a drastic reduction in the use of fossil fuels is considered by many to be essential to slow and eventually stop global warming. For this reason, alternative energy resources such as solar power are now important areas of scientific research. You can learn about one type of alternative energy source—solar ponds—by doing the **CHEMLAB** at the end of the chapter.

The Nitrogen Cycle

Nitrogen is an essential component of many substances that make up living organisms. It is a key element in protein molecules, nucleic acids, and ATP. Like other elements, the supply of nitrogen on Earth is fixed. It must be recycled, as shown in **Figure 26-20**. Follow the diagram as you read about the nitrogen cycle.

Although nitrogen makes up 78% of Earth's atmosphere, most living things can't use nitrogen in its gaseous state. It must be fixed, or converted to a useful form, by a process called **nitrogen fixation**.

problem-solving LAB

Global warming: fact or fiction?

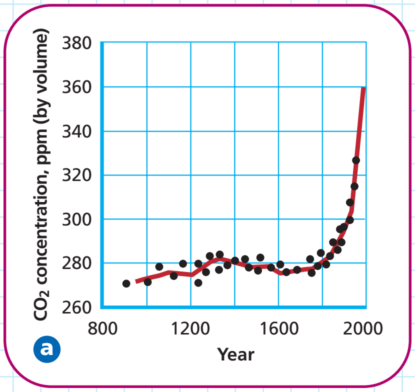
Drawing Conclusions Environmental issues affecting the entire planet usually involve so many variables that it is often difficult to pinpoint a primary source of the problem. Conflicting data from many experiments often divide the views of those in the scientific community. The effect of carbon dioxide emissions on global warming has been a particularly controversial issue because efforts to reduce carbon dioxide emissions may require humans to make dramatic changes in their lifestyles and could exact enormous demands on the world economy.

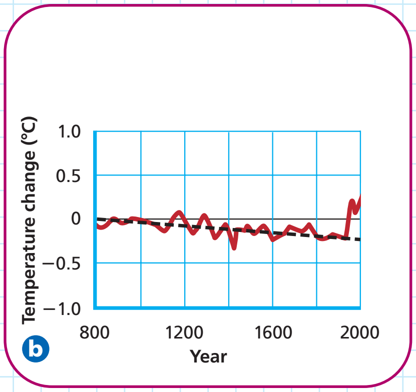
Analysis

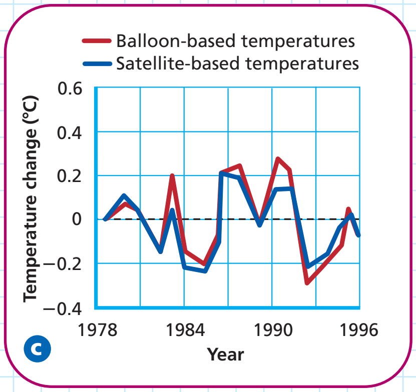
Each graph shows an indicator that is being used to monitor global warming. **Diagram a** shows the atmospheric CO_2 concentration for the past millennium. **Diagram b** shows the average temperature change of Earth's surface during the past millennium. **Diagram c** shows the average temperature change of Earth's atmosphere since 1978.

Thinking Critically

1. Before the twenty-first century, what was the trend (the dotted line in **diagram b**) for Earth's average surface temperature? What does this trend predict for the average surface temperature in the year 2000?
2. What do the atmospheric temperature data suggest? How does this compare to the surface data? What could cause this discrepancy?
3. In comparing these three graphs, how strong is the relationship between global warming and the concentration of carbon dioxide in the atmosphere? Is there a reason for concern? What other environmental influences would you consider to help answer this question?







CONTENTS

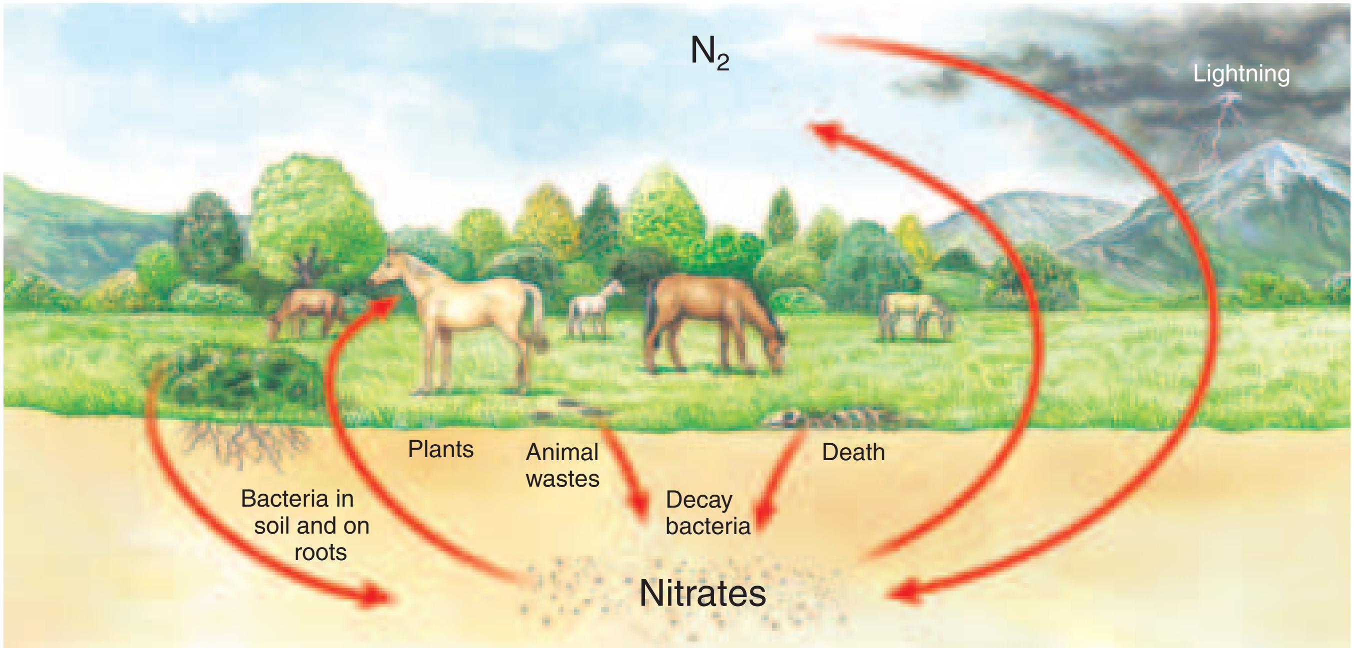


Figure 26-20

In the nitrogen cycle, atmospheric nitrogen gas is converted to nitrates, which plants use to make biological compounds. Eventually, nitrates are converted back to nitrogen gas.

Two primary routes for nitrogen fixation exist in nature. In the atmosphere, lightning combines N_2 and O_2 to form NO.

$$N_2(g) + O_2(g) \longrightarrow 2NO(g)$$

Once NO is formed, it is oxidized to NO_2.

$$2NO(g) + O_2(g) \longrightarrow 2NO_2(g)$$

In the atmosphere, rain converts NO_2 to HNO_3, which then falls to Earth as aqueous NO_3^-.

$$2NO_2(g) + H_2O(l) \longrightarrow HNO_2(aq) + HNO_3(aq)$$

Nitrogen fixation is also accomplished by nitrogen-fixing bacteria, which live in the soil and on the roots of certain legumes such as peas, beans, peanuts, and alfalfa. In this process, N_2 is first reduced to NH_3 and NH_4^+, then oxidized to NO_3^-.

Plants absorb nitrate ions through their roots and use them to synthesize complex nitrogen compounds. Because animals can't synthesize these complex molecules, they must get them by eating plants or other animals. Nitrogen compounds that are unused by the animals' bodies are excreted as waste. Soil microorganisms convert this waste to N_2 and nitrogen is recycled back into the environment.

Section 26.4 Assessment

16. Diagram and label the important parts of the carbon cycle.

17. Describe the two primary routes of nitrogen fixation.

18. What two cellular processes are important parts of the carbon cycle?

19. **Thinking Critically** Levels of CO_2, a major greenhouse gas, fluctuate on a seasonal basis. Recalling how carbon is cycled through the environment, explain the seasonal fluctuations of CO_2.

20. **Applying Concepts** How might the greenhouse effect lead to global warming?

chemistrymc.com/self_check_quiz

CHEMLAB 26 CBL

Solar Pond

If you made a list of popular types of alternative energy sources, solar energy probably would be near the top. Of course, the energy we use from all sources ultimately originates from the Sun. It would seem that solar energy would be the easiest to use. The problem is how to store solar energy when the Sun is not shining. In this experiment, you will investigate one method that could be used to trap and store solar energy.

Problem

Build a small-scale model of a solar pond and test how it traps and stores solar energy.

Objectives

- **Construct** a small-scale solar pond using simple materials.
- **Collect** temperature data as the solar pond model heats and cools.
- **Hypothesize** as to why a solar pond is able to trap and store energy.

Materials

CBL System
graphing calculator
ChemBio program
link-to-link cable
temperature probes (2)
150-watt light bulb
socket and clamp for bulb
black plastic frozen-dinner dish
waterproof tape
table salt
hot plate
stirring rod
250-mL beaker
beaker tongs
TI-Graph Link (optional)
ring stand and clamp
250-mL graduated cylinder

Safety Precautions

- **The light bulb will become hot when it is turned on.**
- **Do not touch the hot plate while it is on.**

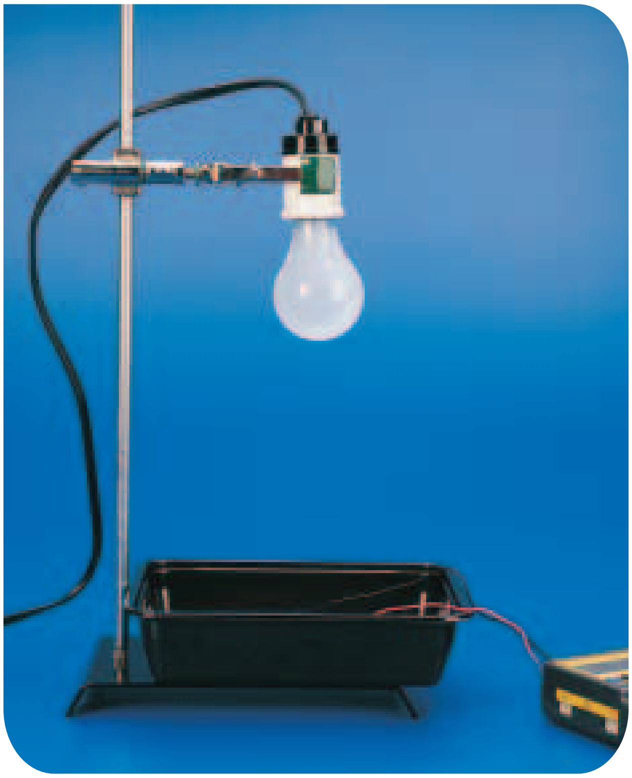
Pre-Lab

1. Read the entire **CHEMLAB.**
2. Prepare all written materials that you will take into the laboratory. Include safety precautions and procedure notes.
3. Water is transparent to visible light but opaque to infrared radiation. How do you think these properties will affect your solar pond model?
4. If you used only tap water in your model, convection currents would bring warmer, less dense water from the bottom to the surface. Do you think this will happen with your solar pond model? Explain your answer.
5. Predict which of the two layers of the model will have the higher final temperature. Explain your prediction.

Procedure

1. Prepare a saturated table salt (NaCl) solution by heating 100 mL of tap water in a beaker on a hot plate. When the water is boiling, slowly add enough table salt to saturate the solution while stirring with a stirring rod. Remove the beaker from the hot plate with beaker tongs and allow the solution to cool slowly overnight.
2. The next day, prepare the solar pond model. Place the black plastic dish on the lab bench where you want to run the experiment. Use a small piece of waterproof tape to attach one of the temperature probes to the bottom of the black plastic dish. Plug this probe into Channel 1 of the CBL System. Slowly pour the 100 mL of saturated salt solution into the dish.
3. Carefully add about 100 mL of tap water on top of the saturated salt-water layer in the dish. Use care not to mix the two layers. Suspend the end of the second temperature probe in the tap-water layer and plug it into Channel 2 of the CBL System.

4. Connect the graphing calculator to the CBL System using the link cable. Turn on both units. Run the ChemBio program. Choose 1:SET UP PROBES from MAIN MENU. Choose 2 probes. Under SELECT PROBE, choose 1:TEMPERATURE. Enter 1 for Channel. This is for the probe at the bottom of the salt water. Under SELECT PROBE, choose 1: TEMPERATURE. Enter 2 for Channel. This is for the probe in the tap-water layer.
5. Under MAIN MENU, choose 2: COLLECT DATA. Choose 2: TIME GRAPH. For time between samples in seconds, choose 30. For number of samples, choose 60. This will allow the experiment to run for 30 minutes. Set the calculator to use this time setup. Input the following: Ymin = 0, Ymax = 30, Yscl = 1. Do not start collecting data yet.
6. Position the 150-watt light bulb about 15 to 20 cm over the top of the solar pond model. Turn on the light. Press ENTER on the calculator to begin collecting data. After about 6 to 8 minutes, turn off the light bulb and move it away from the solar pond model. Do not disturb the experiment until the calculator is finished with its 30 minute run.



Cleanup and Disposal

Rinse the salt solution off the temperature probes.

Analyze and Conclude

1. **Graphing Data** Make a copy of the graph from the graphing calculator. If you have TI-Graph Link and a computer, do a screen print.
2. **Interpreting Graphs** Describe the shape of each curve in the graph of time versus temperature before and after the light bulb was turned off. Explain the significance of the difference.
3. **Comparing and Contrasting** Which layer of your solar pond model did the best job of trapping and storing heat?
4. **Applying Concepts** Why does the graph of time versus temperature decrease more rapidly near the surface when the light bulb is turned off?
5. **Forming a Hypothesis** Make a hypothesis to explain what is happening in your model.
6. **Designing an Experiment** How would you test your hypothesis?
7. **Error Analysis** How might your results have been different if you had used a white dish by mistake instead of a black dish? Explain.

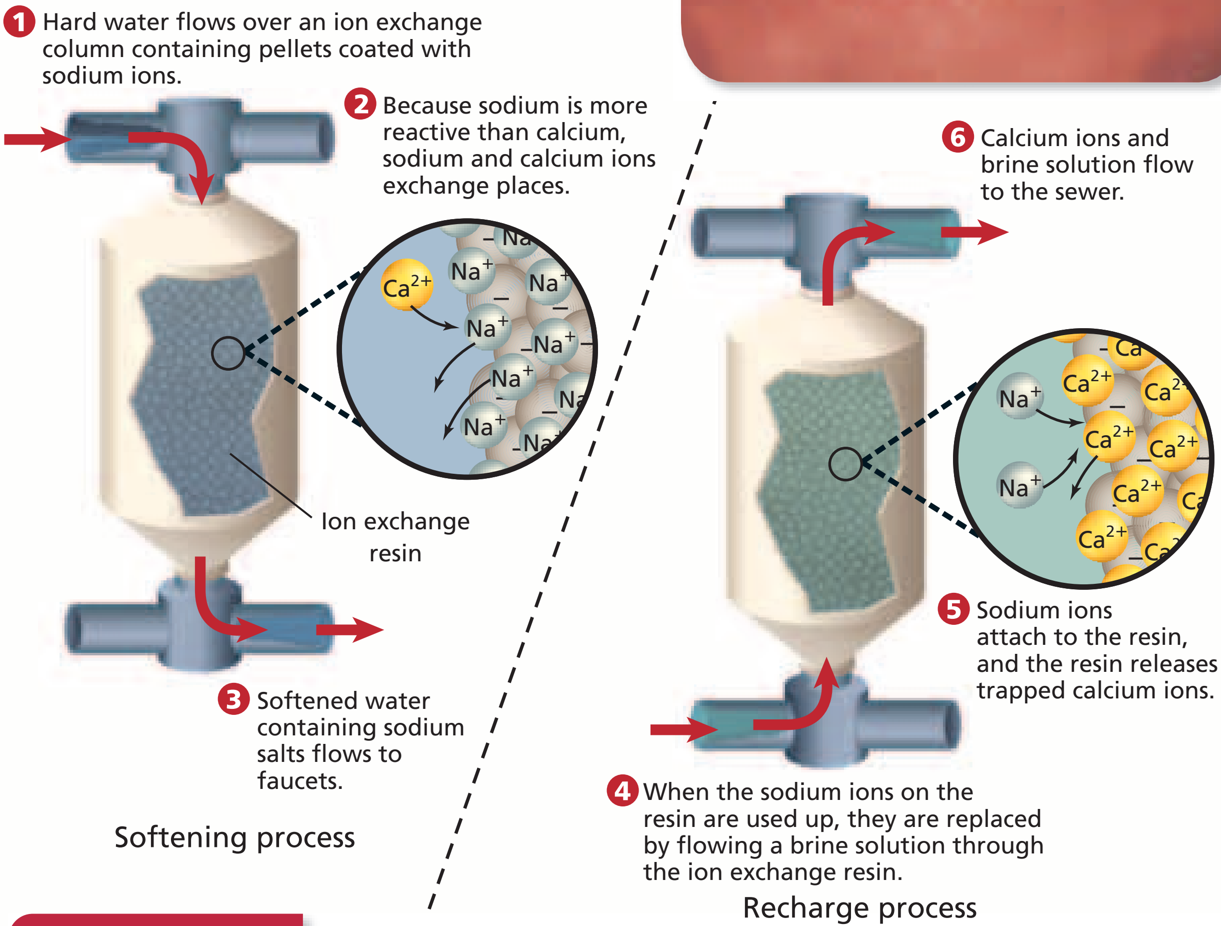
Real-World Chemistry

1. Water in a lake rises to the surface when heated and sinks to the bottom when cooled in a process called convection. Compare and contrast the density of the water as it rises with the density of the water as it sinks.
2. The El Paso Solar Pond was the first in the world to successfully use solar pond technology to store and supply heat for industrial processes. It was built with three main layers: a top layer that contains little salt, a middle layer with a salt content that increases with depth, and a very salty bottom layer that stores the heat. Which layer has the greatest density? The least density? Why doesn't the storage layer in the El Paso Solar Pond cool by convection?

How It Works

Water Softener

Water that contains substantial amounts of dissolved calcium and magnesium salts is called hard water. Water acquires these salts when it passes through soil and rocks that contain calcium and magnesium carbonates. While these salts are not toxic, they react with soaps and detergents to form an insoluble scum on sinks, bathtubs, and showers. When clothes are washed in hard water, some of the insoluble material adheres to the clothes and alters the way they feel. A device called a water softener can solve the hard-water problem by removing the excess calcium and magnesium ions.



Thinking Critically

1. **Predicting** Would you expect a water softener to be effective in removing materials such as sugar, alcohol, grease, and oil? Explain your answer.

2. **Using Resources** Find information about water softening processes that use ions other than sodium ions. Report your findings to the class.

Summary

26.1 Earth's Atmosphere

- Earth's atmosphere is divided into the troposphere, stratosphere, mesosphere, thermosphere, and exosphere. The layers vary according to altitude and temperature.
- Nitrogen and oxygen make up the majority of the atmospheric gases.
- Photodissociation and photoionization are important processes that absorb high-energy ultraviolet radiation in the upper atmosphere.
- The ozone layer in the stratosphere forms a protective barrier against harmful high-energy ultraviolet radiation. Levels of ozone have been depleted by chemical reactions with CFCs in the upper atmosphere above the North and South Poles.
- Photochemical smog is a major pollutant in many urban centers and is formed from chemicals that are produced principally by internal combustion engines.
- Emissions of SO_2 from the burning of fossil fuels have led to the production of acid rain.

26.2 Earth's Water

- Water is continuously recycled in the environment by the processes of evaporation, condensation, and precipitation.
- Earth has massive oceans that contain large quantities of dissolved salts. Salinity is a measure of the mass of these dissolved salts.
- Salinity is expressed as grams of salt per kilogram of seawater.
- Reverse osmosis can be used to desalinate ocean water and make it fit for human use.
- Freshwater is a precious natural resource. Municipal water supplies must be treated to ensure that they are safe to use. Sewage treatment plants process water that has been used so that it can be returned safely to the environment.

26.3 Earth's Crust

- Earth is divided into a core, mantle, and crust. The core is further divided into an inner and outer core. The crust is where living things reside. The crust can be divided further into the solid lithosphere, liquid hydrosphere, and gaseous atmosphere.
- The lithosphere contains a large number of elements. Most of these occur as minerals.
- Minerals are solid, inorganic compounds found in nature. They have distinct crystalline structures and chemical compositions. Minerals of various elements are found in the lithosphere mainly as oxides, carbonates, and sulfides.
- An ore is a substance, commonly a mineral, from which the metal it contains can be extracted and purified at a reasonable profit.

26.4 Cycles in the Environment

- Carbon dioxide, one of the principal components in the carbon cycle, is taken up by plants during photosynthesis and given off by plants and animals as a product of cellular respiration.
- The CO_2 in the atmosphere is a major cause of the greenhouse effect. Increases in greenhouse gases may cause global warming. Scientists do not agree on the causes or consequences of global warming.
- Nitrogen gas is converted into biologically useful nitrates by nitrogen fixation. Nitrogen is returned to the atmosphere by a cycle in the environment.

Vocabulary

- atmosphere (p. 841)
- desalination (p. 851)
- global warming (p. 859)
- greenhouse effect (p. 859)
- hydrosphere (p. 850)
- lithosphere (p. 855)
- nitrogen fixation (p. 860)
- salinity (p. 851)
- stratosphere (p. 842)
- troposphere (p. 842)

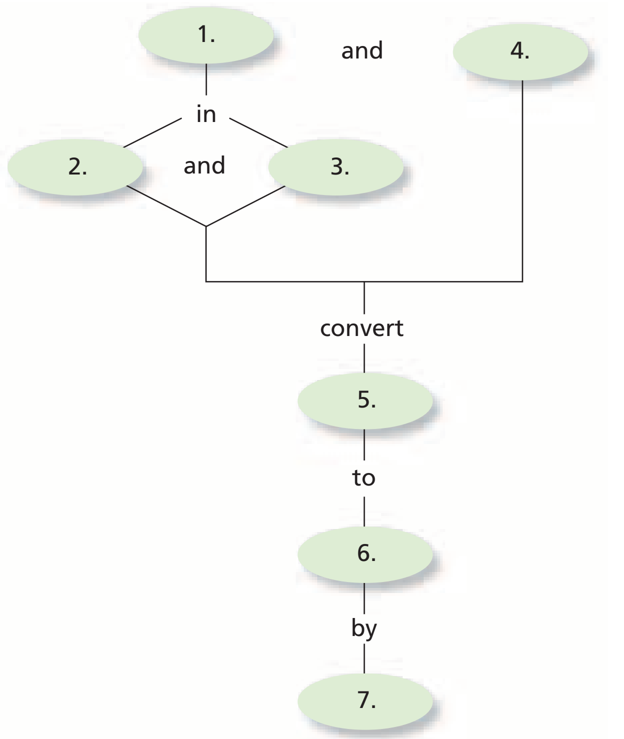
chemistrymc.com/vocabulary_puzzlemaker

Chemistry Online

Go to the Chemistry Web site at **chemistrymc.com** *for additional Chapter 26 Assessment.*

Concept Mapping

21. Complete the concept map using the following terms: roots of legumes, nitrogen oxides, soil, bacteria, nitrogen fixation, nitrogen gas, lightning.



Mastering Concepts

22. What is ozone? (26.1)

23. Why is smog more correctly termed photochemical smog? (26.1)

24. What kind of radiation causes molecules to be ionized in the upper atmosphere? (26.1)

25. What is the basis for the division of the atmosphere into layers? (26.1)

26. How do chlorine atoms act as a catalyst for ozone decomposition? (26.1)

27. What steps can be taken to reduce sulfur dioxide emissions into the environment? (26.1)

28. What provides the energy for the water cycle? (26.2)

29. What are the two most abundant ions in seawater? (26.2)

30. Why does the chemical composition of the oceans remain constant over time? (26.2)

31. What is the function of a semipermeable membrane in reverse-osmosis desalination? (26.2)

32. What are the four most abundant elements in the lithosphere? (26.3)

33. How does the position of a metal in the periodic table determine whether the element exists in nature as an oxide, a carbonate, or a sulfide? (26.3)

34. During what process is CO_2 from the troposphere converted into carbohydrates? (26.4)

35. What is the greenhouse effect? (26.4)

36. In what two ways is nitrogen fixed? (26.4)

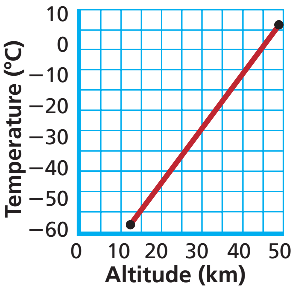
Mastering Problems

Calculations About the Atmosphere (26.1)

37. How many liters of nitrogen are there in a 25.3-liter sample of air?

38. Identify the layer of the atmosphere that is represented by the following graph of temperature versus altitude.

39. Assuming a temperature of 20.0°C and an atmospheric pressure of 729 mm Hg, calculate the number of particles of carbon dioxide gas in one cubic meter of dry air.



Calculations About the Hydrosphere (26.2)

40. Water must have a salt concentration less than 500 ppm by mass to be fit for human use. Assuming that the salt is all NaCl, what is the molarity of this concentration?

41. Construct a circle graph to illustrate the amount of water used for various purposes by an average person each day.

42. What is the molarity of NaCl in a saltwater solution with a salinity of 6 g/kg? Assume that the only salt in the solution is NaCl and that the solution has a density of 1.0 g/mL.

Calculations About the Lithosphere (26.3)

43. **Table 26-5** shows the mass percent of iron in the universe, in Earth as a whole, and in various layers of Earth. Explain the differences in terms of the process that caused formation of Earth.

Table 26-5

Abundance of Iron in Various Locations	
Location	**Percent by mass**
Whole universe	0.19
Whole Earth	34.6
Atmosphere, Lithosphere, Hydrosphere	4.7
Mantle	13.3
Core	88.6

44. Earth's crust is 0.87% hydrogen by mass. The lithosphere is only 0.15% hydrogen. Account for this difference.

45. What is the mass percent of iron in each of the following iron minerals: FeS_2, Fe_2O_3, Fe_3O_4? If the iron can be extracted with equal ease from all three minerals, which would you use as a source of iron?

Calculations About Natural Cycles (26.4)

46. About 30 million tons of HNO_3 are produced each year when lightning fixes nitrogen in the atmosphere. What is the mass percent of nitrogen in HNO_3? How much nitrogen does 30 million tons of HNO_3 contain?

47. If a plant consumes 50 g carbon dioxide in the process of photosynthesis during a given time period, how many liters of oxygen would it produce at 1 atm and 25°C? The balanced equation for photosynthesis is

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

Mixed Review

Sharpen your problem-solving skills by answering the following.

48. Why must living organisms rely on nitrogen fixation for their source of nitrogen?

49. What is the major cause of the greenhouse effect?

50. What is the purpose of adding CaO and $Al_2(SO_4)_3$ in municipal water treatment?

51. Write balanced equations for the destruction of ozone by CFCs.

52. Why does nitrogen cause freshwater pollution?

53. In what form do plants use nitrogen? In what biological molecules is nitrogen found?

54. Write balanced equations showing the formation of acid rain.

55. Using balanced equations, compare photoionization and photodissociation of an oxygen molecule in the upper atmosphere.

56. What two elements would you expect to be most abundant in Earth's hydrosphere? Why?

Thinking Critically

57. **Recognizing Cause and Effect** Environmental chemistry has a number of cause-and-effect relationships. Describe these relationships in **a)** the formation of acid rain, **b)** ozone depletion.

58. **Interpreting Data** Why are photodissociation and photoionization reactions more common in the upper atmosphere than in the lower atmosphere?

59. **Applying Concepts** Why do oxygen atoms exist for a longer period of time in the upper atmosphere than in the stratosphere?

Writing in Chemistry

60. Write a short story tracing the path that a carbon atom in a carbon dioxide molecule might follow. Assume that the CO_2 molecule is in the troposphere.

61. Prepare an instruction sheet for a portable, reverse-osmosis desalination apparatus that can be used for camping. Research and include information on how efficient the apparatus is, how much pressure must be used, and how much drinking water can be produced in a given amount of time.

62. Metallurgy is the study of extracting and purifying metals from their ores. Conduct research to learn how iron is extracted from its ores, how it is purified, and how steel is made. Make a poster showing the steps in these processes, and include a short summary of each step and the chemical equations involved.

Cumulative Review

Refresh your understanding of previous chapters by answering the following.

63. Why is it necessary to perform repeated experiments in order to support a hypothesis? (Chapter 1)

64. A 49.01-g sample of lead displaces 4.5 mL of water. What is the density of lead? (Chapter 2)

65. Are the following physical or chemical changes? (Chapter 3)

a. water boils
b. charcoal burns
c. sugar dissolves in tea
d. potassium reacts with water
e. an ice cube melts

66. The isotope of carbon that is used to date artifacts contains six protons and eight neutrons. What is the atomic number of this isotope? How many electrons does it have? What is its mass number? (Chapter 4)

67. **Table 26-6** shows abundance of the two isotopes of silver found in nature. The more abundant isotope has an atomic mass of a little less than 107, but the average atomic mass of silver on the periodic table is about 107.9. Explain why it is higher. (Chapter 5)

Table 26-6

Abundance of Silver	
Isotope	**Abundance**
Ag-107	51.8%
Ag-109	48.2%

68. For each of the following elements, tell how many electrons are in each energy level and write the electron dot structure. (Chapter 6)

a. Ar
b. Mg
c. N
d. Al
e. F
f. S

69. Use the periodic table to separate these 12 elements into six pairs of elements having similar properties. (Chapter 7)

Ca, K, Ga, P, Si, Rb, B, Sr, Sn, Cl, Bi, Br

70. Write the formula for the binary ionic compound that forms from each pair of elements. (Chapter 8)

a. manganese(III) and iodine
b. calcium and oxygen
c. aluminum and fluorine
d. potassium and sulfur
e. zinc and bromine
f. lead(IV) and oxygen

71. Name the following molecular compounds. (Chapter 9)

a. NO
b. IBr
c. N_2O_4
d. CO
e. SiO_2
f. ClF_3

72. Classify each of the following reactions. (Chapter 10)

a. $N_2O_4(g) \longrightarrow 2NO_2(g)$
b. $2Fe(s) + O_2(g) \longrightarrow 2FeO(s)$
c. $2Al(s) + 3Cl_2(g) \longrightarrow 2AlCl_3(s)$
d. $BaCl_2(aq) + Na_2SO_4(aq) \longrightarrow BaSO_4(s) + 2NaCl(aq)$
e. $Mg(s) + CuSO_4(aq) \longrightarrow Cu(s) + MgSO_4(aq)$

73. Calculate the total number of ions in 10.8 g of magnesium bromide. (Chapter 11)

74. Calculate the mass of AgCl formed when 85.6 g of silver sulfide (Ag_2S) react with excess hydrochloric acid (HCl). (Chapter 12)

75. Why will water in a flask begin to boil at room temperature as air is pumped out of the flask? (Chapter 13)

76. How many moles are contained in a 2.44-L sample of gas at 25.0°C and 202 kPa? (Chapter 14)

77. How would you prepare 5.0 L of a 1.5*M* solution of glucose ($C_6H_{12}O_6$)? (Chapter 15)

78. Compare the energy of the reactants and the products for a reaction in which ΔH is negative. Is the reaction endothermic or exothermic? (Chapter 16)

79. Identify the following hydrocarbons as alkane, alkene, or alkyne. (Chapter 22)

a. 1-hexyne
b. 3-methyldecane
c. propene
d. *cis*-2-butene

80. Water is released in a reaction in which two different functional groups condense to form an ester. What two functional groups take part in this reaction? (Chapter 23)

81. Name the two functional groups in an amino acid that become linked when a peptide bond is formed. (Chapter 24)

82. What element is formed if magnesium-24 is bombarded with a neutron and then ejects a proton? Write the balanced nuclear equation. (Chapter 25)

Use these questions and the test-taking tip to prepare for your standardized test.

1. Photodissociation, photoionization, and photochemical smog are all caused by the reaction of atmospheric gases with high energy

a. infrared radiation.
b. ultraviolet radiation.
c. cosmic rays.
d. microwaves.

2. What is the most abundant gas in Earth's atmosphere?

a. O_2
b. N_2
c. CO_2
d. H_2

3. When high-sulfur coal is burned, the following series of reactions occurs to produce acid rain:

$$S(s) + O_2(g) \rightarrow SO_2(g)$$

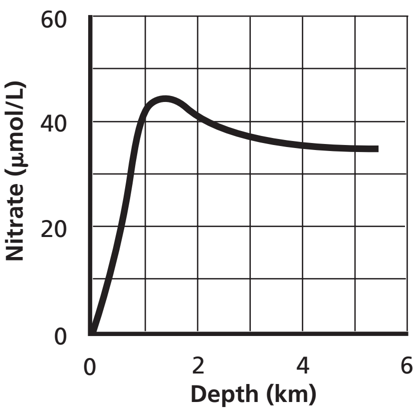
$$3SO_2(g) + O_3(g) \rightarrow 3SO_3(g)$$

$$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$$

A coal is classified as high-sulfur by the United States Department of Energy if it contains more than 763 g of sulfur per unit. A unit is defined as the amount of coal needed to produce 1.0×10^6 British thermal units (BTUs) of heat. If a unit of coal containing 768 g of sulfur is burned, how much sulfuric acid (H_2SO_4) will be produced?

a. 2.35×10^3 g
b. 4.08×10^3 g
c. 7.06×10^3 g
d. 7.53×10^4 g

Interpreting Graphs Use the graph to answer questions 4–6.



4. The nitrogen cycle occurs in the oceans as well as in the soil. Nitrates (NO_3^-) at the surface of the ocean are almost completely used up by living organisms. As these organisms die, they sink. As they sink, the nitrogen compounds inside their bodies are oxidized back to NO_3^-. In very deep waters, ocean currents mix the water and decrease NO_3^- concentration. These processes explain why the graph shows NO_3^- concentration

a. continuously decreasing with depth.
b. continuously increasing with depth.
c. decreasing and then increasing with depth.
d. increasing and then decreasing with depth.

5. Nitrate concentration reaches a maximum at approximately what depth?

a. 5500 m
b. 500 m
c. 3000 m
d. 1500 m

6. At a depth of 4000 m, about how many grams of NO_3^- are found in each liter of seawater?

a. 1.6×10^{-3} g
b. 2.2×10^{-3} g
c. 3.5×10^{-7} g
d. 2.0×10^3 g

7. In the water cycle, evaporation must be balanced by which processes?

a. condensation and sublimation
b. ionization and precipitation
c. precipitation and condensation
d. dissolution and precipitation

8. Because the denser elements sank to the center of Earth as the new planet cooled, all of the following elements are relatively rare in Earth's crust EXCEPT

a. aluminum.
b. gold.
c. platinum.
d. lead.

9. Why do the proportions and amounts of dissolved salts in the oceans remain almost constant?

a. the sources from which the ocean receives its salts have constant compositions
b. the rates at which salts are added to and taken from the oceans balance each other
c. none of the dissolved salts are ever removed from the seawater
d. living organisms have no use for any of the salts dissolved in seawater

TEST-TAKING TIP

If It Looks Too Good To Be True Beware of answer choices in multiple-choice questions that seem ready-made and obvious. Remember that only one answer choice for each question is correct. The rest are made up by the test-makers to distract you. This means that they may look very appealing. Check each answer choice carefully before finally selecting it.