

SCIENCE BACKGROUND—*The Water Cycle*

Water (H₂O) is the most abundant compound on Earth. It is a fundamental substance in nature that is essential to most life. It makes up 60 percent of the weight of our bodies and covers more than 70 percent of the world's surface.

Earth's water supply is very dynamic. Water on Earth is constantly on the move. This continuous movement of water among the land, oceans, and air is called the **water cycle**.

Although none of the matter on Earth is ever destroyed, substances do change form. They can change **states**—for example, from solid to liquid to gas. The water cycle is the repeated pattern of Earth's limited supply of water changing states, over and over and over, for millions, even billions, of years—since oceans were formed on the planet.

Water can be a **solid, liquid, or gas**. As a solid, water is found in the form of ice or snow. As a liquid, it is the well-known fluid that fills oceans, seas, lakes, and rivers. And as the gas called **water vapor**, it is constantly present in the atmosphere. Water is the rare substance that can exist in all three states at normal Earth temperatures. Unlike most substances, which become more dense as they solidify, water becomes less dense. The fact that ice floats on water is one of the conditions that made life on Earth possible. If oceans, lakes, and ponds froze from the bottom up, instead of the top down, it would have been very difficult for aquatic life to survive the winter, much less an Ice Age.

Most of Earth's water is stored in the oceans. In fact, more than 97 percent of Earth's water is the **salt water** in Earth's oceans and seas. Of the less than 3 percent that is fresh, more than three-quarters is frozen in **glaciers**, ice sheets, and ice caps. And almost a quarter is stored as **groundwater** and **soil moisture**.

The dissolved salts in the ocean originated in rocks on land. Continental weathering and erosion produced mineral-rich runoff, which flowed into the rivers and emptied into the oceans. (This process continues today, with rivers carrying millions of tons of dissolved salts and sediments to the oceans every year.) Bedrock beneath the ocean floor, underwater springs, and underwater volcanic eruptions also add salts to ocean water. Water leaves the ocean only by evaporation, and the salts are left behind. Without the melting of ice caps and the flow of fresh water from rivers, the oceans would keep getting saltier. Instead, the salinity of ocean water remains fairly stable at about 3.5 percent.

When substances change state, energy is either used or released. The water cycle is the means by which heat energy is transferred around the globe. This powerful “heat pump” is responsible for global weather patterns, ocean currents, and climate. **Weather** is the conditions in the atmosphere at a given place and time. It includes such factors as precipitation, cloud formation, and humidity, all of which are components of the water cycle. **Climate** refers to the average weather in a region over a long period of time. The main processes that carry out this transfer of energy affecting weather and climate are **evaporation** and **condensation**.

Evaporation is the process through which a substance changes from the liquid state to the gaseous state. Evaporation requires energy. Given that more than one trillion tons of water evaporate each day, the amount of energy transferred is truly staggering. The sun provides a heat source for the evaporation of surface water. Generally speaking, evaporation occurs more rapidly in summer than in winter, and more rapidly during daylight hours than at night. Most of the evaporation on Earth occurs over the oceans.

Once evaporated, the water is in the form of gaseous water vapor. The amount of water vapor in the air can vary considerably depending on the season, time of day, and geographical location. **Humidity** is a measure of the amount of water vapor in the air at any given time and place. Air containing a large amount of water vapor is said to be humid. **Relative humidity** is the amount of water vapor in the air in proportion to the greatest amount that is possible at a given temperature and pressure.

Condensation is the process by which a substance changes from the gaseous state to the liquid state. This process liberates, or gives off, energy. When water vapor condenses, it forms liquid water droplets on solid surfaces. When condensation occurs at high altitudes, the water droplets cling to tiny bits of dust, smoke, and salt called *condensation nuclei*. The water droplets form **clouds**. When the droplets become big enough, they fall to the Earth as **precipitation**—rain, snow, sleet, or hail, depending on the temperature of the air through which the droplets fall. Most of the precipitation on Earth occurs over the oceans.

If the sun shines while rain is falling, a **rainbow** may be visible in the sky. As the raindrops fall, each one refracts the light, contributing to the rainbow only for a very brief moment. The sum of the separation of light by all the raindrops creates the rainbow.

When precipitation occurs over land, the water can follow several paths. It can be pooled in lakes and ponds. It can flow over land into streams and rivers, in the form of **runoff**, and eventually be returned to the ocean. It can infiltrate the ground and percolate down to become groundwater. Or it can be absorbed into the soil where it becomes available for uptake by plants.

Plants are an important part of the water cycle. The roots of plants absorb moisture from the soil. The water then moves through the plant's stems to the leaves, where it evaporates and enters the atmosphere. This process is called **transpiration**.

One of our most valuable natural resources is the groundwater beneath our feet. Water seeps into the ground at different rates, depending on the porosity and permeability of the rock layers. Empty spaces, or **pores**, in rocks below the water table become saturated with water. A water-bearing rock that readily gives up water to a well is called an **aquifer**. Aquifers supply much of the world's drinking water.

Just because a well yields water doesn't mean the water is safe to drink, however. Groundwater can be contaminated by chemicals from pesticides and fertilizers, by road salts, by bacteria from wastes, and by other pollutants found in and on the soil. All drinking water supplies must be tested for dangerous substances. **Water treatment plants** investigate water quality and purify water supplies.

SCIENCE BACKGROUND—*Force and Motion*

Most of the activities we perform each day involve moving things. For an object to move, a **force—a push or a pull**—must act upon it. Scientifically speaking, when a force is applied to an object and the object moves, **work** is accomplished.

Machines are devices that help us do work by helping us move things easier, faster, or farther. They may be complicated, consisting of many parts and requiring electricity or fuel to operate—or they may be quite simple, consisting of just one moving part and requiring only the force provided by a human being or an animal.

Simple machines are the basic components of which all other machines are made. They include the **lever, wheel and axle** (including **gears**), **pulley, inclined plane, wedge**, and **screw**. Most simple machines work by helping us move objects using less force. However, in order to use less force, that force must be applied over a longer **distance**. That is the **tradeoff** inherent in all simple machines.

The **lever** is the first type of simple machine. All levers have four parts: a rigid bar called the **arm**; the **fulcrum** around which the arm **pivots**; the **load**; and the **effort**, which is the force applied to move the load. In a **first-class lever** (the subject of this activity), the fulcrum is located between the effort and the load. Applying force to the effort end causes the load end to be lifted. In this way, a lever transfers and changes the direction of force. Moving the fulcrum changes the amount of force necessary to lift the load, as well as the distance through which the load and effort each move.

The second type of simple machine is the wheel and axle. But first a distinction must be made between rotating wheels and a wheel and axle machine. A rotating wheel is not a

simple machine, although using a wheel reduces the amount of force it takes to move an object. The wheel does this by overcoming **friction** between the object and the surface over which it moves. Friction is a force that resists **motion**. Friction is produced whenever two surfaces rub together. A wheel and axle machine is made by inserting a shaft into the center of a wheel, such that the wheel and axle turn as a unit. In this way, force is transmitted between the wheel and the axle. The difference in size between the wheel and axle modifies force as it is transmitted. A small force applied over a large distance (the circumference of the wheel) is converted into a larger force applied over a small distance (the circumference of the axle).

A gear is a special type of wheel with **teeth** evenly spaced around the outer edge. When two gears are placed side by side, such that their teeth mesh, applying force to one gear causes the other to move in the opposite direction. In this way, gears transmit and change the direction of force. When two gear wheels of different sizes are connected, they work like a wheel and axle to modify force. This modification of force is evident in the **speed** at which the gear wheels each turn, with the larger gear wheel always turning more slowly—and with more force—than the smaller gear wheel.

A pulley is a third type of simple machine. A pulley is a grooved wheel that turns around a stationary axle. A rope (or chain) rides in the groove of the wheel, causing the wheel to turn easily as the rope gets pulled. A fixed pulley is a pulley that does not move. A single, fixed pulley does not reduce the amount of force needed to lift the load. In fact, it may take slightly more effort due to friction. Instead, a single, fixed pulley changes the direction of applied force, enabling you to pull down in order to lift the

load. With your body weight and **gravity** to assist you, that makes the work seem easier. A movable pulley is one that moves along the rope as the rope is pulled. A single, movable pulley helps make work easier by reducing the amount of force it takes to lift a load. That is because half of the load is supported by someone or something else, and half is supported by you. However, the rope must be pulled twice as far in order to get the load to move half as much.

The inclined plane is the fourth type of simple machine. An inclined plane, commonly called a ramp, is a flat surface that slopes. It is the only type of simple machine that does not move. Instead, objects are moved up an inclined plane in an effort to raise them. The advantage of using one is that it takes less force to drag an object up an inclined plane than it does to lift it straight up. However, the object must be moved over a greater distance, that is, over the length of the inclined plane.

A fifth type of simple machine is the wedge. A wedge is simply an inclined plane that moves. Wedges are often used to separate objects. When force is applied to the wide end of the wedge, the narrow end of the wedge is driven into the object, widening the opening and allowing the wedge to penetrate deeper with each application of force. Wedges can also be used to lift objects. The thin edge of the wedge is inserted under the object to be lifted, then force is applied to the wide edge of the wedge. It takes less force to push the wedge under the object than it does to lift the object. But in order to lift the object a short distance (the height of the wedge), you need to move the wedge a long distance (the length of the wedge).

The sixth and final type of simple machine is the screw. A screw is really just an inclined

plane wrapped around a cylinder. The spiral ridges around the shaft of the screw are known as the **threads**. Screws are used most often to attach things. As the screw is turned, the threads cut into the object being attached and pull it up the shaft of the screw. The closer together the threads on the shaft, the easier it is to screw in the screw, but the more turns that must be made. That is because the inclined plane of which the screw is made is longer, with a more gradual slope.

SCIENCE BACKGROUND—*Sound*

Sound waves are produced by the **vibration** of matter. They are a disruption of a medium that travels through that medium. Like other types of waves, sound waves need energy for their production. They then carry that energy from one place to another. Sound waves can travel through solids, liquids, and gases. Only in a complete vacuum can there be no sound waves.

All matter is composed of molecules, which tend to remain about the same distance from one another if undisturbed. But when a sound wave passes through the matter, they are forced to move. For example, when a plucked string begins to vibrate, it pushes the air molecules to one side, causing them to crowd together. Then the string moves back past its original position and on to the other side, leaving a space. Air molecules move back into the space, but they are more spread out than before. As the string continues to vibrate, a series of compressions and rarefactions of air molecules move away from the string, affecting the movement of air farther and farther away from the vibrating string. We perceive these alternating **compressions** and **rarefactions**, which occur in liquids and solids as well as air, as sound waves.

All types of waves have certain things in common. The **wavelength** is the distance from the crest, or top, of one wave to the crest of the next wave. That distance depends on how fast the waves are produced; it varies with the speed of an object's vibration. Waves from slow vibrations have long wavelengths; those from fast vibrations have short wavelengths.

The **frequency** of a wave is the number of waves produced per second; it is the same as the number of vibrations per second. Frequency is measured in hertz (*Hz*).

Frequency and wavelength are inversely related: as the frequency increases, the wavelength decreases; as the frequency decreases, the wavelength increases.

The frequency of sound waves affects the **pitch**—the “highness” or “lowness”—of the resulting sound. The more vibrations per second, the higher the frequency, and the higher the pitch. The fewer vibrations per second, the lower the frequency, and the lower the pitch.

Waves can also be measured in terms of their **amplitude**, or size. The amount of energy carried by most waves is related to the amplitude of the wave. The amplitude of a wave is measured as the distance from a crest of a wave to the normal resting position of the medium through which it is moving. The more energy a wave is carrying, the greater is the wave's amplitude.

The amplitude of sound waves determines the **volume**—the loudness or softness—of the resulting sound. The more energy put into creating the waves, the greater their amplitude, and the louder the resulting sound. The less energy put into the waves, the smaller their amplitude, and the softer the sound.

As sound waves of varying size, shape, and speed pass through the air, they may reach your **ear**. They enter through the **outer ear** and pass along the **ear canal** to the **eardrum**, a thin membrane that separates the outer ear from the **inner ear**.

When sound waves hit the eardrum, it begins to vibrate. These vibrations are then transferred to three small bones, the hammer, anvil, and stirrup, located in the middle ear. The stirrup vibrates against another membrane, the oval

window, which forms the boundary between the **middle ear** and the inner ear.

From the oval window, the sound waves are transferred to a liquid-filled chamber in the inner ear. The vibrations in the liquid stimulate thousands of sensory hair cells lining the chamber, and the energy in the liquid is converted to electro-chemical energy. The impulses travel along the **auditory nerve** to the brain, which interprets the impulses as sounds.

Different musical instruments produce many different kinds of sound waves because many different kinds and shapes of materials are vibrating as they are played. When the musicians in an orchestra all play the same note on their instruments, they produce a sound with the same pitch. They may even play the note at about the same volume, and yet every instrument will produce its own distinctive quality of sound.

The quality of the sounds—the difference between sounds of the same pitch and volume—depends on the vibrations that produce the sounds. The lowest frequency that can be produced by playing a certain note is known as the **fundamental frequency**. However, other vibrations of higher frequencies, known as **overtones**, are also produced at the same time. The overtones alter the sound. Each instrument has a characteristic set of overtones that is different from the set of overtones of every other instrument. As a result, each instrument has a characteristic sound, which can be distinguished from that of every other instrument.

SCIENCE BACKGROUND—*Food Chains and Webs*

A single organism in an environment is an **individual**. Individuals of the same kind living in the same environment make up a **population**. All the populations of organisms living together in an environment make up a **community**.

A community, when considered with its environment, is an **ecosystem**. It includes the plants, animals, and microorganisms that make up the living community as well as the interactions they have with the environment. An ecosystem can be on land or in water. An ecosystem can be as large as the Pacific Ocean or as small as a drop of water.

All living things within an ecosystem are connected. Plants grow in **soil** and are eaten by animals. Other animals, in turn, eat those animals. When the plants and animals die they are decomposed and returned to the soil as nutrients.

Soil is the outermost layer of Earth's surface. It is composed of both inorganic (weathered rock particles) and organic (decayed plants and animals) material. Soil contains mineral nutrients that are essential to plant growth such as nitrogen, phosphorus, and potassium—the same nutrients in lawn and garden fertilizers.

Green plants have the unique capacity to use the sun's energy to produce food energy. They do this by transforming carbon dioxide (CO_2) from the air and water (H_2O) into carbohydrates ($\text{C}_6\text{H}_{12}\text{O}_6$) and oxygen (O_2). The plant uses the carbohydrates (starches and sugars) for food. The oxygen is emitted into the air we breathe. The process, known as **photosynthesis**, can take place only in organisms that contain **chlorophyll**, the molecule that gives all green plants their color.

Because of this ability to produce their own food, green plants are known as **producers**. Producers use sunlight to make food.

Most other living things on Earth are directly or indirectly dependent upon this food. Many animals eat green plants directly, while other animals eat those animals. Since these animals are not able to produce their own food energy and must obtain it by eating, they are called **consumers**. First-order consumers eat producers directly. Second-order consumers eat first-order consumers.

When plants and animals die, specialized organisms called **decomposers** break them down in a process called decomposition or **decay**. Through this process, organic (living or once-living) material is changed into inorganic (nonliving) nutrients. The nutrients are returned to the soil where they support the growth of the green plants and the cycle begins again.

The sequence of producer to consumer to decomposer is known as a **food chain**. For example, a prairie food chain might begin with plants that are eaten by grasshoppers. The grasshoppers are then eaten by mice, which in turn are eaten by hawks. When these organisms die, bacteria, fungi, or earthworms will decompose them.

However, the grasshopper may feed on several different types of plants, and may be eaten by toads as well as mice. Mice may also eat grain, and be eaten by snakes in addition to hawks. Overlapping food chains that link many organisms together form a **food web**. In most ecosystems, the complex interactions between organisms are best represented by food webs rather than chains.

An **energy pyramid** shows how energy is transferred through a food web. The size of

each layer of the pyramid represents the amount of energy stored at that level; the largest block is on the bottom and the smallest is on top. This illustrates that most energy is lost in the transfer from one feeding level to the next. In fact, only a minute fraction of the sun's energy ever makes it to the top of the web. It is consumed at each level or dissipates into forms that are no longer useful for sustaining life. As a result, food energy must continually be replenished by the photosynthesizing work of producers.

Historically, human interaction with food webs has resulted in the extermination of other species. By educating ourselves about the basic dynamics of food chains and food webs, we will be better able to make decisions in the future regarding our interactions with other organisms.

SCIENCE BACKGROUND—*Plant and Animal Populations*

An **organism** is a living thing such as a plant or an animal. All the stages that a living thing goes through during its life are called a **life cycle**.

The life cycle of many types of plants begins with a **seed**. The life cycle of many types of animals begins with an **egg**.

Some insects have four stages in their life cycles. In these insects, the young insect that hatches from the egg does not resemble the adult form. This is the **larva** stage, during which the insect eats and grows. The larva then enters the **pupa** stage, during which metamorphosis occurs. When the insect emerges from this stage, it is a fully formed **adult**. Other insects have only three stages in their life cycle: egg, **nymph**, and adult. In these insects, the nymph form somewhat resembles the adult form. When the adult **reproduces**, another life cycle begins.

A single organism is an **individual**. However, an individual is rarely found living alone. It usually lives in a group of its own kind, or **species**. A group of organisms of the same species living in any one area, or **environment**, is called a **population**. All the populations of organisms living together in an environment make up a **community**.

A community, when considered with its nonliving environment, is an **ecosystem**. It includes the plants, animals, and microorganisms that make up the living community as well as the interactions they have with the nonliving environment.

Many different kinds of populations usually inhabit an ecosystem. They may share the same habitat, such as a pond, marsh, meadow, or tide pool. In a shared habitat, different populations are usually dependent on one another for survival—mainly for food.

All living things within an ecosystem are connected. **Plants** grow in soil and are eaten by **animals**. A plant-eating animal will be food for a meat-eating animal, and that animal, in turn, will be food for yet another animal.

Green plants have the ability to produce their own food. For this reason, they are known as **producers**. Producers use sunlight to make food. Plants also produce the oxygen that animals need to breathe, and plants absorb the carbon dioxide that animals produce during respiration.

Most other living things on Earth are directly or indirectly dependent on the food produced by green plants. Many animals eat green plants directly or eat animals that do. Since these animals are not able to produce their own food energy and must obtain it by eating, they are called **consumers**. First-order consumers eat producers directly. Second-order consumers eat first-order consumers.

The animal being hunted and eaten is called the **prey**. The animal doing the hunting and eating is called a **predator**. The predator-prey relationship in the food web is a natural balance that is continually shifting in favor of one or the other. If a predator depletes a prey population, it will thereby deplete its own population. As predators become scarce, the prey population has a chance to revive. Thus the cycle continues and balance is restored.

Predator-prey interactions are just one of the environmental pressures that can cause evolutionary **adaptations**. An adaptation is a physical feature or a behavior that becomes prevalent in a population because it gives the organism an advantage—helps it survive to reproduce—in that species' environment.

For example, the English peppered moth occurs in two varieties, light gray and dark gray. On trees with pale lichens growing on the bark, the light gray moth blends in better. In parts of the country that have heavy industrial pollution, the lichens die off, exposing the darker tree bark. Then the dark moths blend in better with their environment. The light gray moths are more easily seen and preyed upon by birds. After just a few generations, dark moths are more prevalent than light moths in areas with industrial pollution.

This type of adaptation—when a species evolves to better blend in with its environment—is called **camouflage**. When a species evolves to look like a more dangerous species, the adaptation is called **mimicry**.

Despite adaptations that may help an organism survive, eventually, each will come to the end of its life cycle. When plants and animals die, specialized organisms called **decomposers** break them down in a process called **decomposition** or decay. Through this process, organic (living or once-living) material is changed into inorganic (nonliving) nutrients. The nutrients are returned to the soil where they support the growth of green plants, which begins the cycle again.

However, when all the members of a species die, the species becomes **extinct**. For example, the American Passenger Pigeon is extinct. The last living specimen died in the Cincinnati Zoo on September 1, 1914. Although the North American population had once numbered in the billions, European settlers hunted the birds to **extinction**. A population that is in danger of becoming extinct is called **endangered**.