Introduction

In the beginning, God created the heavens and earth, and all that is in them. As His crowning creation, He made humans, whom He gave dominion over the earth (Genesis 1:28). In this "dominion mandate," God told man to subdue and take dominion over every living thing on Earth. To accomplish this, man needed to understand living things: how they reproduce, how they grow, and how they die. Throughout recorded history, man has used his knowledge of living things to provide food and shelter for mankind, cure diseases, and help his fellow man. Biology is the systematic study of the many things man has learned about living things since Creation and how this knowledge can be used to benefit mankind.

The study of biology is important not only to benefit mankind, but also to draw man to God. The fingerprints of the Designer are seen throughout nature. From the intricate processes inside a cell to the beauty of a wildflower, we can see the attributes of God in His creation.

Man uses his knowledge of living things to meet his physical needs.

Living things survive by interacting with each other through behaviors such as feeding and pollination.

The millions of chemical reactions and processes occurring simultaneously inside a growing cell reveal the creativity and ingenuity of God. The splendor of a delicate flower shows us that the Creator values beauty. He has instilled that same desire for beauty in each of us.

Living things depend directly and indirectly on many other organisms to survive. Neither a bacterium nor a wildflower can exist independently of other living things. Through a variety of interactions such as feeding, competition, and pollination, living things form a complex system in which every organism affects many other organisms. Through its complexity and order, nature proclaims its creation by an all-knowing and perfect Creator.

In Psalm 139:14, David wrote, "I will praise thee; for I am fearfully and wonderfully made: marvellous are thy works; and that my soul knoweth right well." When God created man in His image, He gave man the ability to think, reason, and make decisions. This was made possible by what is perhaps God's greatest creation, the human brain. The reasoning power of the brain has allowed man to accomplish many amazing things, both bad and good.

Studying biology will give you a chance to exercise the thinking and reasoning powers God has given you to better understand creation. As you learn more about nature, you will repeatedly see the fingerprints of the Designer.

How to Use Biology

Structure and Setup of the Textbook

This Biology textbook is divided into ten units. The first four units discuss the concepts that direct how living things function both internally and within their environments. The last six units survey the main groups of living things and discuss the characteristics, physiology, life cycle, and ecology of each group.

Each unit is divided into twelve lessons, which contain several recurring features to help you learn, understand, and retain the main concepts that are being taught.

First, a list of lesson objectives comes at the beginning of each lesson. The lesson objectives state what you should be able to do after completing each lesson. Studying the lesson objectives will help you ensure that you are understanding the content of each lesson, and it will help you prepare for quizzes and tests.

2.10 Objectives

After this lesson, students should be able to...

1. Define the different types of biodiversity.
2. Explain how preserving biodiversity was part of God's commands to man after Creation.

Next, vocabulary terms are boldfaced where they are first used in the text. They are also defined on the page where they are first used. Pronunciations are given for more difficult words. A glossary that lists all the vocabulary terms is in the back of the textbook.

biology: the study of living organisms

Finally, a list of Concept Review questions comes at the end of each lesson. These questions do not replace the accompanying LightUnits, but they do reinforce the objectives and provide a way to quickly assess whether you are grasping the lesson content. The answers to these questions can be found in Appendix A.

2.10 Concept Review

1. What are some of the benefits that people receive from biodiversity?
2. What are some basic ways that people can preserve biodiversity?

Interest Boxes and Sidebars

The "Dissecting Words" boxes, indicated by a scissors icon, list Greek and Latin word parts that compose some of the terms used in the study of biology. These word parts, along with many others, are compiled in Appendix C.

Dissecting Words

auto–*self*

Literal meaning:
autotroph–*to nourish oneself*

Related words:
automobile, automatic,

Another series of sidebars, indicated by an icon of a hand holding the world, describes various examples of amazing design in God's creation.

The Black Swallower

The black swallower (*Chiasmodon niger*) lives in the twilight zone, where food is somewhat scarce and hard to see.

The remaining sidebars discuss a wide range of interesting topics related to the lesson content.

Contents

Unit 1 Life, Matter, and Energy

Unit 2 Ecology

Biomes and Ecosystems

Communities and Populations

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Introduction to the Cell

Cellular Processes

The Cell's Role in Genetics

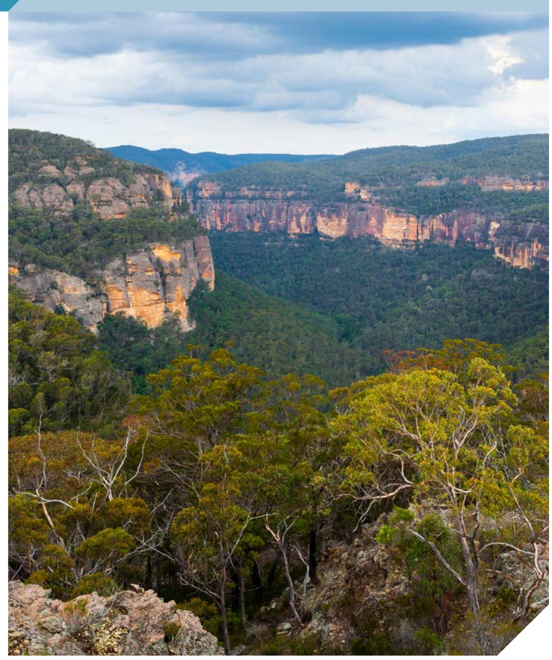
Unit 4 Genetics

Mendelian Genetics

Advanced Genetics

Limitations of Genetic Diversity

Unit 5 Plants: Form and Function



Plants and Their Purpose

Plant Structure

Plants and Their Environment

Unit 6 Plants: Reproduction and Cultivation

Plant Diversity

Plant Reproduction

Plant–Human Interactions

Unit 7 Fungi, Microorganisms, and Viruses

Fungi

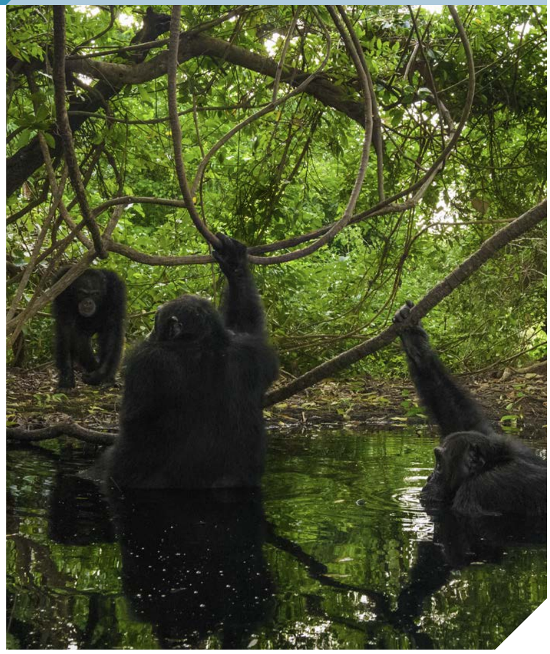
Protists

Bacteria and Viruses

Unit 8 Invertebrates

Unit 9 Vertebrates

Unit 10 Animal Processes and Behavior



UNIT 1

Life, Matter, and Energy

Problem Elephants

Asia is a crowded continent, home to 4.5 billion people and about 40,000 wild Asian elephants (*Elephas maximus*). But both are running out of room. As the human population increases, the elephants' native habitat is fragmented by roads, farmland, and villages. Illegal logging has destroyed vast forests. These changes have diminished the elephants' sources of food and water.

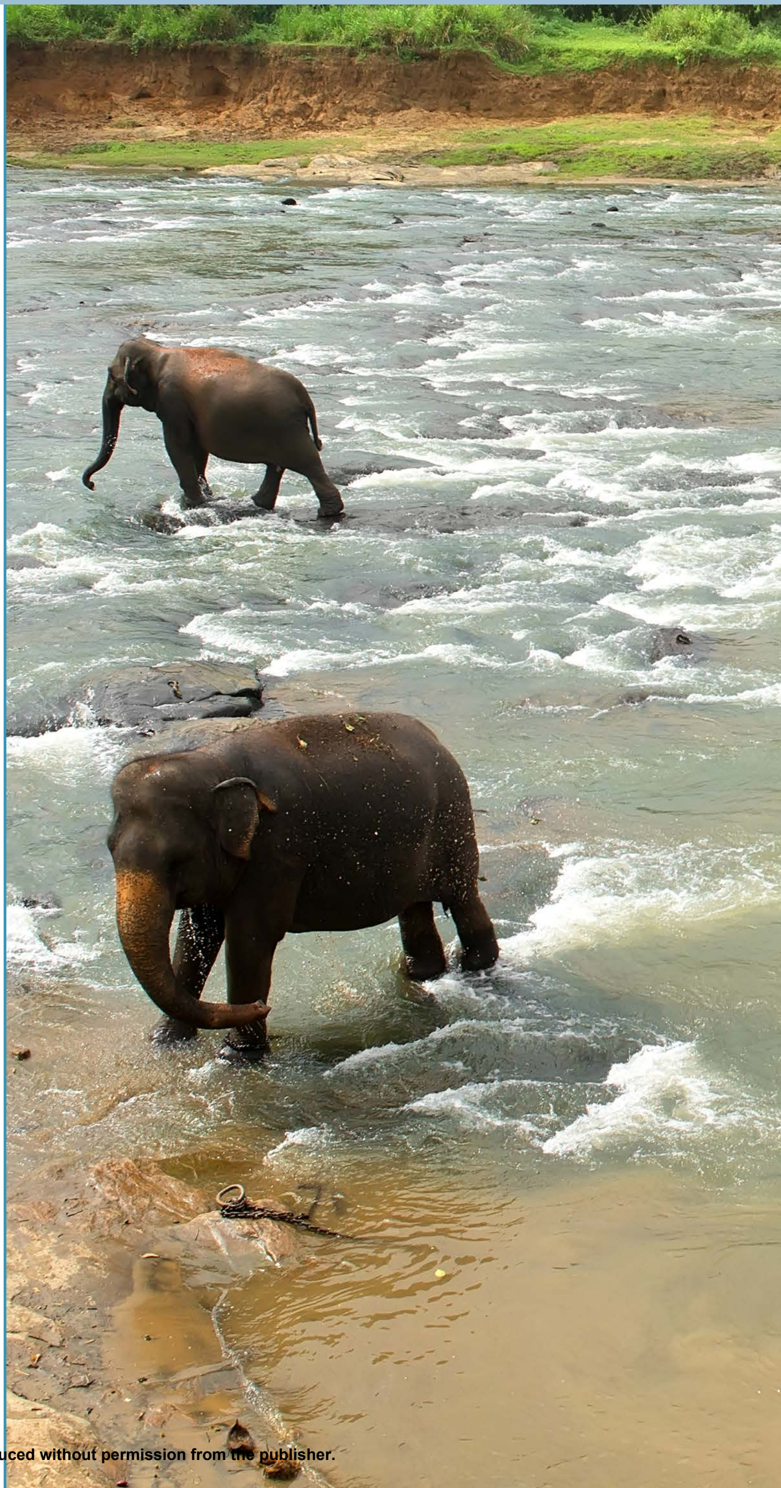
Elephants prefer to follow the same migration routes every year, and these routes often lead through human civilization. The results can be devastating to the local people. In the elephants' quest for nourishment, they rampage through houses, ruin crops, and worst of all, threaten human lives. In India alone, elephants kill about five hundred people each year.

One December morning, an elephant entered the Indian village of Uanpetla. While traveling through a rice paddy, the elephant saw a man named Kanak Rai and charged. Terrified, Kanak fled across the field, but he tripped and fell. Onlookers shouted in horror as the elephant attacked and trampled him into the ground. After chasing the elephant away, the villagers found Kanak alive but severely hurt.

However, most people do not survive elephant assaults. In April of 2022, a farmer named Naidu was watering his mango and jackfruit trees when an elephant entered the grove. When the elephant saw Naidu, it attacked. Villagers heard Naidu's cries and rushed to help, but they arrived too late. The elephant had killed Naidu and returned to the forest.

In some places, nightly attacks are so frequent that the people sleep in trees. Desperate to protect their livelihoods, village men drive the elephants away with stones, firecrackers, and homemade spears.

Can Asian elephants survive as their life-giving food and water sources continue to disappear? Can villagers protect their crops and still live safely? Is there room for both elephants and people in Asia?



Section 1 An Overview of Life

1.1 Objectives

After this lesson, students should be able to . . .

1. Explain why living things are some of the best evidence for a Creator.
2. State what biology studies.
3. List the characteristics of life.
4. Explain why an object or organism is or is not alive based on the characteristics of life.
5. Explain why life is more than just a collection of chemicals.

1.1 Life and Its Designer

He eased off the last rung of the ladder, turned, and stepped forward. His heart pounded, every nerve and muscle alert. But not a bird flew, not a dog barked, not a fly buzzed. Not a living thing stirred, because nothing was alive. Around him stretched miles of rock and dust without a single green leaf. Beneath his feet no ants crawled, no earthworms burrowed. The dirt was devoid even of bacteria.

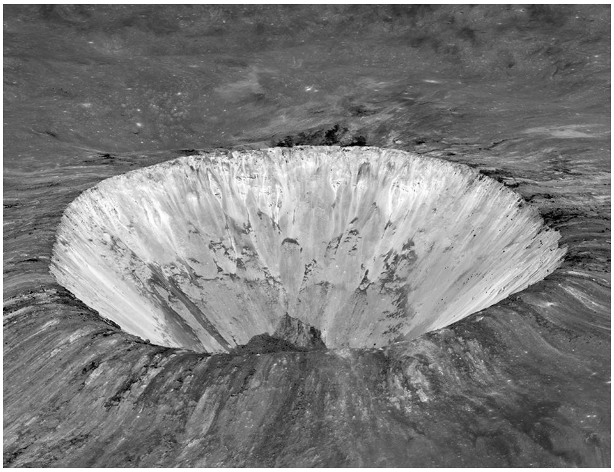
He, Neil Armstrong, was on the Moon.

After his friend "Buzz" Aldrin descended the ladder, they explored the surface together. Everywhere they went, no living things stirred. Only they, in the sealed atmospheres of their suits, were alive.

Later the two men left the Moon, blasting off to join Michael Collins, their crew member who had been circling the Moon in their spacecraft. With their departure, the number of living organisms on the Moon returned to zero. It was not a landscape of death, since only living things die. It was a landscape devoid of life.

For three days the men traveled toward the blue dot of Earth, its swirling clouds and blue oceans growing ever larger. On July 24, 1969, they reached the outer edge of Earth's atmosphere and began angling toward a splashdown in the Pacific Ocean.

Far below them lay vast lands and waters, crowded with life. In misty green rainforests, bright macaws flew and dark spider monkeys swung. In hot deserts, lizards scrambled, snakes slithered,



The Moon (left), like most of the universe, appears to be devoid of life. In contrast, Earth (right) is covered with life.

and fat cacti slowly grew in the blazing sunlight. Even on the frozen continent of Antarctica, thousands of penguins waddled and swam.

Beneath them too was civilization: houses, farms, towns, and cities. Countless acres of cultivated crops flourished in the fertile soil: wheat and corn, melons and blueberries, tulips and sunflowers, potatoes and sugarcane.

Just before seven o'clock that morning, their capsule splashed into the waters of the Pacific underneath three large red-and-white parachutes. The astronauts bobbed in the ocean, waiting to be picked up and taken to the nearby ship. The ocean they floated on contained whales, sharks, squid, fish, and countless microorganisms. The three astronauts had come many miles, from a place where they were the only living things, to this familiar place where they were surrounded with life. They were home.

Biology is the study of Earth's most precious gift: life. Man has not found life anywhere else in the universe. When describing a moment on his trip to the Moon, Neil Armstrong said, "It suddenly struck me that that tiny pea, pretty and blue, was the Earth. I put up my thumb and shut one eye, and my thumb blotted out the planet Earth. I didn't feel like a giant. I felt very, very small."

Here on Earth, life is astonishingly abundant and varied. It would be difficult to find a square foot of ground without life. Even in deep ocean trenches and beneath polar ice, men have found bacteria and unusual life forms growing and thriving. Why is this? Isaiah 45:18 says, "For thus saith the Lord that created the heavens; God himself that formed the earth and made it; he hath established it, he created it not in vain, he formed it to be inhabited: I am the Lord; and there is none else."

The Great Designer

The study of living things connects us to the Creator in a special way. When God desired to emphasize His sovereignty to Job, He called Job's attention to His living creation. "Doth the hawk fly by thy wisdom, and stretch her wings toward the south? Doth the eagle mount up at thy command, and make her nest on high?" (Job 39:26, 27).

Living things provide some of the greatest evidence for an intelligent Creator. For example, the various structures of living things have clear functions and perform specific activities. The eyes of an owl permit it to see; its wings and feathers allow it to fly. The roots of a plant anchor it and permit it to absorb water and minerals from the soil.

Dissecting Words

Understanding Scientific Terms

Many of the words we use in science have Greek or Latin roots. For example, we get the word *biology* from the Greek word *bios* (one's life, lifetime) and the suffix *-logy* (branch of study), which comes from the Greek ending *-logia.*

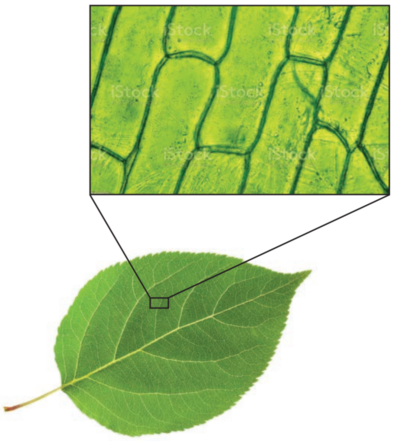
Most of these Greek or Latin roots are used in multiple English words. The prefix *bio-* (from Greek *bios*) is used not only in the word *biology,* but also in several hundred other words. By learning the meanings of some of these word parts, you will be able to determine the meanings of many new words when you come across them.

Related Terms

biomass, bioluminescence, biography

biology: the study of living things

Many owls have ears that are asymmetrically placed to allow them to hear better. The outermost openings on this owl skull are the ear openings.



Complex processes within each leaf cell keep the leaf alive.

Another evidence of the Designer is specialized features that equip living things for unique environments and special lifestyles. For instance, many owls have asymmetrically placed ears. One ear is high on the owl's head and angles downward, while the other ear is lower and angles upward. This ear placement causes sounds to have a different volume in each ear depending on the elevation of the sound source relative to the owl. This amazing design helps the owl locate prey in the dark or beneath snow or thick grasses.

In many cases, several features working together equip a living thing for a particular lifestyle. Not only does the owl have sensitive ears, it also has eyes adapted for night hunting and feathers specialized to muffle the sound of flight. If a single feature points to intentional purpose and design, how much more an array of features!

The complexity of living things is further evidence for a Designer. Many living things have intricate structures with complex designs; often they perform activities that require a series of coordinated steps. Nowhere is this better illustrated than in a cell. Cells are so tiny that two hundred average-sized ones could fit across a pinhead, yet they teem with activity and complex structures. In addition, cells contain all the information for your entire body. Some have estimated that this information, if written in English, would fill as many as one thousand books of one thousand pages each.

Not only are individual organisms complex, they also form complex relationships with the organisms around them. For example, specialized fungi grow among the roots of most plants. The fungi absorb water and nutrients that the plants use, and in exchange, they receive sugars produced by the plants. These fungi influence the size and chemical composition of the plants they interact with, which in turn affects the pollinators and herbivores that visit the plants. Creation is filled with such complex relationships and interactions. The more we study the natural world, the more we find evidence that each organism was designed by the Creator to interact with other organisms to form a balanced web of life.

Finally, we see beauty throughout nature. Notice the lovely symmetry and shape of the barn owl's face. Consider the lovely colors and delightful scents of wildflowers. What can the beautiful creation teach us about the Creator? How truly the psalmist wrote, "Marvellous are thy works" (Psalm 139:14).

Of course, the natural world is not perfect. You do not have to look far to find disease and death marring the beauty of creation.

These problems do not result from a flaw in the Creator, but from the fall of man in the Garden of Eden. Since the Fall, degeneration and death have affected every form of life on Earth. Even so, the beauty of God's design is still evident in nature.

Many specialized features work together to equip the barn owl (*Tyto alba*) and other living things for their lifestyles.

Life Defined

Generally, it is easy to determine whether something is alive or not. Butterflies and daisies are alive; rocks and waterfalls are not. But what about bracket fungi on a rotten log or a lovely crystal slowly growing in a solution? What about a piece of coral from the ocean or a stalactite in a cavern?

How do you decide what is alive and what is not? Most of the time you can just tell, but sometimes it is not easy. Over the years, biologists have tried to compile clear guidelines. Following is a list of characteristics that all living things must have.

1. Come from preexisting life.
2. Made of cells.
3. Need energy to live.
4. Sense and respond to changes around them.
5. Grow, mature, and die.
6. Contain DNA, the information molecule.
7. Reproduce after their kind.

Similar lists contain a different number of characteristics. That is because many of these attributes can either be grouped together or broken down into further detail. The next lesson will examine each of these characteristics, but before that, we will return to the question: What is life?

It is much easier to list the characteristics of living things than to say what life is. Life is not easily defined. It is more than a collection

Some organisms, such as corals (left) and bracket fungi (right), do not appear to be alive at first glance.

of certain chemicals or information. Putting all the correct structures in place, even adding DNA with all the appropriate information, does not make something alive. What is the "spark" that takes lifeless substances and gives them the ability to use energy, make new substances, grow, and reproduce? For decades scientists have searched for this spark of life without success. They have worked to reduce life to its most basic forms, and in doing so, they have discovered that even the simplest life forms are still incredibly complex.

Life is a quality that was imparted by God to living things at Creation and has been passed down from living things to their offspring ever since. As older organisms die, new organisms grow and take their place. Life is only a temporary state. Nevertheless, living things have been touched by the creative power of God in a special way.

1.1 Concept Review

1. What do the structures, complexity, and relationships of living things give evidence of?
2. What is the study of life called?
3. What equips living things for unique environments and specific lifestyles?
4. What have scientists discovered when they have reduced life to its most basic forms?

1.2 Characteristics of Living Things

1.2 Objectives

After this lesson, students should be able to . . .

1. Explain how the fact that life comes from preexisting life points toward a Creator God.
2. Explain what the cell theory states.
3. Describe the difference between unicellular and multicellular life.
4. Explain why cells need energy to live.
5. Explain what autotrophs and heterotrophs are.
6. Explain why asexual reproduction produces offspring with no genetic diversity, while sexual reproduction produces offspring with genetic diversity.

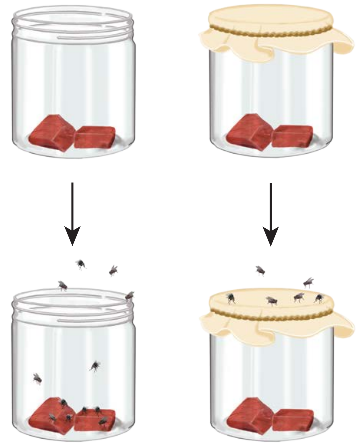
Every living organism has every characteristic of life from the list introduced in the previous lesson. In contrast, nonliving things possess few or none of these traits.

Come From Preexisting Life

Hundreds of years ago, many people believed that simple life such as worms and flies could spontaneously develop from nonliving things, a theory known as spontaneous generation. The Italian scientist Francesco Redi decided to test this theory. In his experiments, Redi placed raw meat and a dead fish in two sets of flasks. He covered one set with gauze so that air could get in but living creatures could not. He left the second set open. After several days, Redi observed maggots on the objects in the open flasks, but none in the ones covered with gauze. After further experiments, he concluded his findings in the quote, "All life comes from life."

Today we have enough evidence to know that living things can only come from similar preexisting life. We know food spoils because bacteria and fungi that cause spoilage have been introduced to that food. We recognize that maggots grow in meat only if a fly has first laid its eggs on the meat. Mosquito wigglers appear in water only if mosquitoes have laid their eggs in the water.

If living things come only from preexisting life, something or someone initiated life at some point. Christians believe this was a Creator God.

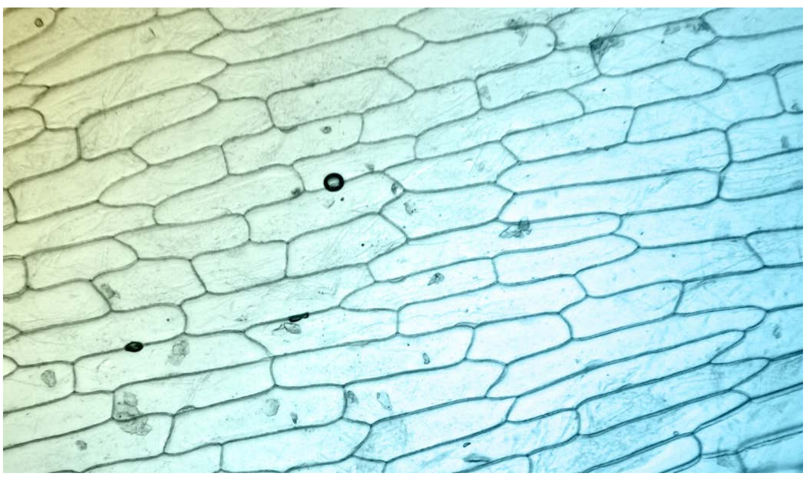


Redi's experiments showed that maggots appeared on meat that flies could reach, but not on meat in gauze-covered jars.

Made of Cells

If you used a microscope to examine the bracket fungi that were mentioned earlier, you would see cells. That would not be true of the crystal or the stalactite even though they both appear to grow. The coral might be more difficult to categorize. What is often called coral is the leftover shell of a coral polyp. Once the living portion of the coral—the polyp—dies, it leaves behind a long-lasting structure made of calcium carbonate (limestone), which does not have cells. However, the original coral polyp was made of cells.

All living things are composed of cells. This principle is known as the **cell theory.** Some organisms, like bacteria, are **unicellular.** Other organisms, called **multicellular** organisms, are made up of many cells working together. Regardless of whether a cell is living an independent life as a unicellular organism or is functioning as part of a multicellular organism, the cell is the smallest level at which life can exist. Individual parts of a cell will not continue to live and reproduce if they are removed from the cell.



This plant tissue exhibits the cellular structure that characterizes all living things.

cell theory: all living things are composed of cells

unicellular (yü ni sel′ yə lər): consisting of a single cell

multicellular (məl tē sel′ yə lər): consisting of multiple cells

Flowers That Follow the Sun

Young sunflowers turn their heads throughout the day to continually face the sun. By sunset, they are facing westward, but during the night, they turn to face east again to catch the morning rays. This continues throughout a sunflower's growth, but when a sunflower is mature, the movement stops. Mature sunflowers only face east.

Research has shown that tracking the sun helps young sunflowers grow faster. However, when sunflowers mature, they redirect their energy from growing to producing seeds. By facing east at all times, mature sunflowers catch the morning sun, which warms them faster in the mornings. Warm flowers attract more bees, which means pollination increases, allowing the flower to produce more seeds.

Need Energy

Just as an engine cannot run without fuel, living organisms cannot function without a source of energy. This need for energy begins at the cellular level.

A cell teems with activity. It constructs new cell parts, moves substances within the cell, takes in new substances, gets rid of wastes, and reproduces. All these activities require a cell to have a continuous supply of energy. If a cell does not have constant energy, it will die. Food provides this necessary energy.

Cells of plants, some algae, and a few bacteria can obtain energy directly from the sun and use it to make their own food. Organisms that make their own food are called **autotrophs.** Animals, fungi, and most bacteria must consume plants or other living things to obtain energy for their cells. Organisms that cannot make their own food, but must feed on other organisms, are called **heterotrophs.**

Dissecting Words

auto–*self*
hetero–*other, different*
troph–*to nourish, nutrition*

Literal meaning:
autotroph–*to nourish oneself*
heterotroph–*to be nourished by another*

Related words:
automobile, automatic, heterozygous, eutrophic

Sense and Respond to Change

Living things spend their lives in environments that are constantly changing, often in dangerous or life-threatening ways. In one sense, organisms are at the mercy of their environment, but they are designed to sense changes in their surroundings. They can often respond in various ways to protect themselves. If an organism does become diseased or injured, its cells sense the problem and respond by working to repair and heal the organism.

Living things maintain life by constantly sensing changes and responding to them. A lizard moves into the sun to warm up

autotroph (ȯ′ tō trōf′): an organism that makes its own food, such as a plant or alga

heterotroph (he′ tə rō trōf′): an organism that does not make its own food, but feeds on other organisms

A common cuttlefish (*Sepia officinalis*) can change its color almost instantly to match its surroundings.

and then back into the shade when the sun becomes too hot. An earthworm senses light and moves away from it to avoid drying out. A plant adjusts the angle of its leaves in relation to the sun to maximize the amount of energy it will receive. Animal cells sense when cellular calcium levels have become too high and respond by pumping calcium out of the cell.

Grow, Mature, and Die

Living things move through a life cycle of early life, maturity, and death. These stages mark their lifespan. Growth in a living thing is more than adding substance the way a crystal or a stalactite does. Living things grow by taking in new substances, breaking them down, and reorganizing them into living structures. For example, a sweet corn plant absorbs water from the soil and carbon dioxide from the air. Using energy from sunlight, the plant converts the water and carbon dioxide into **glucose,** a simple sugar. The corn plant then uses the glucose to provide energy for growth and to make the starches and sugars in the ear of sweet corn.

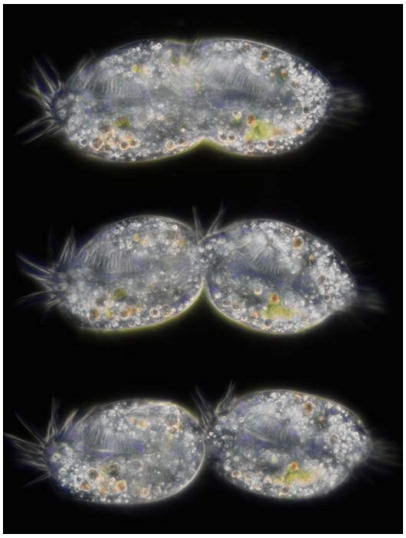
Contain DNA

Deoxyribonucleic acid (DNA) is a complex **molecule** found in every cell. DNA stores immense amounts of information that directs the characteristics of cell structures and the activities of the cell. DNA is a blueprint that controls the construction of proteins. Under the direction of DNA, specific proteins are assembled in specific sequences to organize lifeless chemicals into living systems.

glucose: a simple sugar; the most common energy source for organisms

deoxyribonucleic acid (DNA) (dē äk′ si rī′ bō n(y)ü klē′ ik a′ səd): a molecule that carries genetic information, which is the blueprint for the cell

molecule (mä′ li kyül′): a particle made up of two or more atoms bonded to each other



Many unicellular organisms reproduce asexually by splitting into two genetically identical cells.

Baby animals are similar to their parents because they inherit genetic information from their parents.

Reproduce

"And God blessed them, saying, Be fruitful, and multiply" (Genesis 1:22). From the beginning, God built into every living kind the ability to pass on life to new organisms of the same kind. The information written into DNA was designed to be replicated and passed on to the next generation.

At Creation, each kind was given its own **genetic** information. Puppies look similar to full-grown dogs because they have inherited dog information in their DNA. You are a human being created in God's image because you have inherited human information in your DNA from your parents. The DNA you received contains a mixture of the specific human characteristics carried by your father and mother. The same basic human information has been passed down accurately through scores of generations since Adam and Eve.

Some organisms reproduce by splitting into two parts after duplicating their own DNA. Each of the two daughter organisms receives a full copy of the parent's DNA. Both daughters are essentially identical to the parent. This is known as **asexual reproduction.** Other organisms require a male and a female to reproduce. Each parent supplies half the DNA. **Sexual reproduction** produces offspring that have DNA derived from two organisms. This allows continuing variation in the offspring.

Observe the living things around you. Notice how each one demonstrates the criteria of this lesson. Consider an ivy plant, a cod, a eucalyptus tree, and an elephant. Each of these living organisms comes from preexisting life. They are made of cells that contain

Dissecting Words

a–*not*

Literal meaning:
asexual–*not sexual*

Related words:
abiotic, asymmetrical, asymptomatic

genetic: having to do with hereditary material (DNA)

asexual reproduction (ā sek′ shü əl rē′ prə dək′ shən): reproduction that involves only one parent organism; offspring are practically identical to the parent

sexual reproduction: reproduction that involves two parent organisms; offspring have a blend of the parents' genetic material

DNA and need energy to survive. Each living thing responds to its environment, grows, and eventually dies. These all reproduce living organisms like themselves. As you explore biology this year, notice how these traits characterize each of the organisms you study.

1.2 Concept Review

1. Since all life comes from preexisting life, what can we be certain of?
2. What principle states that all living things are composed of cells?
3. What determines whether an organism is an autotroph or a heterotroph?
4. What molecule stores the information that directs cell processes?

1.3 Classification of Living Things

1.3 Objectives

After this lesson, students should be able to . . .

1. List the levels of Linnaeus's classification system.
2. Write and abbreviate the scientific name of an organism when given all the taxonomic levels the organism resides in.
3. Classify a list of organisms into the correct kingdom.
4. Explain why the Biblical "kind" is not the same as a species.
5. Explain why the concept of subspecies is necessary.
6. Construct the scientific name of a subspecies when given the necessary information.

Did you ever wonder where to find a *Notophthalmus viridescens?* Probably not, but maybe you have been to a zoo and really wanted to see a particular kind of animal. Where would you begin to look—in the elephant exhibit, with the big cats, in the reptile house, or maybe with the hoofed mammals?

During the six days of Creation, God called plants and animals into being by large categories: grasses, herbs, fruit-bearing trees, sea creatures, birds, creeping things, cattle, and beasts of the earth. Those categories help us understand what types of creatures were created each day. Whenever we want to talk about something or try to find it among other things, categories are useful. When you go into a library with thousands of books, you can find a specific book quickly because the books are classified according to topic.

However, classifying all living things is no easy task. The number of currently identified **species** is around 1.5 million, and up to 20,000 new species are discovered each year. How can we begin to study them all? We cannot, but because God created many organisms with similar features, we can study characteristics of categories or groups of these living things.

species: a group of similar organisms that interbreed naturally and produce fertile offspring

Classifying Kingdoms

For centuries, students of living things have sought to classify both plants and animals as a way to understand them better. One of the earliest attempts at classification divided plants and animals into two groups: "useful" and "not useful." As more and more plants and animals were discovered, a better system of organization was needed.

New Species Discoveries

While many new species are discovered by scientists in remote areas, some species are "created" when a currently recognized species is split into multiple species. Others are found in old museum collections. Insects comprise about half of the new species that are discovered each year. New mammal discoveries are much rarer.

The Myanmar snub-nosed monkey (*Rhinopithecus strykeri*) was discovered in Myanmar in 2010. This monkey sneezes in the rain because its upturned nose collects water. It sits out most rainy spells with its face down and its head between its knees.

The Samkos bush frog (*Chiromantis samkosensis*), another recent discovery, was first described in 2007. This Cambodian frog has green blood and turquoise-colored bones.

In the mid-1700s, Carolus Linnaeus (li nē′ əs), a Swedish naturalist, developed a system for classifying organisms. His system is still used today with a few modifications. In many respects, it is like an outline. It places plants and animals into groups and subgroups and then even smaller subgroups. Linnaeus chose to classify organisms according to structural similarities, traits that could easily be seen. He sought to carefully observe God's creation and understand the similarities as well as the unique features of each kind of life.

Linnaeus started his system of **taxonomy** by dividing living things into two kingdoms—plants and animals—but he did not have the scientific tools we have at our disposal today. Since his time, the development of better microscopes has allowed scientists to study the internal structures of living things in much greater detail. Scientists have found that many organisms do not fit neatly into the categories of plants and animals.

For example, mushrooms and other fungi lack chlorophyll, and they cannot photosynthesize to make their own food like plants. They also lack the tissue structure of plants. However, they clearly lack many characteristics of animals. If fungi are neither plants nor animals, where do they fit in Linnaeus's classification system?

The purpose of classification systems is to help us study the diverse living things in our world. Scientists decided that the differences between plants and fungi were great enough to warrant creating a new kingdom just for fungi. To better understand the world of **microorganisms, taxonomists** decided to place them in a separate kingdom as well. Finally, an additional kingdom was created for bacteria.

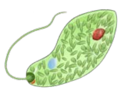
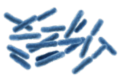
Fungi differ from plants in their tissue structure and their inability to make their own food.

taxonomy (tak sä′ nə me): the science of classifying organisms

microorganism: an organism too small to be seen without a microscope

taxonomist (tak sä′ nə mist): a scientist who classifies organisms

Today, most biologists divide organisms into five or six kingdoms. In this biology course we will use a five-kingdom classification system.

Five-Kingdom Classification System			
Kingdom	Type of Organism	Description	Examples
Animalia	animals 	• multicellular • heterotrophic	mammals, fish, birds, reptiles, amphibians, insects, spiders
Plantae	plants 	• multicellular • most autotrophic	trees, flowers, shrubs, vines, mosses, ferns
Fungi	mushrooms and other fungi 	• most multicellular • decomposers	mushrooms, molds, lichen, yeasts
Protista	microscopic organisms 	• unicellular or loosely associated groups of single cells • heterotrophic (algae autotrophic)	algae, protozoa, water molds, slime molds
Monera	bacteria (microscopic) 	• most unicellular and heterotrophic (cyanobacteria autotrophic) • decomposers • prokaryotic	bacteria, cyanobacteria (blue-green algae)

We will refer to the information in this chart throughout our study of biology.

Taxonomy: Classifying Life

After Linnaeus divided living things into the plant and animal kingdoms, he divided both of those two kingdoms into smaller divisions known as phyla. He further divided each phylum (singular form of *phyla*) into classes and then into smaller groups. Today, as then, this classification system has seven levels: kingdom, phylum, class, order, family, genus, and species.

The kingdom level contains many, many organisms with very general similarities. Each successively lower level has fewer organisms. However, at each lower level, organisms share more traits. Finally, at the species level, there is only one specific type of organism.

As an example of classification, consider *Notophthalmus viridescens.* Although we need only those two words to identify this organism, we will give the full taxonomic name to illustrate the various levels of taxonomy: Animalia Chordata Amphibia Caudata Salamandridae *Notophthalmus viridescens.* That is a long name for a small animal, but

The eastern newt (*Notophthalmus viridescens*) lives on land during its juvenile stage (left). In this stage, it is called a red eft. Adult eastern newts live in the water (right).

from its name, you may already have some idea of what this creature is. You can probably tell it is an animal and not a plant. You may also recognize names from some of the other levels. Here is the full name fitted into the taxonomy levels.

Kingdom: Animalia—animals (over 1 million members)
Phylum: Chordata—animals with backbones (47,000)
Class: Amphibia—cold-blooded, smooth-skinned vertebrates (4,460)
Order: Caudata—amphibians with tails (400)
Family: Salamandridae—newts and true salamanders (70)
Genus: *Notophthalmus*—North American newts (3)
Species: *Notophthalmus viridescens*—eastern newt (1)

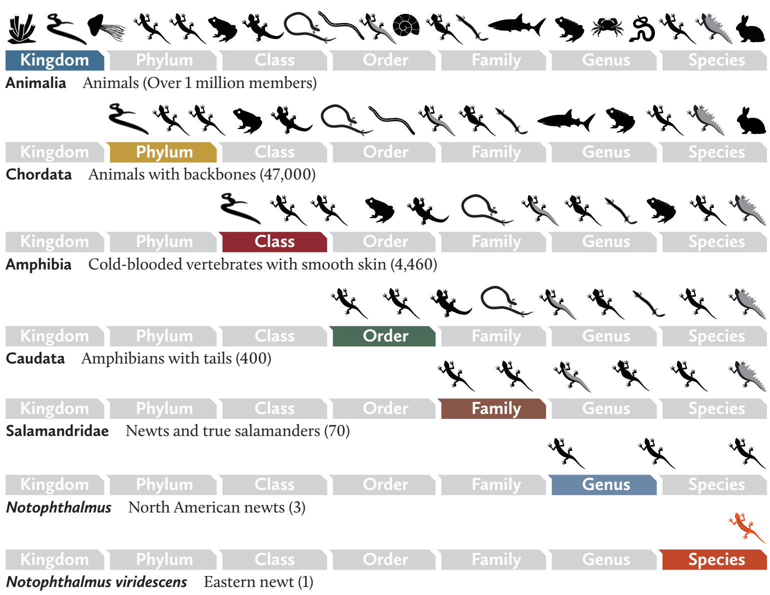


Figure 1.3-1 Each successive taxonomy level becomes more specific, with members sharing more similarities than the members of previous levels.

As you can see, each subdivision has fewer and fewer members. Each subdivision also tells us a little more specifically what this creature is—an eastern newt. You may have seen one of these colorful newts (similar to a salamander) in the woods or even in your window well. The juvenile terrestrial stage of this species is called an eft. After a year or two of living on land, the efts lose their brilliant coloring and return to the water for their adult life. You probably would not recognize them as the same creature you saw in the woods.

Classification Difficulties

Plants, animals, and other life forms do not always fit neatly into the classification groups we make for them. One confusing area is the concept of species. What exactly is a species? Biologists do not totally agree on a definition, but a species is usually defined as a group of similar organisms that interbreed naturally and produce **fertile** offspring.

Grizzly bears (*Ursus arctos*) and mountain lions (*Puma concolor*) cannot interbreed, so they are considered separate species. In captivity, grizzly bears have been bred to several other types of bears with at least some of the offspring being fertile. However, since this rarely occurs in nature, the grizzly and these other bears are still considered separate species. There are exceptions to the criteria for species, so this definition is a guide, not an absolute rule.

This grolar bear is the offspring of a grizzly bear (*Ursus arctos*) and a polar bear (*U. maritimus*). Grizzly and polar bears are considered separate species since they do not regularly interbreed in the wild.

fertile: able to produce offspring

Ligers and Tigons

Lions (*Panthera leo*) and tigers (*Panthera tigris*) rarely interbreed in nature; therefore, they are considered separate species. However, they have been crossbred successfully in captivity. The offspring of a male lion and a female tiger is called a *liger,* and the offspring of a male tiger and a female lion is called a *tigon.*

Although they may appear cute, ligers and tigons often suffer from various deformities. Most of them are sterile, and many die at a young age. Because their behavior is a mixture of lion characteristics and tiger characteristics, these animals find it difficult to interact with either lions or tigers. They also suffer from other genetic defects and obesity.

Ligers can be huge, weighing as much as 400 kg (900 lb) and measuring 3.3 m (10.8 ft) from head to tail. Biologists think the size of ligers is caused by an interplay between male and female lion genes. Male lions pass on genes that encourage large size, while female lions pass on genes that discourage large size. Tigers have no comparable genetic balancing. When interbred, male lions pass on genes for large size that female tigers cannot counteract. The result is that ligers tend to be larger than either of their parents, while tigons tend to be the same size or slightly smaller than their parents.

These canines are all gray wolves, but they are members of different subspecies: *Canis lupus arctos* (left), *Canis lupus pallipes* (center), and *Canis lupus arabs* (right).

The confusion about animals that can interbreed, but rarely do so in nature, may point to the Biblical **kind.** "And God said, Let the earth bring forth the living creature after his kind" (Genesis 1:24). The Bible never specifies the meaning of *kind.* Linnaeus originally intended for the term *species* to mean the same as the Biblical *kind,* but over time, the meaning of *species* has changed. A kind is probably best represented by a genus or family.

It seems that at Creation there was a dog kind, a cat kind, a bear kind, and so forth. God endowed the parents of each kind with enough genetic information to result in offspring with significant variation. Over time, groups of these offspring could have become different enough to be considered separate species. This process is different from evolution because genetic information is being lost, not created.

Two members of the same species are not always identical. Many species consist of several populations, often geographically separated, with distinctive characteristics. These diverse populations of a single species are called **subspecies.** Subspecies are not as clearly defined as species are, but the concept of subspecies can still help us understand differences between populations of a single species.

Sometimes taxonomists find it difficult to determine which category they should place an organism into. Since classification systems are man-made, they may not reflect the true relationships between organisms. However, they are biologists' best attempts to simplify the study of living things. As such, they are a useful tool.

kind: a God-established grouping of organisms that typically includes many similar species that have a common ancestor from the original Creation; may be able to interbreed, but rarely do so in nature

subspecies: one of several characteristically distinctive populations of a species

Binomial Nomenclature

You may wonder why taxonomists give organisms such strange names. One of the reasons is that today's taxonomists continue to follow Linnaeus's system of using Latin and latinized Greek names. Linnaeus chose to use Latin names because Latin was the language of scholars of his day. Any scholar, regardless of his native language, could understand it. Furthermore, since Latin was a "dead" language, the meaning of words would not continue to change over the years the way they do in spoken languages. Lastly, formal Latin names prevented confusion when a species had more than one common or local name. The eastern newt is also called a red-spotted newt. Which is correct? Either is fine in common usage, but the name *Notophthalmus viridescens* clearly indicates the exact species.

But why use two names for a species? This again was introduced by Linnaeus. It is referred to as **binomial nomenclature.** It is like having a first name and a last name. These two names represent the genus and the species of the organism, so they are sometimes called the generic and specific names. The two names are collectively called the organism's **scientific name.** Notice that the genus name is always capitalized and that both parts of the name are italicized. When used repeatedly, scientific names are often abbreviated by using only the first letter of the genus name, followed by a period. For example, *Notophthalmus viridescens* would be abbreviated *N. viridescens.*

Often, both words in a scientific name describe the organism. In the case of *N. viridescens,* the genus name *Notophthalmus* means "eye markings," referring to the round spots, and *viridescens* means "greenish tint," suggestive of the coloration of the adults.

The scientific names of subspecies are written with three words; the first two words are the scientific name of the species, and the third word describes the subspecies. For example, the scientific name of the gray fox is *Urocyon cinereoargenteus.* The subspecies that lives in southern California is *Urocyon cinereoargenteus californicus,* while the gray fox of New England is the subspecies *Urocyon cinereoargenteus borealis.*

This animal has many common names: cougar, mountain lion, puma, panther, and catamount. It can be more clearly identified by its scientific name, *Puma concolor.*

How Do I Pronounce *Notophthalmus viridescens?*

Like this: nō´ tof thal´ məs vē´ ri des´ sens. Actually, you needn't be too concerned you will pronounce scientific names incorrectly. These names are used globally, and they are pronounced many different ways in different areas. It is generally safe to pronounce the word as it looks, according to the normal rules of pronunciation.

1.3 Concept Review

1. Into what two kingdoms did Linnaeus divide all living things?
2. What are the seven levels of Linnaeus's classification system?
3. Which classification levels are used in binomial nomenclature?
4. What extra classification level do biologists sometimes use to classify diverse populations of a species?

binomial nomenclature (bī nō′ mē əl nō′ mən klā′ chər): a system of naming an organism by using its genus and species name

scientific name: the generic and specific name of an organism

1.4 Matter and Energy

1.4 Objectives

After this lesson, students should be able to . . .

1. Explain what an element is and how the number of protons is related to each type of atom.
2. State the charges and other characteristics of protons, neutrons, and electrons.
3. Describe what causes atoms to become ions.
4. Explain how ionic and covalent bonds form.
5. Identify the number and chemical symbols of common types of atoms in chemical formulas.
6. Explain the difference between kinetic and potential energy.
7. Explain how organisms can store and release the potential energy in chemical bonds.

The Portuguese man o' war (*Physalia physalis*) rides the ocean under a large translucent gas bladder. Using this bulbous float like a sail, it sweeps the ocean with its 10-meter (30-foot) tentacles, armed with millions of microscopic stingers. Each stinger carries a neurotoxin to paralyze and kill small sea creatures. The tentacles gently lift the hapless prey to the man o' war's fingerlike stomachs, which engulf and absorb the prey with digestive chemicals.

What materials make up the delicate gas float and tentacles of the Portuguese man o' war? What mechanisms craft its tiny stingers and load them with toxins? What forces hoist paralyzed sea creatures and convert them into energy and nutrients?

Every structure and function of every plant and animal is rooted in chemistry. Complex chemical reactions drive every life process. To better understand these functions and processes, you must become familiar with the chemistry that makes them possible.

The structures and functions of the Portuguese man o' war are formed and controlled by chemistry.

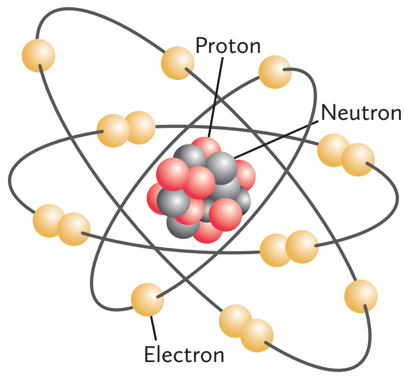
Atoms and Elements

All matter, including every plant and animal, is built of atoms connected in different ways to form a vast variety of chemical **compounds.** Atoms are considered to be the smallest unit of matter. Atoms are composed of three smaller particles: protons, neutrons, and electrons. Protons and neutrons are the heaviest of these particles. They form a tight cluster, or **nucleus,** in the center of the atom. The nucleus is surrounded by a cloud of orbiting electrons. Electrons are tiny compared to protons and neutrons, but they are important to an atom's chemical behavior.

Each type of atom contains a specific number of protons. Different atoms of the same type can have different numbers of neutrons and electrons, but the number of protons never varies. For example, carbon atoms always have six protons, and helium atoms always have two protons.

A substance made of only one type of atom is called an **element.** An element cannot be broken into different types of atoms. Water is not an element because it is made of both hydrogen and oxygen atoms. Iron is an element because it contains only one type of atom, each containing exactly twenty-six protons. No chemical reaction could divide iron into different types of atoms.

Scientists have discovered over one hundred different elements, but only about two dozen of these are important to living organisms. Each element can be referred to with a symbol. For example, N is the chemical symbol for nitrogen, a major component of Earth's atmosphere. C represents carbon, an element found in all life.



Atoms are composed of protons, neutrons, and electrons.

Atomic Behavior

Much of an atom's behavior is dictated by its protons and electrons. These two particles have a mysterious attraction for each other. Scientists describe the attraction by saying that protons have a positive charge and electrons have a negative charge. Opposite charges attract each other while like charges repel. Neutrons have no charge, so they are not attracted to other particles.

Many atoms are neutral, meaning they have an equal number of protons and electrons. The charge from each positive proton cancels out a charge from a negative electron. Some atoms, called **ions,** have an unequal number of protons and electrons. Ions carry a net positive or negative charge.

compound: a substance composed of two or more types of atoms

nucleus (nü′ klē əs)**:** a cluster of protons and neutrons in the center of an atom

element: a substance composed of only one type of atom

ion (ī′ än′)**:** a charged atom containing an unequal number of protons and electrons

For example, neutral calcium atoms contain twenty protons and twenty electrons. However, most calcium atoms have only eighteen electrons. Since these ions have two more protons than electrons, they have a positive charge of two. A calcium ion with a positive charge of two is written as Ca^{2+}.

Ionic and Covalent Bonds

Ions form when an atom donates electrons to another atom, making the donor positive and the recipient negative. Since opposite charges attract, these ions pull on each other, forming a connection called an **ionic bond.**

Many compounds important to life contain ionic bonds. When a sodium atom (Na) meets a chlorine atom (Cl), it donates one electron to the chlorine atom. The sodium atom becomes positive because it has *fewer* electrons than protons. The chlorine atom becomes negative because it has *more* electrons than protons. The negative chloride ion forms an ionic bond with the positive sodium ion; together they become sodium chloride (NaCl), also known as table salt.

$$Na^{+} + Cl^{-} \rightarrow NaCl$$

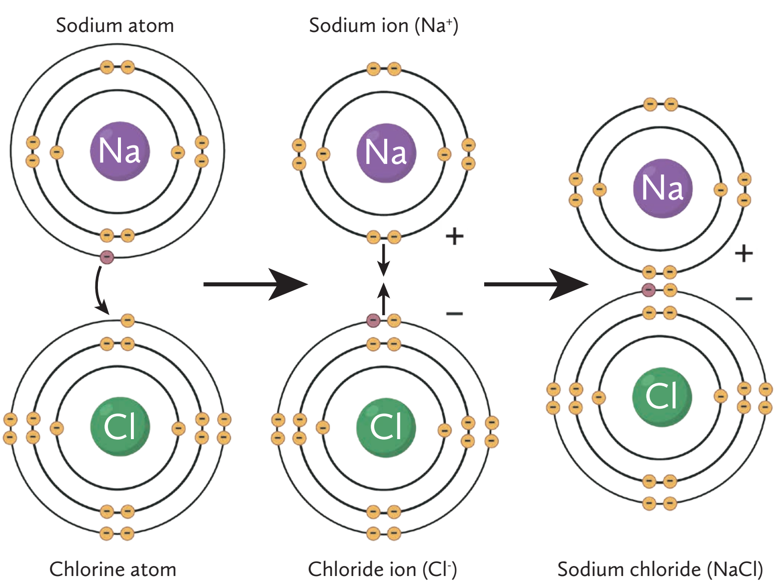


Figure 1.4-1 When a sodium atom meets a chlorine atom, it donates an electron to the chlorine atom (left), forming an ionic bond (center, right).

ionic bond (ī ä′ nik   bänd′): a bond formed between ions with opposite charges

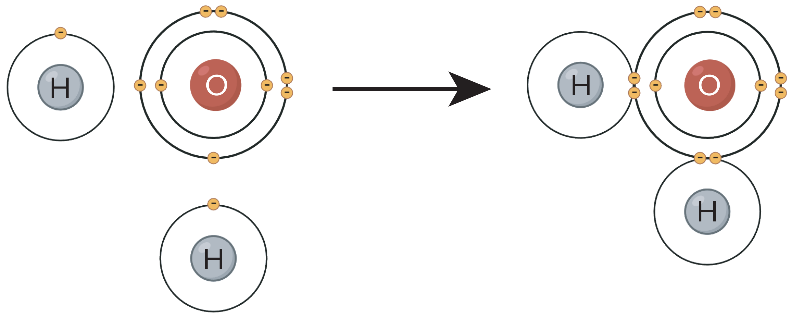


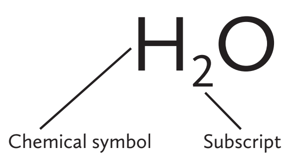
Figure 1.4-2 The hydrogen atoms and the oxygen atom in a water molecule share electrons with each other to form two covalent bonds.

Atoms can also connect through **covalent bonds.** These bonds form when two atoms share a pair of electrons. Each covalent bond involves two shared electrons that orbit around both atoms. Two atoms can also form double or triple covalent bonds by sharing four or six electrons.

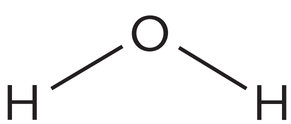
Molecules and Compounds

When atoms connect using covalent bonds, they form a molecule. The compounds that compose plants and animals are molecules.

Chemical formulas are used to describe the composition of compounds. For example, the chemical formula of water is H_2O. This formula tells us that every molecule of water contains two hydrogen atoms and one oxygen atom. The chemical formula of methane is CH_4, which means that a methane molecule contains one carbon atom and four hydrogen atoms. Each chemical symbol represents an element. If a subscript follows a chemical symbol, it specifies how many atoms of that element are present within the molecule. A chemical symbol that is not followed by a subscript signifies a single atom.



Chemists use diagrams to show the shapes of molecules. Letters represent the atoms, while the lines that connect the atoms represent covalent bonds. Here is the diagram of a water molecule.



Chemical Symbols of Common Elements	
Hydrogen	H
Helium	He
Carbon	C
Nitrogen	N
Oxygen	O
Sodium	Na
Phosphorus	P
Sulfur	S
Chlorine	Cl

covalent bond (kō vā′ lənt bänd′): a bond formed between two atoms sharing electrons


A crouched leopard has potential energy (left). When the leopard springs, the potential energy is converted to kinetic energy (right).

Energy

Organisms harvest the energy they need to survive from their food. This is possible because the molecules in their food store energy.

Two main types of energy are important in biology: kinetic energy and potential energy. **Kinetic energy** is energy in motion. For example, a swinging hammer has kinetic energy that can drive a nail into wood. **Potential energy** is stored in an object. A stretched rubber band contains potential energy. It converts this energy to kinetic energy when it is released.

Molecules can also have kinetic and potential energy. In a glass of water, the water molecules are in constant motion, colliding with and bouncing off each other. This is kinetic energy. As the molecules collide, they transfer kinetic energy back and forth.

We experience kinetic energy at the molecular level as heat. In fact, temperature is a measure of molecular kinetic energy. In other words, molecules with low kinetic energy move slowly and have a low temperature. Molecules with higher kinetic energy move faster and have a higher temperature.

Molecules store potential energy within their bonds. When these chemical bonds break and form, energy is either absorbed or released. In organisms, chemical reactions release the potential energy stored in the chemical bonds of their food to power life processes.

kinetic energy (kə ne′ tik e′ nər jē): energy related to motion

potential energy: stored energy

1.4 Concept Review

1. What drives every life process?
2. Where are the protons and neutrons of an atom found?
3. What are two methods by which atoms can connect to form molecules?
4. How many atoms of carbon and oxygen are found in a molecule of carbon dioxide (CO_2)?
5. What two forms of energy are important to life processes?

1.5 Chemical Reactions

The bombardier beetle is a harmless-looking insect, but its abdomen carries a nasty surprise for predators. When threatened, the beetle sprays a potent combination of chemicals at its adversary. As the chemicals mix, they react violently, hitting the predator with an explosion of boiling chemical irritants.

The intense heat of a bombardier beetle's spray comes from a **chemical reaction** between its defensive chemicals. A chemical reaction occurs whenever chemical bonds break or form. Since chemical bonds store potential energy, chemical reactions are accompanied by large energy changes. Organisms use these energy changes to power their life activities.

The bombardier beetle can defend itself by using a chemical reaction to produce a boiling spray.

Chemical Equations

Chemists describe the **reactants** and **products** of a chemical reaction with chemical equations. This equation describes the formation of water from hydrogen and oxygen molecules.

$$2H_2 + O_2 \rightarrow 2H_2O$$
$$\text{reactants} \rightarrow \text{product}$$

In other words, when *two* hydrogen molecules (H_2) react with *one* oxygen molecule (O_2), they form *two* water molecules (H_2O).

The large numbers specify how many molecules of each type are involved in the reaction. If no number appears before a molecule,

1.5 Objectives

After this lesson, students should be able to . . .

1. Describe what occurs during a chemical reaction.
2. Explain all the information contained in a chemical equation.
3. Describe the difference between exergonic and endergonic reactions.
4. Explain why photosynthesis is an endergonic reaction.
5. Explain why reactions require activation energy.
6. Describe the function of a catalyst.

The Chemical Bombs of the Bombardier Beetle

How can a bombardier beetle produce a boiling chemical irritant without destroying itself? These beetles are designed with two special chambers that keep the reactants separate. When needed, the reactant chemicals mix in a special reaction chamber. The reaction produces intense pressure, which enables the beetle to shoot the chemical up to 20 cm (8 in). The reaction chamber is fitted with a one-way valve that produces a pulsating jet, which allows the beetle to cool between pulses. The valve also prevents the mixture from reentering the beetle's body.

chemical reaction: a change in matter that occurs when chemical bonds break or form

reactant: a substance that reacts during a chemical reaction

product: a substance produced by a chemical reaction then only one molecule is involved. Chemical equations must contain the same number of atoms of each element on both sides of the arrow. Each side of this equation contains four hydrogen atoms and two oxygen atoms, even though they are arranged into different molecules.

Energy and Chemical Reactions

The total amount of energy before and after a reaction is always the same. In other words, chemical reactions don't create or destroy energy; they convert energy into different types. For example, when hydrogen and oxygen form water, they convert some of the potential energy stored in their chemical bonds into kinetic energy in the form of heat. In this reaction, the reactants (hydrogen and oxygen) have more potential energy than the product (water).

Because temperature is directly related to molecular kinetic energy, an energy change usually results in a temperature change. If the temperature increases during a reaction, we know that potential energy became kinetic energy. If temperature decreases, kinetic energy was converted into potential energy.

The total amount of matter before and after a reaction is also the same, even though the atoms may be arranged into different molecules. Chemical reactions never create or destroy matter.

Exergonic Reactions

Exergonic reactions release energy into the environment. The products of an exergonic reaction contain less potential energy than the reactants.

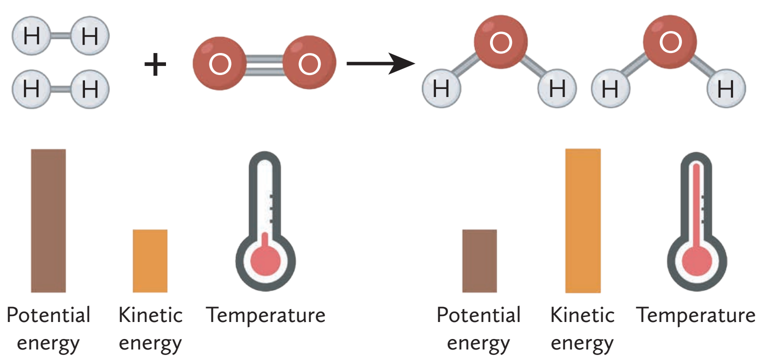


Figure 1.5-1 Hydrogen and oxygen combine to form water, releasing energy in the process. The energy that is released was initially stored in the chemical bonds of the hydrogen and oxygen molecules.

exergonic reaction (ek' sər gä' nik rē ak' shən): a reaction in which energy is released

The formation of water (H_2O) from hydrogen (H_2) and oxygen (O_2) is a violent reaction. Some of the potential energy in the hydrogen and oxygen rapidly becomes kinetic energy, and it is released as an explosion of heat and light. The energy that is released in exergonic reactions is sometimes shown on the products side of a chemical equation.

$$2H_2 + O_2 \rightarrow 2H_2O + heat$$

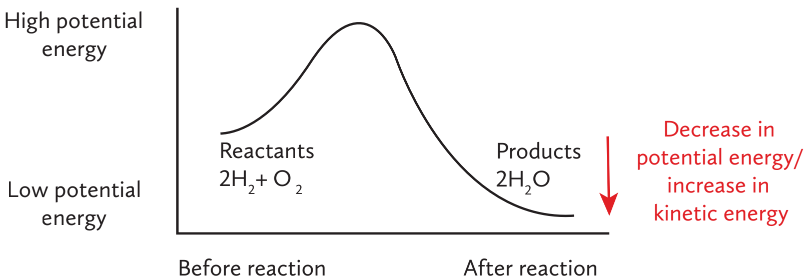


Figure 1.5-2 Exergonic reaction

Because this reaction converts potential energy into kinetic energy, it is an exergonic reaction. Figure 1.5-2 shows the total potential energy before, during, and after the reaction. Notice that the product (water) contains less potential energy than the reactants. The missing potential energy became kinetic energy and was lost to the environment as heat.

The spray from the bombardier beetle triggers an exergonic reaction like the exergonic reaction between hydrogen and oxygen gas. As the beetle's defensive chemicals react, they release a large amount of potential energy as kinetic energy, causing the explosion and boiling temperatures.

Endergonic Reactions

Endergonic reactions absorb energy from the environment. The products of an endergonic reaction contain more potential energy than the reactants.

Ammonium nitrate (NH_4NO_3) is often used in fertilizers. In water, it breaks into two molecules, ammonium (NH_4^+) and nitrate (NO_3^-). This reaction cools its environment by converting kinetic energy from the environment into potential energy. The energy absorbed by an endergonic reaction is sometimes shown on the reactants side of a chemical equation.

$$NH_4NO_3 + heat \rightarrow NH_4^+ + NO_3^-$$

endergonic reaction (en′ dər gä′ nik rē ak′ shən): a reaction in which energy is absorbed

Here is the energy diagram of this endergonic reaction. Notice that the products contain more potential energy than the reactants. The energy for this increase was absorbed as heat from the environment.

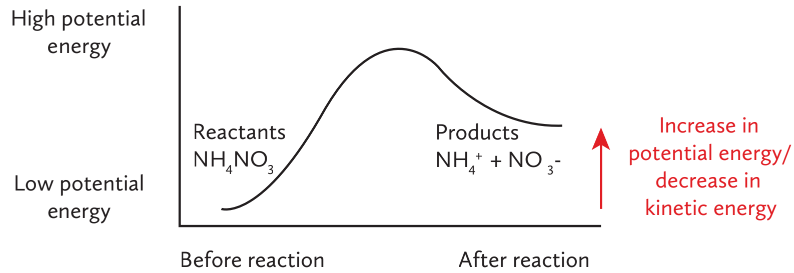


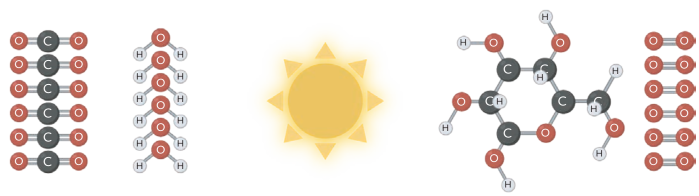
Figure 1.5-3 Endergonic reaction

Photosynthesis and Cellular Respiration

Endergonic and exergonic reactions convert energy from the sun to a form that plants and animals can use.

Plants capture the sun's energy in an endergonic reaction called **photosynthesis.** This reaction converts carbon dioxide (CO_2) and water (H_2O) into oxygen (O_2) and a molecule called glucose ($C_6H_{12}O_6$). This reaction is endergonic because the product, glucose, contains more potential energy than the reactants. This energy was absorbed from sunlight. Photosynthesis occurs in many complicated steps, but it is easily summarized by its chemical equation:

$$6CO_2 + 6H_2O + \text{energy (light)} \rightarrow C_6H_{12}O_6 + 6O_2$$



Animals and other organisms absorb glucose in their food; then glucose releases its potential energy during **cellular respiration.** Cellular respiration is a complex exergonic reaction that releases the potential energy in glucose. Its equation is the reverse of photosynthesis:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy (biological activity)}$$

Figure 1.5-4 shows how sunlight uses photosynthesis and cellular respiration to power almost all biological activity on Earth. It also shows how these complicated chemical reactions complement each other to sustain life.

photosynthesis (fō′ tō sin′ thə səs): a reaction performed by plants that uses carbon dioxide, water, and energy from the sun to produce glucose

cellular respiration (sel′ yə lər res′ pə rā′ shən): a reaction that animals and plants use to release the potential energy stored in glucose

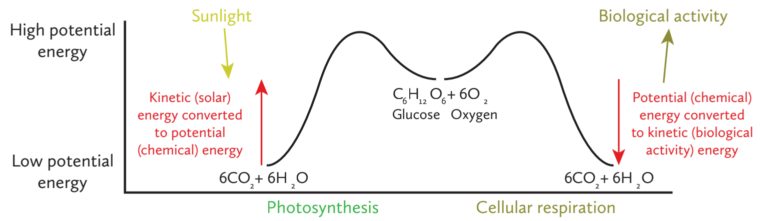


Figure 1.5-4 Photosynthesis and cellular respiration are complementary reactions.

Activation Energy, Catalysts, and Enzymes

Chemical reactions require a certain amount of energy before they can occur. For example, a newspaper will not burn until it is heated by a source such as the flame of a match. This initial energy requirement is called a reaction's **activation energy.**

In an energy diagram, the hill separating the products and reactants represents the activation energy. The higher the hill, the more activation energy the reaction requires. If there is not enough energy available, the reaction will not occur.

A **catalyst** lowers the activation energy of a chemical reaction. In this energy diagram, notice that a catalyst reduces the reaction's activation energy but does not change the energy of the reactants and the products.

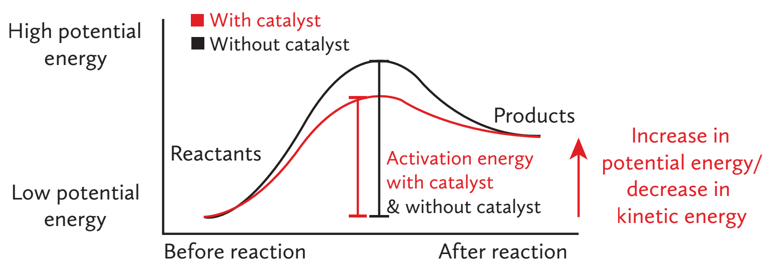


Figure 1.5-5 Catalysts lower the activation energy of reactions.

Plants and animals perform thousands of chemical reactions with high activation energies. Photosynthesis and cellular respiration, for example, involve dozens of chemical reactions that require some sort of catalyst. Organisms produce biological catalysts called **enzymes** to assist these reactions.

For example, an enzyme called carbonic anhydrase helps form carbonic acid from water and carbon dioxide. This reaction allows blood to dissolve more carbon dioxide.

$$CO_2 + H_2O \xrightarrow{\text{Carbonic Anhydrase}} H_2CO_3$$

Carbonic anhydrase is a gigantic molecule made of carbon, nitrogen, oxygen, and other elements. Carbon dioxide and water

activation energy: the energy needed to start a chemical reaction

catalyst: a substance that lowers the activation energy of a reaction

enzyme: a protein catalyst used by organisms

Enzyme Deficiency Diseases

When a person's body cannot manufacture a certain enzyme, they may develop an enzyme deficiency disease. Without the enzymes to process particular substances, these substances can build up within a person's body. The results can be mild enough to not be noticeable or severe enough to cause permanent mental retardation.

Lactose intolerance is a relatively common condition that occurs when an individual does not produce enough lactase, the enzyme that breaks down lactose. People with lactose intolerance may experience stomach pain, nausea, or diarrhea after eating dairy products, which contain lactose.

Phenylketonuria (PKU) is a more serious enzyme deficiency disease. Babies with PKU cannot break down phenylalanine, an amino acid found in protein. Phenylalanine levels increase in the blood, eventually causing severe brain damage. Babies born in the United States are tested for this disease within forty-eight hours of birth. If affected individuals follow a strict diet, they can avoid the worst of the complications and live fairly normal lives.

Individuals with pseudocholinesterase enzyme deficiency cannot make an enzyme that breaks down general anesthesia. If an affected person does not get tested, the condition will go unnoticed. During surgery, these people cannot break down the muscle relaxants in anesthesia. After surgery, they may regain consciousness without being able to breathe or ask for help. Most times they must remain on a breathing machine several hours longer than other people. Interestingly, people with pseudocholinesterase enzyme deficiency are more susceptible to harm from certain agricultural sprays since these substances are also broken down by the same enzyme.

interact with a small region on the enzyme called the **active site.** When both reactants are in the active site, carbonic anhydrase helps them react to form carbonic acid.

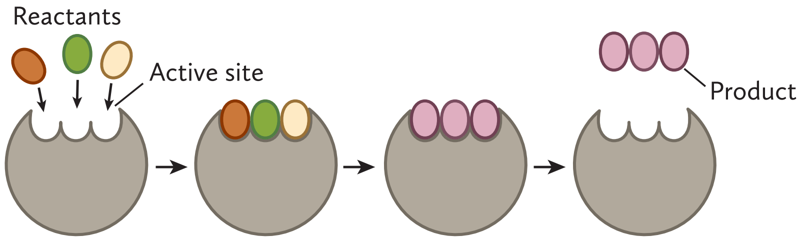


Figure 1.5-6 An enzyme can help a reaction occur when the necessary reactants are in the active site of the enzyme.

Organisms make thousands of enzymes, each specific to a certain reaction. Photosynthesis and cellular respiration rely on myriads of enzymes to produce glucose and harvest its energy. In the stomach, enzymes break down food into small particles. Other enzymes produce building materials, degrade wastes, or fight disease.

1.5 Concept Review

1. What two parts of a chemical reaction are shown in a chemical equation?
2. What type of chemical reaction converts potential energy to kinetic energy?
3. What type of chemical reaction converts kinetic energy to potential energy?
4. What requirement must be met to start a chemical reaction?

active site: the region on an enzyme where a reaction occurs

1.6 Water

All the chemistry of life relies on water. From fish swimming in the ocean to cacti living in Earth's driest desert, all plants and animals need water to survive. Water is vital to life because it has several unique chemical properties. These properties promote every chemical reaction in biology, and therefore, they promote life itself.

1.6 Objectives

After this lesson, students should be able to . . .

1. Explain what causes the water molecule to be polar.
2. Describe how hydrogen bonds cause the properties of water.
3. Describe the different parts of a solution.
4. Explain the chemical definitions of acids and bases.

Staying Hydrated in the Desert

Many organisms can easily obtain an adequate supply of water from their environment. In very dry climates, however, plants and animals cannot rely on conventional methods of acquiring water. Instead, these desert dwellers were created with ingenious features that allow them to survive in their hostile environment.

For example, some cacti survive by absorbing moisture from fog. When fog envelops these cacti, miniscule droplets of water collect on their spines. The structure of the spines (cone-shaped, with microscopic grooves) causes the droplets to move along the spines toward the plant, whether the spines point up or down. As soon as a droplet reaches the base of a spine, water-absorbing structures draw the water into the cactus where it can be used in cellular processes.

Plants cluster around this oasis because it provides the water they need to survive.

Polarity and Hydrogen Bonds

A water molecule consists of two hydrogen atoms bonded to an oxygen atom, giving the molecule a bent shape. Simple as it is, the structure of a water molecule gives water many of the properties that make it vital for life.

Even though the entire molecule is neutral, areas of the molecule have partial charges. The oxygen is partially negative, while the hydrogens are partially positive. Molecules with such charge differences between their atoms are called **polar molecules.**

When water molecules bump into each other, the positive hydrogens from one molecule pull on the negative oxygen from another molecule. This attraction is called a **hydrogen bond.** A water molecule can form hydrogen bonds with four other water molecules. Hydrogen bonds are weaker than ionic or covalent bonds, but they have an important place in biology.

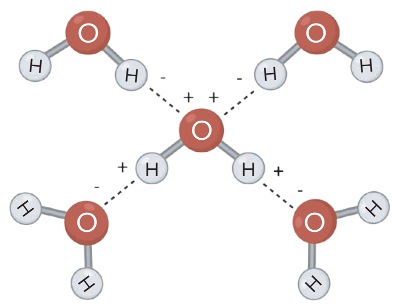


Figure 1.6-1 Water molecules form a hydrogen bond when the hydrogen atom in one molecule is attracted to the oxygen atom in another molecule.

Hydrogen bonds explain the behavior of water in its three phases. As a liquid, water molecules constantly form and break hydrogen bonds. When water is heated, its molecules gain kinetic energy until they escape their hydrogen bonds and float into the atmosphere as steam. When liquid water cools, its molecules lose kinetic energy

polar molecule: a molecule with slight differences in charge between its atoms

hydrogen bond: an attraction between the hydrogen atom in one molecule and an oxygen, fluorine, or nitrogen atom in another molecule until they can no longer break their hydrogen bonds, forming ice. Ice is less dense than liquid water because the hydrogen bonds hold the water molecules farther apart than if they were jumbled together randomly. Floating ice allows life to exist below the surface by insulating the water from freezing temperatures.

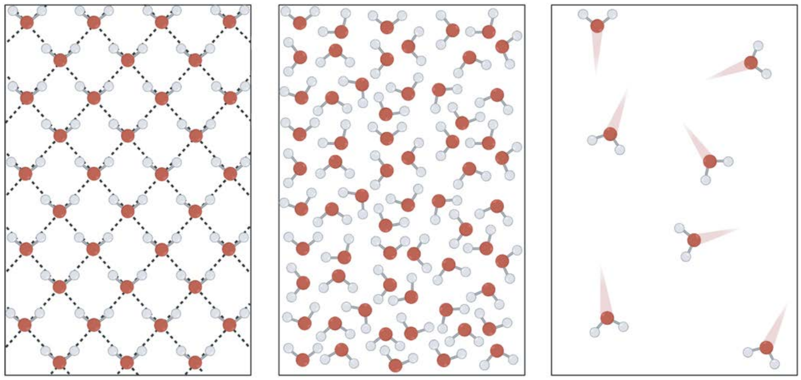


Figure 1.6-2 Water behaves differently in its solid (left), liquid (center), and gas (right) phases because of its hydrogen bonds.

Cohesion and Adhesion

Cohesion occurs when a substance is attracted to itself. Water is cohesive because its molecules form hydrogen bonds with each other. Cohesion causes the surface of water to resist breaking and stretching. This is called **surface tension.** Some animals, such as water striders, take advantage of this surface tension to travel across the surfaces of creeks and ponds.

cohesion: attraction between molecules of the same substance

surface tension: resistance of the surface of a liquid to break or stretch because of cohesion

Any compound that contains an oxygen-hydrogen bond can form hydrogen bonds with water. For this reason, water is also good

This water strider can stand on the surface of the water because cohesion keeps the surface from breaking under the weight of the insect.

This water has not fallen from the needles because cohesion is holding it together as droplets, and adhesion is causing it to stick to the needles.

at **adhesion,** forming an attraction with a different material. In a glass tube, the surface of the water curves up at the edges due to its adhesion to the glass.

Adhesion and cohesion work together to cause capillary action. You can observe this phenomenon by submerging one end of a small tube in water. Adhesion with the walls of the tube pull water molecules upward. These molecules pull more molecules with them through cohesion, and the water rises within the tube. Plants use capillary action to help draw water up their stems.

Water as a Solvent

When water dissolves another substance, such as sodium chloride or sucrose (table sugar), it forms a **solution.** Solutions are a type of mixture in which a **solvent,** such as water, dissolves a **solute,** such as sucrose, by pulling the ions or molecules apart from each other. Solutions are important in biology because cells are mostly filled with solutions of proteins, salts, sugars, and other compounds dissolved into water.

Water easily dissolves ionic and polar molecules. These chemicals are described as **hydrophilic,** or "water-loving," because they dissolve well in water. Ionic and polar substances dissolve in water

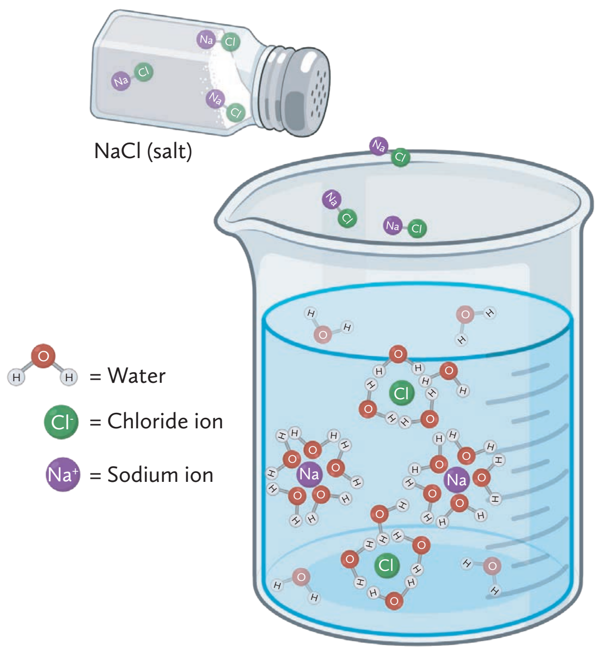


Figure 1.6-3 The polarity of water allows it to readily dissolve ionic substances such as sodium chloride (NaCl).

Dissecting Words

hydro–*water*
phil–*loving*
phob–*fear*

Literal meaning:
hydrophilic–*loving water*
hydrophobic–*fearing water*

Related words:
hydrate, hydrant, photophilic, Philadelphia, claustrophobia, technophobic

adhesion: attraction between molecules of two different substances

solution: mixture in which one or more substances are dissolved by another substance

solvent: the substance doing the dissolving in a solution; often a liquid

solute: the substance being dissolved in a solution

hydrophilic (hī′ drə fi′ lik)**:** tending to dissolve in water

Soil pH and Hydrangea Colors

Soil acidity can drastically change the color of certain varieties of hydrangeas. A soil pH below 5.5 will yield blue flowers, while a pH above 6.5 will yield pink flowers. If the pH is between 5.5 and 6.5, the flowers will be purple. Gardeners can control the color of the blossoms by adding sulfur to lower the pH or adding lime to raise the pH.

because their ions and molecules have charges that are attracted to the charged areas of the water molecules. This attraction allows the water molecules to pull the ions or molecules apart from each other to dissolve the substance. Once the ions or molecules are pulled apart from each other, the water molecules surround the dissolved particles to prevent them from rejoining.

Nonpolar substances (molecules without partial positive and negative charges) are **hydrophobic.** These compounds do not dissolve in water because they have no partially charged regions to attract the partially charged regions of water molecules. If you pour a hydrophobic compound such as vegetable oil into a glass of water, the two liquids will repel each other and form separate layers.

This illustrates a general principle that "like dissolves like." In other words, polar chemicals dissolve other polar chemicals. Similarly, nonpolar chemicals (like vegetable oil) dissolve other nonpolar chemicals. But polar and nonpolar molecules do not mix well.

Acids, Bases, and Buffers

In pure water, about 1 in every 550 million water molecules breaks spontaneously into a hydrogen ion (H^+) and a hydronium ion (OH^-). The reaction is reversible, so these ions can quickly reform into water molecules. Here is the chemical equation of this spontaneous reaction; the double-sided arrow shows that this reaction can proceed in both directions.

$$H_2O \leftrightharpoons OH^- + H^+$$

Acids are chemicals that add hydrogen ions (H^+) to water. When a solution contains more H^+ ions than OH^- ions, we say it is acidic. **Bases** are the opposite; they absorb hydrogen ions from water. When water has more OH^- ions than H^+ ions, we say it is basic.

We use the pH scale to describe how acidic or basic a solution is. The pH scale extends from 0 to 14. Neutral solutions contain the same number of H^+ and OH^- ions, so they have a pH of 7. Acidic solutions have a pH below 7; basic solutions have a pH above 7.

In most organisms, even small fluctuations in pH can be life-threatening. Organisms make **buffers** to help them maintain a nearly neutral pH. Buffers are chemicals that absorb H^+ ions when they are too numerous and release H^+ ions when they are too scarce. Buffers keep the pH of an organism nearly the same, even when it absorbs acids or bases.

hydrophobic (hī′ drə fō′ bik): not dissolving in water

acid: a chemical that adds hydrogen ions to water and lowers the pH of a solution

base: a chemical that reduces hydrogen ions in water and raises the pH of a solution

buffer: a substance that helps maintain a stable pH

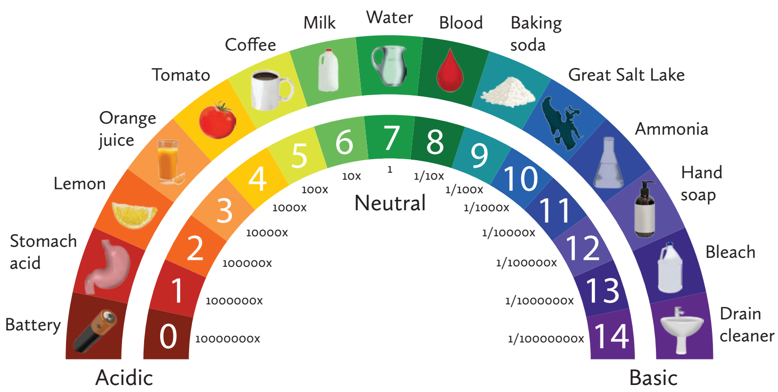


Figure 1.6-4 The pH scale describes how acidic or basic a substance is.

Blood contains a robust buffer system in the form of bicarbonate (HCO_3^-) and carbonic acid (H_2CO_3) that keeps the pH of blood between 7.35 and 7.45. Exercise and other bodily functions can produce acids or bases, so the buffer system must work to neutralize them and keep the blood at an optimal pH.

1.6 Concept Review

1. What type of molecule has areas with partial charges?
2. What type of bond do water molecules form with each other?
3. In a solution, is water the solvent or the solute?
4. What determines whether a solution is an acid or a base?

1.7 Carbohydrates and Lipids

All life contains four classes of molecules: carbohydrates, lipids, proteins, and nucleic acids. These shared molecules, called biomolecules, allow energy and materials to flow efficiently between organisms. The Galápagos tortoise can digest and absorb the fruit in its diet because it needs the same biomolecules that are in the fruit. Similarly, the jack-o'-lantern mushroom can digest dead wood because it needs the same biomolecules that are found in a decaying tree.

1.7 Objectives

After this lesson, students should be able to . . .

1. Explain how polymers form.
2. Explain why glucose is the most important carbohydrate.
3. Compare monosaccharides, starches, glycogen, and cellulose.
4. Describe the structure of lipids.
5. Explain the importance of lipids in living things.
6. Explain how the hydrophilic head and hydrophobic tail of some lipids make them work well to construct cell membranes.

Biomolecules and Polymerization

Organisms are made largely of carbon. This element is especially useful in biology, partly because carbon atoms can form four covalent bonds. These bonds allow carbon to form a huge variety of large and complex molecules. Organisms produce these biomolecules to grow and perform life activities.