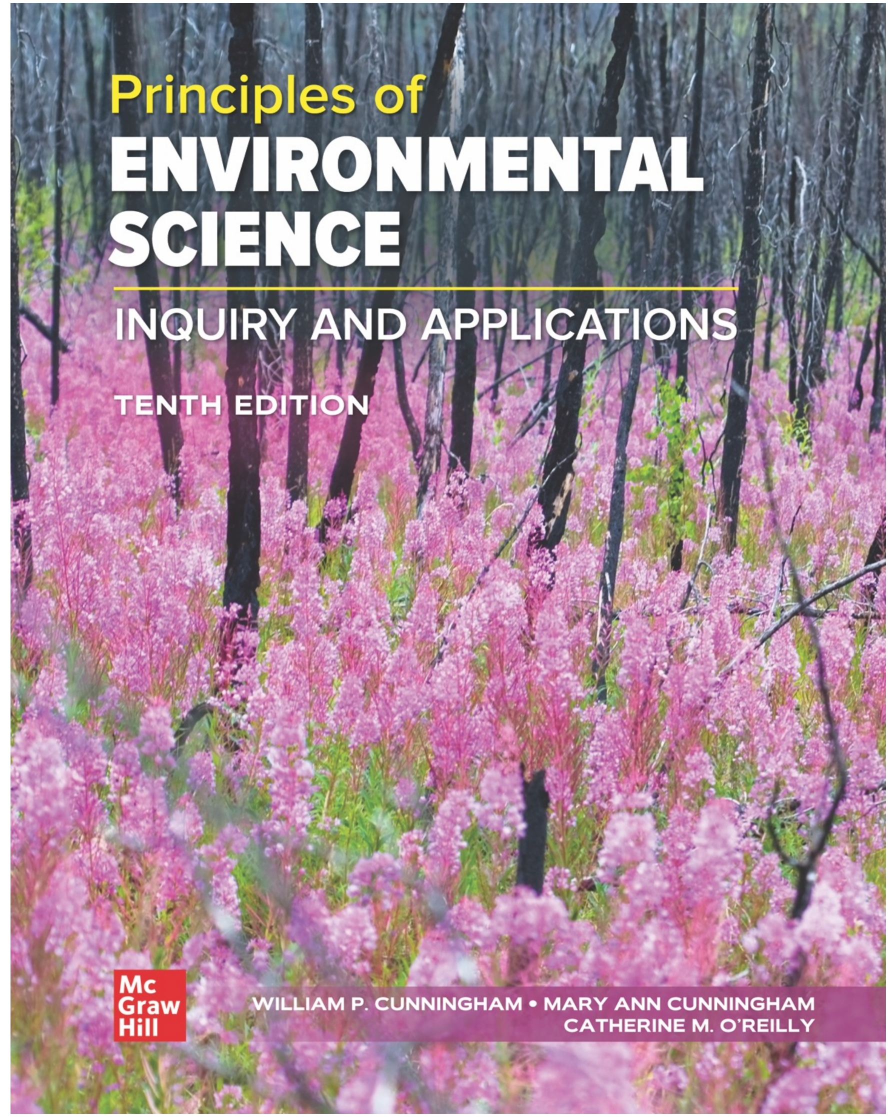
Because learning changes everything.®

Chapter 2 Lecture Outline



Learning Outcomes

After studying this chapter, you should be able to answer the following questions:

What are systems, and how do feedback loops affect them?

Explain the first and second laws of thermodynamics.

Ecologists say there is no “away” to throw things to, and that everything in the universe tends to slow down and fall apart. What do they mean?

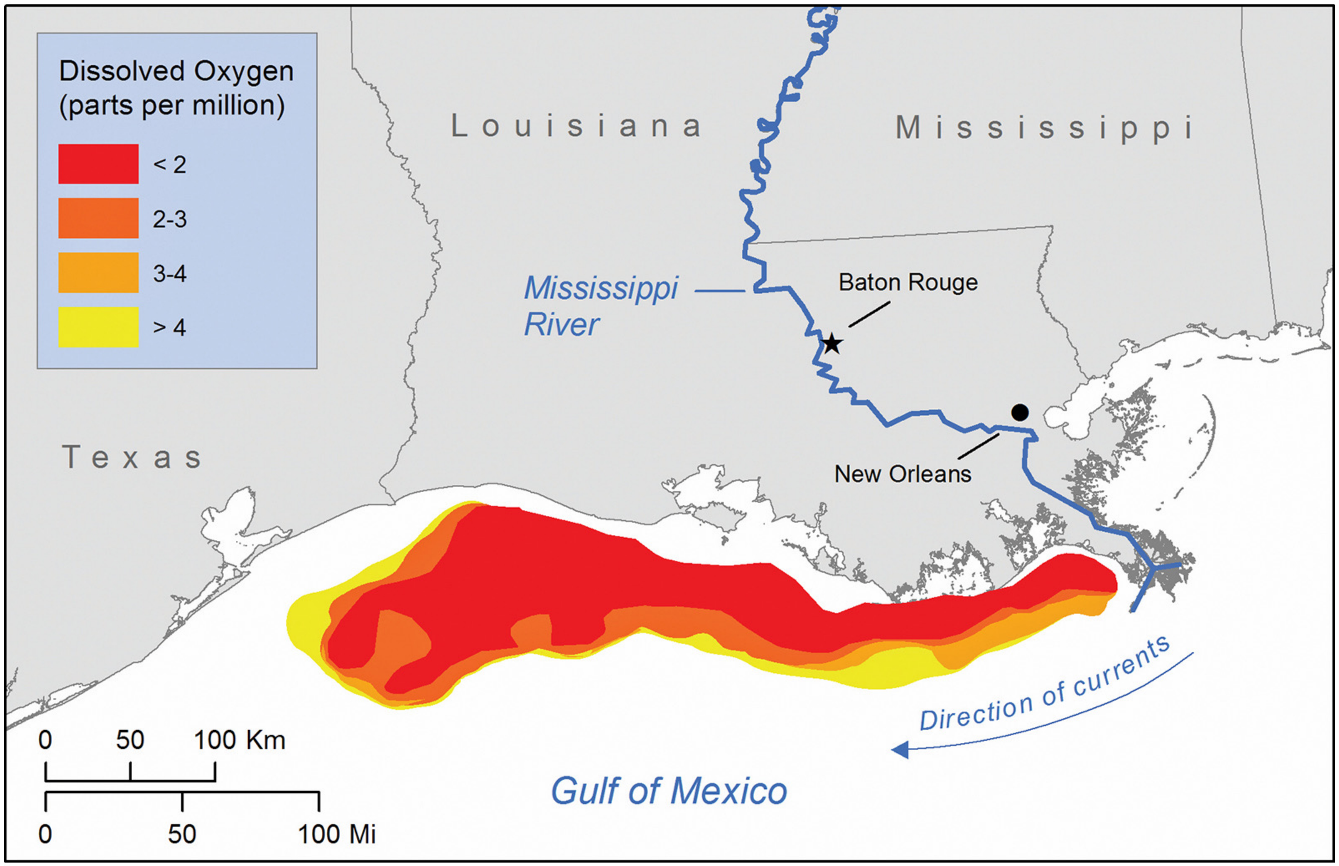
Explain the processes of photosynthesis and respiration.

What qualities make water so unique and essential for life as we know it?

Why are big, fierce animals rare?

How and why do elements such as carbon, nitrogen, phosphate, and sulfur cycle through ecosystems?

CASE STUDY: Death by Fertilizer–Hypoxia in the Gulf of Mexico



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Source: N. Rabalais, LSU/LUMCON, http://www.noaa.gov/media-release/gulf-of-mexico-dead-zone-is-largest-ever-measured

Most institutions demand unqualified faith; but the institution of science makes skepticism a virtue.

–Robert King Merton

2.1 Systems Describe Interactions

A **system** is a network of interdependent components and processes with materials and energy flowing from one component of the system to another.

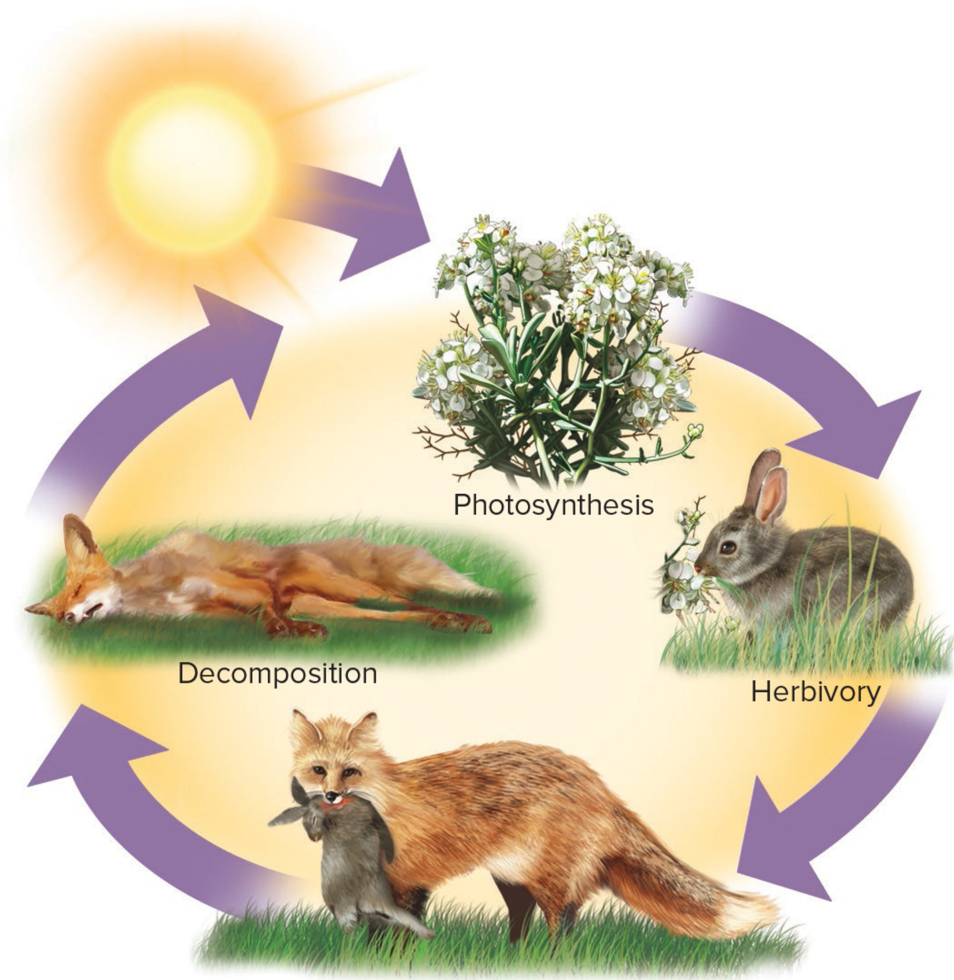
An **ecosystem** is a complex assemblage of animals, plants, and their environment, through which materials and energy move.

Systems Can Be Described in General Terms

A simple system consists of:

- **state variables** (also called compartments), which store resources such as energy, matter, or water.
- **flows**, or the pathways by which those resources move from one state variable to another.

An Ecosystem



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Systems Can Be Described in Terms of Their Characteristics

Open systems are those that receive inputs from their surroundings and produce outputs that leave the system.

A **closed system** exchanges no energy or matter with its surroundings.

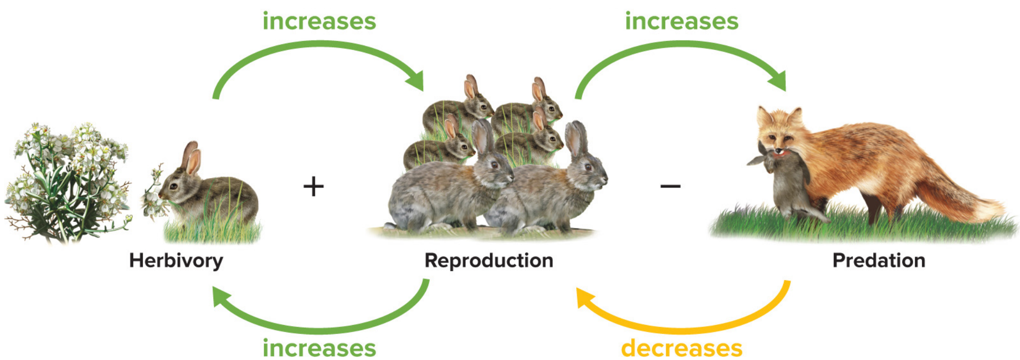
Throughput is a term we can use to describe the energy and matter that flow into, through, and out of a system.

Feedback Loops Help Stabilize Systems

Systems function in cycles, with each component eventually feeding back to influence the size or rate of itself.

A **positive feedback loop** tends to increase a process or component.

A **negative feedback loop** diminishes a process or component.



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Emergent Properties and Systems

The term **emergent properties** is used when the characteristics of a whole system are greater than the sum of its parts.

2.2 Elements of Life

Matter is anything that takes up space and has mass**.**

Matter exists in three distinct states—

- Solid.
- Liquid.
- Gas.

The principle of **conservation of matter** states that, under ordinary circumstances, matter is neither created nor destroyed but rather is recycled over and over again.

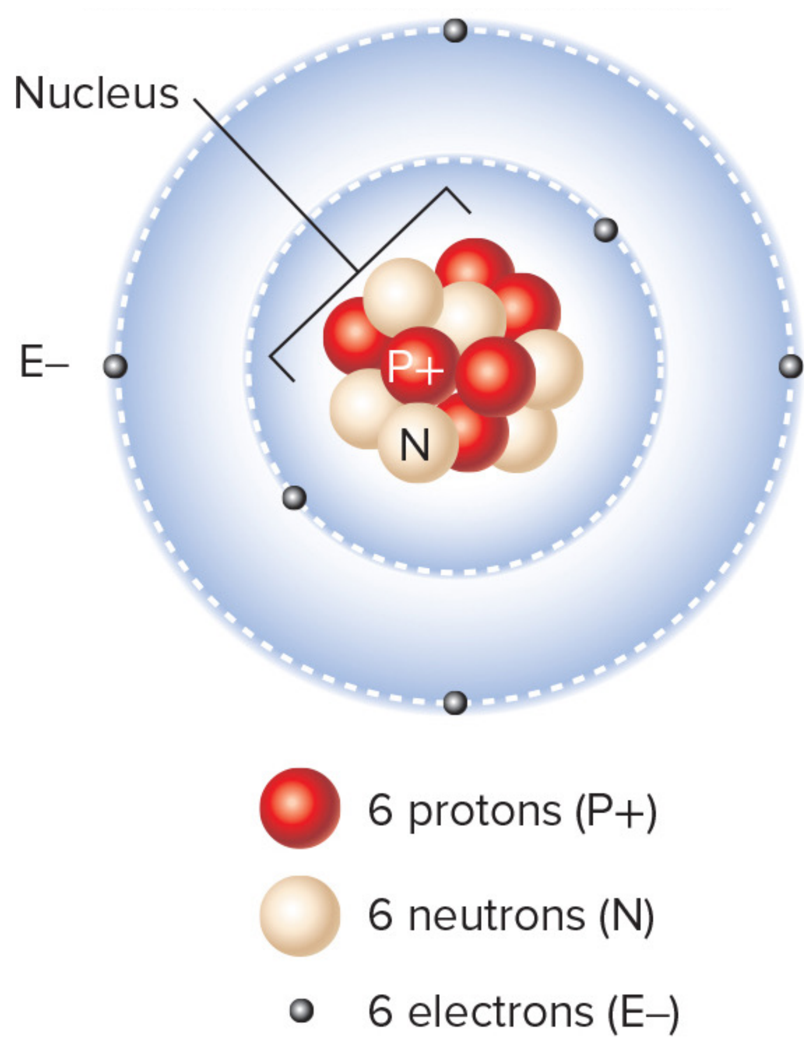
Elements Have Predictable Characteristics

Matter consists of **elements** such as P (phosphorus) or N (nitrogen), which are substances that cannot be broken down into simpler forms by ordinary chemical reactions.

Atoms are the smallest particles that exhibit the characteristics of an element.

Atoms are composed of a **nucleus**, made of positively charged **protons** and electrically neutral **neutrons**, circled by negatively charged **electrons.**

Structure of a Carbon Atom



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Elements Have Unique Structure

Each element is listed in the periodic table according to the number of protons per atom, called its **atomic number.**

The number of neutrons in the atoms of an element can vary slightly.

The **atomic mass** is the sum of the protons and neutrons in each nucleus.

Isotopes are forms of a single element that differ in their atomic mass.

Electrical Charges Keep Atoms Together 1

Atoms frequently gain or lose electrons, acquiring a negative or positive electrical charge. Charged atoms (or combinations of atoms) are called **ions.**

Negatively charged ions (with one or more extra electrons) are **anions**.

Positively charged ions are **cations**.

A sodium (Na) atom, for example, can give up its sole electron to become a sodium ion $\left(Na^{+}\right)$.

Chlorine (Cl) readily gains electrons, forming chlorine ions $\left(Cl^{-}\right)$.

Electrical Charges Keep Atoms Together 2

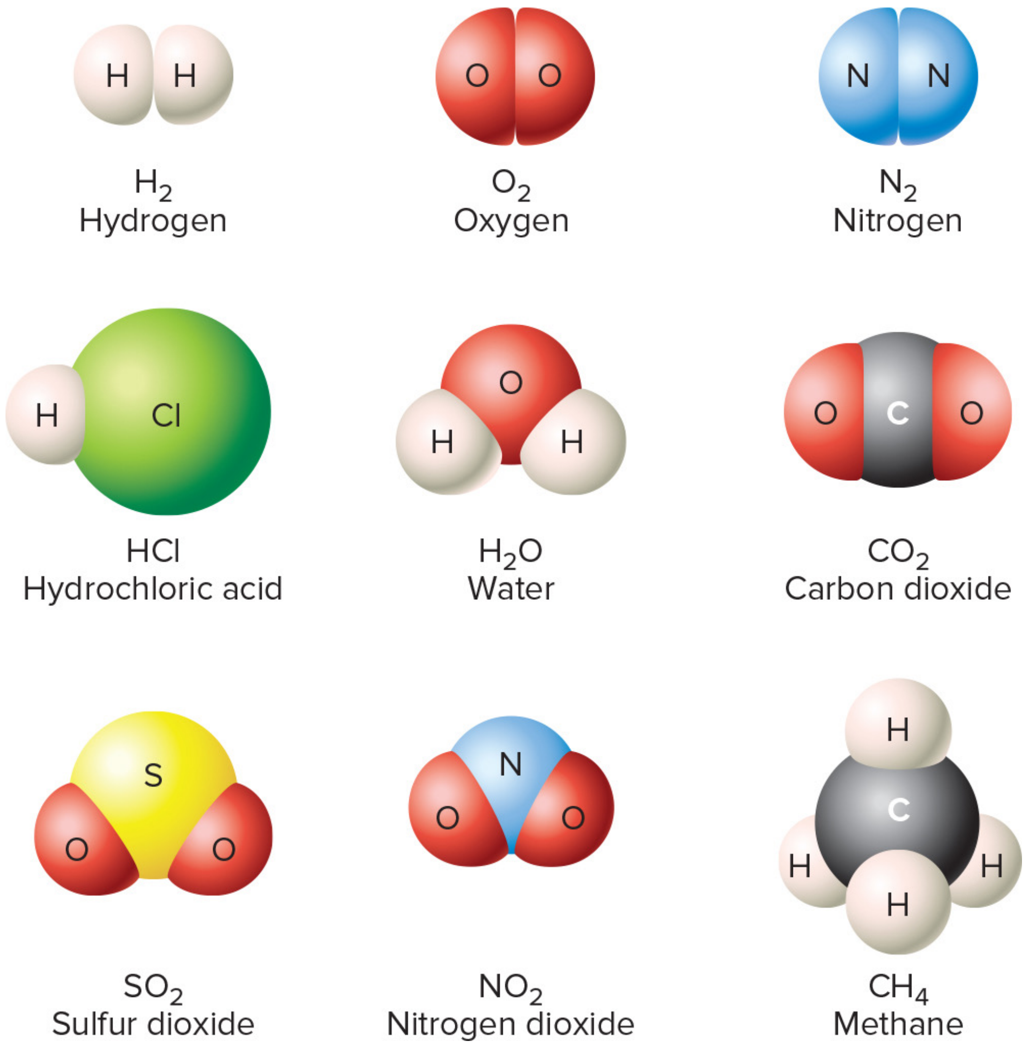
Atoms of elements often join to form **compounds,** or substances composed of different kinds of atoms.

A pair or group of atoms that can exist as a single unit is known as a **molecule**.

When ions with opposite charges form a compound, the electrical attraction holding them together is an **ionic bond**.

Sometimes atoms form bonds by sharing electrons, forming **covalent bonds**.

Common Molecules



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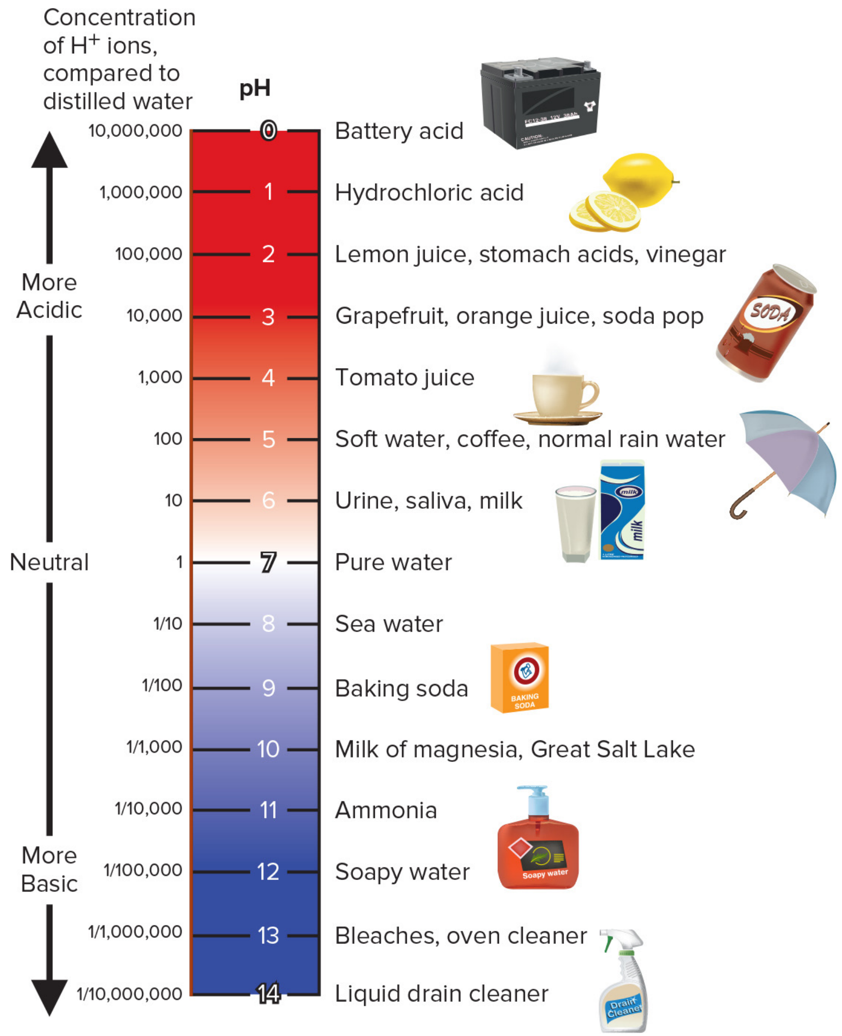
Acids and Bases Release Reactive H^+ and OH^-

Substances that readily give up hydrogen ions $\left[H^+\right]$ in water are known as **acids.**

Substances that readily bond with H^+ ions are called **bases** or alkaline substances. Such substances release hydroxide ions $\left[OH^-\right]$.

We describe acids and bases in terms of **pH.** Acids have a pH below 7; bases have a pH greater than 7. A solution of exactly pH 7 is “neutral.”

The pH Scale



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Organic Compounds Have a Carbon Backbone

Carbon is a special element because chains and rings of carbon atoms form the skeletons of **organic compounds**, the material of which biomolecules, and therefore living organisms, are made.

The four major categories of organic compounds in living things (“bio-organic compounds”) are:

- Lipids.
- Carbohydrates.
- Proteins.
- Nucleic acids.

Four Categories of Organic Molecules 1

Lipids (including fats and oils) store energy for cells and provide the core of cell membranes and other structures.

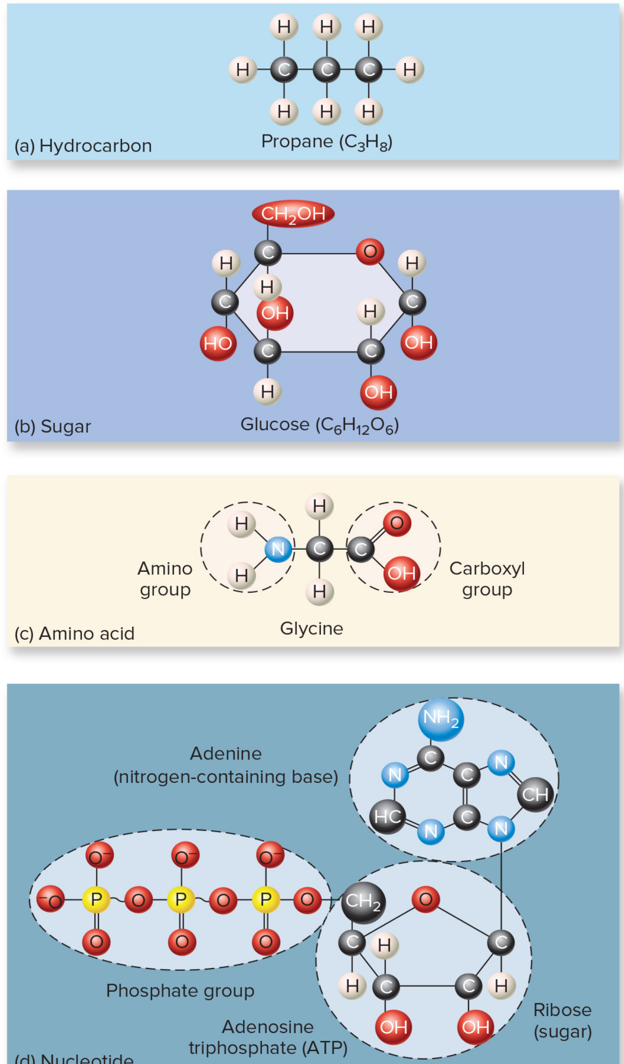
Carbohydrates (including sugars and starches) also store energy and provide structure to cells. They usually consist of a long chains of simple sugars like glucose.

Four Categories of Organic Molecules 2

Proteins are composed of chains of amino acids folded into complex 3-D shapes. Proteins provide structure to cells and are used for countless cell functions, including enzymes.

Nucleotides are complex molecules made of a 5-carbon sugar, one or more phosphate groups, and a nitrogen-containing base. Nucleotides are extremely important as signaling molecules and as sources of energy within cells. They also form long chains called nucleic acids *(RNA or DNA)* that store and express genetic information.

Organic Molecules



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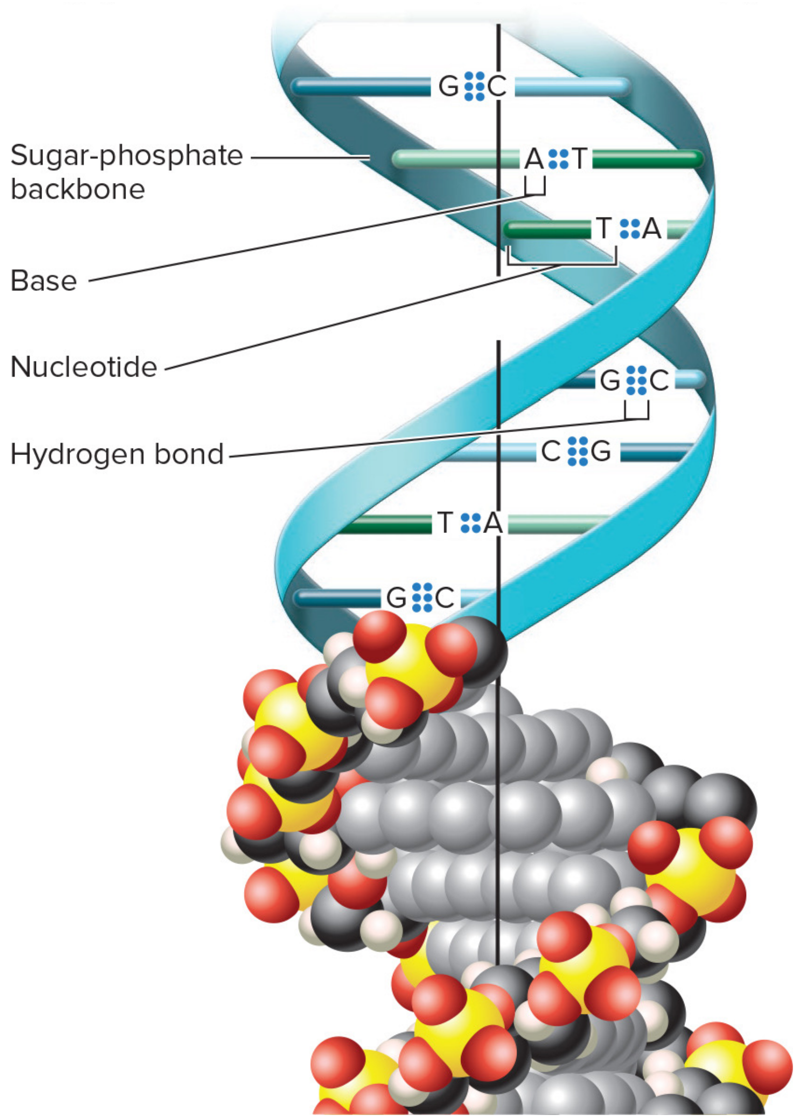
Double Helix Structure of DNA



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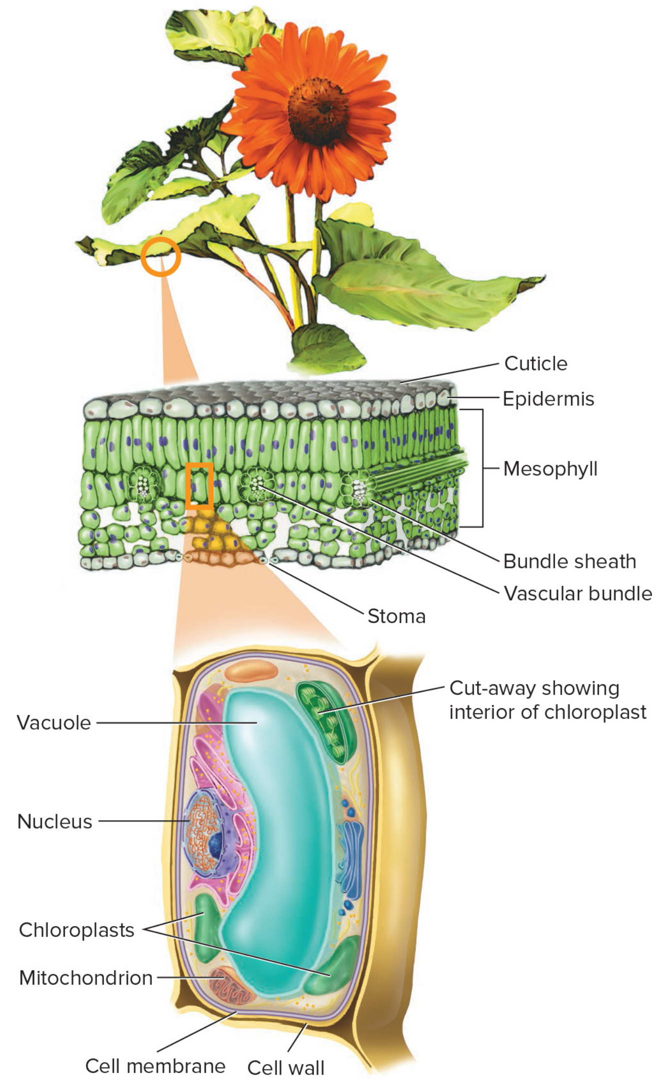
Cells Are the Fundamental Units of Life

All living organisms are composed of **cells**, minute compartments within which the processes of life are carried out.

Cells are assembled of bio-organic compounds in complex ways. Cells exhibit an emergent property we call life.



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Nitrogen and Phosphorus Are Key Nutrients

Carbon (C) is captured from air by plants, and oxygen (O) and hydrogen (H) derive from air or water.

The additional elements nitrogen (N) and phosphorus (P), are essential parts of the proteins, lipids, sugars, and nucleic acids in cells.

You derive these elements by consuming food molecules, but plants must extract these elements from their environment.

Low levels of N and P often limit growth in ecosystems where they are scarce. Abundance of N and P can cause runaway growth.

2.3 Energy

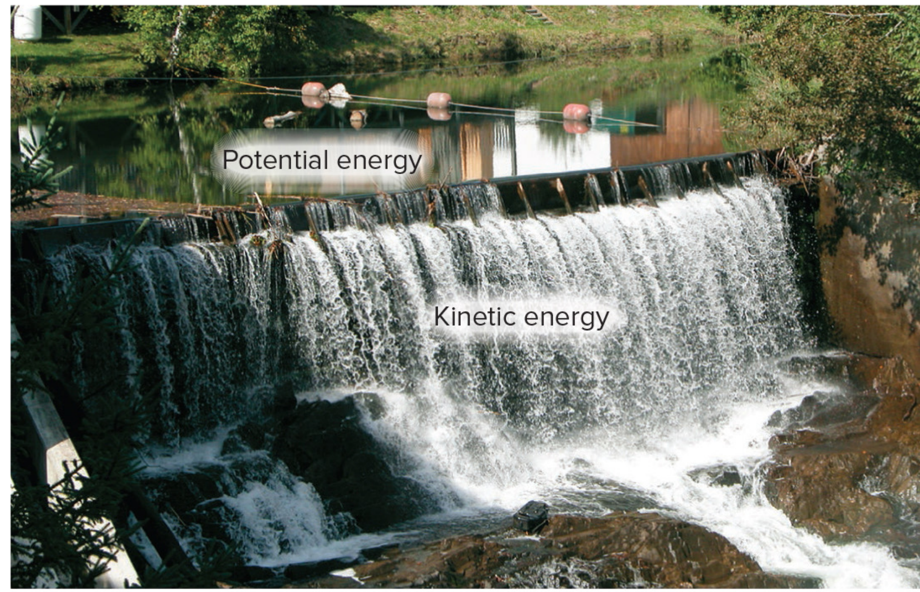
Energy is the ability to do work such as moving matter over a distance or causing a heat transfer between two objects at different temperatures.

Energy can take many different forms. Heat, light, electricity, and chemical energy are examples that we all experience.

Kinetic Energy

The energy contained in moving objects is called **kinetic energy**.

Examples include a rock rolling down a hill, wind blowing through the trees, water flowing over a dam, or electrons speeding around the nucleus of an atom.



Potential Energy

Potential energy is stored energy that is available for use.

A rock poised at the top of a hill and water stored behind a dam are examples of potential energy.

Chemical energy stored in the food that you eat and the gasoline that you put into your car are also examples of potential energy that can be released to do useful work.

Energy Basics

Heat describes the energy that can be transferred between objects of different temperatures.

The study of thermodynamics deals with how energy is transferred in natural processes.

The **first law of thermodynamics** states that energy is *conserved.*

The **second law of thermodynamics** states that, with each successive energy transfer or transformation in a system, less energy is available to do work.

The second law recognizes that disorder, or **entropy,** tends to increase in all natural systems.

2.4 Energy for Life

For nearly all life on earth, the sun is the ultimate energy source.

This energy is captured by green plants which are often called **primary producers** because they create carbohydrates and other compounds using just sunlight, air, and water.

There are organisms that get energy in other ways. These organisms gain their energy from **chemosynthesis,** a process which allows them to extract energy from inorganic chemical compounds such as hydrogen sulfide (H_2S).

Some Producers Use Chemosynthesis

Source: NOAA

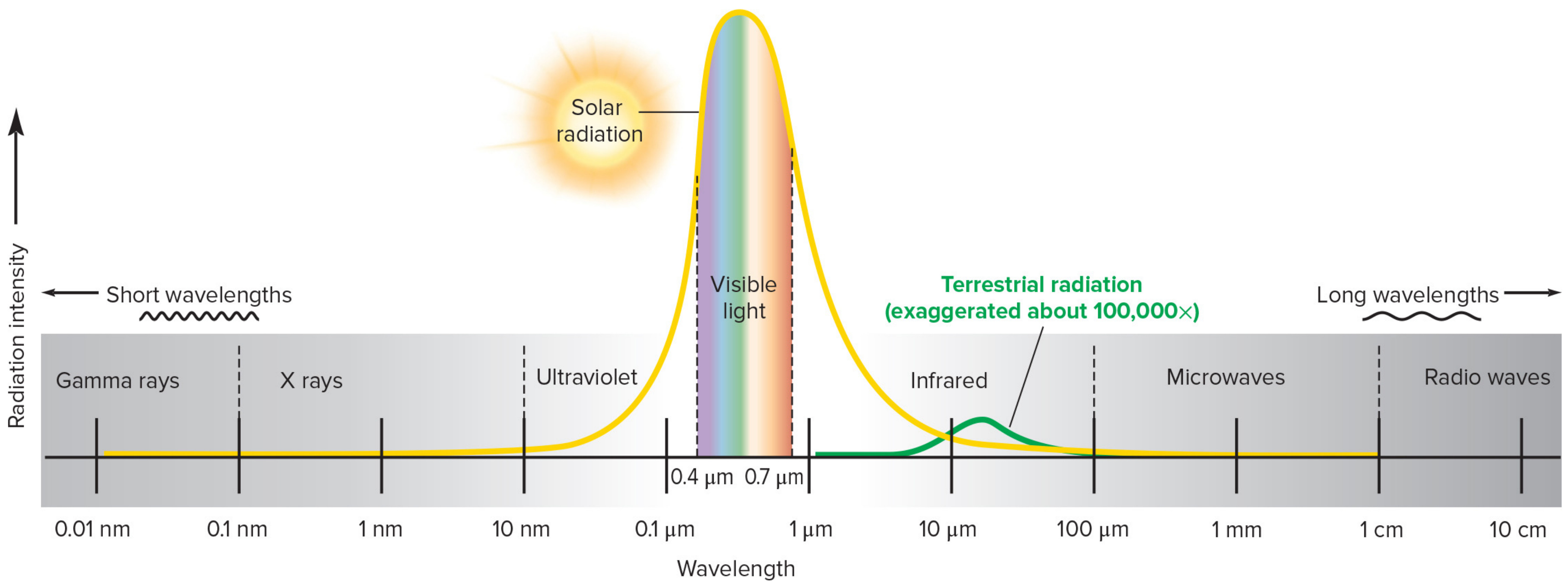
Green Plants Get Energy from the Sun

Thermonuclear reactions from our sun emit powerful forms of radiation, including potentially deadly ultraviolet and nuclear radiation.

Nearly all organisms on the earth’s surface depend on solar radiation for life-sustaining energy, which is captured by green plants, algae, and some bacteria in a process called **photosynthesis.**

Photosynthesis converts light energy into useful, chemical energy in the bonds that hold together organic molecules.

The Electromagnetic Spectrum



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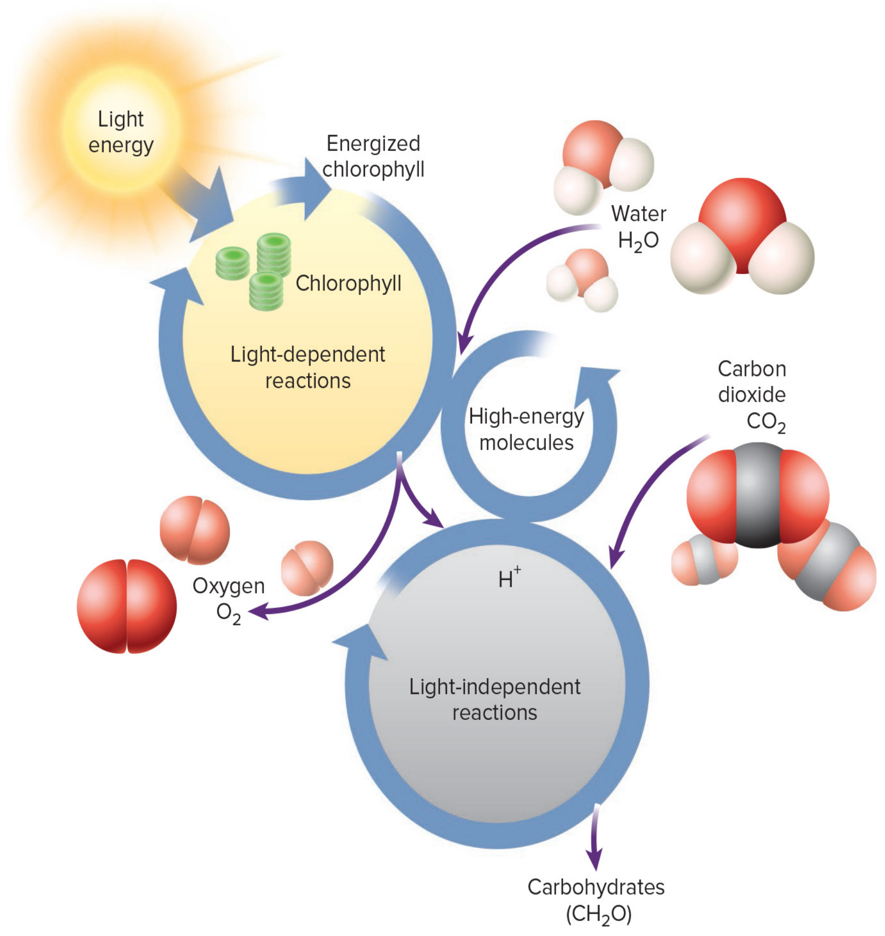
How Does Photosynthesis Capture Energy?

Photosynthesis occurs in tiny organelles called **chloroplasts** that reside within plant cells.

The most important key to this process is **chlorophyll**, a unique green molecule.

Photosynthesis relies on two interconnected cyclic sets of reactions referred to as the **light dependent** and **light independent reactions**.



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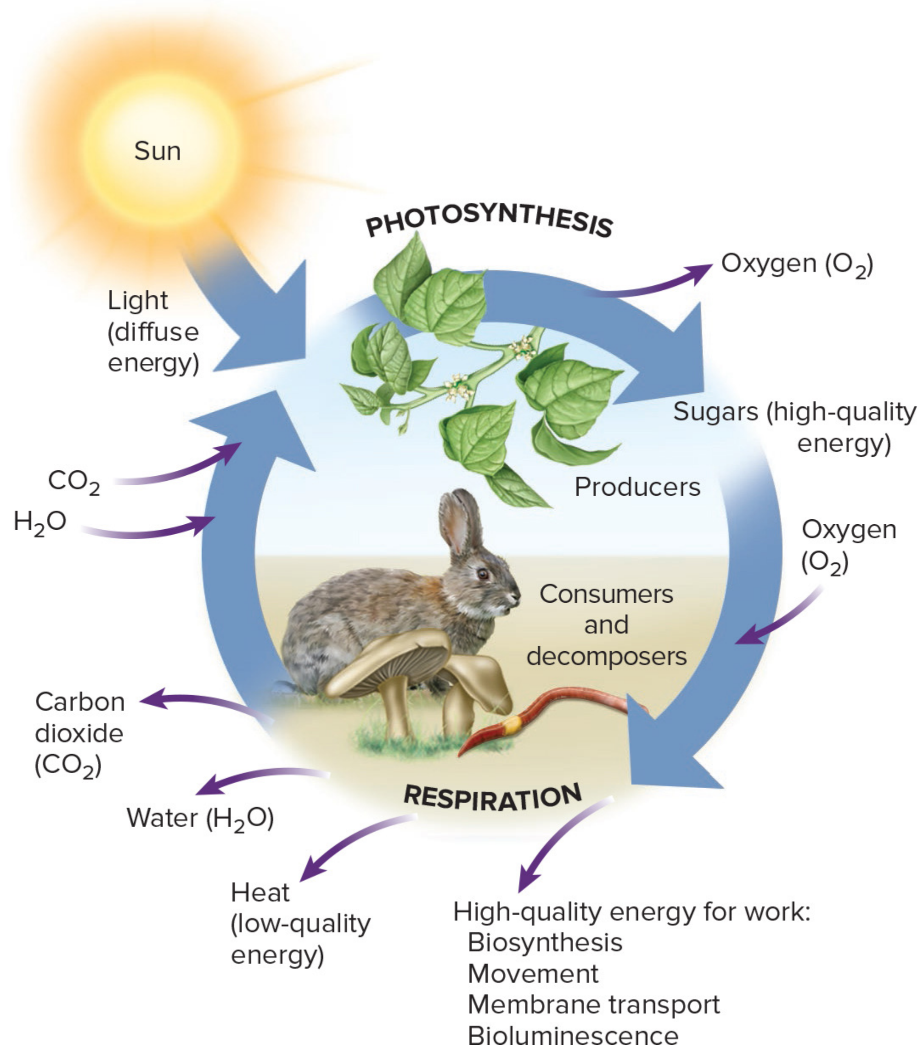
Respiration & Photosynthesis

The glucose produced by **photosynthesis** is an energy-rich molecule that fuels all metabolic processes of cells.

The energy in its chemical bonds can be released in a process called **cellular respiration**, which is the reverse of photosynthesis:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2 + \text{released energy}$$

Energy Exchange in Ecosystems



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2.5 From Species to Ecosystems

While many biologists study life at the cellular and molecular level, ecologists study interactions at the species, population, biotic community, or ecosystem level.

In Latin, *species* literally means “kind.” In biology, **species** refers to all organisms of the same kind that are genetically similar enough to breed in nature and produce live, fertile offspring.

Organisms Occur in Populations, Communities, and Ecosystems

A **population** consists of all the members of a species living in a given area at the same time.

All of the populations of organisms living and interacting in a particular area make up a **community.**

An **ecosystem** is composed of a biological community and its physical environment.

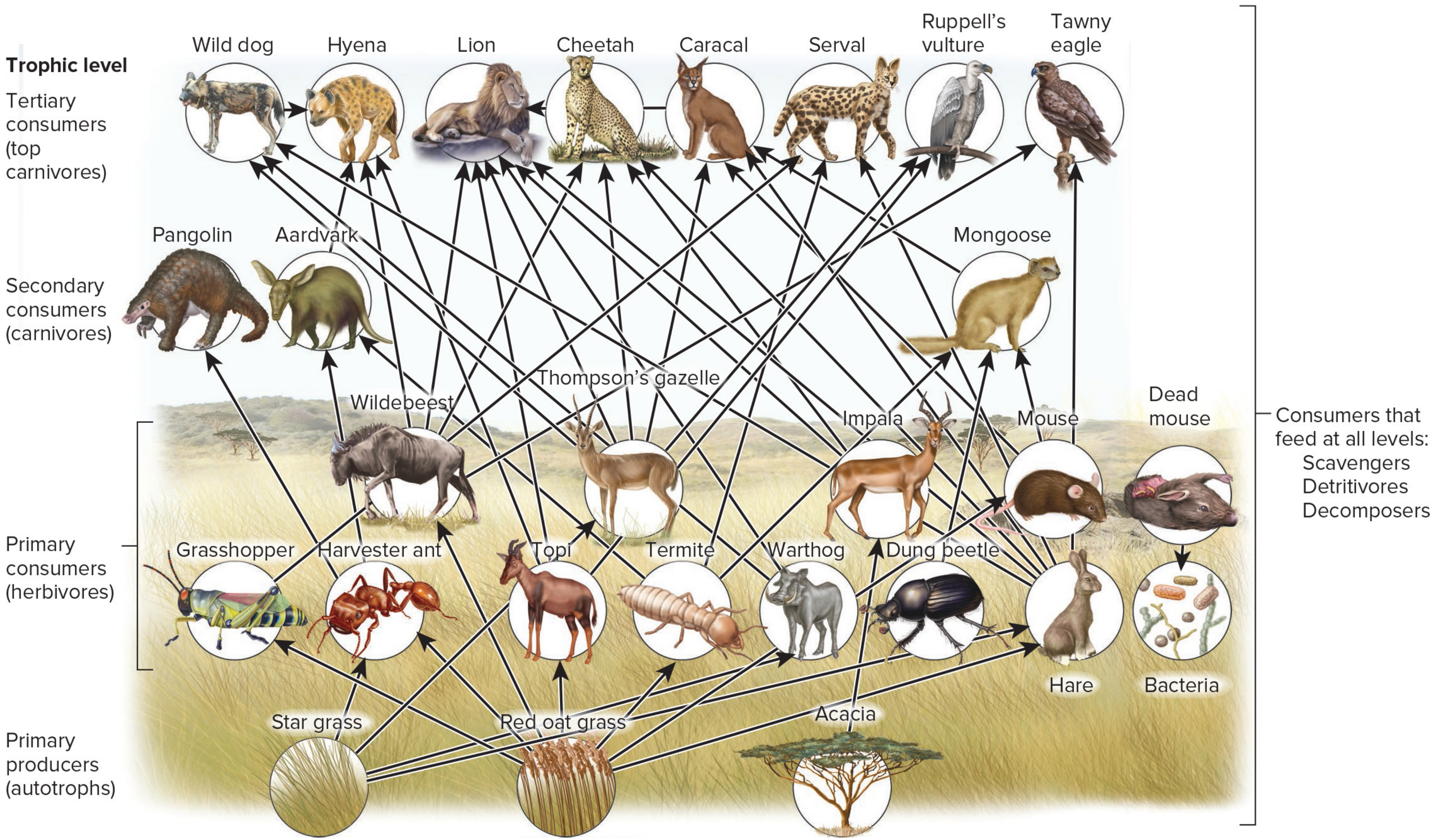
Food Chains, Food Webs, and Trophic Levels Link Species

In ecosystems, some consumers feed on a single species, but most consumers have multiple food sources.

Similarly, some species are prey to a single kind of predator, but many species in an ecosystem are beset by several types of predators and parasites.

In this way, individual food chains become interconnected to form a **food web.**

Food Web of an African Savanna



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Trophic Levels

A **trophic level** is an organism’s feeding status in an ecosystem.

Primary producers or **autotrophs**, feed themselves using only sunlight, water, carbon dioxide, and minerals.

Other organisms in the ecosystem are **consumers** (or **heterotrophs**) of the chemical energy harnessed by the primary producers.

Herbivores are consumer who are plant eaters, **carnivores** are flesh eaters**,** and **omnivores** eat both plant and animal matter.

Parasites, Scavengers, and Decomposers Are Recyclers

Like omnivores, these recyclers feed on all trophic levels.

Scavengers, such as jackals and vultures, clean up dead carcasses of larger animals.

Detritivores, such as ants and beetles, consume litter, debris, and dung.

Decomposer organisms, such as fungi and bacteria, complete the final breakdown and recycling of organic materials.

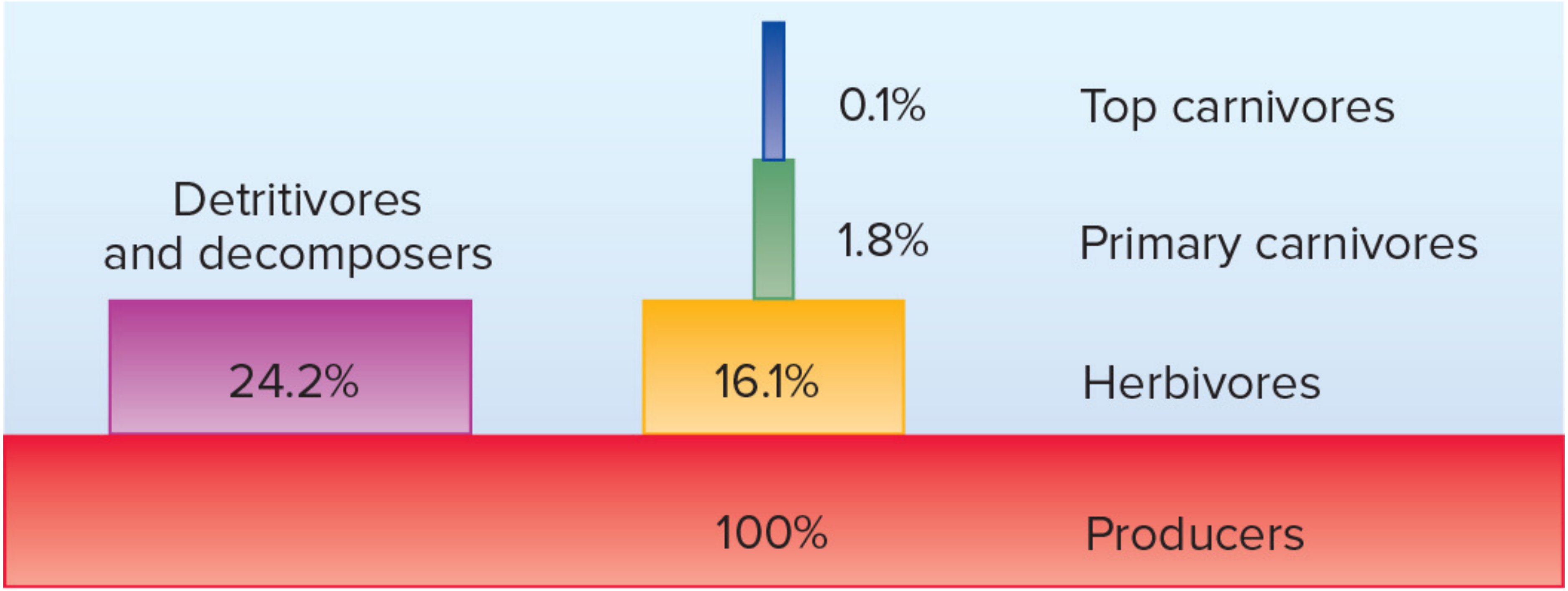
Ecological Pyramids Describe Trophic Levels 1

If we consider organisms according to trophic levels, they often form a pyramid with a broad base of primary producers and only a few individuals in the highest trophic levels.

Top predators are generally large, fierce animals, such as wolves, bears, sharks, and big cats.

While there is endless variation in the organization of ecosystems, the pyramid idea helps us describe generally how energy and matter move through ecosystems.

Ecological Pyramids Describe Trophic Levels 2



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2.6 Biogeochemical Cycles and Life Processes

The elements and compounds that sustain us are cycled endlessly through living things and through the environment.

On a global scale, this movement is referred to as biogeochemical cycling.

As the great naturalist John Muir said, “When one tugs at a single thing in nature, he finds it attached to the rest of the world.”

The Hydrologic Cycle 1

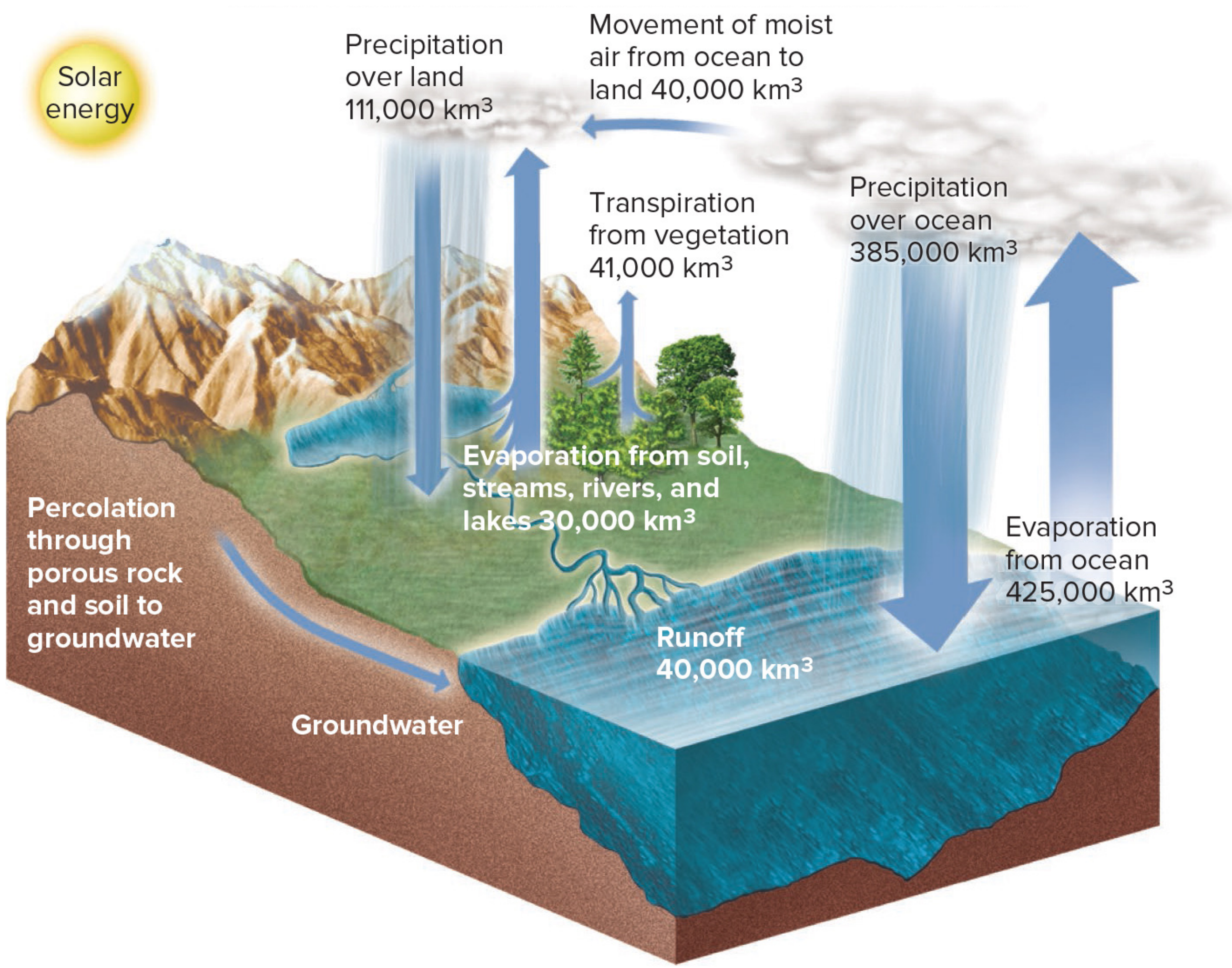
The path of water through our environment is perhaps the most familiar biogeochemical cycle.

Most of the earth's water is stored in the oceans, but solar energy continually evaporates this water, and winds distribute water vapor around the globe.

Water condenses over land surfaces, in the form of rain, snow, or fog, supporting terrestrial ecosystems.

Organisms emit the moisture they have consumed through respiration and perspiration. Eventually this moisture reenters the atmosphere or enters lakes and streams which ultimately returns it to the ocean.

The Hydrologic Cycle 2



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The Carbon Cycle 1

The **carbon cycle** begins with photosynthetic organisms taking up carbon dioxide. This is called carbon fixation because carbon is changed from gaseous CO_2 to an organic molecules like sugar.

This sugar molecule is absorbed into the bloodstream, of animals where it is made available to the cells for cellular respiration or the production of more complex biomolecules.

If it is used in respiration, it may be exhaled as CO_2 in an hour or less, and a plant could take up that exhaled CO_2 the same afternoon.

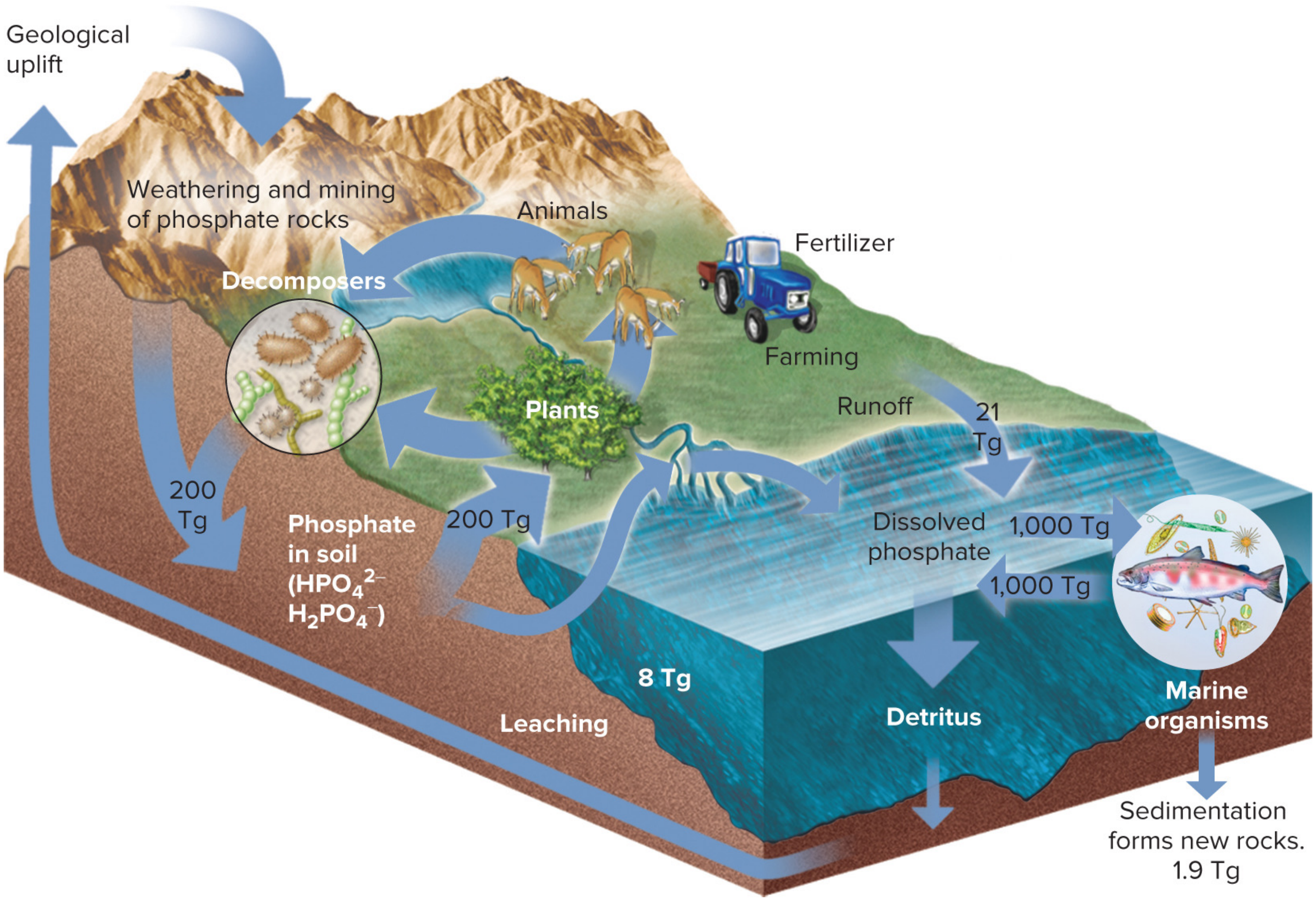
The Carbon Cycle 2

The carbon atoms from the sugar molecule could remain a part of the body until it decays after death.

Similarly, carbon in the wood of a thousand-year-old tree will be released only when fungi and bacteria digest the wood and release carbon dioxide as a by-product of their respiration.

Recycling may take a very long time. Fossil fuels like coal and oil are the remains of organisms that lived millions of years ago. Their carbon atoms are not released until the coal and oil are burned.

The Carbon Cycle 3



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The Nitrogen Cycle 1

Plants acquire nitrogen from nitrogen-fixing bacteria that live in and around their roots.

These bacteria combine gaseous N_2 with hydrogen to make ammonia (NH_3) and ammonium $\left(NH_4^+\right)$.

Other bacteria then combine ammonia with oxygen to form nitrites $\left(NO_2^-\right)$.

A third group of bacteria converts nitrites to nitrates $\left(NO_3^-\right)$, which green plants can absorb and use.

Plant cells absorb nitrates, and use them to build amino acids and eventually proteins.

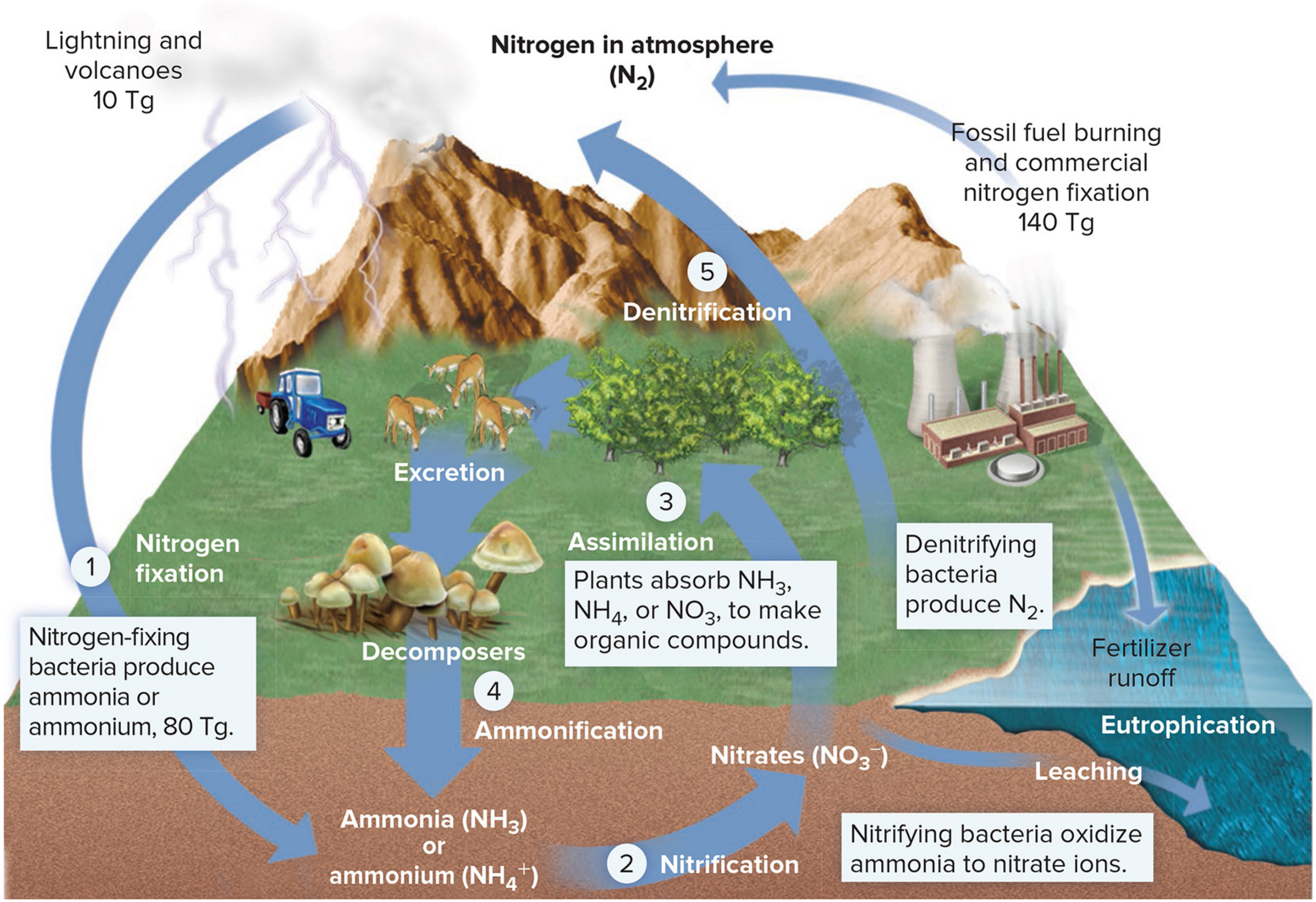
The Nitrogen Cycle 2

Plant proteins are consumed by animals and incorporated into their own protein molecules.

Nitrogen reenters the environment through the death of organisms. Fungi and bacteria decompose dead organisms, releasing ammonia and ammonium ions for nitrate formation.

Denitrifying bacteria break down nitrates $\left(NO_3^-\right)$ into N_2 and nitrous oxide (N_2O), gases that return to the atmosphere.

The Nitrogen Cycle 3



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The Nitrogen Cycle 4

Nitrogen molecules (N2) are converted to useable forms in the bumps (nodules) on the roots of this bean plant.

Each nodule is a mass of root tissue containing many bacteria that help convert nitrogen in the soil to a form that the bean plant can assimilate and use to manufacture amino acids.

Kelly Marken/Shutterstock

The Phosphorous Cycle 1

The **phosphorus cycle** takes millions of years.

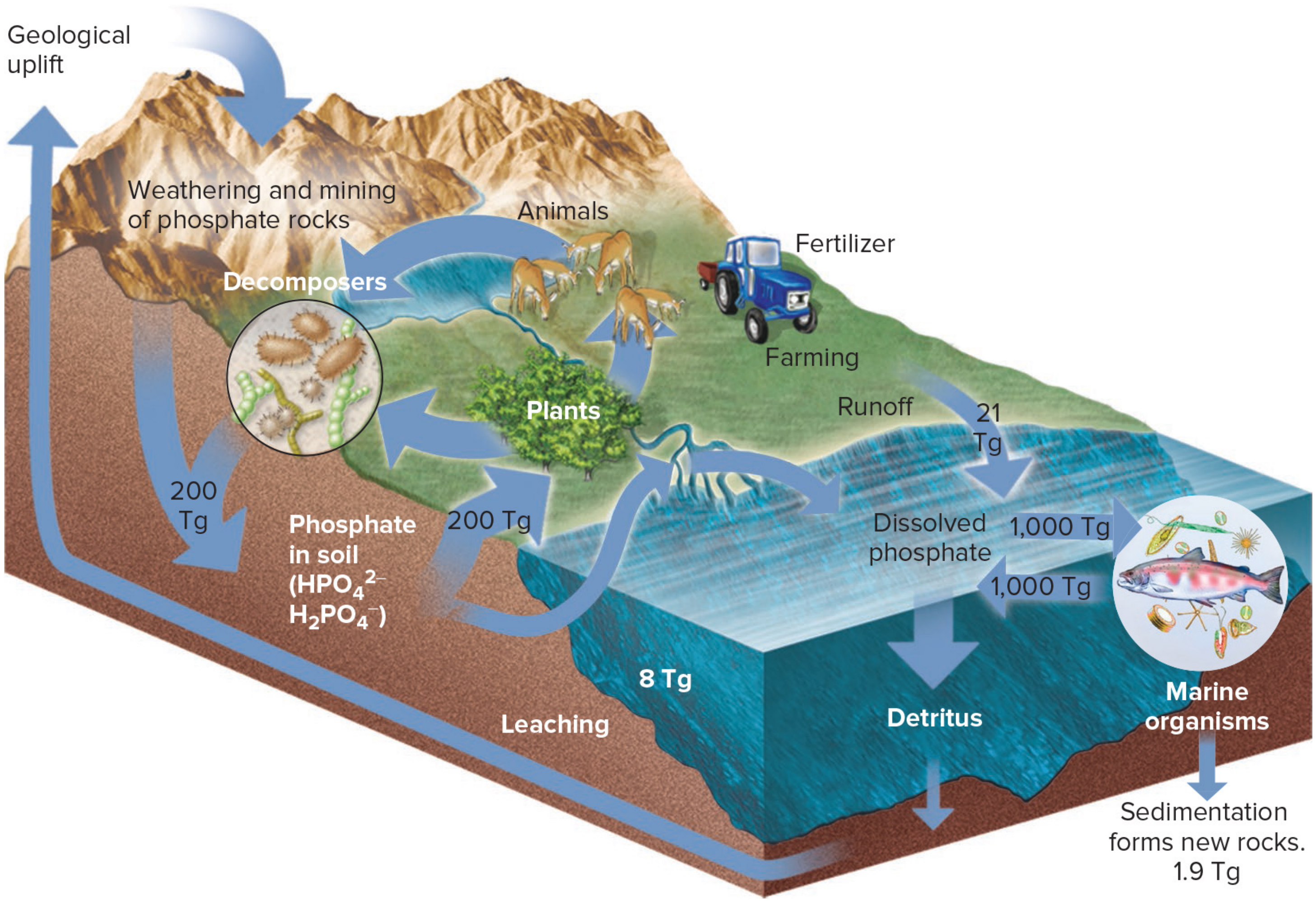
Minerals become available to organisms after they are released from rocks or salts.

Producer organisms take in inorganic phosphorus, incorporate it into organic molecules, and then pass it on to consumers.

In this way, phosphorus cycles through ecosystems.

Excess phosphates in bodies of water can stimulate explosive growth of algae, upsetting ecosystem stability.

The Phosphorous Cycle 2



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The Sulfur Cycle 1

Most of the earth’s sulfur is tied up underground in rocks and minerals; weathering, emissions from deep seafloor vents, and volcanic eruptions release this inorganic sulfur into the air and water.

Living organisms, especially bacteria, also sequester sulfur in biogenic deposits or release it into the environment.

The Sulfur Cycle 2

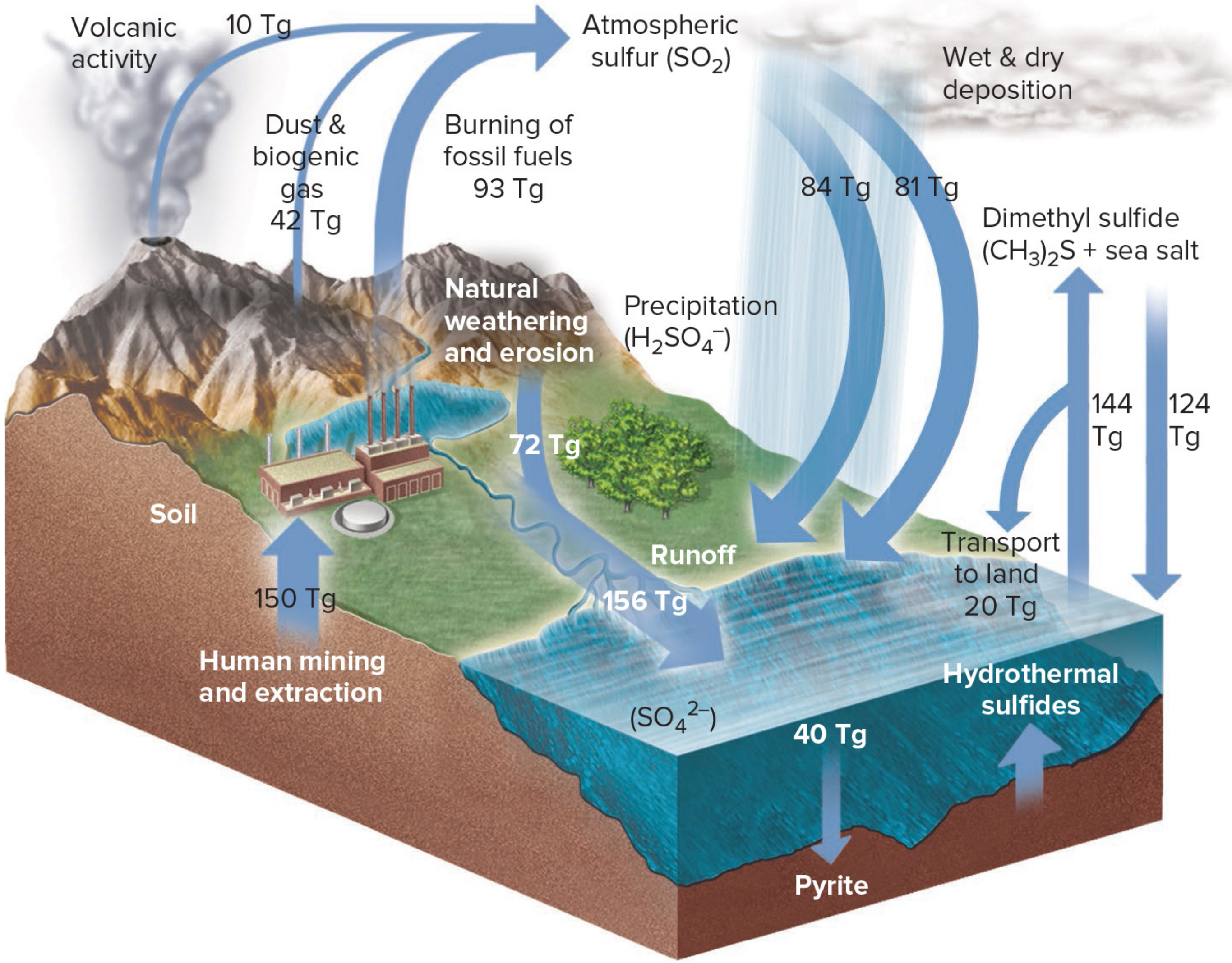
Human activities also release large quantities of sulfur, primarily through burning fossil fuels. These processes can contribute to **acid precipitation**.

The biogenic sulfur emissions of oceanic phytoplankton may play a role in global climate.

The phytoplankton release sulfur compounds into the atmosphere which can reflect sunlight, cooling the earth.

This may be a feedback mechanism that keeps Earth’s temperature within a suitable range for life.

The Sulfur Cycle 3



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Take-Away Points

The movement of matter and energy through systems maintains the world's living environments.

Matter consists of atoms, which make up molecules or compounds. Among the principal substances we consider in ecosystems are water, carbon, nitrogen, phosphorus, and sulfur.

Primary producers provide the energy and matter in an ecosystem.

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