Chapter 3 Matter, Energy, and Life

Key Terms

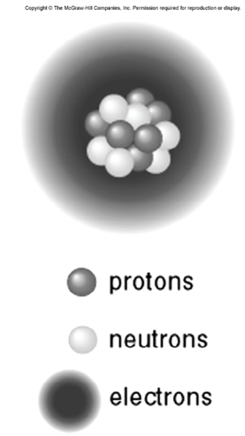
acid
ammonification
assimilation
atom
atomic number
base
biomass
carbohydrate
carbon cycle
carbon sink
carnivore
cell
cellular respiration
chemical energy
community
compound
conservation of matter
consumer
covalent bond
decomposer
denitrification
detritovore
ecological pyramid
ecosystem
element
energy
entropy
enzyme
food chain
food web
heat
herbivore
hydrologic cycle
ion
ionic bond
isotope
kinetic energy
lipid
molecule
nitrification
nitrogen cycle
nitrogen fixation
nucleic acid
omnivore
organic compound
oxidation
pH
phosphorus cycle
photosynthesis
population
potential energy
producer
protein
pyramid of biomass
pyramid of energy
pyramid of numbers
radioisotopes
reduction
salt
scavenger
species
sulfur cycle
thermodynamics
trophic level

Skills

1. Recall introductory chemistry terminology, including elements and atoms.
2. Differentiate between ionic and covalent bonds.
3. Classify acids, bases, and salts based upon their chemical properties.
4. Distinguish between organic and inorganic compounds.
5. Discriminate between the four major groups of organic compounds found in living things.
6. Define cell, and describe cellular structure.
7. Define energy, and identify the different types of energy important to living organisms.
8. Summarize the first and second laws of thermodynamics.
9. Examine the role of the sun in life on earth.
10. Characterize the interaction between photosynthesis and cellular respiration, including their role in the carbon cycle.
11. Identify the ecosystem hierarchy levels.
12. Distinguish between food chains, food webs, and trophic levels.
13. Draw the three types of ecological pyramids.
14. Diagram the nitrogen, carbon, and phosphorus cycles. Include in the diagram the processes that make up the cycles.

Introductory Chemistry

Figure 3.1 Atomic structure



Matter is anything that occupies space and has mass. Matter is made up of elements, substances that cannot be broken down into simpler substances by conventional means. An atom is the smallest particle of an element that still retains the properties of that element. Examples of elements important to environmental science include hydrogen, carbon, chlorine, phosphorus, uranium, and lead. Atoms have positively charged protons and uncharged neutrons in the center, called the nucleus. The mass of protons and neutrons is similar. Rotating around the nucleus in a predictable location are electrons, which are negatively charged. Electrons are much smaller than the nuclear particles. The net charge on an atom is neutral, because the number of protons equals the number of electrons.

The atomic number of an element is the number of protons it contains. The atomic mass of an element is the number of protons plus the number of neutrons. A single element may have several different isotopes, which means although they always have the same number of protons, the number of neutrons may vary. For example Uranium has an atomic number of 92, meaning it has 92 protons. The isotopes of uranium are U-235, U-238, and U-239 and they have 143, 146, and 147 neutrons, respectively. Some isotopes are unstable due to the presence of the neutrons and may emit particles and/or energy. These isotopes are known as radioactive isotopes or radioisotopes.

> **Take Note:** You will need to be familiar with the various elements in living organisms. You should also know which elements have a utilitarian use and may be mined by humans. Knowing which elements are found in the earth's crust is also important. You will need to know which metals are considered heavy metals and understand the damage that they cause to humans and the environment. It is important that you know how specific isotopes are used in science and industry. You should also know the problems associated with their use and the waste generated by their use.

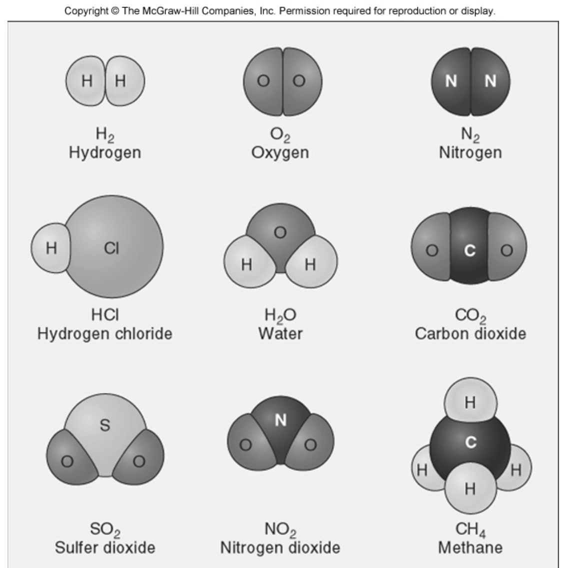


Figure 3.2 Common molecules

A molecule is composed of two or more atoms that exist as a single unit, such as H_2, N_2,, O_2 or CO_2. A compound is a substance composed of different types of chemically bonded elements. For example, water (H_2O), table salt (NaCl), and methane (CH_4) are compounds. All compounds are therefore molecules, but not all molecules are compounds.

Elements form compounds and molecules to have a stable number of electrons. An ionic bond is formed when one element loses or gains electrons to form an ion, or charged particle. The two ions are then held together due to their opposite charges. The atom that gains the electron is said to be reduced and the atom that loses the electron has been oxidized. The reaction is deemed a redox or reduction—oxidation reaction—because it occurs simultaneously. A negatively charged ion is called an anion and a positively charged ion is known as a cation.

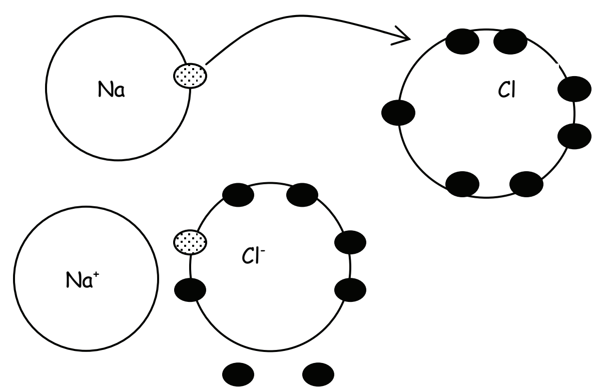


Figure 3.3 Ionic Bond: Na will give up its one electron in its outer shell to Cl to be stable. Na has one less electron than protons, so it now has a plus one charge and is a cation, Na^{+1}. The Cl atom has gained an electron in its outer shell and has thus become negative by one charge and is the anion Cl^{-}. The ions are held together due to their attraction for the opposing charge, forming an ionic bond.

A covalent bond is formed when two atoms share electrons. Some atoms tend to hold electrons more closely to the nucleus and are deemed more electronegative than the atom with which it is sharing the electrons. An example of this uneven distribution of charge can be seen in water, where the oxygen is slightly negatively charged and the two hydrogens are slightly positively charged. In this event, although the molecule is not charged, portions of the molecule are polar because the electrons tend to remain more closely in association with the more electronegative atom (O in this example). These molecules are called polar molecules because they possess electrical charge that is unequally distributed.

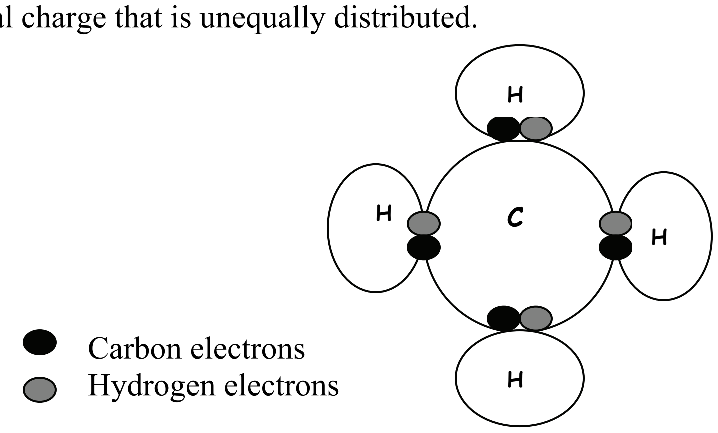


Figure 3.4 Methane. The carbon atom shares its four electrons with four hydrogen atoms, thus forming a covalent bond. Neither carbon nor hydrogen is highly electronegative, so the electrons are shared equally between the atoms.

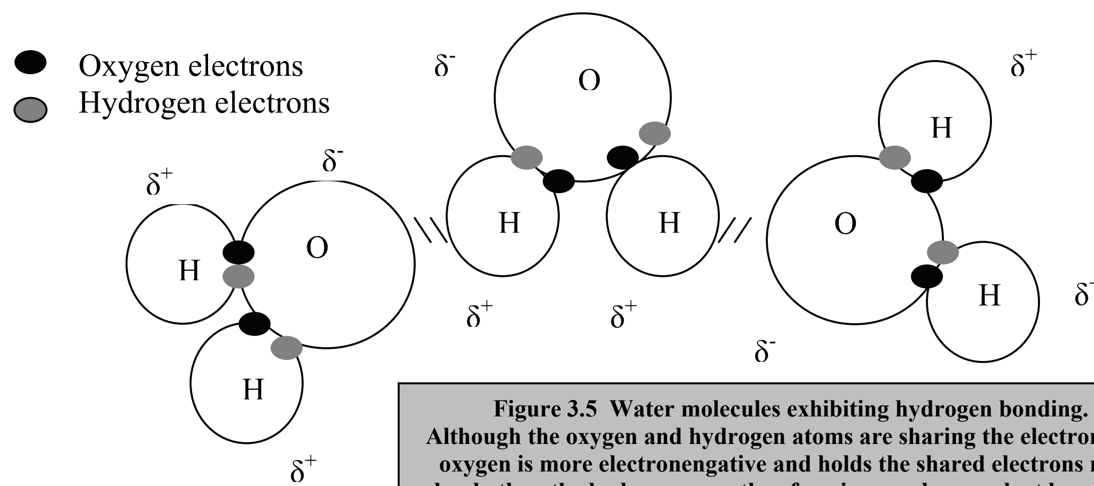


Figure 3.5 Water molecules exhibiting hydrogen bonding. Although the oxygen and hydrogen atoms are sharing the electrons, the oxygen is more electronegative and holds the shared electrons more closely than the hydrogen can, thus forming a polar covalent bond. The slightly positive (δ^+) hydrogen from one water molecule is attracted to the slightly negative (δ^-) oxygen from another water molecule, forming a hydrogen bond.

Typically the formation of chemical bonds releases energy, or is an exergonic reaction. The breaking of bonds is usually endergonic, or an energy absorbing reaction. Whether a chemical reaction is exergonic or endergonic depends on the relative amounts of energy absorbed or released in each step of the reaction. The energy required to initiate a chemical reaction is known as activation energy.

Water

Water's unique properties depend on **hydrogen bonding**. This is a special typoe of polarity only found in water and other molecules where a hydrogen atom is covalently bonded to a very electronegative atom like O, N or F. Consult a chemistry textbook for a more in-depth discussion of hydrogen bonding.

The polar nature of water is extremely important in explaining its properties that are essential for life.

- Water forms hydrogen bonds with other water molecules, and some other polar molecules. It can dissolve most polar molecules and ions. Water has therefore been deemed the "universal solvent," since it can dissolve polar molecules (such as sucrose) and ions (such as table salt).
- Water hydrogen bonding to other water molecules is known as cohesion, and creates the property known as surface tension. Surface tension is the resistance of water surface to being penetrated by an object, such as a water strider walking on a pond.
- Water hydrogen bonding to other polar molecules is known as adhesion, which in conjunction with cohesion results in capillary action. Capillary action is when water is drawn through a channel or vessel. For example, the water flowing through the xylem of a plant is capillary action.
- Water has a high heat of vaporization, which means it takes a lot of heat to convert it from liquid to gas.

- Water has a high specific heat, meaning it must absorb a lot of heat for the temperature to rise.
- Unlike most materials, water expands when it freezes, assisting soil formation due to frost wedging in the crevices of rocks. The water expands, so it is less dense when it is frozen than liquid water. Therefore, ice floats on the surface of lakes, allowing survival of the organisms in the lake even in the dead of winter.
- Water spontaneously ionizes into hydrogen ions and hydroxide ions. These ions remain in equivalent amounts in pure water, and water therefore has a neutral pH.

Take Note: The nature of water must be understood to fully understand water's role in living organisms, ecosystems, and weather. Although most questions on the AP exam will address water pollution, resources, treatment, and use, you must understand the nature of water molecules that give it the unique chemical and physical properties that cause it to be known as the universal solvent.

Acids, Bases, and Salts

An acid is a substance that is a proton or hydrogen ion (H^+) donor when placed in water. Examples of acids include hydrochloric acid (HCl) and acetic acid (CH_3COOH). Bases are substances that release hydroxide ions (OH^-) in water and therefore accept hydrogen ions to form water. An example of a strong base is sodium hydroxide (NaOH). The pH of a solution is the negative base ten logarithm of the concentration of hydrogen ions. The pH scale is from 1–14 with 7 being neutral. Below pH 7 is acidic and above pH 7 is basic or alkaline. Therefore, a substance with a pH of 4 contains 1 X 10^{-4} (0.0001) H^+ ions and a substance with pH of 6 has 1 X 10^{-6} (0.000001) H^+ ions. The solution of pH 4 is therefore 100 times more acidic than the solution with pH of 6.

When an acid is combined with a base, water and a salt are formed, neutralizing the pH. For example, $HCl + NaOH \rightarrow NaCl + H_2O$. A buffer is a substance that allows significant additions of an acid or base without altering the pH of a system because it can accept or donate H^+ ions. An excellent natural buffer is calcium carbonate (limestone or, when powdered, lime).

Take Note: You must be well versed in acids formed from anthropogenic and natural pollutants and their effects on ecosystems to do well on the AP exam. You need to understand the relationship between pH and the H ion concentration. You should be able to understand the principles of pH to be able to discuss acid deposition and how humans can prevent or remediate damage from acids.

Organic Compounds

An organic compound is one that contains carbon. Carbon has the capacity to share four electrons in covalent bonds, and therefore is important in the structure of living organisms. Carbon molecules form large macromolecules because they can be found in long chains and can form ring compounds. Organic molecules found in living organisms include carbohydrates, lipids, proteins, and nucleic acids. See the macromolecule chart in Figure 3.6 for classification of these macromolecules.

Cells

A cell is the smallest unit that can carry out all of life's functions. Cells are separated from their environment by a membrane that regulates entry and exit of materials for the cell. Organelles are small structures within a cell that carry out specific activities for the cell. Cells that have membrane-bound organelles are called eukaryotes and cells that lack membrane-bound organelles are called prokaryotes. All prokaryotes are bacteria. Eukaryotes include both uni- and multicellular organisms such as protists, fungi, plants, and animals.

Figure 3.6 Macromolecule chart

Macromolecule	Elements	Subunits	Role in living organisms	Examples
Carbohydrate	C, H, O	Simple sugars, monosaccharides	Energy storage, cellular structure	Sugar (glucose, sucrose), starch, cellulose
Lipid	C, H, O Nonpolar	Fatty acids, steroids	Energy storage, cell membranes, cell signaling (hormones)	Waxes, fats, oil, phospholipids, some hormones
Protein	C, H, O, N (S)	Amino acids	Enzymes (protein catalysts that speed up chemical reactions by lowering activation energy), structural components, cell signaling (hormones), cell markers	Enzymes, antibodies, hemoglobin, some hormones, actin, and myosin in muscles
Nucleic Acids	C, H, O, N, P	Nucleotides	Nucleic acids—genetic material Nucleotides—cell signaling and energy storage	DNA/RNA—nucleic acids cAMP, ATP—nucleotides

Energy

Energy is the ability to do work. Energy of motion is called kinetic energy, and the energy of an object due to its position is potential energy. Some potential energy is in the form of chemical energy, such as the energy in a candy bar that will be available to your body after you consume it. Energy is measured in work (joules) or heat units (calories). A joule (J) is the work done when 1 kg accelerates 1 m/s/s. A calorie is the amount of energy needed to increase the temperature of 1 g of water 1ºC. One calorie = 4.184 J.

Heat is the energy transferred between two objects of differing temperature. Diffuse energy is considered low-quality energy because it is not useful for work. For example, the energy in the ocean is too diffuse to be useful, but the energy in coal is concentrated and is thus considered high-quality energy.

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Take Note: The AP exam will contain numerous examples of problems using energy conversions. Students must be adept at these energy conversions. These questions may be found not only in the essay portion of the exam, but conversion problems may also be found in the multiple-choice portion. A basic understanding of energy and thermodynamics is essential to understanding alternative and conventional energy resources.

Thermodynamics

Thermodynamics is the study of energy conversion. There are two laws that govern energy changes. The first law of thermodynamics, also known as the law of conservation of energy, states that energy can neither be created nor destroyed; it can only change from one form to another. This law applies to conventional energy conversions-not nuclear reactions. In nuclear reactions matter and energy are converted simultaneously, leading to the coupling of two laws-the law of conservation of matter and the law of conservation of energy.

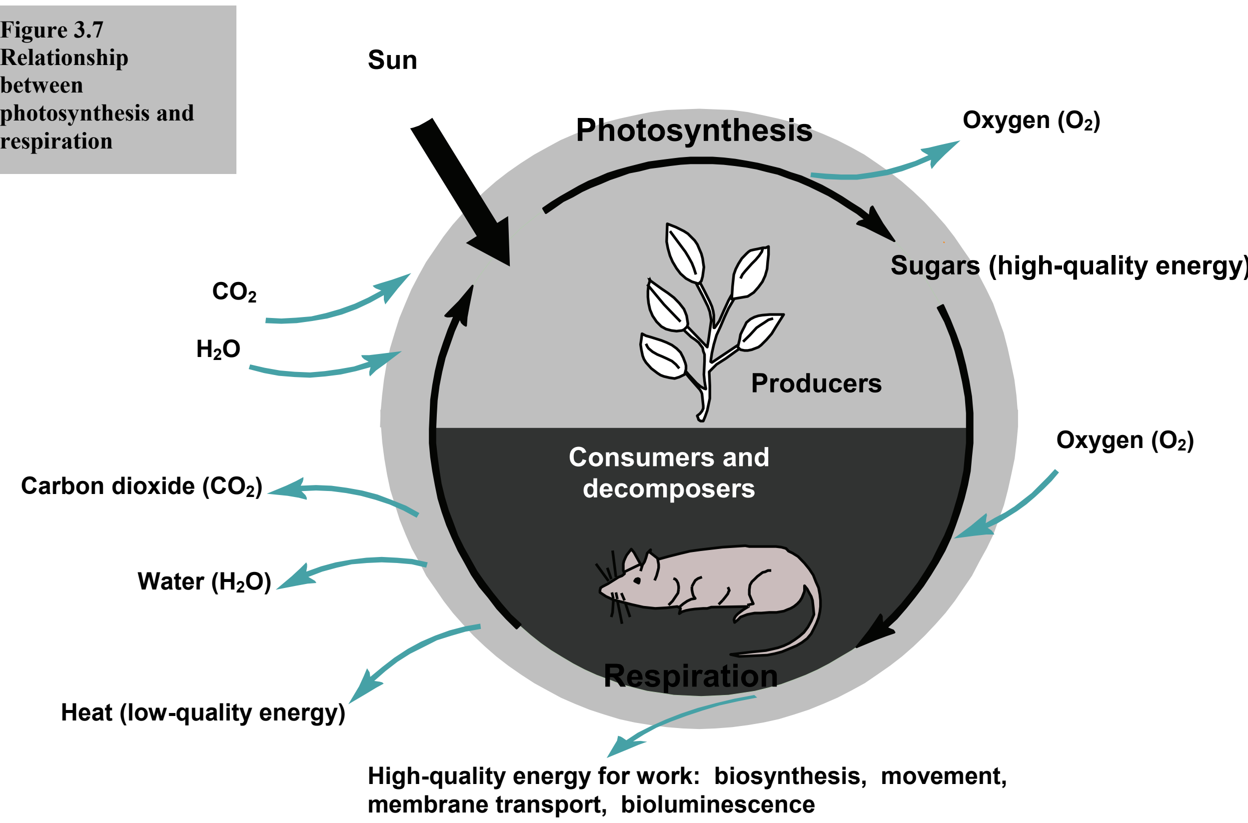
The second law of thermodynamics states that with each energy conversion in a closed system, the energy change proceeds toward entropy, or a state of disorganization. Disorganization is favored in nature because it is more stable than organization. A good example is a stack of soda cans forming a pyramid on a table. The stack is very organized, but unstable as you could easily knock it over. All the soda cans lying on their side on the table are disorganized, but stable.

The Sun

The sun is the principle source of energy for nearly all life on earth. It provides heat that warms the earth and allows life to exist. The sun also provides the photons, packets of light energy, absorbed by pigments in plants, algaes, and cyanobacteria to initiate photosynthesis. Photosynthesis uses water and carbon dioxide in the atmosphere to produce simple sugars, which the plant can then use for energy and can bind in polymers for storage and structural components. The by-product of photosynthesis, oxygen, is released into the environment. About 1 percent of the sun's energy that reaches the earth is converted by photosynthetic organisms into chemical energy. Organisms that create their own food are called producers. Not all producers are photosynthetic. Some are chemosynthetic, using the inorganic materials in the environment to create chemical energy needed to sustain life. An organism that obtains its nutrients from other organisms is called a consumer. The process of cellular respiration occurs in both producers and consumers. Cellular respiration is the breaking of the chemical bonds created during photosynthesis to release the contained energy to use for life's processes. The reactants in photosynthesis are the products of cellular respiration and vice versa; thus, the two processes are inextricably intertwined.

There are communities found deep in the ocean near volcanic vents, in hot springs, or in other extreme environments, where **chemosynthesis** (chemical reactions releasing energy from inorganic molecules) is the source of energy for the organisms, not photosynthesis. The number of organisms that these communities support and what percentage of the earth's biomass these "non-photosynthetic" communities make up is unknown at present.

Figure 3.7
Relationship between photosynthesis and respiration



Ecosystem Hierarchy

An organism is an individual that can carry out all of the characteristics of life. A species is defined as a group of similar looking organisms that can reproduce and produce fertile offspring under natural conditions. For example the gray wolf, *Canis lupus*, is a separate species from the dog, *Canis familiaris*. A population is a group of organisms of the same species living in the same place at the same time—all the gray wolves in Yellowstone National Park. A community is a group of interacting populations, such as the wolves, deer, rabbits, aspens, and birds living in the park. The ecosystem is the complex interactions of the biological community and its environment. The living components are deemed biotic (bio – life) and the nonliving components are abiotic (a—without; bio—life). In the park, the abiotic components that affect the biotic community would be temperature, precipitation, altitude, soil, wind, and so on.

The biosphere is the portion of earth that supports life, including the lower atmosphere and the upper crust.

organism→species→population→community→ecosystem→biosphere

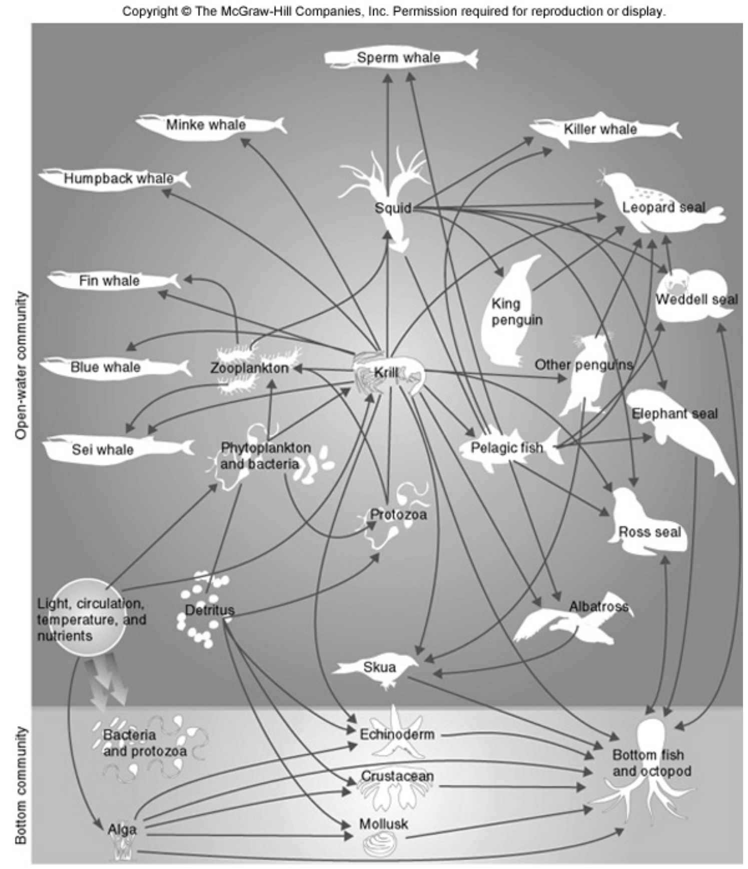
Food Chains, Food Webs, and Trophic Levels

Producers in an ecosystem can also be called autotrophs (auto—self; troph—feed). They create the food, or biomass, that all of the consumers, or heterotrophs (hetero—other), feed upon. The amount of biomass that an ecosystem yields is called the productivity of the area. The number of creatures that can survive in an ecosystem is a result of the biomass produced in the area. Photosynthesis is called the primary productivity because all life in the ecosystem is dependent upon the producers. Net primary productivity (NPP) is the rate at which photosynthetic organisms make sugars minus the sugars used in cellular respiration required for the survival of the producer. The NPP is the material available to the consumers in the ecosystem.

A food chain is a series of links that illustrates how energy moves through an ecosystem. The chain always begins with a producer and the arrows are always placed in the direction of the energy flow. Food chains rarely have more than five links, due to the energy lost at each feeding, or trophic, level. Food chains are overly simplified interactions. In reality, organisms have more than one food source and may be the food source of more than one organism. The resulting linked food chains are called a food web, a much more realistic diagram of feeding and energy transfer in an ecosystem. Herbivores (herb—plant; vore—eat) eat vegetation. Carnivores (carn—meat) eat other consumers. Omnivores (omni—all) ingest both plants and other consumers. Scavengers, such as hyenas or condors, consume the dead carcasses of other animals. A detritovore ingests detritus, the partially broken down leaf litter, plant remains, and dung present in an ecosystem. Detritovores include earthworms, millipedes, and ants. Decomposers are specialized bacteria and fungi that break down organic material in the environment and then absorb the nutrients.

Food Chain Algae→bluegill→bass→osprey

Figure 3.8 Food web



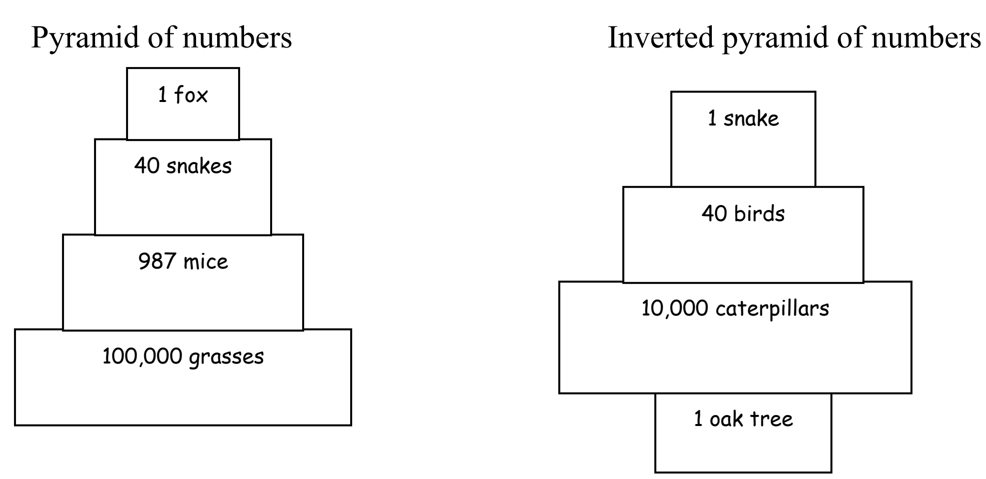
Take Note: You must be able to generate food chains/webs in specific ecosystems. You must also be able to understand energy flow through food webs. The terminology of the different trophic levels will be used in numerous ways on the exam.

Ecological Pyramids

In addition to food chains, there is another way to diagram the passage of biomass and energy in an ecosystem. An ecological pyramid is a schematic representation of the food chain used to illustrate the broad base of producers typically required to support the other organisms in an ecosystem. There are three major types of pyramids.

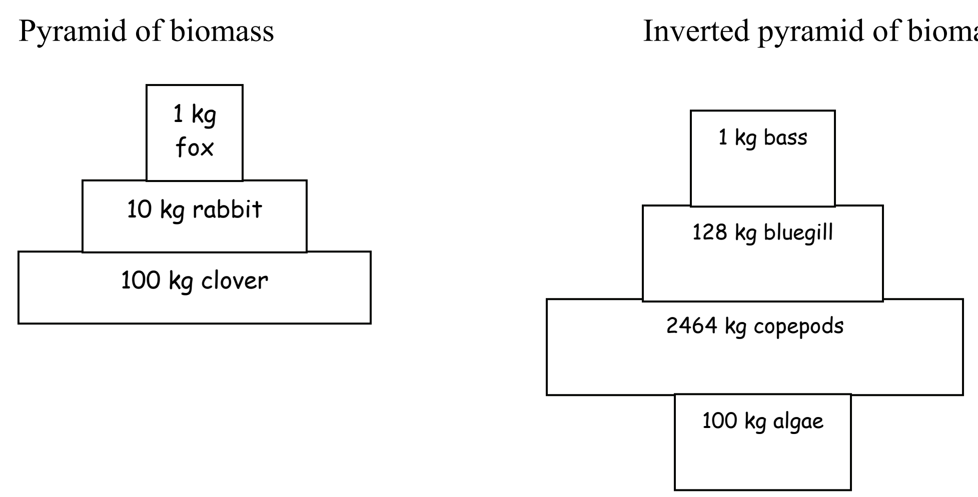
- Pyramid of numbers
  - Shows the numbers of organisms at each trophic level
  - May be inverted in aquatic ecosystems because of the high reproductive rate of algae and some forests due to few trees providing the biomass for the herbivores

Figure 3.9 Example of pyramids of numbers



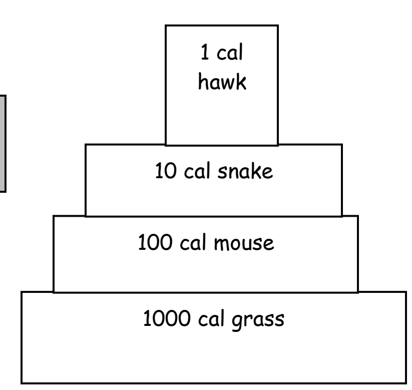
- Pyramid of biomass
    - Demonstrates the mass of organisms at each trophic level
    - May be inverted in aquatic ecosystems due to high reproductive rate of algae capable of feeding a larger biomass of zooplankton

Figure 3.10 Pyramids of biomass



- Pyramid of energy
    - Energy is lost between successive trophic levels due to a variety of reasons
    - Consumer may not be able to digest all of the organism that it ingested
    - Consumer may have had to expend energy to catch its food
    - Consumer may not be able to eat the entire organism that it killed
    - Consumer loses thermal energy
    - As a result of these losses, ecosystems lose anywhere from 80–95 percent of their available energy between trophic levels. The average transfer of energy between trophic levels is about 10 percent.

Figure 3.11 Pyramid of energy



Biogeochemical cycles

Because matter is not created nor destroyed, so it must be cycled on earth. The cycling of matter is exceptionally important for moving materials from the biotic to the abiotic portions of the biosphere. These cycles are therefore called biogeochemical cycles. The macronutrient cycles that are most important are the water, carbon, nitrogen, phosphorus, and sulfur cycles. These are cycles, so there is no beginning and no end. Understand the conversion from one form to another and human interferences in these cycles.

Take Note: You must understand the role of the cycled nutrients in living things to be successful on the AP exam. Some questions have required students to understand the implications of humans interfering in matter cycling. Also understand how human interference in the cycles impacts the environment. Be specific and give examples of anthropogenic pollutants and/or environmental damage to answer any essays given. For example, the hydrologic cycle may not have appeared as a diagram, but past essay questions have addressed water diversion projects, impacts of the water cycle on soil, and surface water contamination. All of these questions demand an understanding of the way in which water cycles on earth.

Hydrologic or Water Cycle

Water is released from surface water through evaporation. Evapotranspiration is the loss of water from the leaves of a plant as they exchange gases necessary during photosynthesis. Once in the atmosphere the water molecules undergo condensation, and then precipitation occurs, returning the water to the earth. The water will infiltrate the soil and percolate down into the deeper layers of the soil or it will become runoff. The percolated water may become part of the groundwater, which flows steadily underground toward the ocean. The water may also be used by plants during photosynthesis. The runoff will become part of the surface water, entering lakes or flowing water systems. The hydrolic cycle is powered by the sun and gravity.

Human intervention in the hydrologic cycle includes:

- Ground and surface water depletion
- Ground and surface water pollution
- The clearing of vegetation, particularly in temperate and tropical rainforests, interferes with the cycle by decreasing transpiration

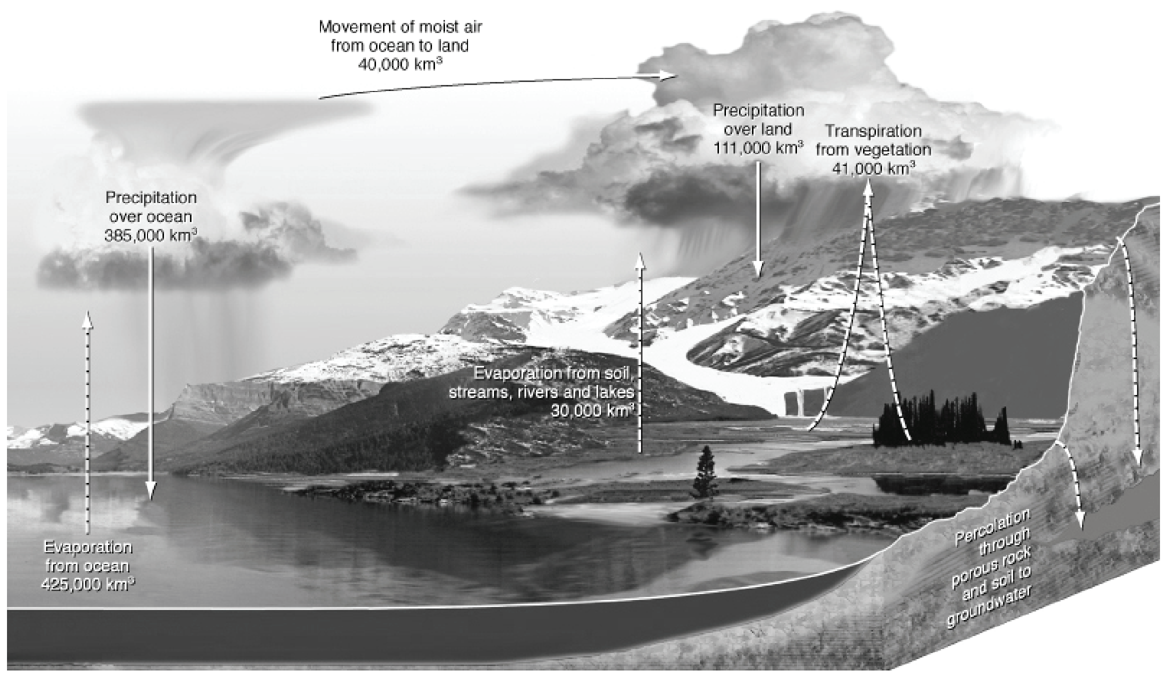


Figure 3.12 Hydrologic Cycle

Carbon Cycle

CO_2 makes up 0.035 percent of the atmosphere. It is used by plants during photosynthesis and incorporated into carbohydrates. The carbohydrates are then used during cellular respiration, giving off CO_2 into the atmosphere again. Decomposers degrade the remains of plants and animals and return the CO_2 to the atmosphere as well. Much of the carbon on earth is in the form of limestone, a type of sedimentary rock. In the oceans carbon is found dissolved as carbonate and bicarbonate ions. Large amounts of calcium carbonate ($CaCO_3$) deposits are found on the ocean floor, as they are the hard remains of organisms such as mollusks and corals. Heavily vegetated areas are called carbon sinks because they store large amounts of carbon in the biomass. In ancient times these heavily vegetated areas formed fossil fuels, also carbon sinks.

Human intervention in the carbon cycle

- Since the industrial revolution, we have dramatically increased the CO_2 in our atmosphere due to:
  - deforestation, which decreases the plants available for photosynthesis, thus decreasing the uptake of CO_2
  - forests burning and returning the carbon in the biomass of the forest to the atmosphere by releasing it from the sink
  - increased combustion of fossil fuels, releasing carbon from the sinks
- Increased CO_2 in the atmosphere has exacerbated global warming by holding in infrared heat around earth that would normally escape into space.

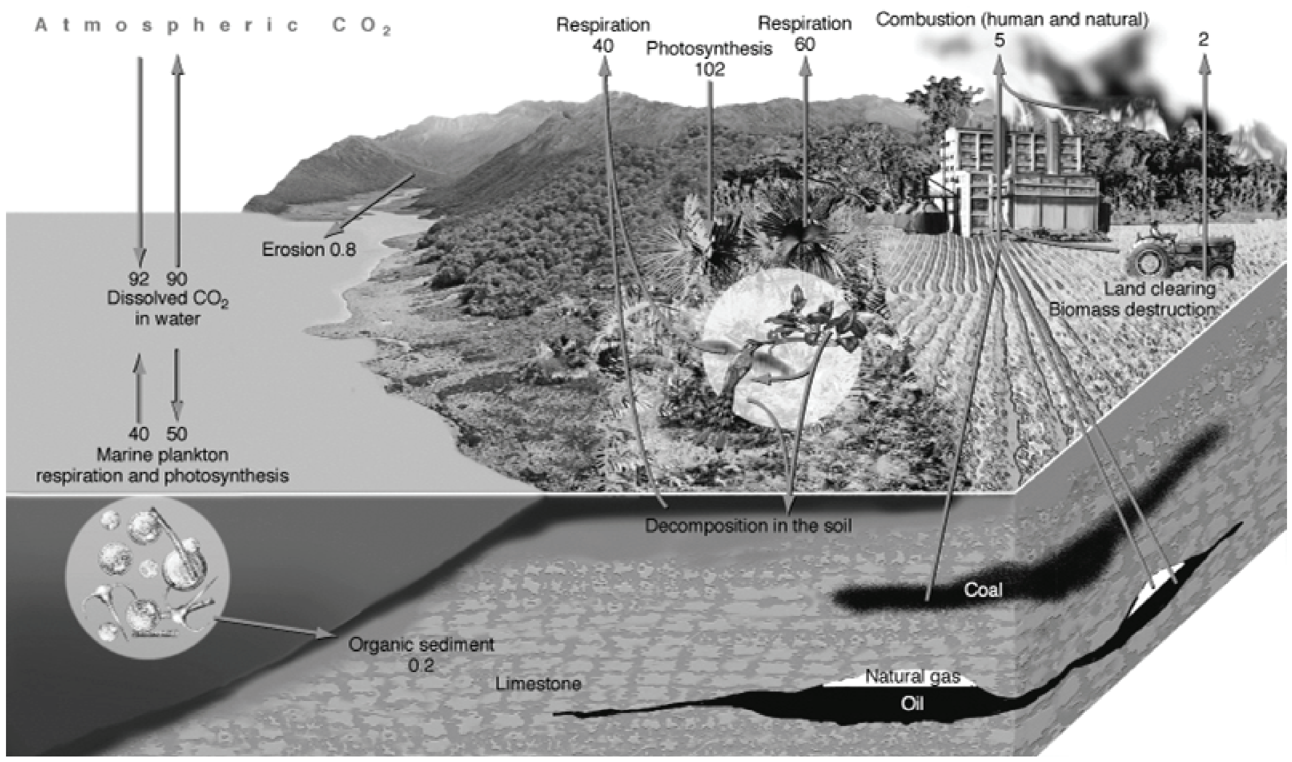


Figure 3.13 Carbon cycle
Numbers indicate approximate exchange of C in gigatons (Gt) per year.

Nitrogen Cycle

The nitrogen cycle has five major steps. Nitrogen fixation is the conversion of atmospheric N_2 into ammonia (NH_3). Some bacteria, such as *Rhizobium* and some cyanobacteria, are capable of breaking the triple covalent bond found in the diatomic nitrogen gas and combining the nitrogen with hydrogen to form ammonia. *Rhizobium* lives in the root nodules of legumes such as soybeans, alfalfa, peas, and clover. Some plants can use ammonia, but more can use nitrates. The next step is called nitrification. Other bacteria convert the ammonia into nitrites (NO_2^-, not usable by plants) and then a different group of bacteria convert the nitrites into nitrates (NO_3-, which plants can use). Assimilation is when the plant roots absorb ammonia, ammonium ions, or nitrates and make the substances they require for life. Ammonification takes place when the dead nitrogen rich organisms, their parts, or their metabolic wastes are converted to ammonia and ammonium ions by decomposition by bacteria. Denitrification is the process of nitrate ions being converted back to nitrogen gas, released into the atmosphere. This is a process carried out by yet another group of bacteria. Nitrogen can be an important limiting factor in terrestrial ecosystems because it is easily leached from the soil.

Human intervention in the nitrogen cycle:

- NO is released when fossil fuels are combusted. NO in the atmosphere forms nitric acid, which results in acid deposition (eventually causing terrestrial and aquatic ecosystems to become more acidic) and smog formation.
- N_2O gas is a greenhouse gas and is derived from livestock waste and use of commercial fertilizer
- Nitrogen is removed from an ecosystem if plants are removed
- Nitrogen, when added to aquatic ecosystems from agricultural runoff and municipal waste treatment, induces eutrophication, an enrichment of the ecosystem resulting in an algal bloom that has far reaching consequences

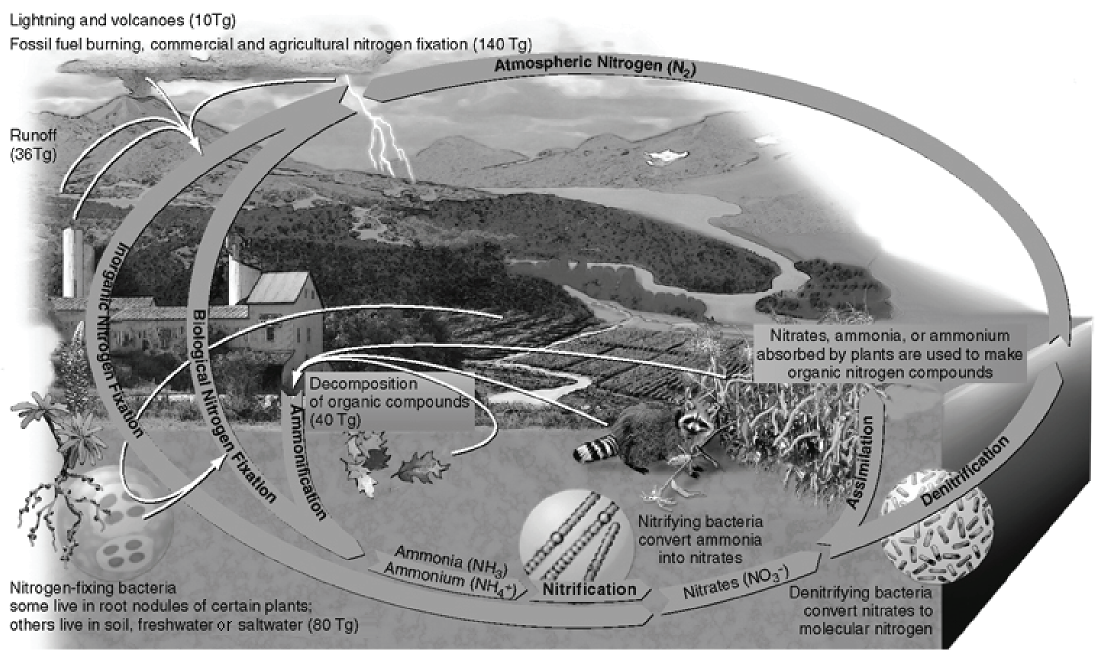


Figure 3.14 Nitrogen

Phosphorus Cycle

The phosphorus cycle is very slow because there is no atmospheric stage. Nearly all of the phosphorus is in living organisms or in rock, because the ions of phosphorus do not dissolve well in water. Most is found in insoluble rock on the ocean floor as a phosphorus sink. The rock containing phosphates must be weathered to release the minerals or removed by mining. The phosphorus is taken up by producers and transferred to consumers. The decay of their bodies releases the phosphorous again. Guano, the phosphorus-rich feces from fish-eating birds, is a part of the cycle.

Human intervention in the phosphorus cycle:

- Phosphate mines that form large pits and result in runoff pollution

- Removing vegetation lowers phosphorus availability in the ecosystem
- Similar to increases in nitrogen, increases in phosphorus leads to eutrophication in aquatic ecosystems. Phosphorus is present in agricultural runoff and effluent from sewage treatment plants.

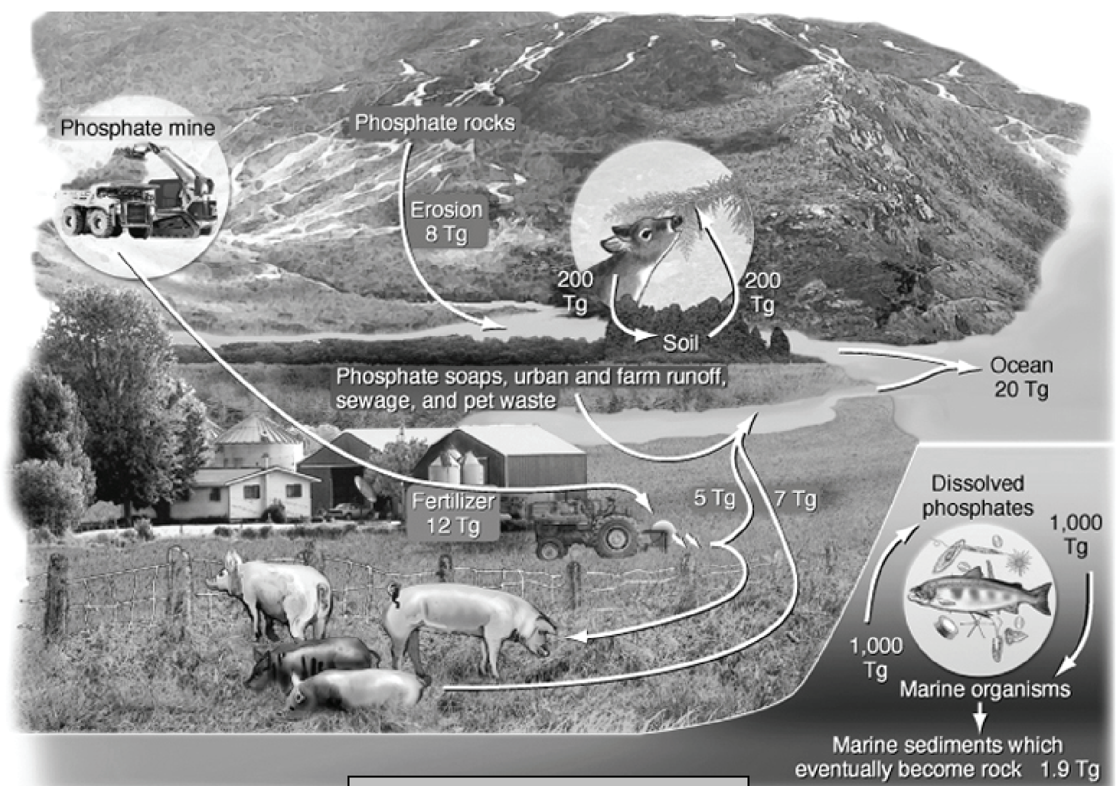


Figure 3.15 Phosphorus cycle

Sulfur cycle

Most sulfur is found in rock as iron disulfide (pyrite) or as mineral salts, like calcium sulfate (gypsum). The sulfur is released primarily by weathering and volcanic activity. The sulfur is taken up by the producers, passed to the consumers, and released again after decomposition.

Human intervention in the sulfur cycle:

- Fossil fuel combustion releases sulfur dioxide, which forms sulfuric acid in the atmosphere and results in acidification of ecosystems, reduced visibility, and human health problems
- Refining of petroleum and smelting releases sulfur compounds
- Coal mining results in sulfur release, which may cause damage to aquatic ecosystems if near surface water
- Large amounts of sulfur dioxide and sulfate aerosols cool the atmosphere because they prevent the penetration of UV radiation

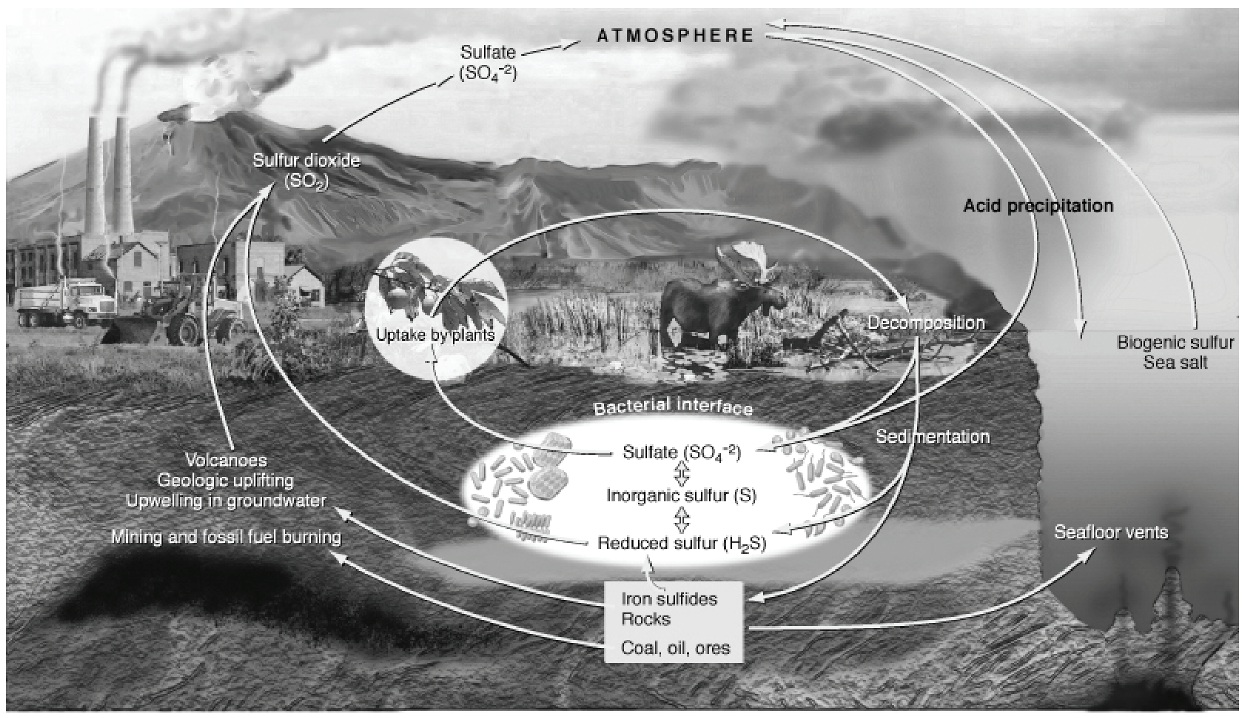


Figure 3.16 Sulfur

Questions

1. In a pond algae has 10,000 kcal of available energy. If the zooplankton, which consumes the algae, has 1000 kcal of available energy. What is the available energy to the minnow that consumes the zooplankton?
   a. 1,000 J
   b. 100 J
   c. 200 J
   d. 10 J
   e. 1 J

2. Nitrogen in the atmosphere is converted into ammonia by the process called
   a. nitrification.
   b. denitrification.
   c. nitrogen fixation.
   d. ammonification.
   e. assimilation.

3. A solution with a pH of 2 is ___ times more acidic than a solution with a pH of 5.
   a. 10
   b. 30
   c. 100
   d. 300
   e. 1,000

4. Which of the following organisms is an herbivore?
   a. bobcat
   b. wolf
   c. rabbit
   d. eagle
   e. snake

5. Plants require phosphorus to form which compound?
   a. simple sugars
   b. deoxyribonucleic acid
   c. proteins
   d. carbohydrates
   e. lipids

6. Which of the following is an example of kinetic energy?
   a. water in a reservior
   b. gasoline in a motor
   c. wind blowing at the beach
   d. a stretched rubber band
   e. a rock at the top of a hill

7. Cellular respiration produces which of the following gases?
   a. CO_2
   b. CH_4
   c. O_2
   d. N_2
   e. H_2

Use the passage for questions 8 and 9.

In the African savanna, Thompson's gazelles consume short grasses. The gazelles are a food source for cheetahs. The gazelle remains are ingested by hyenas and vultures.

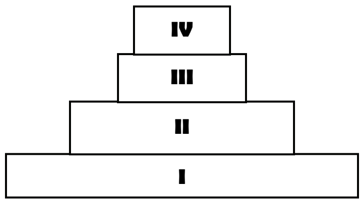
8. What role do the hyenas play in this ecosystem?
   a. herbivore
   b. carnivore
   c. scavenger
   d. decomposer
   e. detritovore

9. The organisms described make up a(n)
   a. ecosystem.
   b. community.
   c. population.
   d. species.
   e. biosphere.

10. Humans interfere in the hydrologic cycle in all of the following ways except:
    a. building dams that flood ecosystems.
    b. channelizing rivers to allow easier boat passage.
    c. transpiration from leaves enters the atmosphere.
    d. deforestation in tropical areas.
    e. pumping groundwater for irrigation.

11. An isotope differs from other elements of the same atomic number due to its different number of
    a. protons.
    b. atoms.
    c. ions.
    d. neutrons.
    e. electrons.

Use the diagram to answer questions 12–15.



12. Organisms in trophic level II in the diagram would be classified as
    a. autotrophs.
    b. decomposers.
    c. scavengers.
    d. herbivores.
    e. carnivores.

13. The organisms at level IV would most likely be classified as
    a. primary consumers.
    b. primary producers.
    c. secondary consumers.
    d. herbivores.
    e. top carnivores.

14. Which of the following statements is true about the pyramid of energy in the diagram?
    a. The energy from level IV will be passed back to level I eventually.
    b. The autotrophs would be found at level IV.
    c. The biomass at level IV is greater than the biomass at level I.
    d. The energy available to each subsequent tropic level continues to increase.
    e. The energy lost to the surrounding environment is thermal energy, which is unrecoverable.

15. The energy available to tropic level IV would be what percent of the total energy available in I?
    a. 0.1 percent.
    b. 10 percent.
    c. 50 percent.
    d. 75 percent.
    e. 100 percent.

16. Photosynthesis products used during cellular respiration include
    a. CO_2, water, and sugars.
    b. water, oxygen, and sugars.
    c. carbon dioxide, water, and energy.
    d. oxygen and sugars.
    e. energy and oxygen.

17. The only biogeochemical cycle with no atmospheric component is the ___________ cycle.
    a. phosphorus
    b. nitrogen
    c. sulfur
    d. water
    e. carbon

18. Which of the following characteristics of water is correct?
    a. Water has low heat of vaporization.
    b. Water contracts as it freezes.
    c. Water is nonpolar and is attracted to nonpolar substances.
    d. Water exhibits cohesion, the tendency to attach to other molecules.
    e. Water spontaneously ionizes into hydrogen and hydroxide ions.

19. Humans interfere in the sulfur cycle by
    a. burning wood for cooking.
    b. using inorganic fertilizers.
    c. burning coal to generate electricity.
    d. using pesticides on cotton farms.
    e. deforestation of tropical forests.

20. All of the following are carbon sinks except
    a. coral reefs.
    b. tropical rain forests.
    c. coal seams.
    d. mangrove swamps.
    e. deserts.

Explanations

1. b. The algae has 10,000 kcal of energy. By assuming that 10 percent of the energy is available to subsequent trophic levels, the zooplankton has 1,000 kcal available and the minnow would have 100 kcal available.
2. c. Nitrogen gas in the atmosphere is converted into ammonia by nitrogen fixation. Nitrification is the conversion of the ammonia in soil into the useful nitrates that can be incorporated into the plants tissues. Denitrification is the formation of nitrogen gas from ammonia. Ammonification is the formation of ammonia from nitrogen containing wastes. Assimilation is the uptake of nitrates by a plant.
3. e. The pH scale is logarithmic. A solution with a pH of 2 has a hydrogen ion concentration of 1×10^{-2}. A solution with a pH of 5 contains 1×10^{-5} hydrogen ions. The difference between the two numbers is 1,000 fold.
4. c. Bobcats, wolves, eagles, and snakes all consume other animals and are therefore carnivores. Rabbits are herbivores because they eat vegetation.
5. b. Simple sugars, carbohydrates, and lipids contain the elements C, H, and O. In addition to those three elements, proteins also contain N. DNA is the only choice that has P as part of its structure.
6. c. Water in a reservoir and a rock at the top of a hill are gravitational potential energy. Gasoline in a motor is stored chemical energy. The stretched rubber band is stored mechanical energy. The wind blowing is energy of motion, or kinetic energy.
7. a. Neither cellular respiration nor photosynthesis produces hydrogen, nitrogen, or methane gas. None of those gases were mentioned as a part of the life-sustaining energy conversions found in photosynthesis and respiration. The choices are between carbon dioxide and oxygen gas. Respiration uses oxygen and produces carbon dioxide as a by-product.
8. c. The gazelle is an herbivore because it eats grasses. The cheetah is a carnivore as it eats the gazelle's meat. No detritovore or decomposer is mentioned in the question. The hyena and the vulture are scavengers, as they clean up dead carcasses.
9. b. Communities are groups of interacting populations. Therefore, a description of the biotic factors is a description of a community.
10. c. Dams interfere with the hydrologic cycle by flooding ecosystems and preventing water flow downstream. Channelizing rivers allow for more rapid water flow, thus interfering with the cycle. Deforestation removes trees and thus interferes with transpiration and absorption. Pumping groundwater interferes with natural aquifers. Only transpiration is a natural occurrence and is therefore the answer.
11. d. An isotope of an element contains a different number of neutrons. The number of protons defines the element. An atom is the smallest particle that exhibits the characteristic of an element. An ion is a charged atom due to gain or loss of electrons. The number of electrons equals the number of protons.
12. d. The organisms in level I are producers, so level II must therefore be herbivores.
13. e. Level I are the producers in the ecosystem. Level II is comprised of herbivores, thus level III must be carnivores. Level IV feeds upon level III, so they must be top carnivores.
14. e. According to the second law of thermodynamics, all energy proceeds toward entropy, or disorganized thermal energy. This pyramid is not inverted therefore *c* could not be correct. Energy cannot be created nor destroyed it can only change form therefore *b* is

untrue. Producers only make up the first trophic level so *d* is untrue. Energy in systems cannot cycle, thus *a* is also untrue.

15. a. The energy available to the tropic level IV is .1% of the energy available in I because of the 10% rule.
16. d. Photosynthesis uses carbon dioxide and water so they are not answers. Sugars are required for respiration, so *e* is not correct.
17. a. All of the other biogeochemical cycles have some part of the cycle where the elements exist as a gas in the atmosphere.
18. e. Water has a high heat of vaporization, expands as it freezes, and is polar. Cohesion is the tendency for water to stick to itself.
19. c. Coal combustion releases sulfur oxides. Wood combustion and deforestation interfere with the carbon cycle, and inorganic fertilizers interfere with nitrogen and phosphorus cycles. Pesticides do not generally impact the biogeochemical cycles.
20. e. Coral reefs, tropical rain forests, coal seams, and mangrove swamps are carbon sinks because they store a tremendous amount of carbon. Deserts have little biomass and thus store little carbon.