Natural Biogeochemical Cycles

5

CARBON CYCLE

Carbon is the basic building block of life and the fundamental element found in carbohydrates, fats, proteins, and nucleic acids (DNA and RNA). Carbon is exchanged among the biosphere, geosphere, hydrosphere, and atmosphere. Although carbon is found in rocks, it is a minor component when compared with the mass of either oxygen or silicon atoms in rocks. Carbon is found in carbon dioxide (CO_2), which makes up less than 1% of the atmosphere.

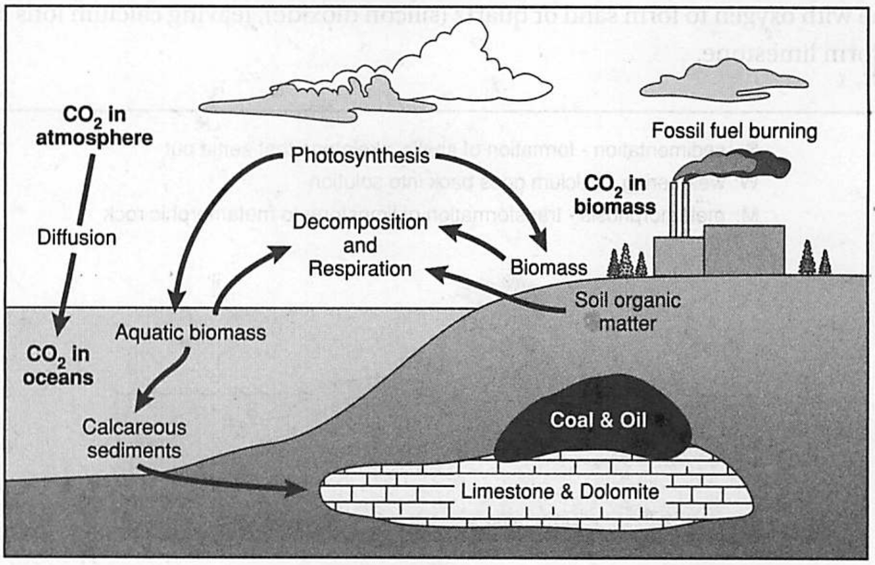


Figure 5.1 The carbon cycle viewed as chemical processes

The major reservoirs or "sinks" of carbon include:

- **PLANT MATTER:** A portion of atmospheric carbon (15%) is removed through photosynthesis by which carbon is incorporated into plant structures and compounds:

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

n.b.

- **TERRESTRIAL BIOSPHERE:** Forests store about 90% of the planet's aboveground carbon and about 75% of the planet's soil carbon. Carbon can be stored for very long periods of time in old-growth forests, limestone ($CaCO_3$), and peat, which serve as long-term carbon sinks.
- **OCEANS:** The carbon in carbon dioxide dissolved in seawater is utilized by phytoplankton and kelp for photosynthesis. Carbon is also required by marine organisms for the production of shells, skeletons, and coral.

The oceans are gaining about 2 gigatons (4×10^{12} kg) of carbon each year; however, most of it is not involved with rapid exchanges with the atmosphere. When carbon dioxide mixes with seawater, it has the effect of reducing the availability of carbonate (CO_3^{2-}) ions, which many organisms, such as corals, marine plankton, and shellfish, need to build their shells. carbonic acid

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$$

The increase in the hydrogen ion (H^+) concentration decreases the pH of seawater, making it more acidic. Simultaneously, carbonate ions (CO_3^{2-}) are consumed by the hydrogen ions to form even more bicarbonate ions (HCO_3^-). The net effect is that one unit of carbonate ion is consumed for each unit of carbon dioxide added to seawater. Because the forward and reverse reactions run simultaneously, both the pH and the availability of carbonate are reduced as the atmospheric concentration of carbon dioxide rises.

$$CO_2 + H_2O + CO_3^{2-} \rightleftarrows 2HCO_3^-$$

- **SEDIMENTARY DEPOSITS:** Limestone ($CaCO_3$) and carbon trapped in fossil fuels and coal. Limestone is the largest reservoir of carbon in the carbon cycle. The calcium comes from the weathering of calcium-silicate rocks, which causes the silicon in the rocks to combine with oxygen to form sand or quartz (silicon dioxide), leaving calcium ions available to form limestone.

complex, but useful

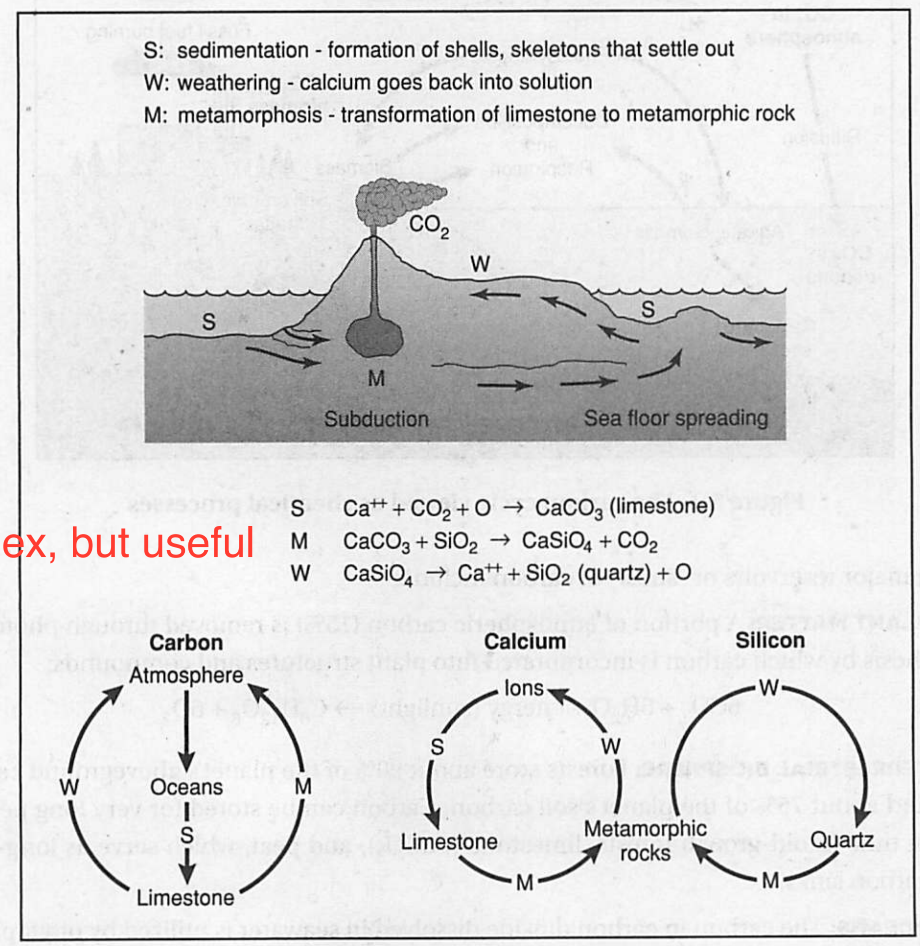
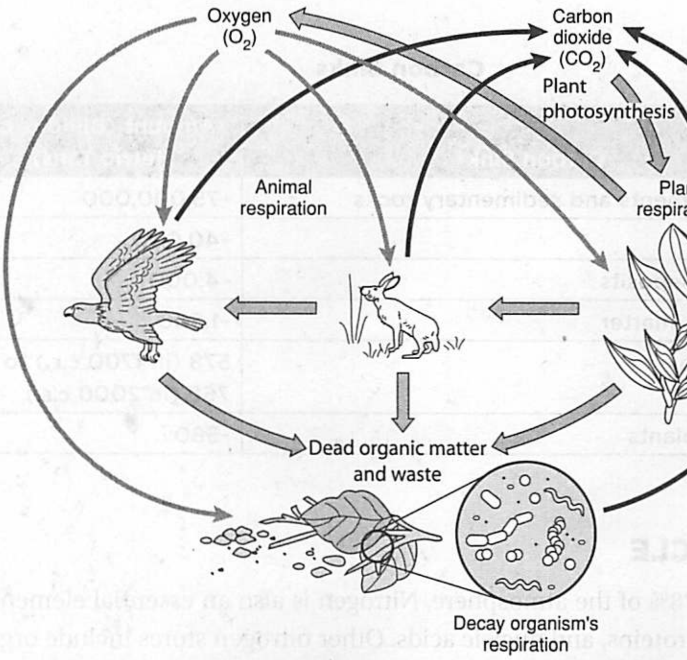


Figure 5.2 Inorganic carbon cycle

Carbon is released back into the atmosphere through:

- Cellular respiration of plants and animals that break down glucose into carbon dioxide and water: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy.



good diagram

Figure 5.3 The carbon cycle viewed as an ecosystem cycle

- When oxygen is not present, anaerobic respiration occurs and releases carbon into the atmosphere in the form of methane (CH_4) (e.g., as marsh gas or flatulence released in the form of methane gas from ruminant animals, like cattle, dairy cows, deer, sheep, etc.). n.b.
- Decay of organic material by the action of decomposers; if oxygen is present, the carbon is released in the form of carbon dioxide; if oxygen is absent, it is released in the form of methane (CH_4).
- Burning fossil fuels (e.g., wood, coal, etc.).
- Weatherization of rocks and especially the erosion of limestone, marble, and chalk, which break down to carbon dioxide and carbonic acid (H_2CO_3).
- Volcanic eruptions.
- Release of carbon dioxide by warmer ocean waters.
- Strip mining and deep plowing, which disturb the soil, releasing CO_2.
- Incineration of wastes, which releases ash and soot (carbon) along with carbon dioxide and carbon monoxide.

Every year, billions of tons of carbon are exchanged between the atmosphere, plants, soils, and the ocean. These exchanges are largely driven by the activity of plants and soil microbes through the processes of photosynthesis and cellular respiration. The total amount of carbon contained in the vegetation and soil sinks is more than three times the total carbon in the atmosphere. Vegetation and microbes are the most important biological components, decomposing plant litter and dead wood in the soil and returning billions of tons of carbon to the atmosphere each year through cellular respiration. The global carbon cycle is largely biological and was in a relatively steady state prior to the Industrial Revolution. Since that time, the shift to burning fossil fuels has released the trapped carbon in the form of carbon dioxide gas.

Carbon Sinks

Carbon Sink	Amount (Billions of Metric Tons)
Marine sediments and sedimentary rocks	~75,000,000
Ocean	~40,000
Fossil fuel deposits	~4,000
Soil organic matter	~1,500
Atmosphere	578 (in 1700 C.E.) to 766 (in 2000 C.E.)
Terrestrial plants	~580

TIP

Know *all* steps involved in the nitrogen cycle. You will find more questions about the nitrogen cycle than any other cycle on the APES exam.

NITROGEN CYCLE

Nitrogen makes up 78% of the atmosphere. Nitrogen is also an essential element needed to make amino acids, proteins, and nucleic acids. Other nitrogen stores include organic matter in the soil and the oceans (1 million times more nitrogen is found in the atmosphere than is contained in either land or ocean waters).

The natural cycling of nitrogen, in which atmospheric nitrogen is converted to nitrogen oxides by lightning and deposited in the soil by rain where it is assimilated by plants and either eaten by animals (and returned as feces) or decomposed back to elemental nitrogen by bacteria, includes the following processes:

n.b.
- **NITROGEN FIXATION:** Atmospheric nitrogen is converted into ammonia (NH_3) or nitrate ions (NO_3^-), which are biologically usable forms of nitrogen. The key participants in nitrogen fixation are legumes, such as alfalfa, clover, and soybeans, and nitrogen-fixing bacteria known as *rhizobium*.
- **NITRIFICATION:** Ammonia (NH_3) is converted to nitrite (NO_2^-) and nitrate (NO_3^-), which are the most useful forms of nitrogen to plants.
- **ASSIMILATION:** Plants absorb ammonia (NH_3), ammonium ion (NH_4^+), and nitrate ions (NO_3^-) through their roots.
- **AMMONIFICATION:** Decomposing bacteria convert dead organisms and wastes, which include nitrates, uric acid, proteins, and nucleic acids, to ammonia (NH_3) and ammonium ions (NH_4^+)—biologically useful forms.
- **DENITRIFICATION:** Anaerobic bacteria convert ammonia into nitrites (NO_2^-), nitrates (NO_3^-), nitrogen gas (N_2), and nitrous oxide (N_2O) to continue the cycle.

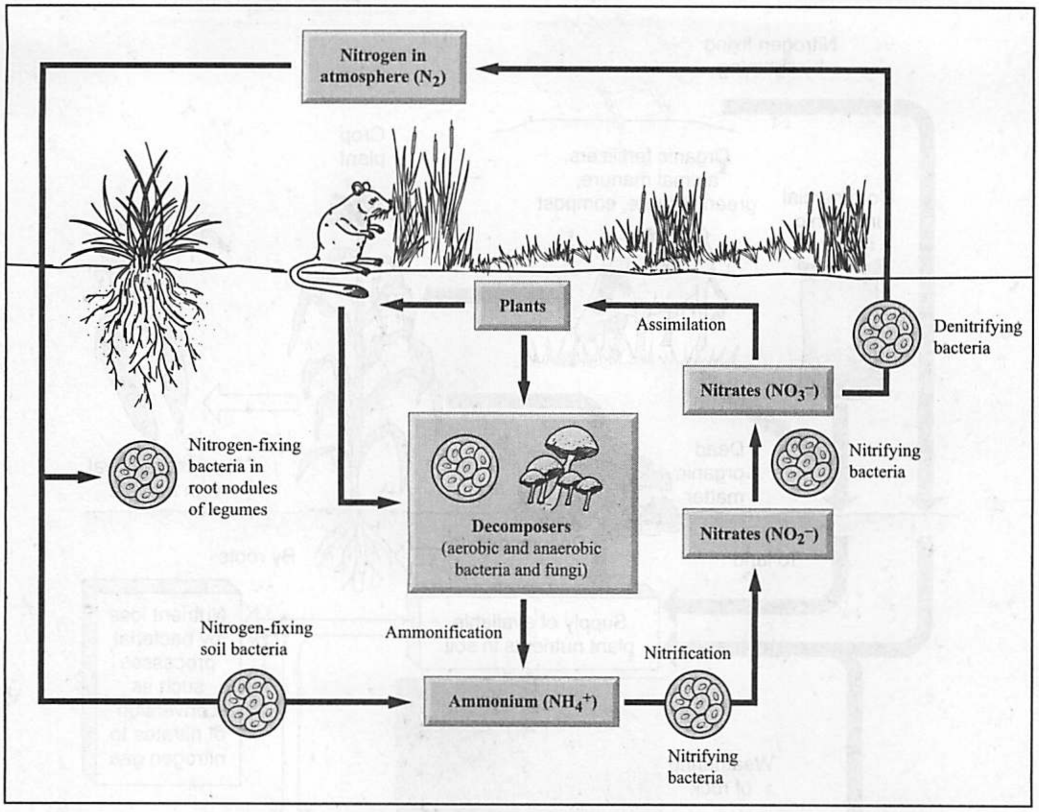


Figure 5.4 The nitrogen cycle

Effects of Excess Nitrogen

Fossil fuel combustion has contributed to a sevenfold increase in nitrogen oxides (NO_x) to the atmosphere, particularly nitrogen dioxide (NO_2). NO_x is a precursor of tropospheric (lower atmosphere) ozone production and contributes to smog and acid rain and increases nitrogen inputs to ecosystems.

Ammonia (NH_3) in the atmosphere has tripled as the result of human activities since the Industrial Revolution. Ammonia acts as an aerosol and decreases air quality.

Nitrous oxide (N_2O) is a significant greenhouse gas and has deleterious effects in the stratosphere, where it breaks down and acts as a catalyst in the destruction of atmospheric ozone. N_2O is in a large part emitted during nitrification (conversion of ammonium to nitrate and nitrite) and denitrification (converting oxides back to nitrogen gas or nitrous oxides for energy generation) processes that take place in the soil. The largest N_2O emissions are observed where nitrogen-containing fertilizer is applied in agriculture.

Human activity has more than doubled the annual transfer of nitrogen into biological available forms through:

- Extensive cultivation of legumes (particularly soy, alfalfa, and clover)
- The extensive use of chemical fertilizers and pollution emitted by vehicles and industrial plants (NO_x)
- Biomass burning
- Cattle and feedlots
- Industrial processes

n.b.

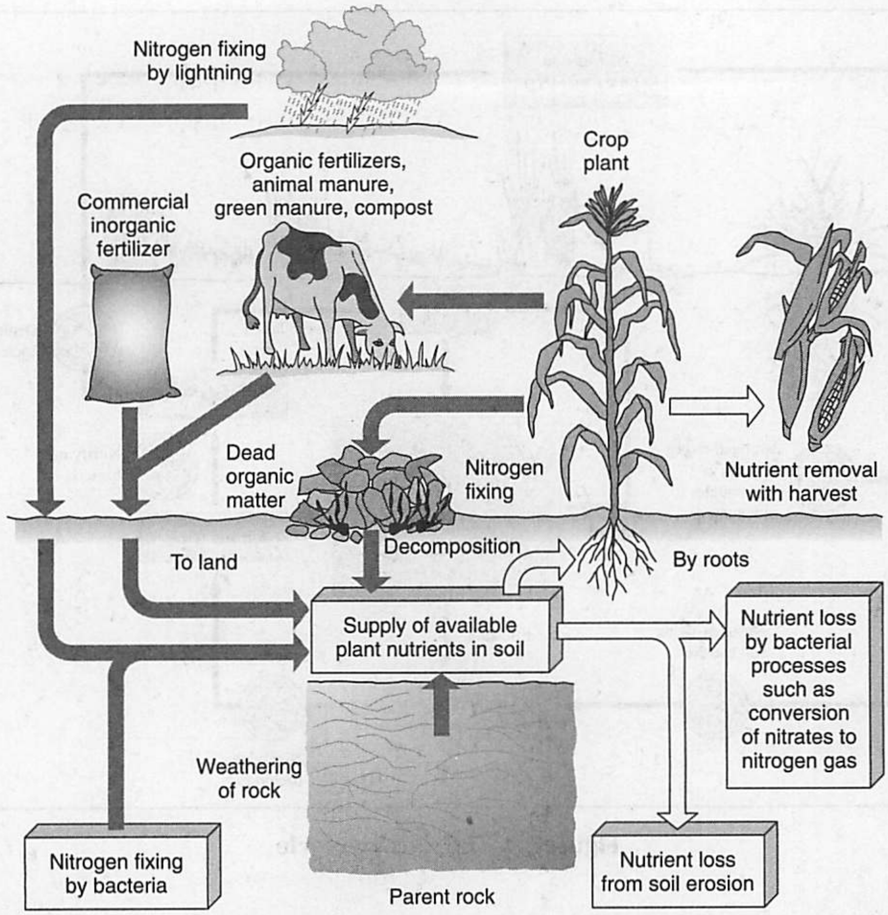


Figure 5.5 Plant nutrient pathways

PHOSPHORUS CYCLE

none in atmosphere

Phosphorus is essential for the production of nucleotides, ATP, fats in cell membranes, bones, teeth, and shells. Phosphorus is not found in the atmosphere but, rather, the primary sink for phosphorus is in sedimentary rocks. Generally, phosphorus is found in the form of the phosphate ion (PO_4^{3-}) or the hydrogen phosphate ion (HPO_4^{2-}). Phosphorus is slowly released from terrestrial rocks by weathering and the action of acid rain. It then dissolves into the soil and is taken up by plants. It is often a limiting factor for soils due to its low concentration and solubility and is a key element in fertilizer. A fertilizer labeled 6-24-26 contains 6% nitrogen, 24% phosphorus, and 26% potassium.

Unlike the carbon, nitrogen, sulfur, or water cycles, the phosphorus cycle does not involve a gaseous or atmospheric phase. Since phosphorus is trapped in rocks and minerals, it must undergo a weathering process to be released before it can be utilized.

Humans have impacted the phosphorus cycle in several ways:

- Humans have mined large quantities of rocks containing phosphorus for inorganic fertilizers and detergents.
- Clear-cutting tropical habitats for agriculture decreases the amount of available phosphorus as it is contained in the vegetation.

- Humans allow runoff from feedlots, from fertilizers, and from the discharge of municipal sewage plants. The runoff collects in lakes, streams, and ponds, causing an increase in the growth of cyanobacteria (blue-green bacteria), green algae, and aquatic plants. In turn, this growth results in decreased oxygen content in the water, which then kills other aquatic organisms in the food web.
- Humans apply phosphorus-rich guano and other phosphate-containing fertilizers to fields.

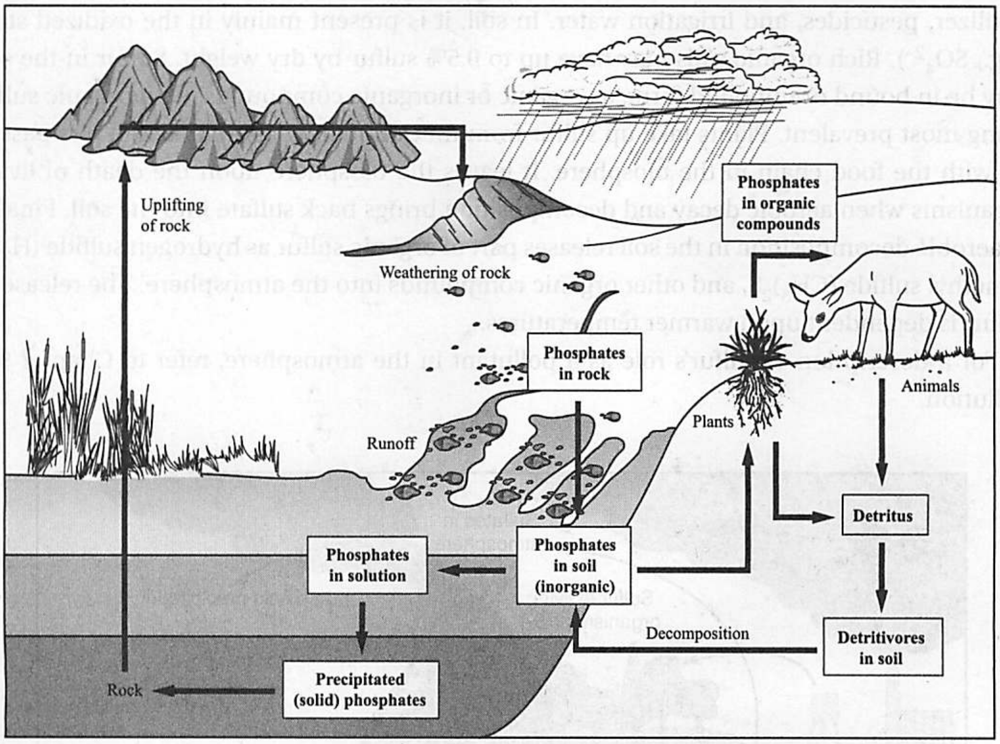


Figure 5.6 The phosphorus cycle

SULFUR CYCLE

Elemental or pure sulfur is commonly found in underground deposits or near natural hot springs or volcanoes. It's also found in the combined form in many minerals.

Sulfur in the Lithosphere

The sulfur content of rocks varies considerably (e.g., sedimentary rocks have the most while igneous rocks have the least). Sulfur in the lithosphere is mobilized by slow weathering of rock material. Dissolved in runoff, it moves with river water and is deposited as sediments in the oceans. Eventually it uplifts to the surface again, thus completing the geological part of the sulfur cycle.

Sulfur in the Hydrosphere

The main storage of sulfur in the oceans is through dissolved sulfate. The most volatile sulfur compound in seawater is dimethyl sulfide (DMS; $(CH_3)_2S$), which is produced by algal and bacterial decay with its highest concentrations found in coastal marshes and wetlands. Sulfur new info is the second most abundant compound in rivers with concentrations fluctuating highly with seasons and frequency of drought, flood, and normal flow. Rivers transport about 110 million tons (100 Tg) of sulfur per year to the oceans.

Sulfur in the Soil

Sulfur is a major essential nutrient in the biosphere and is concentrated mainly in soil from where it enters the biosphere through plant uptake. Its main sources are deposition from the atmosphere, weathering of rocks, release from decay of organic matter and anthropogenic fertilizer, pesticides, and irrigation water. In soil, it is present mainly in the oxidized state (e.g., SO_4^{2-}). Rich organic soils may have up to 0.5% sulfur by dry weight. Sulfur in the soil may be in bound or unbound form, as organic or inorganic compounds, with organic sulfur being most prevalent. Plants take up sulfur from the soil mainly as sulfate, and it is passed on with the food chain in the biosphere. It leaves the biosphere upon the death of living organisms when aerobic decay and decomposition brings back sulfate into the soil. Finally, anaerobic decomposition in the soil releases part of organic sulfur as hydrogen sulfide (H_2S), dimethyl sulfide $(CH_3)_2S$, and other organic compounds into the atmosphere. The release of sulfur is dependent upon warmer temperatures.

For a description of sulfur's role as a pollutant in the atmosphere, refer to Chapter 9—Pollution.

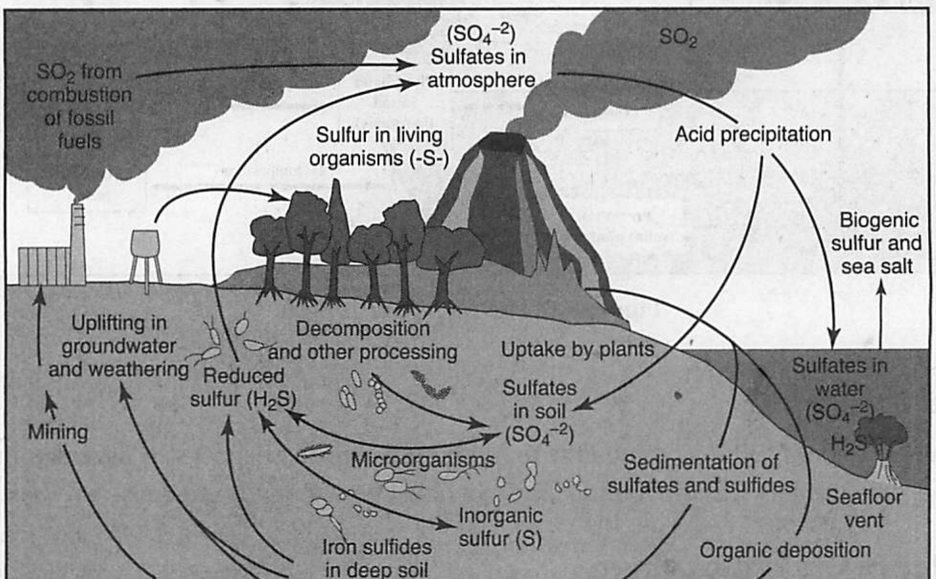


Figure 5.7 The sulfur cycle

WATER CYCLE

The water cycle is powered by energy from the sun. Solar energy evaporates water from oceans, lakes, rivers, streams, soil, and vegetation. The oceans hold 97% of all water on the planet and are the source of 78% of all global precipitation. Oceans are also the source of 86% of all global evaporation, with evaporation from the sea surface keeping Earth from overheating. If there were no oceans, surface temperatures on land would rise to an average of 153°F (67°C).

n.b. cooling effect of evaporation

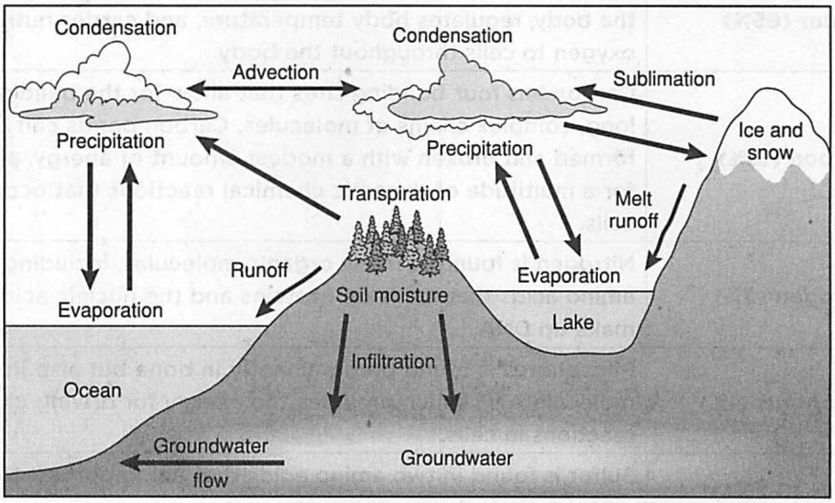


Figure 5.8 The water cycle

The water cycle is in a state of dynamic equilibrium by which the rate of evaporation equals the rate of precipitation. Warm air holds more water vapor than cold air. Processes involved in the water cycle include evaporation, evapotranspiration, condensation, infiltration, runoff, and precipitation.

Human Impact on the Water Cycle

Human Activity	Impact on Water Cycle
Withdrawing water from lakes, aquifers, and rivers	Groundwater depletion and saltwater intrusion
Clearing of land for agriculture and urbanization	Increased runoff Decreased infiltration Increased flood risks Accelerated soil erosion
Agriculture	Runoff contains nitrates, phosphates, ammonia, etc.
Destruction of wetlands	Disturbing natural processes that purify water
Pollution of water sources	Increased occurrences of infectious agents such as cholera, dysentery, etc.
Sewage runoff, feedlot runoff	Cultural eutrophication
Building power plants	Increased thermal pollution

ROLE OF H_2O, C, N, P, AND S IN THE HUMAN BODY

The following chart outlines the role of water, carbon, nitrogen, phosphorus, and sulfur in the human body.

Element—Compound (% by weight in the human body)	Role in the Human Body
Water (65%)	Water helps to dissolve minerals, making them accessible to the body, regulates body temperature, and carries nutrients and oxygen to cells throughout the body.
Carbon (18%)	Carbon has four bonding sites that allow for the building of long, complex chains of molecules. Carbon bonds can be formed and broken with a modest amount of energy, allowing for a multitude of dynamic chemical reactions that occur in cells.
Nitrogen (3%)	Nitrogen is found in many organic molecules, including the amino acids that make up proteins and the nucleic acids that make up DNA.
Phosphorus (1%)	Phosphorus is found predominantly in bone but also in the molecule ATP, which provides the energy for driving chemical reactions in cells.
Sulfur (0.25%)	Sulfur is found in two amino acids that are important for giving proteins their shape. methionine and cysteine

MULTIPLE-CHOICE QUESTIONS

1. Which of the following is NOT a primary depository for the element listed?

    (A) Carbon—coal
    (B) Nitrogen—nitrogen gas in the atmosphere
    (C) Phosphorus—marble and limestone
    (D) Sulfur—deep ocean deposits
    (E) All of the above are correct.

2. Burning fossil fuels coupled with deforestation increases the amount of ________ in the atmosphere.

    (A) NO_2
    (B) CO_2
    (C) SO_2
    (D) O_3
    (E) All of the above are correct.

3. In the nitrogen fixation cycle, cyanobacteria in the soil and water and *Rhizobium* bacteria in root systems are responsible for converting

    (A) organic material to ammonia and ammonium ions
    (B) ammonia, ammonium ions, and nitrate ions to DNA, amino acids, and proteins
    (C) ammonia and nitrite ions to nitrate ions
    (D) nitrogen and hydrogen gas to ammonia
    (E) ammonia to nitrite and nitrate ions

4. The cycle listed that has the most immediate effect on acid precipitation would be the

    (A) carbon cycle
    (B) sulfur cycle
    (C) water cycle
    (D) phosphorous cycle
    (E) rock cycle

5. Nitrogen is assimilated in plants in what form?

    (A) Nitrite, NO_2^-
    (B) Ammonia, NH_3
    (C) Ammonium, NH_4^+
    (D) Nitrate, NO_3^-
    (E) Choices B, C, and D

6. Plants assimilate sulfur primarily in what form?

(A) Sulfates, SO_4^{2-}
(B) Sulfites, SO_3^{2-}
(C) Hydrogen sulfide, H_2S
(D) Sulfur dioxide, SO_2
(E) Elemental sulfur, S

7. Humans increase sulfur in the atmosphere and thereby increase acid deposition by all of the following activities EXCEPT

(A) industrial processing
(B) processing (smelting) ores to produce metals
(C) burning coal
(D) refining petroleum
(E) clear-cutting

8. Phosphorus is being added to the environment by all of the following activities EXCEPT

(A) runoff from feedlots
(B) slashing and burning in tropical areas
(C) stream runoff
(D) burning coal and fossil fuels
(E) mining to produce inorganic fertilizer

9. Carbon dioxide is a reactant in

(A) photosynthesis
(B) cellular respiration
(C) the Haber-Bosch process of manufacturing ammonia
(D) nitrogen fixation
(E) None of the above

10. The primary biological process that removes carbon from the atmosphere and moves it to the biosphere is

(A) organic decay
(B) photosynthesis
(C) cellular respiration
(D) anaerobic respiration
(E) fossil-fuel-burning power plants and automobiles

11. Clearing of land for either habitation or agriculture does all of the following EXCEPT

    (A) increases runoff
    (B) increases flood risks
    (C) increases potential for landslides
    (D) increases infiltration
    (E) accelerates soil erosion

12. All of the following have an impact on the nitrogen cycle EXCEPT

    (A) the application of inorganic fertilizers applied to the soil
    (B) the action of aerobic bacteria acting on livestock wastes
    (C) the overplanting of nitrogen-rich crops
    (D) the discharge of municipal sewage
    (E) the burning of fossil fuels

13. Which of the following is a macronutrient essential for the formation of proteins?

    (A) Sulfur
    (B) Nitrogen
    (C) Iron
    (D) Cobalt
    (E) Molybdenum

14. Which of the following bacteria are able to convert soil nitrites to nitrates?

    (A) *Nitrosomonas*
    (B) *Nitrobacter*
    (C) *Rhizobium*
    (D) *Penicillium*
    (E) *Clostridium*

15. Which of the following are the largest phosphorus sinks?

    I. The atmosphere
    II. Ocean sediment
    III. Lakes
    IV. Sedimentary rock
    V. Tropical rainforests

    (A) I and III
    (B) II and IV
    (C) II, III, and IV
    (D) III, IV, and V
    (E) I, II, III, IV, and V

16. The cycle that is most common to all other cycles is the

(A) nitrogen cycle
(B) carbon cycle
(C) hydrologic cycle
(D) life cycle
(E) the rock cycle

17. The energy that drives the hydrologic cycle comes primarily from

(A) trade winds
(B) solar energy and gravity
(C) Earth's rotation on its axis
(D) ocean currents and wind patterns
(E) solar radiation

18. Which one of the following processes is working against gravity?

(A) Precipitation
(B) Percolation
(C) Runoff
(D) Transpiration
(E) Infiltration

19. Ammonium ions (NH_4^+) are converted to nitrate (NO_3^-) and nitrite ions (NO_2^-) through which process?

(A) Assimilation
(B) Denitrification
(C) Nitrogen fixation
(D) Nitrification
(E) Ammonification

20. Which form of nitrogen is most usable by plants?

(A) Nitrate
(B) Nitrite
(C) Nitrogen gas
(D) Ammonia
(E) Atomic nitrogen

FREE-RESPONSE QUESTION

By: Brian Palm, Catholic Memorial School, West Roxbury, MA
A.B. Dartmouth College, Hanover, NH
MSc Oxford University, UK

Phosphorus mining provides humans with an important product called ammonium phosphate. This key ingredient is used as a fertilizer that helps to increase crop yields in our agricultural system. Ammonium phosphate is derived from calcium phosphate rock that is strip-mined and pulverized on several U.S. states. Producers extract the calcium phosphate and then add sulfuric acid to form phosphoric acid which is later modified to produce the desired product, ammonium phosphate.

As an unfortunate by-product of this process, phosphogypsum is produced. In fact, five tons of phosphogypsum are produced for every ton of ammonium phosphate. The runoff from the phosphogypsum has a pH between 1 and 2.

Florida generates 75% of the ammonium phosphate used by U.S. farmers each year. It currently has one billion tons of phosphogypsum stored at 25 sites around the state, and miners are adding 30 million tons of phosphogypsum to those piles each year.

(a) Using the information above, what is the annual demand of ammonium phosphate by U.S. farmers?

(b) If the U.S. comprises 20% of the world's production, how much ammonium phosphate is produced globally?

(c) Based on this world total, how much of the toxin phosphogypsum is produced on an annual basis?

(d) Identify and describe TWO environmental consequences that result from the extraction/processing of phosphorus.

(e) Describe ONE strategy to mitigate the environmental damage caused by extraction or processing.

(f) Describe ONE alternative strategy that might reduce the need for phosphorus mining.

MULTIPLE-CHOICE ANSWERS AND EXPLANATIONS

1. **(C)** The primary sinks for phosphorus are ocean sediments and certain islands rich in guano.
2. **(B)** Burning fossil fuels releases sulfur oxides (SO_x), carbon oxides (carbon dioxide on complete combustion, or carbon monoxide on incomplete combustion) and nitrogen oxides (NO_x). Ozone is not produced by burning fossil fuels. Deforestation releases carbon dioxide. Since the question said "coupled," the gas that is common to both processes is carbon dioxide.
3. **(D)** This is the first step in the nitrogen cycle and is called nitrogen fixation.
4. **(B)** Sulfur dioxide produced by industry enters the atmosphere and returns to Earth as sulfuric acid.
5. **(E)** The nitrite ion is toxic to plants. In the nitrogen cycle, during assimilation, plant roots absorb nitrate.
6. **(A)** Hydrogen sulfide and sulfur dioxide are toxic to living organisms. Some sulfate compounds are soluble in water, which allows the sulfate ion to be able to be absorbed by plants. Elemental sulfur is not soluble in water and therefore cannot be absorbed.
7. **(E)** Clear-cutting produces carbon dioxide, not sulfur dioxide.
8. **(D)** Animal manure and guano are rich in phosphate. In the tropics, most of the nutrients are contained within the vegetation. Little is being retained in the soil since much of it leaches due to high rainfall. Phosphorus would therefore be released back into the environment by cutting down vegetation and then burning it—thereby releasing it and being subjected to runoff. Mining phosphates for fertilizer and industrial products takes phosphorus out of sinks and puts it into the environment. Burning coal and petroleum does not add appreciable amounts of phosphorus to the environment.
9. **(A)** The reaction for photosynthesis is $6CO_2 + 6H_2O + \text{sunlight} \rightarrow C_6H_{12}O_6 + 6O_2$. Cellular respiration is the reverse of photosynthesis.
10. **(B)** Photosynthetic organisms convert 100 billion metric tons of atmospheric carbon dioxide into biomass each year.
11. **(D)** Infiltration is the movement of water into the soil. Removing vegetation decreases infiltration by not allowing water to percolate through the soil slowly. Since runoff is increased, the potential for flooding increases. As the soil structure loses its integrity, the chances of landslides increase. Runoff also carries with it topsoil and nutrients, thus accelerating soil erosion.
12. **(B)** The bacteria that normally work to decompose livestock wastes are anaerobic, operate only in environments with little or no oxygen, and produce nitrous oxide (N_2O). Digesters can be constructed to reduce livestock wastes to methane gas (CH_4), which can then be burned as a fuel.
13. **(B)** The growth of all organisms depends on the availability of macro- and micronutrients, and none is more important than nitrogen, which is required in large amounts as an essential component of proteins, nucleic acids, and other cellular constituents.
14. **(B)** *Nitrosomonas* bacteria oxidize ammonia to nitrite: $NH_3 \rightarrow NO_2^-$. *Nitrobacter* then oxidize nitrite to nitrate: $NO_2^- \rightarrow NO_3^-$. Denitrifying bacteria anaerobically reduce nitrate to nitrogen gas: $NO_3^- \rightarrow N_2$.

15. **(B)** Phosphorus normally occurs in nature as part of a phosphate ion (i.e., orthophosphate), PO_4^{3-}. Most phosphates are found as salts (e.g., calcium, phosphate, magnesium phosphate, etc.) in ocean sediments and sedimentary rocks. Over time, geologic processes can bring ocean sediment to land, and weathering will carry terrestrial phosphates back to the ocean.
16. **(C)** Water plays a part somewhere in every cycle.
17. **(B)** Solar energy allows water to change phase (water to gas, liquid to ice, etc.) and gravity causes rain to fall and rivers to flow.
18. **(D)** Transpiration is the process by which water moves upward (against gravity) from the soil through the roots and out through the leaves of plants.
19. **(D)** Nitrification is the biological oxidation of ammonia into nitrite ions followed by the oxidation of nitrites into nitrates. The oxidation of ammonia into nitrites is done by *Nitrosomonas* and *Nitrosococcus* bacteria. The oxidation of nitrite ions into nitrate ions is done by *Nitrobacter* bacteria.
20. **(A)** Nitrite and ammonia are more toxic to plants than nitrate. Plants cannot use nitrogen from the atmosphere directly.

FREE-RESPONSE ANSWER

10 Total Points Possible

(a) Maximum 1 point total: 1 point for the correct answer, which must show the correct setup.

Using the information above, what is the annual demand of ammonium phosphate by U.S. farmers?

The annual demand is calculated by using the annual production values from Florida to determine the total U.S. production. Since 30 million tons are produced in Florida AND because 75% of the U.S. total comes from Florida, 40 million tons are produced annually. This is because 30 represents 75% of 40. A range of calculation setups are possible. The correct answer is 40 million tons.

$$\frac{30\ \cancel{\text{million tons (FL)}}}{1} \times \frac{100\ \text{million tons (U.S.)}}{75\ \cancel{\text{million tons (FL)}}} = \mathbf{40\ million\ tons}$$

(b) Maximum 1 point total: 1 point for the correct answer, which must show the correct setup.

If the U.S. comprises 20% of the world's production, how much ammonium phosphate is produced globally?

Since the United States produces 20% of the world total, the correct answer is derived by multiplying 40 million by 5, yielding a correct answer of 200 million tons.

$$\frac{40\ \cancel{\text{million tons (U.S.)}}}{1} \times \frac{100\ \text{million tons (world total)}}{20\ \cancel{\text{million tons (U.S.)}}} = \mathbf{200\ million\ tons\ produced}$$

(c) *Maximum 2 points total: 1 point for the correct setup and 1 point for the correct answer.*

Based on this world total, how much of the toxin phosphogypsum is produced on an annual basis?

The following setup is suggested, though inclusion of units is not required. The correct answer can be displayed in the following formats: 1 billion tons, 1,000 million tons, 1×10^9 tons.

$$\frac{2 \times 10^8 \text{ \sout{tons ammonium phosphate produced}}}{1} \times \frac{5 \text{ tons phosphogypsum}}{1 \text{ \sout{ton ammonium phosphate produced}}} =$$

$$\mathbf{1 \times 10^9 \text{ tons phosphogypsum}}$$

(d) *Maximum 4 points total: 1 point for identifying each environmental consequence (2 points) and 1 point for describing each environmental consequence (2 points).*

Identify and describe TWO environmental consequences that result from the extraction/processing of phosphorus.

The low-pH runoff that results from phosphogypsum was identified in the question's background information. Responses may include environmental consequences that result from acid mine drainage, such as low-pH or the acidification of aquatic ecosystems adjacent to the mines/processing facilities. Habitat destruction or the direct consequences of acidic environments will result in species loss or reductions in biodiversity.

Strip mining is one of the more impactful types of mining in terms of habitat destruction as vegetation and soils are removed entirely to access the resources below.

The use of large mining vehicles produces a range of air pollutants that can also be connected to environmental impacts. CO_2 additions will cause climate change, which would consequently result in species decline and habitat destruction. Particulates from Earth-moving activities and/or the particulates released from fossil fuel consumption of the mining equipment may reduce the photosynthetic capabilities of adjacent plant life.

(e) *Maximum 1 point total: 1 point for describing the mitigation strategy.*

Describe ONE strategy to mitigate the environmental damage caused by extraction or processing.

A range of mitigation strategies are acceptable. Bioremediation is often used in this type of situation where toxin-tolerant plants are used to absorb and take up toxins from the soil or surrounding water bodies. Certain bacteria may also be used to convert some of the harmful toxins, turning them into more benign products. Photoremediation is also used in a process where light is used to break down toxins. Topsoil from other areas might also be brought in to recreate a soil system that can support plant life, helping to stabilize disturbed soil.

(f) *Maximum 1 point total: 1 point for describing the alternative strategy.*

Describe ONE alternative strategy that might reduce the need for phosphorus mining.

Credit can be earned for describing any strategies that reduce the demand/need for phosphorus fertilizers. This can include suggesting alternatives such as organic fertilizer substitutes; the use of sustainable farming practices, such as crop rotation that utilizes other crops; natural replenishment (through composting or something similar); or using crops that demand less phosphorus (genetically modified crops are acceptable).

UNIT III
Population
(10%–15%)

Areas on Which You Will Be Tested

A. **POPULATION BIOLOGY CONCEPTS**—population ecology, carrying capacity, reproductive strategies, and survivorship.

B. **HUMAN POPULATION**—

1. Human population dynamics—historical population sizes, distribution, fertility rates, growth rates and doubling times, demographic transition, and age-structure diagrams.
2. Population size—strategies for sustainability, Case Studies, and national policies.
3. Impacts of population growth—hunger, disease, economic effects, resource use, and habitat destruction.