## Chapter 15: Chemical Cycles and Climate Change

### Instructional Sequence

#### Section 15.1: Chemical Cycles

- **Two 45-minute class periods**
  1. Complete Chapter 15 Pretest.
  2. Complete Investigation 15A: Carbon Dioxide and Living Things.

#### Section 15.2: Global Climate Change

- **Two 45-minute class periods**
  2. Read Section 15.2, pp. 373 to 378 and complete Section Review on page 379.
  3. Complete Chapter Assessment, pp. 380 to 381.

### Learning Goals

#### Section 15.1: Chemical Cycles
- Trace the pathways by which elements are recycled in nature.
- Identify specific processes associated with chemical cycles.
- Discover how living organisms within ecosystems are affected by or interact with Earth’s chemical cycles.

#### Section 15.2: Global Climate Change
- Define climate change and describe factors that influence global climate change.
- Explain the greenhouse effect.
- Research and discuss public policy initiatives designed to combat negative effects of global climate change.

### Investigations and Materials

#### Investigation 15A: Carbon Dioxide and Living Things
- Materials (per group): Safety goggles and apron, 4.40-mL clear plastic containers with screw caps, Masking tape, Marker, 2 5-cm sprigs of an aquatic plant, Bromothymol blue (BTB) solution, Straw, Beakers (500 mL), Funnel, Aluminum foil, Tweezers, Blank white paper, Lamp, Plant seeds, Two jars with covers, Strainer, Container used for filtering, Ruler

#### Investigation 15B: Oceans and the Carbon Cycle
- Materials (per group): Two 500 mL beakers, Red cabbage juice solution, BTB (bromothymol blue) solution, Simulated seawater, Distilled water, pH paper (range 4.5 to 9), 250 mL graduated cylinder, 2 straws, Lab apron, Safety goggles

#### Investigation 15C: Natural Resources
- Materials (per group): One open container per two students, 2 types of dried beans or nuts—100 beans per pair (90% one color/type, 10% another color/type), Blindfold, Large clear cup or glass, Small mixing bowl, 2 mL cooking oil, 10 mL sand, 30 mL soil, 1 stick of modeling clay, Water

### Assessment Tools

- Chapter 15 Pretest
- Section 15.1 Review
- Standardized Test Practice
- Chapter 15 Assessment
- ExamView® Test Bank
  - Multiple Choice
  - Multi-format
### NGSS Connection: Chapter 15

#### Performance Expectations

This chapter builds conceptual understanding and skills for the following performance expectations.

- **HS-ESS2-6.** Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.
- **HS-ESS3-1.** Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.
- **HS-ESS3-2.** Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.
- **HS-ESS3-5.** Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.
- **HS-ESS3-6.** Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

#### Science and Engineering Practices

- Developing and Using Models
- Analyzing and Interpreting Data
- Constructing Explanations and Designing Solutions
- Engaging in Argument from Evidence
- Using Mathematical and Computational Thinking

#### Earth Science Core Ideas

- Earth's Systems
- Earth and Human Activity

#### Crosscutting Concepts

- Energy and Matter
- Stability and Change
- Cause and Effect

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**Program Resources – Available at curiosityplace.com**

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**These resources and more at curiosityplace.com**

- Printable Student Masters
- Assessment
- Answer Keys
- Presentation Slides
- Simulations
- Science Content Videos
- Equipment Setup Videos
- E-books

**Graphic Organizers**

- 15A Interconnected Cycles

**Teaching Illustrations**

- The Water, Carbon, and Oxygen Cycles
- The Carbon Cycle
- Simple Food Chain

**Skill and Practice Worksheets**

- Svante Arrhenius Biography

**Graphic Organizers**

- 15B Global Climate Change

**Teaching Illustrations**

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**Technology Connection**

- Harvesting the Wind

**Chapter Activity**

- Supplying Our Energy Needs

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**SAMPLE**
Investigation 15A: Carbon Dioxide and Living Things

Photosynthesis and respiration are two important processes in the carbon cycle. In this investigation, students use bromothymol blue (BTB) solution as an indicator for the presence or absence of carbon dioxide. Students use color changes (or the lack thereof) to tell whether photosynthesis or cellular respiration occurred in two experiments.

Key Question

How do living things exchange carbon dioxide?

Objectives

• Explore the role of CO$_2$ in biologically important chemical reactions.
• Compare and contrast respiration and photosynthesis.
• Discuss the significance of photosynthesis and respiration to the carbon cycle.

Setup

1. One to three class periods are needed to complete the investigation. See the Managing the Investigation teaching tip on page 344 for a proposed schedule.
2. Students work in small groups of three to five.
3. Prepare 100 mL volumes of BTB solution in advance to minimize students’ handling of the solution.

Materials

Each group should have the following:

- Safety goggles and apron or lab coat
- 4 40-mL clear plastic containers with screw caps
- Masking tape
- Marker
- 2 5-cm sprigs of an aquatic plant
- 100 mL Bromothymol blue (BTB) solution
- Straw
- Beakers (500 mL)
- Water
- Funnel
- Aluminum foil
- Tweezers
- Blank white paper
- Lamp
- Clover or grass seeds
- 2 jars with screw caps
- Strainer
- Clear container used for filtering
- Ruler

Vo·cab·u·lar·y

photosynthesis - the process that plants use to convert sunlight energy into chemical energy.
respiration - the process by which living organisms use oxygen to obtain energy from food.

Safety

Students should wear protection for their eyes (safety goggles) and clothing (lab coat or apron) for the duration of Investigation 15A.

Bromothymol blue (BTB) solution is used during the investigation. The solution poses possible risk if it is ingested, inhaled, or absorbed through the skin; therefore, it is necessary to inform students about proper first-aid techniques. Should students experience accidental eye contact with BTB, immediately flush the eyes for 10–15 minutes. In the event of skin contact, use mild soap and water to clean the skin. It may also be beneficial to apply an emollient to soothe the skin after cleaning.

If BTB is inhaled, move the affected person to an area where fresh air is available. In extreme cases (if the person is not breathing), it may be necessary to provide artificial respiration. Contact a medical professional if a large amount of BTB solution is ingested.
Thinking about respiration

In respiration, glucose in carbohydrate molecules reacts with oxygen to produce carbon dioxide and leftovers. Glucose is only one type of molecule that cells use up. All types of cells, including animal and plant cells, undergo this process. In respiration, glucose (a carbohydrate) reacts with oxygen to produce carbon dioxide and leftovers. The word “light” above the arrow means that light is not required to make the reaction happen.

Materials
- Safety goggles
- Apron

WARNING: Wear safety goggles and an apron during this investigation.

Safety tip: Wear safety goggles and an apron during this investigation.

Stop and think
- Why did you need to make sure the BTB solution had completely changed color before starting the experiment?
- Why was tube 3 called the control group? Why was it a control group in the experiment?
- Predict what you think will happen to the color of the BTB solution in each of the four containers.
- Did the results from Experiment B support your hypothesis from Part 5, step 6?
- From Experiment A, in which container(s) did photosynthesis occur? Use your data and knowledge of photosynthesis to explain your answer.
- Did the results from Experiment A support your hypothesis from Part 4c?
- From Experiment B, which container did respiration occur? Use your data and knowledge of respiration to explain your answer.
- Did the results from Experiment B support your hypothesis from Part 5, step 7?
- Why was light a variable in Experiment A, but not a variable in Experiment B?
- Explain the importance of bromothymol blue in both experiments.
- Applying your knowledge:
  a. Use a relationship between photosynthesis and respiration? Explain how these two processes are related, and how they are important pathways of the carbon cycle.
  b. How is energy involved in the processes of photosynthesis and respiration? Which process stores energy? Which process releases energy? Where does the energy come from?

Investigation 15A: Carbon Dioxide and Living Things

How do living things exchange carbon dioxide?

The carbon cycle is a series of different pathways through which carbon atoms are recycled in the world. The air you breathe contains carbon dioxide. The plants you eat and the air you breathe are both made up of carbon dioxide. Plants use a process called photosynthesis to capture carbon dioxide. Photosynthesis requires carbon dioxide, plants and animals break down carbon dioxide and water in a process called respiration. Both processes also produce oxygen. In this investigation, you will explore how living things exchange carbon dioxide.

Investigation 15A: Carbon Dioxide and Living Things

Materials
- Safety goggles
- Apron

WARNING: Wear safety goggles and an apron during this investigation.

Thinking about photosynthesis

Photosynthesis uses a chemical reaction called photosynthesis to store energy from the Sun in high-energy molecules and oxygen. The word “light” above the arrow means that light is not required to make the reaction happen.

Materials
- Safety goggles
- Apron

WARNING: Wear safety goggles and an apron during this investigation.

Safety tip: Wear safety goggles and an apron during this investigation.

Stop and think
- Why did you need to make sure the BTB solution had completely changed color before starting the experiment?
- Why was tube 3 called the control group? Why was it a control group in the experiment?
- Predict what you think will happen to the color of the BTB solution in each of the four containers.
- Did the results from Experiment B support your hypothesis from Part 5, step 6?
- From Experiment A, in which container(s) did photosynthesis occur? Use your data and knowledge of photosynthesis to explain your answer.
- Did the results from Experiment A support your hypothesis from Part 4c?
- From Experiment B, which container did respiration occur? Use your data and knowledge of respiration to explain your answer.
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Teaching Investigation 15A

You have already learned that living things depend on carbon-containing compounds. One carbon compound that is very important for living things is carbon dioxide, or CO$_2$.

Write the words carbon dioxide and the chemical formula on the board.

Carbon dioxide is made up of two different types of atoms. What are they?

Carbon and oxygen atoms make up carbon dioxide.

Very good. Do you think that both of these elements are important to living organisms? What do you already know about carbon and oxygen that leads you to respond as you do?

Students may have a number of responses. Accept all that are reasonable.

In previous chapters, students have already learned about biologically important molecules, such as carbohydrates, lipids, and proteins. Use this time to review the types of atoms found in each type of molecule. Students should recognize that carbon and oxygen atoms are essential to each of these molecules.

Those are great responses. What do you know about carbon dioxide?

Most students will have some basic knowledge about carbon dioxide. For example, students may be familiar with carbon dioxide as a greenhouse gas, a product of burning fossil fuels, or a component of Earth’s atmosphere. List all responses on the board.

As you can see, carbon dioxide is a very important molecule. It has both beneficial and harmful effects. In today’s investigation, you will learn about the role of carbon dioxide in two different processes: photosynthesis and cellular respiration.

Thinking about respiration

Both photosynthesis and cellular respiration are chemical reactions. What happens during a chemical reaction?

Atoms are rearranged and new substances are formed.

This is true. Chemical reactions involve the rearranging of atoms. In order for these atoms to be rearranged and result in new substances, energy is needed. In the first part of the investigation, you will learn a little more about cellular respiration. In cellular respiration, carbohydrates react with oxygen to produce carbon dioxide and water. This chemical reaction is represented in your handout.

Point out to students the worded representation of the reaction.

Every cell in your body uses this reaction to release energy stored in carbohydrates. When you breathe, you take in oxygen, a reactant in cellular respiration. You exhale carbon dioxide, a product of cellular respiration. All types of animal and plant cells undergo cellular respiration. Although cellular respiration and breathing are similar, they are not the same.

Do not spend too much time differentiating the two processes here; speak only to the difference if students are confused.

Managing the Investigation

The two major experiments (A and B) in this investigation have 50- and 45-minute wait times, respectively. Depending on the length of your class period, you may need to complete the investigation over several days. Here is a suggestion based on a 45-minute class period.

Day 1: Complete Parts 1 and 2 of the investigation as part of a general discussion about carbon-based molecules and their importance to living things. Then have students label all of their containers that will be used in Experiments A and B (Parts 3 and 5.)

Day 2: Students complete Experiment A. While awaiting the results from the investigation, students complete Part 4. Then complete steps 1–3 in Part 6.

Day 3: Students complete Experiment B. While awaiting results, students write their hypotheses. Then they complete steps 4–6 in Part 6. Have students complete Part 7 as a homework assignment, then discuss their responses in class the next day.

If you are on a 90-minute block schedule, then you may complete the entire investigation in one day. Or, you may complete the investigation over two days by combining the activities for days two and three.

Thinking about respiration

a. The initial color was blue.
b. The solution turned yellow.
c. It changes to yellow.
d. It would turn back to blue.
In Part 1, your mission is to detect the presence of carbon dioxide in a sample. You will use bromothymol blue solution to do so. Each group will need 100 mL of the BTB solution. I have already prepared beakers with the correct amount of solution. You will use a straw to gently blow bubbles into the solution until it completely changes color. Before you work with the BTB, it is best to perfect your technique with a sample of water.

Model the technique for students first. Then have them practice the technique using water. Once you feel students are ready, proceed with the BTB solution. Warn students that BTB may be harmful if ingested, inhaled, or absorbed through the skin. View the safety precautions provided. If you are uncomfortable using BTB as an indicator, substitute with cabbage indicator, which you can prepare on your own.

What color was the BTB solution when you began the investigation? How did the color change after you blew bubbles into the beaker?

The BTB solution is blue at first, but it turned yellow after carbon dioxide was added. Bromothymol blue solution is an indicator. In this example, it is being used as an indicator for carbon dioxide, which you provided as you used the straw to blow air, or respire, into the beaker.

Thinking about photosynthesis

Carbon dioxide is important in a second process: photosynthesis. Look at the chemical equation used to represent photosynthesis in Part 2. You can see that carbon dioxide and water react in the presence of light to produce glucose and oxygen. How does this chemical reaction compare to the reaction for respiration?

The products of one reaction are the reactants of the other.

Think about what is happening in this reaction as you answer the questions in Part 2. Do you think the presence of plants in water causes the amount of carbon dioxide to change in any way, or does it stay the same?

Carbon dioxide levels would be less. Because carbon dioxide is a reactant in the chemical reaction, it is “used up” in the reaction.

Do any of the substances mentioned in the photosynthesis equation offer a clue as to whether photosynthesis is more likely to occur during the day or at night?

Photosynthesis happens in the presence of energy from the Sun; therefore, it is most likely to occur during the day.

Investigating photosynthesis—Experiment A

Let’s do an experiment to learn more about photosynthesis. You will need four clear plastic containers with screw caps. Label each container as described in your procedure. Next, you will need the BTB solution from Part 1. Be sure the solution is still yellow.

Direct students to blow into the solution again to ensure that it is totally yellow.
Look at Table 1 in Part 6. In the middle column, write the color of the solution in each container.

All containers should contain yellow solution.

Using a funnel, pour 25 mL of the solution into each of the four test containers. Cap tubes #3 and #4. Place a 5-cm piece of aquatic plant in containers #1 and #2. Make sure each plant is completely submerged in the solution. Cap these containers. Wrap tubes #2 and #4 with aluminum foil to block out any light. Place the four capped tubes upright in front of a lamp. Make sure that the tubes are at least eight inches away and that light is hitting all tubes equally on the side. Your setup should look similar to the one shown in Part 3.

Prepare a setup in advance as a reference for students.

These plants will sit for 50 minutes. In the meantime, move on to Part 5 and set up the next experiment.

After students set up Experiment B, have them complete the questions in Part 4.

4 Stop and think

When you set up Experiment A, you were reminded several times to ensure that your BTB solution was yellow. Why do you think this was important?

Carbon dioxide is necessary for photosynthesis. The yellow-colored BTB solution indicated the presence of carbon dioxide; therefore, the setups were all equal in terms of CO₂ presence.

When scientists conduct an experiment, a control group serves a specific purpose. What is a control group, and why do you think tubes #3 and #4 qualify as control groups?

The control group is used to validate the results of an experiment; therefore, it is not exposed to the exact testing conditions in some way. In this experiment, tubes #3 and #4 contain no plants. In the absence of plants, the experimenter can confirm that only the plants (rather than some other source) are removing the carbon dioxide from the solution.

What do you expect the results of Experiment A to be? Write a hypothesis to express your prediction.

Students make predictions and write hypotheses.

5 Investigating respiration—Experiment B

Obtain two jars with screw caps and label each with a marker and masking tape. One jar should be labeled with seeds and the other no seeds. Cover the bottom of jar #1 with plant seeds. Add equal amounts of bromothymol blue solution to each jar. Be sure to use enough solution to cover the seeds. The initial color of the solution should be blue for this experiment. Why do you think this is so?

The BTB solution should be void of carbon dioxide before the respiration experiment.

Record in Table 2 the initial color of the solution in both jars. Cover both jars and place them in similar conditions for at least 45 minutes.

Students complete the setup.
Consider what you know about respiration, then make a prediction about what will happen (in terms of color changes) in each jar. Express your prediction in the form of a hypothesis.

Students discuss predictions with group members and write a hypothesis.

**Recording your data**

Carefully unwrap the containers from Experiment A, the photosynthesis experiment. Use the tweezers to remove the plants from containers #1 and #2. What are the final colors of each solution? How do your results compare with your predictions? Write your answers in Table 1.

Students record the color of each solution. Allow time for students to share if their predictions matched the actual results.

Move on to the jars you used in Experiment B, the respiration experiment. Pour the solution from jar 1 (labeled with seeds) into another clear container using a strainer. Be careful to avoid transferring any seeds to the new container as you pour the solution. What is the color of this solution? What color is the solution in the container with no seeds? Record your results in Table 2.

The solution in the container with seeds should be yellow. The solution in the container without seeds should remain blue.

**Analyzing the results**

Look over your observations from Experiment A. Did photosynthesis occur in any containers?

Photosynthesis occurred in container #1, with the plant and exposure to light.

What evidence supports that photosynthesis happened in this container?

The color changed from yellow to blue, which means the plant used the carbon dioxide to make food.

Photosynthesis did not occur in any other containers. Container #1 had all of the conditions necessary for photosynthesis to take place. What were the sources of carbon dioxide, water, and light?

The carbon dioxide came from each student blowing into the BTB solution. This is why it turned from blue to yellow. The BTB is an aqueous solution, which means it contains water.

The container was not covered with aluminum foil so it remained exposed to light.

Now think about what happened in Experiment B. What did you observe?

A color change occurred in the jar with seeds.

Respiration uses glucose and oxygen to produce carbon dioxide, water, and energy. In which jar, if any, did respiration happen?

It happened in the jar with seeds.

How can you tell that carbon dioxide was produced in the jar with seeds?

The BTB solution was blue at first and then it turned yellow, which indicates the presence of carbon dioxide.

**Analyzing the results**

a. Photosynthesis occurred in container #1 because the color changed from yellow to blue, indicating that the plant was using carbon dioxide for photosynthesis.

b. Yes, the results supported my hypothesis.

c. Respiration occurred in jar #1 because the color changed from blue to yellow, indicating that carbon dioxide was being produced.

d. Yes, the results supported my hypothesis.

e. Photosynthesis requires light to occur, and respiration does not require light.

f. Bromothymol blue is important because it is an indicator of the presence or absence of carbon dioxide. Carbon dioxide is used in photosynthesis and produced in respiration.

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**Table 1: Data from photosynthesis experiment (Experiment A)**

<table>
<thead>
<tr>
<th>Container</th>
<th>Initial color</th>
<th>Final color</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 Plant: light</td>
<td>yellow</td>
<td>blue</td>
</tr>
<tr>
<td>#2 Plant: no light</td>
<td>yellow</td>
<td>yellow or green</td>
</tr>
<tr>
<td>#3 No plant: light</td>
<td>yellow</td>
<td>yellow or green</td>
</tr>
<tr>
<td>#4 No plant: no light</td>
<td>yellow</td>
<td>yellow or green</td>
</tr>
</tbody>
</table>

**Table 2: Data from respiration experiment (Experiment B)**

<table>
<thead>
<tr>
<th>Container</th>
<th>Initial color</th>
<th>Final color</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 With seeds</td>
<td>blue</td>
<td>yellow</td>
</tr>
<tr>
<td>#2 No seeds</td>
<td>blue</td>
<td>blue</td>
</tr>
</tbody>
</table>
What was the role of light in Experiment A?
Photosynthesis requires light as energy for the reaction to proceed.

Light was a variable in Experiment A, but it was not in Experiment B. Why is this so?
Respiration does not require light; photosynthesis does.

Do you think BTB was an appropriate indicator for both experiments? Tell why you think the way you do.
BTB solution was a good choice because it indicates whether carbon dioxide is present (or absent) in a solution. The results of the experiment match known observations of the presence or absence of carbon dioxide based on the final color of each solution.

8 Applying your knowledge

The carbon cycle traces the pathway of carbon as it moves throughout Earth. Photosynthesis and respiration are important processes in the carbon cycle. Which process removes carbon from the atmosphere?
Photosynthesis removes carbon from the atmosphere.

Which process adds carbon to the atmosphere?
Respiration releases carbon to the atmosphere.

Carbon in Earth’s atmosphere exists mostly as carbon dioxide. When you learned about photosynthesis and respiration, you should have observed that carbon dioxide is involved in both processes. How are respiration and photosynthesis related?
These processes are related because one removes carbon in the form of CO₂ from the atmosphere, while the other releases it to the atmosphere.

In what ways are respiration and photosynthesis important pathways in the carbon cycle?
Lead a discussion to encourage student participation. Have students refer to the diagram of the carbon cycle in the text if they are unable to generate responses on their own.

You have already learned that energy is an important factor in chemical reactions. Energy is sometimes released when a reaction occurs, and it is sometimes absorbed or stored. How is energy involved in the processes of photosynthesis and respiration?
Plants undergo photosynthesis and use energy from the Sun to make food. One product of photosynthesis is glucose, the food for plants. Energy is stored within the chemical bonds of a glucose molecule. During the process of respiration, energy is released. Have students look at the chemical reaction for respiration in Part 1. Point out that energy is written as a product of the reaction, which indicates that energy is released as the bonds of glucose are broken and the atoms are rearranged to form carbon dioxide and water.
Lesson 15.1: Chemical Cycles

When learning about chemical reactions, it is common for students to think of them only in terms of balancing equations on paper. However, it is important that students realize atoms of elements combine and rearrange in many ways that are beneficial and necessary for maintaining life and other processes on Earth. This lesson focuses on chemical cycles—pathways by which elements circulate through the living and nonliving components of our planet.

Start the lesson

Connect to Prior Knowledge: The Law of Energy Conservation in Ecosystems

Ask students to state the law of energy conservation. Then ask students how this law is applicable to ecosystems. From previous life science classes, students may know that an ecosystem includes a group of living organisms and the physical surroundings that influence them. Emphasize that ecosystems are maintained by the flow of energy. For example, as plants undergo photosynthesis, energy enters an ecosystem from the Sun. This energy flows through the ecosystem as organisms consume plants and other organisms. Ask students, “Does energy exit the ecosystem? If so, how does this happen?” Energy does exit the ecosystem, mostly in the form of heat, but it is still conserved. Use this example to help students see that although the energy goes through transformations, it is still conserved. It may be helpful to have students identify the energy transformations occur as energy flows through an ecosystem.

Motivate: Food Chains

Focus students’ attention on the simple food chain shown at right (student text Figure 15.4). Direct students to describe how energy flows in the food chain. Have students identify the producer and different levels of consumers that are a part of the food chain.

As students learn more about food chains, it is important to note that most organisms are not restricted to one type of food. For instance, mice eat not only grasshoppers but grass as well. For this reason, students can best understand food chains by evaluating food webs, which are models that show how living things interact and depend on one another.
Have students expand this simple food chain to create a food web. You may begin by asking students to identify different organisms that eat grass, such as rabbits, grasshoppers, and mice. Continue with questions like, “Does a hawk eat a rabbit?” and so forth. Once students have completed their food webs ask, “How do cycles on Earth contribute to the flow of energy among living organisms?” Have students talk about the role of the carbon and oxygen cycles, the water cycle, and the nitrogen and phosphorus cycles in providing nutrients to all living things.

**Guided Discussion: Earth’s Cycles**

Use a step-by-step approach to talk about the recycling of elements in the carbon, oxygen, nitrogen, phosphorus, and water cycles. For example, you may have students focus on Figure 15.7 as you discuss the water cycle. Ask leading questions such as, “How does water from Earth return to the atmosphere?” Or when discussing the oxygen cycle (Figure 15.8), you may ask students to explain how oxygen is obtained during photosynthesis. Students should recall that oxygen is a product of photosynthesis that results from splitting water molecules. Then ask students to describe what happens to the oxygen according to the diagram. Students should follow the pathway and explain that the fish uses the oxygen during respiration. Continue to ask questions like these as you talk about each cycle.

**Check for understanding**

What are the requirements for an ecosystem to be classified as self-sustaining? (Sample response: A self-sustaining ecosystem is one that has its own source of energy and essential macronutrients and micronutrients that can be recycled through physical processes, like the carbon or nitrogen cycle. The energy source, such as sunlight, must be able to undergo transformations for the benefit of the organisms within the ecosystem.)

**Reteach**

Explain that a cycle does not have a beginning or an end. Have students focus on the diagram in the student text that shows how the water, carbon, and oxygen cycles are interconnected. Ask questions that allow students to follow the possible pathways of each cycle to understand how energy flows within an ecosystem and essential nutrients are recycled. Next, have small groups of students generate a list of three summary statements for the lesson. Encourage students to post these statements on large pieces of chart paper and then read them aloud to generate class discussion.

Nitrogen, an important macronutrient, is moved through living systems by the nitrogen cycle. To be useful to plants, nitrogen must be combined with other elements, such as oxygen. This process is known as nitrogen fixation.

Which of the following statements is the best description for the function of the nitrogen-fixing bacteria that live on the roots of legumes, such as peas and beans?

a. Due to the presence of nitrogen-fixing bacteria, legumes provide nitrogen-rich food for earthworms.

b. Nitrogen-fixing bacteria enable legumes to release nitrogen into the atmosphere.

c. Nitrogen-fixing bacteria provide carbohydrates for legumes.

d. Nitrogen-fixing bacteria provide nitrates, which allow legumes to make proteins.

The correct answer is (d). Nitrogen is a primary component of proteins—an important macromolecule for all organisms. Through the process of nitrogen fixation, bacteria that live on the roots of legumes are able to convert nitrogen from the atmosphere into a usable form for living things, such as plants.

Earthworms do not feed directly on legumes. Instead, they get nutrition from other sources, such as decaying matter in the soil and tiny organisms like rotifers and fungi. Therefore, (a) is incorrect. Legumes do not release nitrogen into the atmosphere, but the bacteria on legumes and other plants change atmospheric nitrogen into usable forms of nitrogen, which makes (b) an incorrect response. Answer (c) is incorrect because nitrogen fixation is about making proteins, not carbohydrates.
Investigation 15B: Oceans and the Carbon Cycle

Carbon sources such as respiration, combustion of fossil fuel, and deforestation release carbon dioxide into Earth’s atmosphere. Some of this carbon dioxide is absorbed by oceans. As students continue to focus on Earth’s cycles, they will learn about the effects of the carbon dioxide taken up by oceans on marine life and processes.

Key Question
What role does the ocean play in the carbon cycle?

Objectives
• Distinguish carbon sources and carbon sinks.
• Identify the effects of increased acidity in Earth’s oceans.
• Compare and contrast the amounts of carbon dioxide absorbed by salt water and fresh water.

Setup
1. One class period is needed to complete the investigation.
2. Students work in small groups of three to five.
3. Prepare the BTB solution and red cabbage juice indicator in advance. To prepare the red cabbage indicator, place the leaves and a cup of boiling water in a blender. Combine the ingredients, then pour the mixture through a strainer to separate the leaves and tinted water. Discard the processed leaves and store the water in a stoppered flask. If a blender is not available, then pour the boiling water over the leaves. Allow 15–20 minutes of steep time, discard the leaves, and then transfer the tinted water to a storage container. Be sure to test the pH of the red cabbage indicator before students use it. The goal is to start with a neutral (or nearly neutral) pH, represented by a dark purple-bluish color.

Materials
Each group should have the following:
• Safety goggles
• Lab apron
• 2 500-mL beakers
• Red cabbage juice solution
• BTB (bromothymol blue) solution
• Simulated seawater (see Teaching tip on page 353)
• Beaker of water
• Distilled water
• pH paper test strips (range 4.5 to 9)
• 250-mL graduated cylinder
• 3 straws
• 2 Blank white sheets of pater

Safety
Students should wear protection for their eyes (safety goggles) and clothing (lab coat or apron) for the duration of Investigation 15B.

Bromothymol blue (BTB) solution is used during the investigation. The solution poses possible risk if it is ingested, inhaled, or absorbed through the skin; therefore, it is necessary to inform students about proper first-aid techniques. Should students experience accidental eye contact with BTB, immediately flush the eyes for 10–15 minutes. In the event of skin contact, use mild soap and water to clean the skin. It may also be beneficial to apply an emollient to soothe the skin after cleaning.

If BTB is inhaled, move the affected person to an area where fresh air is available. In extreme cases (if the person is not breathing), it may be necessary to provide artificial respiration. Contact a medical professional if a large amount of BTB solution is ingested.

Red cabbage juice indicator can be safely discarded by pouring it down the drain if flushed with large amounts of water.
UNIT 4: MATTER AND ITS CHANGES

SAMPLE

CHAPTER 15: CHEMICAL CYCLES AND CLIMATE CHANGE

15B Oceans and the Carbon Cycle

What role do the oceans play in the carbon cycle?

CO₂ is important in living things, but it is also a major greenhouse gas that traps energy from the Sun. Together with water vapor and methane, CO₂ helps make Earth's surface an average temperature of about 15°C.

Investigation 15B

Oceans and the Carbon Cycle

Thinking about the carbon cycle

The carbon cycle has carbon sources and carbon sinks. Anything that releases CO₂ into the atmosphere is a carbon source. Anything that absorbs CO₂ and holds it is a carbon sink.

List the carbon sinks in the diagram.

Safety tip: Wear safety goggles and an apron during this investigation.

Investigation 15B

Oceans and the Carbon Cycle

Materials

- 2 straws
- 250 mL graduated cylinder
- pH paper (range 4.5 to 9)
- Distilled water
- Simulated seawater
- BTB (bromothymol blue) solution
- Red cabbage juice

Investigation 15B

Oceans and the Carbon Cycle

1. Put on your safety goggles and apron.
2. Obtain a 500 mL beaker containing 100 mL of red cabbage juice. Change color as pH changes.
3. Record the initial color and pH of the solution. Use the pH chart below to find the pH value that matches the color you observe.
4. Choose a "buddy" from your group. Other members will share recorded observations.
5. Using the straw, the buddy will gently blow bubbles into the solution. Observe and record each color you observe in the beaker. When your beaker turns green, record your observations in the data table below.

Table 1: Color and pH change

<table>
<thead>
<tr>
<th>pH</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Blue</td>
</tr>
<tr>
<td>8</td>
<td>Violet</td>
</tr>
<tr>
<td>9</td>
<td>Dark red</td>
</tr>
</tbody>
</table>

6. Place each beaker on a blank white sheet of paper.
7. Fill another 500 mL beaker with 100 mL of seawater and label it "seawater." Add 20 drops of BTB solution to each beaker.
8. Using a pipette, measure the pH of each beaker and record it in Table 2.
9. Record your observations in the data table below.
10. Use a pH test strip to measure the final pH and record it in the last row of Table 2.

Analyzing the results

a. How do you think the color of a solution will change as the pH decreases?
b. What happened to the pH of the solution as CO₂ was absorbed?

c. Was your hypothesis correct? Explain why or why not based on your results.

d. What happened to the pH when CO₂ was added to seawater?

e. What are the sources for this extra CO₂?

Analyzing the data

a. Which was the control in this experiment? Distilled water or seawater? Why did you need a control?
b. Based on your results, which sink has the ability to absorb more CO₂ before becoming acidic, distilled water or seawater? Explain your answer.
c. Might the results of this experiment explain part of the reason why some areas are a carbon sink? Justify your answer.
d. What other processes in the oceans store CO₂? What processes release CO₂?

e. Based on the results of the experiment, could the release of more CO₂ from the burning of fossil fuels and deforestation have an effect on the pH of the oceans? Explain your reasoning.

Impact of ocean acidification

Although the natural absorption of CO₂ by the oceans helps absorb excess CO₂, many scientists believe the decrease in pH will have a negative effect on marine calcifying organisms. These organisms include some phytoplankton, mollusks and corals. They absorb CO₂ and bicarbonate ions in their calcifying tissues and carbonates in their calcium carbonate shells and many other carbonate sediments. In fact, England's famous white cliffs of Dover are made mostly of the calcium carbonate shells of calcifying organisms.

F

Analyzing the results

Oceans and the Carbon Cycle

a. What is the pH of seawater in the oceans and has it changed since the Industrial Revolution? (1) How would rising CO₂ levels impact calcifying organisms? (2) What are some steps humans need to take to stop or slow down our impact on the pH of seawater?

b. Suppose you are a marine biologist who is designing an experiment to test the effects of ocean acidification on a species of coral. Name three questions: (1) What is the pH of corals in the ocean and has it changed since the Industrial Revolution? (2) How would rising CO₂ levels impact calcifying organisms? (3) What are some steps humans need to take to stop or slow down our impact on the pH of seawater?

Sample

a. Conduct research on ocean acidification and its effects on calcifying organisms. Try to find answers to these questions: (1) What is the pH of corals in the ocean and has it changed since the Industrial Revolution? (2) How would rising CO₂ levels impact calcifying organisms? (3) What are some steps humans need to take to stop or slow down our impact on the pH of seawater?

b. Suppose you are a marine biologist who is designing an experiment to test the effects of ocean acidification on a species of coral. Name three questions: (1) What is the pH of corals in the ocean and has it changed since the Industrial Revolution? (2) How would rising CO₂ levels impact calcifying organisms? (3) What are some steps humans need to take to stop or slow down our impact on the pH of seawater?
Teaching Investigation 15B

1 Thinking about the carbon cycle

In the last investigation, you learned about photosynthesis and respiration, both of which are important processes in the carbon cycle and to living organisms. As you look at the carbon cycle diagram in Part 1, you can see arrows that indicate the significance of these processes. When you see a shaded arrow, it means that carbon is absorbed. The white arrows indicate processes by which carbon is released.

Project diagram onto whiteboard. Use a pointer to identify photosynthesis and respiration on the carbon cycle illustration as processes that absorb and release carbon dioxide.

As you continue to look at the diagram, you can also see that other processes are part of the carbon cycle. Some, like respiration, release carbon dioxide into Earth’s atmosphere. Others, like photosynthesis, absorb carbon dioxide. Anything that releases carbon dioxide into the atmosphere is a carbon source. Carbon sinks absorb and hold carbon dioxide. Take a few moments to examine the diagram closely. Make lists of the carbon sources and carbon sinks.

Allow time for students to comply.

In addition to its role in life-sustaining processes, carbon dioxide is also a major greenhouse gas produced as a result of human activities, such as burning fossil fuels and deforestation. What is a greenhouse gas?

A greenhouse gas traps heat from the Sun and that maintains Earth’s temperature. Use the overhead to follow the pathway of carbon dioxide released into the atmosphere by burning fossil fuels and deforestation.

Deforestation means that large numbers of trees are cut down. How do you think this adds carbon dioxide to the atmosphere?

Trees remove carbon dioxide from the atmosphere as they undergo photosynthesis. As more trees are cut down, less photosynthesis occurs and less carbon dioxide is removed from the atmosphere. Burning the trees also releases carbon dioxide.

Look again at the carbon cycle diagram in Part 1. Find the oceans, lakes, and rivers. What role do these bodies of water appear to have in the cycle?

Students should note the arrows pointing toward the bodies of water, which indicate that carbon dioxide is absorbed from the atmosphere by the oceans.

Good observation. Oceans and other bodies of water absorb carbon dioxide from the atmosphere. One use of this absorbed carbon dioxide is for photosynthesis. Like terrestrial plant life, plants and other tiny organisms such as phytoplankton and algae within oceans use carbon dioxide to make food. These tiny photosynthetic organisms provide oxygen and are food for other marine organisms; those that are not eaten eventually die and end up on the ocean floor. These organisms still contain carbon that accumulates and is stored in sediment.

Use the diagram to point this out.
CHAPTER 15: CHEMICAL CYCLES AND CLIMATE CHANGE

Look closely at the carbon cycle diagram once more and locate the following words: bicarbonate, carbonate, and calcium carbonate.

Allow time for students to comply.

Aside from the carbon dioxide used by photosynthetic marine organisms, the motion of ocean waves dissolves absorbed carbon dioxide. When carbon dioxide diffuses into water, carbonic acid is formed and further ionizes to produce hydrogen, bicarbonate, and carbonate ions. These ions are available to combine with others, such as calcium, to create new carbon-based substances. As you complete today’s investigation, you will focus on the effects of carbon dioxide absorption within oceans.

**CO₂ absorption and pH**

As mentioned earlier, moving waves in Earth’s oceans dissolve absorbed carbon dioxide. The results of the dissolving process are represented by the chemical reactions shown in Part 2. The first step shows the absorbed carbon dioxide in water reacting to form carbonic acid. The carbonic acid ionizes. What are the resulting ions?

The hydrogen and bicarbonate ions are the results.

The bicarbonate further ionizes and yields carbonate ions. This series of reaction steps demonstrates one approach to describing acids—as compounds that ionize in solution and produce hydrogen ions. For example, the carbonic acid produced in step 1 is a compound that ionizes and produces hydrogen ions and bicarbonate ions.

Focus students’ attention on the series of reaction steps shown in Part 2.

Scientists measure the acidity of a solution by assigning a pH value to it. pH measures the concentration of hydrogen ions in a solution. Think of the ocean as a solution. This ocean solution contains ions, as indicated by the chemical reactions shown in Part 2. How do you think adding more carbon dioxide to the ocean solution might affect its pH?

Have students discuss ideas with members of their group and then express the ideas as a hypothesis.

Let’s experiment to find out. Put on your safety goggles and an apron to protect your clothing. Next, obtain a 500-mL beaker with red cabbage juice solution. You will use red cabbage juice as an indicator to measure pH. As demonstrated in Part 2, pH values range from 1 to 14. The lower the pH value, the more acidic the solution. As pH values change, the color of red cabbage juice solution also changes. A substance with a pH value equal to 7 is neutral, or neither acidic nor basic.

Point out the range of pH values on the scale.

What is the initial pH of the red cabbage juice solution? Use the chart in Part 2 to match its color to a pH value. Write your answer in Table 1.

**Table 1: Color and pH**

<table>
<thead>
<tr>
<th>Color</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>blue</td>
</tr>
<tr>
<td>violet</td>
<td>5-6</td>
</tr>
<tr>
<td>dark red</td>
<td>3-4</td>
</tr>
</tbody>
</table>

Sample data:
a. I think the solution will become more acidic because carbon dioxide reacts with water to form carbonic acid.
One person in your group will be the bubbler. The bubbler’s job is to use the straw to blow bubbles into the solution. Others members of your group will note observations as the person continues to blow bubbles into the solution. The bubbler should continue until no more color changes occur. What do you think is the purpose of blowing bubbles into the red cabbage juice solution? The purpose is to add carbon dioxide. Remind students of the safety precautions they used as they completed Investigation 15A. If necessary, review the process and have students practice and perfect the technique with a beaker of water.

3 Analyzing the results

What was the initial pH of the solution? Students share answers.

What happened to the pH of the solution as the bubbler continued to add carbon dioxide to the solution? The pH of the solution should drop as more carbon dioxide is added.

How do the results of this experiment compare to your predictions? Students share observations.

Let’s summarize your observations in terms of the relationship between increased carbon dioxide in the ocean solution and pH. As more carbon dioxide is added to the ocean solution, its pH is lowered. A lower pH means acidity is increased. Greater acidity means a higher concentration of hydrogen ions in solution. What is the source of these hydrogen ions? Students should realize that the carbonic acid formed as carbon dioxide is added to the water as the source. Use the reactions in Part 2 to review these relationships.

4 Comparing CO₂ absorption in fresh water vs. seawater

Bromothymol blue solution changes color depending on the concentration of ionized carbonic acid present in the solution. In this part of the investigation, you will add carbon dioxide to distilled water and the simulated seawater. You will use the observed color changes to make comparisons about carbon dioxide absorption in fresh water and seawater.

Remind students of safety precautions relative to the BTB solution.

Fill one 500-mL beaker with 100 mL of distilled water and label it distilled water. Fill another 500-mL beaker with 100 mL of simulated seawater and label it seawater. Add 20 drops of BTB solution to each beaker. Using pH test strips, measure the pH of the solution in each beaker and record the measurements in the first row of Table 2. Place each beaker on a blank white sheet of paper.

This will help students see colors more distinctly.
Choose a “bubbler,” “timer,” and “observer” from your group. Using a straw, the bubbler will gently blow bubbles into the distilled water beaker, while the timer measures the time each minute for six minutes, and the observer watches for color changes in the beaker. Record your observations in Table 2. Use a pH test strip to measure the final pH and record it in the last row of Table 2. Repeat steps 7 and 8 for the seawater beaker using a clean straw. If the seawater does not change to a pale yellow, record the lightest color change you observed within six minutes of gentle bubbling.

Students complete the experiments.

5 Analyzing the data

From previous investigations, you learned that scientists use a control when conducting experiments. What was the control in this experiment, and why was it needed?

A control is used to validate the results of an experiment. The distilled water was the control.

What happened to the distilled water as your bubbler added carbon dioxide to it?

Students share observations color changes from blue to green to yellow over time.

How does this compare to what happened to the seawater as carbon dioxide was added?

The seawater should experience less significant color changes over the time allotted for the experiment. For example, the solution may have changed only a little from blue to bluish-green.

The distilled water represents freshwater sources, like groundwater. Based on what you observed, do you think fresh water absorbs more or less carbon dioxide than seawater?

The seawater is able to absorb more carbon dioxide than fresh water.

As you added carbon dioxide to the seawater over the six-minute period, you observed very little changes in color. This indicates that seawater is able to absorb large amounts of carbon dioxide because it took longer to become more acidic. The fresh water turned yellow because it turned acidic faster indicating that it absorbed more carbon dioxide molecules.

Demonstrate the difference between saturated and unsaturated solutions. For an example, obtain two identical containers. Add marbles to the first container until it is filled. Try to add more marbles until they begin to roll out onto the table. Tell students this represents saturation, or the point where no more marbles (molecules) can be added. Use a second container to add marbles. Explain that it represents an unsaturated solution as long as marbles can be added.

Oceans may absorb quite a bit of carbon dioxide over time. How do you think the continued absorption of carbon dioxide may influence the pH of seawater?

The pH of seawater should reflect increased acidity (lower pH).

This is a good observation. As we discussed earlier, processes like burning fossil fuels and deforestation are carbon sources. As more carbon dioxide is released into Earth’s atmosphere, the carbon dioxide absorbed by oceans also increases. Consequently, the pH of the ocean is lowered.

5 Analyzing the data

a. Distilled water was the control. We needed a control so we would have something to compare the seawater with.

b. Seawater has the ability to absorb more CO\textsubscript{2}. As the color changes, the solution becomes more acidic as more and more CO\textsubscript{2} is absorbed. The fresh water turned yellow at around five minutes and then stopped changing color, indicating that it became acidic faster than the seawater. The seawater did not turn yellow during the experiment, indicating that it did not become as acidic as the distilled water and thus could absorb more CO\textsubscript{2}.

c. Yes, the experiment shows that the oceans have the ability to absorb lots of CO\textsubscript{2} because the BTB solution in seawater took much longer to change color, indicating that it absorbed more CO\textsubscript{2}.

d. Other processes that store CO\textsubscript{2} include photosynthesis, production of calcium carbonate shells, and sedimentation. Processes that release CO\textsubscript{2} are respiration and diffusion of CO\textsubscript{2} out of the water.

e. Eventually, it might lower the pH of the oceans, making them more acidic.

f. Yes, because combustion of fossil fuels and deforestation release more CO\textsubscript{2} into the atmosphere, causing a net increase. The oceans would thus absorb more CO\textsubscript{2} causing a lowering of pH.
Impact of ocean acidification

Although the natural absorption of carbon dioxide by the oceans helps absorb excess carbon dioxide from the atmosphere, many scientists believe the decrease in pH will have a negative effect on calcifying marine organisms. These are organisms that construct shells out of calcium carbonate and include some phytoplankton, coccolithophores, corals, crustaceans, and mollusks. Calcifying organisms help store carbon in their calcium shells, and many absorb carbon dioxide for photosynthesis. When these organisms die, their shells sink to the bottom of the ocean and store carbon in calcium carbonate sediments.

Have students look at the carbon cycle diagram to identify these processes. Review the discussions from Part 1 of the investigation to talk about how tiny photosynthetic organisms settle to the bottom of the ocean floor and store carbon, which is eventually combined with the ions produced as carbon dioxide dissolved in the oceans. Use the results from the experiments in Parts 2 and 4 to show the cycling of carbon from one source to another. For example, the carbon stored by phytoplankton combines with the carbonate ions yielded as carbonic acid ionizes.

You can use natural chalk to show students the relationship between dissolved carbon dioxide in oceans and the calcium shells of tiny marine organisms. Explain that natural chalk is calcium carbonate, composed mostly of fossilized sea creatures. Use a mortar and pestle to grind the chalk into small pieces and put the pieces into a beaker. Slowly add vinegar to the chalk pieces. Students should observe that a smoky substance forms. Tell students that the smoky substance is carbon dioxide gas. This observation should reinforce the fact that carbon is stored in the shells of calcifying marine organisms. The carbon dioxide product in the chalk demonstration represents the carbon dioxide given off as carbon is broken down.

Use the Internet to locate photos of the white cliffs of Dover so that students are able to see the chalk cliffs.

In this part of the investigation, you will work with members of your group to learn more about how these calcifying organisms are affected by lower pH levels in oceans.

These questions are great for group research or as a homework assignment. Allow time for students to research and present their findings to the class. If the questions are answered during class time, then assemble enough resources for students to use.
Lesson 15.2: Global Climate Change

Earth has experienced many changes in its climate over the course of its history. For the most part, these climate changes were due to natural occurrences, like changes in Earth’s orbit. But since the Industrial Revolution, human activities have altered Earth’s atmosphere. This lesson focuses on the factors that have changed the global climate.

Start the lesson

Connect to Prior Knowledge: Earth’s Energy Budget

Do any of your students have a part-time job or receive an allowance from their parents? If so, ask students to share how they budget their income or allowance. Encourage students to use chart paper to list or illustrate the way(s) they allocate resources. Do your students always stay within their budgets? Explain that Earth also has a budget with respect to energy. When thinking about how energy flows into and out of the atmosphere, scientists use the energy budget model. As with any budget, balance is important. Earth’s budget remains in balance as long as the amount of energy that leaves the atmosphere is equal to the amount of heat that enters. Maintaining this balance is important to keep global temperatures relatively constant.

Use the diagram (at right) to explain that only-half of Earth’s incoming solar radiation reaches its surface. Much of this energy is re-radiated into the atmosphere as infrared radiation. Ask students what they think happens to this infrared energy. It is actually absorbed by atmospheric gases, such as carbon dioxide and water vapor. Ask students to think about why this is important for maintaining life on Earth. The answer lies in understanding the greenhouse effect. Because atmospheric gases absorb much of the infrared radiation, it does not immediately return to space. Explain that the greenhouse effect keeps Earth’s surface temperature warm. According to some estimates, Earth’s average surface temperature would be 30–35°C cooler than it is currently without it. Ask students to describe how this change might affect the quality of life on Earth. Have them find out about concerns regarding the current state of Earth’s energy budget.

voc·u·lar·y

global climate change - any significant change in Earth’s climate for an extended time period that happens naturally or is human-caused.
greenhouse gases - atmospheric gases that trap heat from the Sun so that Earth stays warm.
global warming - the increase of Earth’s average temperature due to increased concentrations of greenhouse gases in the atmosphere.
greenhouse effect - the warming of Earth that results when greenhouse gases trap heat reflecting from the planet’s surface.
Motivate: Climate Change Scrapbook
Discussions about climate change are an integral part of the scientific and political news cycles. Encourage your students to begin a classroom scrapbook that contains newspaper articles about climate change, its effects, and new policies being implemented in response to the issues. This is a great long-term project and can be used from year to year. You may even have students catalog articles by year, with each group of students reviewing articles from previous years and noting new developments and advancements in climate science and policy. An additional option is to dedicate one section of the scrapbook to climate change news in your local community or state.

Present the content

Address Misconceptions: The Greenhouse Effect
As students learn about the greenhouse effect, they often think of it only in negative terms. Lead a discussion about the greenhouse effect and its role in maintaining Earth’s temperature. Then ask students to think about Earth without the greenhouse effect. Students should realize that Earth would be much colder. Have students list some of the consequences of this drastic reduction in our planet’s temperature. For example, many bodies of water would be frozen. Ask students to describe how this change would alter life on Earth.

Check for understanding
Suppose a new industrial complex is being constructed in your community. Before gaining approval from local authorities, potential tenants are informed that an environmental impact statement must be submitted. Why might local authorities want to see an environmental impact statement prior to allowing the complex to be built? Based on their findings, what is a likely course of action? (An environmental impact statement provides specifics about how actions, such as building a new complex, influence the area’s natural resources. After reviewing the statement, local authorities may find the environmental impact too great and then suggest alternatives to the initial proposition or abandon the idea altogether. If the negative environmental effects are within reasonable limits, the project will likely be approved.)

Reteach
Have students reread “how greenhouse gases work,” on page 374 of the student text and then use Figure 15.12 to reinforce major points. Review the list of greenhouse gases from the science fact sidebar and discuss how they influence Earth’s heat balance.

An Analogy for Global Warming
Use this idea (and the graphic below) to help students visualize global warming. Tell students to imagine an empty bucket with a hole near the bottom. If water is poured into the bucket at the same rate that water spills out of the hole, the bucket will never be filled. However, if the bucket is partially filled with pebbles, it will take longer for the water to get through the bucket and out the hole. Explain that even though the same amount of water still enters and exits the bucket, the water level in the bucket increases because the pebbles are a barrier to the water’s flow rate.

Molecules in Earth’s atmosphere mimic the pebbles in the bucket. The presence of these molecules increases the time needed for infrared radiation to escape into space. Although the same amount of energy (like the water in the bucket) is constantly coming into and leaving the planet, time is required for energy to pass through the atmosphere. While this energy remains in the atmosphere, it keeps Earth warm.
Chapter 15 Answers

15.1 Section Review

1. Nutrients are found in soil and rocks, in the oceans, in rivers and lakes, in the atmosphere, and in biomass.

2. Sample answer: Carbon is an example of a macronutrient (others include hydrogen, oxygen, nitrogen, and phosphorus). Carbon as carbon dioxide is used by plants to make energy-rich sugars and starches that can be used by other living organisms as food.

3. The Sun’s energy is used by the apple tree for growth and reproduction. In time, apple tree flowers develop into apples. The stored energy in the apples (originally obtained from the Sun) can be used as energy for Sally once she eats the apple.

4. The answer is (b) bacteria and fungi.

5. A macronutrient is a nutrient that is needed in large quantities by living things; a micronutrient is needed in small quantities by living things.

6. The Sun is the major source of energy for ecosystems. Photosynthetic organisms (like plants and algae) use sunlight energy to make their own food. This food is then available to other organisms in an ecosystem.

7. In a way, photosynthesis and respiration are opposite processes because the reactants of photosynthesis are the products of respiration, and the products of photosynthesis are the reactants for respiration. During photosynthesis, plants use energy and carbon dioxide (and water) to make sugars. During respiration, organisms (including plants) obtain energy by converting these sugars to carbon dioxide and water. Both reactions are essential for ecosystems to function.

8. Sample food chain in an aquatic ecosystem: microscopic algae are eaten by small crustaceans, small crustaceans are eaten by small fish, small fish are eaten by larger fish, a large fish is eaten by a human being.

9. Decomposers consume waste materials and dead organisms to get energy. By breaking down material from waste and dead organisms, decomposers return nutrients to the ecosystem. For this reason, decomposers can be called nature’s recyclers.

10. Mercury does not dissolve in water; it dissolves in fats. Therefore, when an animal consumes mercury, it dissolves and stays in its fatty tissue and is not eliminated as a waste product.

11. Most of Earth’s oxygen is in the atmosphere and is supplied by photosynthesis. Twenty-one percent of the atmosphere is oxygen.

12. The carbon cycle is important because carbon molecules serve as energy carriers. Plants store energy in carbon bonds when they make sugars and starches. This stored energy is then available for other organisms to consume and use. The nitrogen cycle is important because plants need nitrogen to grow, and all living things need nitrogen to build proteins. The phosphorus cycle is important because plants also need phosphorus to grow and all living things need phosphorus for cell metabolism (phosphorus is part of DNA).

13. Nitrogen is abundant in the atmosphere, but it must be combined with hydrogen or oxygen to be useful to plants (and then useful to other living organisms). Nitrogen fixation is the process carried out by certain bacteria that results in atmospheric nitrogen being converted to ammonium and nitrate.

14. True. The DNA molecule contains phosphorus. Since all living organisms contain DNA, the phosphorus cycle is extremely important.

Challenge p. 372

The Phosphorus Cycle

The phosphorus cycle interconnects with the water, oxygen, and carbon cycles in the following ways. Water contributes to weathering and erosion which causes phosphorus from rocks and minerals to enter soil. Phosphorus then enters plants through roots. In this manner, phosphorus can then be combined with oxygen and carbon atoms to make molecules like DNA. Animals can also incorporate phosphorus into DNA and other molecules when they eat plants. Animals eliminate phosphorus in their waste material where it can then be assimilated back into the soil by decomposers. Phosphorus that accumulates in sediment layers may eventually become a rock. Diagram not shown.

15.2 Section Review

1. Global climate change refers to changes in the factors used to describe a climate (such as temperature, precipitation, or wind) that last for two or more decades. Given this definition, a single, unusually warm winter would not indicate global climate change.

2. Without greenhouse gases to trap the Sun’s heat, Earth would be very cold and inhospitable for life.

3. Burning fossil fuels and deforestation are the two human activities that have led to global warming. Burning fossil fuels and burning down forests both involve combustion reactions that release carbon dioxide into the atmosphere.

4. The Industrial Revolution led to the use of more machines. Since machines need an energy source and since the most used energy sources are fossil fuels,
there has been an increase in greenhouse gases (namely carbon dioxide) in our atmosphere since the Industrial Revolution began.

5. The reactants in a combustion reaction are a carbon molecule (like wood or a fossil fuel) and oxygen. The products of a combustion reaction are carbon dioxide and water. Combustion reactions are performed because they release a lot of energy in the form of light and heat.

6. Both combustion and respiration are used to obtain energy from a carbon molecule. These reactions both need oxygen as a reactant. The products of both reactions are carbon dioxide and water.

7. The increasing amount of greenhouse gases in the atmosphere will trap more heat and cause our planet’s average temperature to increase. Also, an increased average temperature or one that continues to rise means global climate change with some known and unknown consequences for all living things.

8. A Swedish chemist and a Nobel Prize winner, Svante Arrhenius is known for his work on acid and base chemistry. Arrhenius is also recognized that carbon dioxide (CO₂) results from burning fossil fuels and is a greenhouse gas.

9. Roger Revelle and Charles Keeling recorded atmospheric levels of CO₂ at Mauna Loa Observatory (MLO) in Hawaii. Their data provided scientific evidence of increasing concentrations of greenhouse gases in the atmosphere.

10. The Kyoto Treaty is a treaty among nations that recognizes the connection between global warming and greenhouse gas emissions and states a commitment to reduce greenhouse gas emissions.

11. IPCC stands for Intergovernmental Panel on Climate Change. This organization was formed to address global climate change. The members of the IPCC include government-nominated scientists who review scientific evidence for climate change. Scientist members are selected so that there is a balance of points of view, gender, age, and nationality.

12. Yes, the work of the IPCC is consistent with following the scientific method. However, the IPCC does not conduct scientific experiments. Rather, the IPCC is involved in evaluating the conclusions of scientific experiments. This task supports the work of future scientific experiments. Also, these evaluations are made by large group of scientists (rather than a few). Finally, the IPCC publishes its findings so that others can evaluate its conclusions.

13. Sample answer: Yes, I believe the IPCC reports are trustworthy. This is because the members of the IPCC are selected so that there is a balance of points of view, gender, age, and nationality. Also, the work of the IPCC is divided into three parts so that groups can focus on certain aspects of climate change. Finally, the reports of the IPCC are then reviewed by hundreds of other scientists before publication. All this effort ensures that the reports and the experiments that are used as the source for the information for the reports represent sound understanding of the current condition of our climate. Because the IPCC publishes its reports and makes them available to the public for free, the reports are always subject to re-evaluation and interpretation.

14. Effects of global warming that are evident today (possible answers): warming temperatures, rising sea level, decreasing ice coverage, and increasing water vapor in the atmosphere (water vapor is a significant greenhouse gas that affects weather conditions).

15. Effects of global warming that may happen in the future (possible answers): an increase in global temperatures ranging from 1.8 to 4.0°C, rise in sea level ranging from 30 to 40 centimeters, and effects on the oceans, ice cover, and cloud cover that could cause as yet unknown effects on other systems.

16. A carbon footprint is how much greenhouse gas emissions are produced indirectly and indirectly by an individual as a result of daily activities.

17. Yes, an infant can have a carbon footprint. This is because an infant requires heat, food, and material goods to survive. The manufacture or transport of these things involves the production of greenhouse gases.

18. Recycling is an easy, effective way to reduce my carbon footprint. Recycling reduces the need to use and extract more limited resources to make products. This saves on energy use too.

19. Student answers will vary. A list of ways that students can reduce greenhouse gas emissions is listed at the end of section 15.2. The greatest impact on reducing greenhouse gas emissions can be achieved by use less fossil fuel for transportation and electricity.

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Emissions Trading

The idea behind emissions trading is to rely on the free market to determine the “cost” of emitting carbon. Using market forces, this particular strategy for carbon emissions reduction is thought to be more effective at getting companies to reduce their emissions and more effective in promoting new technologies for reducing emissions. Emissions trading (also called “cap and trade”) is controversial because it doesn’t necessarily reduce emissions. For example, a business may be so lucrative that it can afford to keep producing emissions at high levels. Also, emissions trading does not include any oversight that protects people who are outside of the business industry or the very poor. Finally, emissions trading can be complex, hard to manage, and enforce.
Chlorofluorocarbons

Chlorofluorocarbons are a persistent problem because they last a long time in the atmosphere (decades) and continue to react with ozone molecules (and deplete the ozone layer).

Chapter 15 Assessment

Vocabulary

Section 15.1
1. ecosystem
2. chemical cycles
3. food chain
4. photosynthesis; respiration

Section 15.2
5. greenhouse gases
6. global warming; global climate change

Concepts

Section 15.1
1. Chemical cycles like the water, oxygen, and carbon cycle keep nutrients and other essential needs (like water) moving on Earth so that they are available to living organisms. Food for living organisms is part of the carbon cycle, and all living organisms need water and oxygen to survive.
2. Biomass is the matter of living things. Biomass is mentioned in section 15.1 because it is one of the places on Earth where macronutrients and micronutrients are found.
3. During photosynthesis, the carbon in carbon dioxide is used to make sugar and starch molecules (food molecules) for the plant. Some of these molecules may be converted into woody tissue.
4. A meadow ecosystem: dandelion (producer), rabbit, snake, owl (consumers), bacteria (decomposer).
5. Ecosystems include: (a) Tropical rainforest, (c) rotting log and surroundings, and (e) desert.
6. Photosynthesis and respiration are both parts of the water and oxygen cycles because water and oxygen appears in both reactions. For photosynthesis, water is a reactant and oxygen is a product. For respiration, oxygen is a reactant and water is a product.

Section 15.2
12. Answers:
   a. True.
   b. False. Increased concentrations of carbon dioxide and other greenhouse gases are causing global warming.
   c. False. Global climate change can be caused by natural processes and by human activity.
   d. True.
13. Sample answer: The gases in Earth’s atmosphere both allow the Sun’s radiation to reach the surface and prevent this radiation from escaping quickly back to space. Most of the radiation that enters the atmosphere is high energy. The radiation that is re-emitted by Earth’s surface is mostly lower energy, infrared energy (heat). Because the radiation is lower energy, it gets trapped by greenhouse gases and causes Earth to stay comfortably warm. Eventually, this energy does escape back to space so that Earth doesn’t get too warm. However, increasing atmospheric concentrations of greenhouse gases may slow heat loss too much so that Earth’s average temperature rises.
14. Chlorofluorocarbons are the only human-made greenhouse gas.
15. Revelle and Keeling’s work provided scientific evidence that levels of carbon dioxide were increasing in Earth’s atmosphere. Their data and graphs have been used to make the connection between increased levels of carbon dioxide and global climate change.
16. Sample answers can include: (1) Some greenhouse gases only come from human sources (i.e., CFCs). (2) The highest greenhouse gas concentrations are over the Northern Hemisphere which has a higher human population. (3) Study of carbon isotopes reveals that the increased levels of carbon dioxide in our atmosphere come directly from the burning of fossil fuels.
17. Governments are enacting laws that force the reduction of greenhouse gas emissions, developing alternative energy resources, and working with other governments to address global climate change.

Problems
Section 15.1
1. Answers:
   a. Two producers = field of corn, berry plant; Three herbivores = caterpillar, squirrel, field mouse; four carnivores = mountain lion, hawk, snake, frog; two omnivores = robin and crow.
   b. Decomposers could include fungi growing in the corn field and bacteria that decay the bodies of animals that die. Crows eat decaying flesh too, and help with the process of recycling nutrients in their environment.

Section 15.2
2. The heat released during the burning or combustion of fossil fuel is similar to the process of respiration involved in the decomposition of the grass clippings by decomposers. Both processes involve a carbon source (fossil fuel and grass clippings), and both processes release carbon dioxide and water as well as heat.
3. Answers:
   a. Reduce your use of electricity: less energy used and less carbon dioxide emitted due to combustion of fossil fuels.
   b. Use less hot water when you wash your clothes: less energy used to heat the water and less carbon dioxide emitted due to combustion.
   c. Use less energy to heat or cool your house: less energy used and less carbon dioxide emitted due to combustion.
   d. Riding a bicycle instead of using a car: the carbon dioxide emitted by the cyclist is greatly reduced compared to the amount emitted by a car that uses fossil fuels.
   e. Use fewer products made from petrochemicals: These products utilize an already limited resource. Obtaining oil and refining it to make petrochemicals involves energy that produces carbon dioxide.
   f. Grow plants. Plant a tree or plant a garden: Plants absorb carbon dioxide from the atmosphere and can offset carbon dioxide emissions that are a part of your carbon footprint.

Applying your Knowledge
Section 15.1
1. Like photosynthesis, chemosynthesis is a process that makes carbohydrates (energy-storing compounds). However, in chemosynthesis, the energy used to make carbohydrates comes from inorganic molecules like hydrogen sulfide, or methane, instead of energy from the Sun. Chemosynthesis is limited to microorganisms.
2. The white cliffs of Dover provide a visual example of how carbon is stored on Earth. These cliffs are made of the shells of tiny, water-dwelling organisms. The organisms use carbon and calcium to form shells of calcium carbonate, or chalk. When the organisms die, the shells sink to the ocean floor. Piles of calcium carbonate build up over many centuries. Due to geological events, the calcium carbonate ocean floor off the coast of England became a land structure, the white cliffs of Dover.
Section 15.2

3. Answers:
   a. Sample answer: Any technology that reduces the concentration of greenhouse gases in the atmosphere would be welcome. So, it is a “pro” to think about what might be possible especially if it works and is affordable. However, the “con” of focusing on technology to remove greenhouse gases that have been produced is that polluters stop trying to make an effort to reduce the emissions in the first place. Technology needs to be focused on both the processes that lead to emissions and on reducing the emissions once they are released.
   b. Sample answer: The technology exists for carbon capture (from coal-fired power plants, for example), but it is too expensive to put to use. The storage is actually the inexpensive part. The costly part of the technology is how carbon is captured.
   c. Student answers will vary.