reflect

Think about the astronauts living aboard the International Space Station. Like us, they need to breathe, eat, sleep, and use the bathroom. Yet, they are confined to a small spacecraft miles above Earth's surface. How do they maintain adequate supplies of the oxygen, water, and food they need to live? What do they do with their waste?

These astronauts rely on connections to Earth. Space vehicles launched from Earth's surface carry cargo to the station. The vehicles also take away any materials no longer needed by the astronauts. The station's success depends on materials being cycled between the station and Earth.

The International Space Station has been continuously occupied since November, 2000.

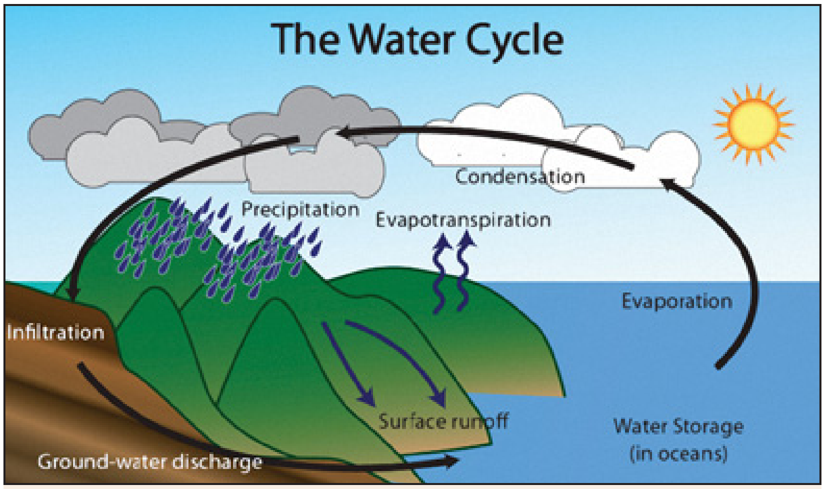
What can we learn about the cycling of matter from the International Space Station? How does this compare to the cycling of matter on Earth?

Matter cycles between many different forms in a closed system.
The International Space Station cannot produce its own resources such as food, water, or oxygen. Instead, astronauts must bring the resources they need to survive from Earth to the space station. As a result, matter moves in and out of the International Space Station. In other words, the amount of matter it contains changes over time.

Contrast the International Space Station with Earth. On Earth, the same matter exists now that existed millions of years ago. This matter has undergone many changes in that time, but the total amount of matter has not changed. It simply cycles between different forms. In this companion, we will study three of the most important ways that matter cycles between different forms on Earth.

Water undergoes changes as it moves through its cycle on Earth.
The first of these important cycles involves water. The diagram on the next page shows the main ways water changes as it goes through cycles on planet Earth. Notice the cycle has a repeating pattern of evaporation, condensation, and precipitation.

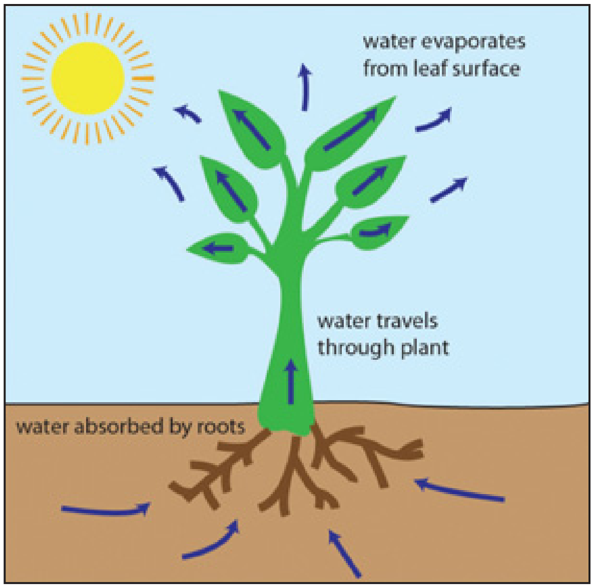
CYCLING OF MATTER



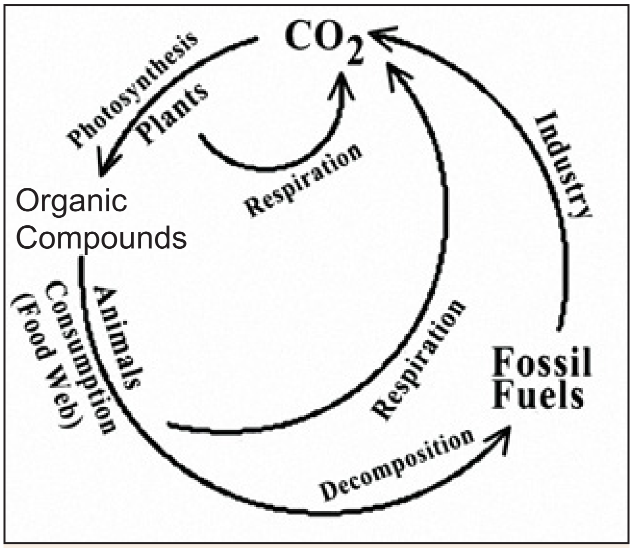
On Earth, water continuously cycles via the processes of evaporation, condensation, and precipitation.

A cycle is continuous—it has no beginning or end. Consider water stored in the liquid state in oceans and other bodies of water. This liquid water *evaporates* to form water vapor (a gas) in the atmosphere. This water vapor then undergoes *condensation*, returning to the liquid state, as clouds form. This liquid water precipitates as rain or snow as it falls back to Earth. Liquid water moves along Earth's surface (as *runoff*) and through underground passages (as *ground water*). Eventually, the water returns to oceans and other bodies of water, and the cycle happens again.

This diagram shows another process that contributes to the water cycle. *Transpiration* involves the movement of water through living plants. During transpiration, plants take up water from the soil through their roots. Water then moves up into the stems, branches, and leaves of the plants. In the leaves, water moves out of pores called *stomata* where it evaporates into the atmosphere. *Evapotranspiration* is the term used to describe the overall movement, via plants, of liquid water from the ground into the atmosphere as water vapor. As you can see, the cycling of water on Earth involves water molecules passing through both living and nonliving systems.



Carbon moves through a cyclic path known as the carbon cycle.
As we noted earlier, the total amount of matter on Earth does not change. Elements such as carbon are present in fixed amounts on our planet. Carbon changes and takes on many different forms. Just like changes to water, changes to carbon tend to follow a cyclic pattern.



A central component of the carbon cycle is carbon dioxide (CO_2).

Let's look at the changes in carbon that make up the carbon cycle. Plants take up carbon from the carbon dioxide (CO_2) present in the atmosphere. Through *photosynthesis*, plants convert carbon dioxide (CO_2) into more complex organic molecules such as glucose ($C_6H_{12}O_6$), a type of sugar. These compounds provide the raw materials used by plants to build stems, branches, roots, leaves, flowers, and fruits. Later, animals eat the plants, taking in these carbon-containing organic molecules as a source of both energy and raw materials for building the bones, muscles, and other structures that make up their own bodies.

In the next part of the cycle, carbon dioxide is produced in three main ways:

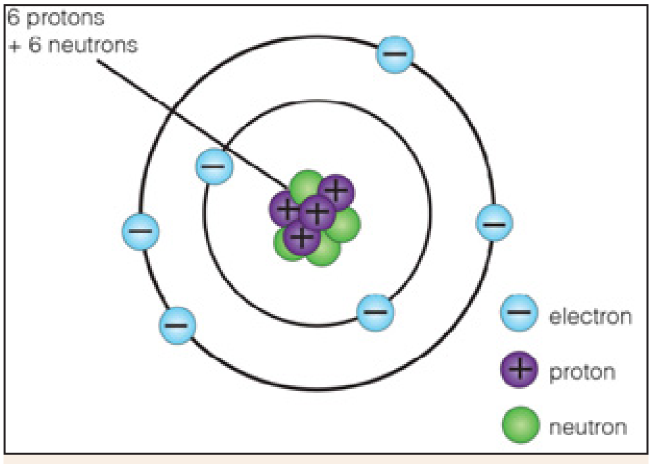
- **Respiration:** Most plants and animals carry out *cellular* respiration. This biochemical process allows organisms to get the energy they need for life-sustaining processes from food. Carbon dioxide is a product of cellular respiration and is released to the atmosphere.
- **Decomposition:** All plants and animals eventually die. After death, their bodies undergo decomposition. During *decomposition,* the large molecules making up the bodies of plants and animals are broken down. The smallest carbon-containing molecule produced by this process is carbon dioxide (CO_2), which is released to the atmosphere.
- **Fossil Fuel Burning:** In certain circumstances, dead plants and animals can become buried under tons of geological sediments. Over long periods of time and under such extreme pressures, the organic compounds making up the dead organisms are transformed into fossil fuels. Oil, natural gas, and coal are the three main fossil fuels. We remove these fuels from Earth and burn them to produce energy for electricity and transportation purposes. Burning fossil fuels releases carbon dioxide (CO_2) into the atmosphere as a product.

CYCLING OF MATTER

look out!

Photosynthesis and respiration are complementary processes that involve changes in carbon. During photosynthesis, plants take carbon from the atmosphere, and plants and other organisms release carbon back into the atmosphere during respiration. However, do not think that photosynthesis and respiration alone make up the carbon cycle. As the diagram on the previous page shows, the carbon cycle consists of more processes than photosynthesis and respiration.

Discover Science: How do scientists study the carbon cycle?
Scientists use isotopes as markers to follow the movement of carbon atoms through the carbon cycle. *Isotopes* are atoms of the same element that differ in mass. Isotopes of the same element have the same number of protons but different numbers of neutrons. It is this difference in neutron numbers that causes isotopes to have different masses. Carbon has three isotopes. Carbon-12 has 6 neutrons and is the lightest isotope. Carbon-13 has 7 neutrons. Carbon-14 has 8 neutrons and is the heaviest of the three. Scientists can trace these isotopes because they are higher in mass than carbon-12.



All carbon isotopes have 6 protons, but different isotopes have different numbers of neutrons. This diagram shows an isotope of carbon-12.

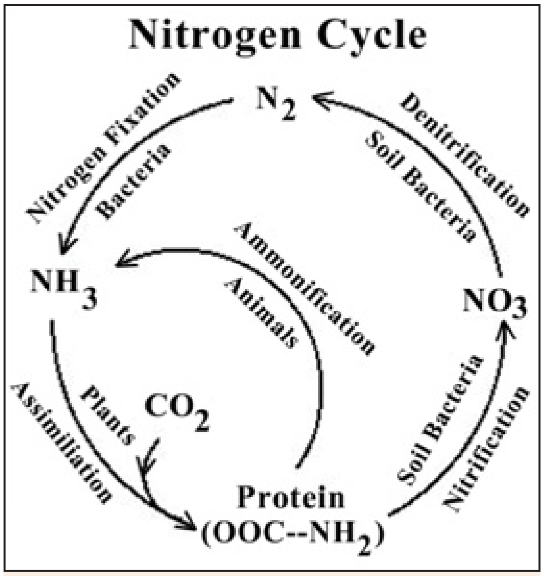
Scientists measure ratios of these isotopes in specific molecules they wish to follow. Then, they continue to measure the ratios as the carbon isotopes move from one molecule to the next in a particular region. Using this method, they can trace the path of carbon from carbon dioxide in the air to plants and eventually to the soil when the plant dies. Such studies help produce more accurate models of the movement of carbon.

look out!

Don’t confuse isotopes with ions. Isotopes are atoms of the same element that have different numbers of neutrons. An ion is an atom that has acquired an electric charge by gaining or losing electrons.

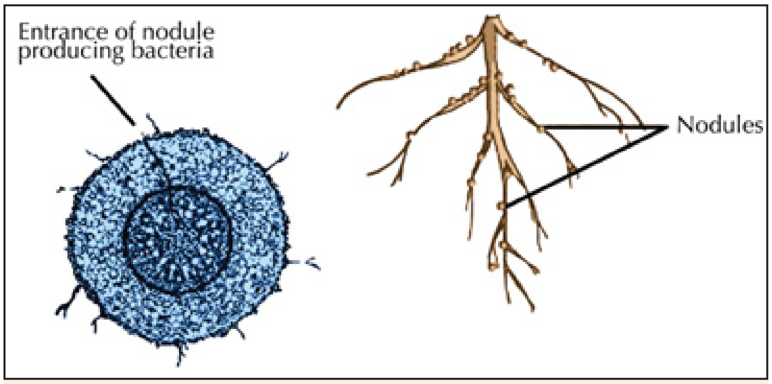
Nitrogen moves through a cyclic path known as the nitrogen cycle.

Nitrogen is another element essential to life. This element is found in proteins that make up the structures of all cells. Nitrogen is also present as a gas in the atmosphere. Each molecule of nitrogen gas (N_2) contains two atoms of nitrogen.



Nitrogen is cycled to and from the atmosphere by the action of bacteria in soil.

Nitrogen moves back and forth between the atmosphere and living things in a complex process known as the nitrogen cycle. Bacteria play critical roles in cycling nitrogen between the atmosphere and living things. Certain species of bacteria are able to take in N_2, a gas, from the atmosphere and convert it to ammonia, NH_3. This process is known as *nitrogen fixation*. Nitrogen fixation is required to convert nitrogen from the air (N_2) into a biologically usable form (NH_3). Only bacteria are able to carry out this very important process.



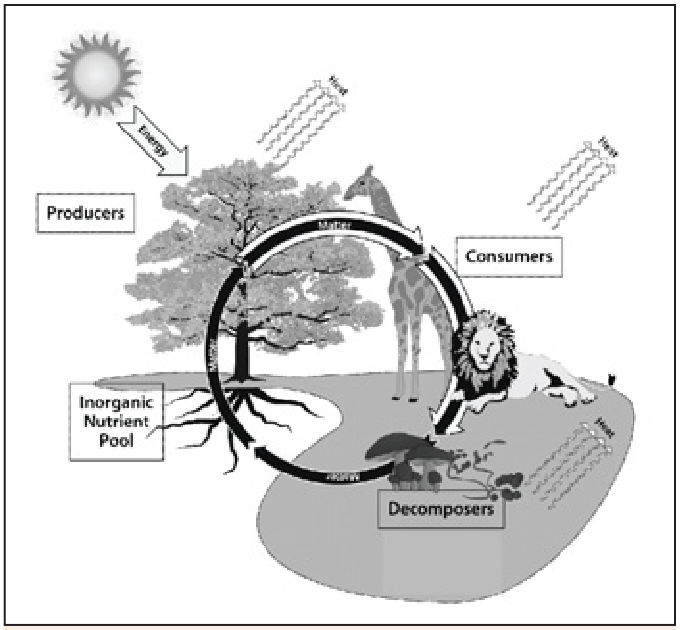
Some plants have nodules on their roots. The nodules contain bacteria that carry out nitrogen fixation.

Nitrogen-fixing bacteria live in *nodules*, or raised bumps, on the roots of some plants. Under the soil, these bacteria live alongside plant root cells. These bacteria take N_2, convert it to ammonia (NH_3), and pass it along to the plant cells. Plant cells take up the ammonia (NH_3) and incorporate it into proteins. Plant proteins then supply nitrogen to the animals that eat them. In turn, these animals provide nitrogen to the animals that feed on them and so on through the food web.

CYCLING OF MATTER

After plants and animals die, their proteins break down into smaller molecules. Bacteria in the soil convert the nitrogen in these molecules into nitrate, NO_3, another form of nitrogen. More bacteria then work on the nitrate (NO_3) to convert it back into nitrogen gas (N_2). This form of nitrogen then enters the atmosphere where the cycle can begin all over again.

Living organisms assist in the cycling of some matter.
Taken together, the water, carbon, and nitrogen cycles all contribute to the cycling of matter on Earth. As you have seen, living organisms are involved as well. Matter tends to move from *producers* to *consumers*. When these organisms die, their bodies are broken down by *decomposers*. Bacteria and fungi in soil are especially important decomposers for the cycling of matter. These organisms are essential to the decay process that allows complex forms of matter to return to simpler forms such as carbon dioxide (CO_2), nitrogen gas (N_2), and water (H_2O). Decomposers release matter back into the soil and where producers use it to grow and produce food.



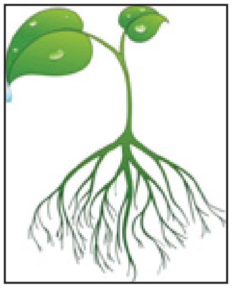
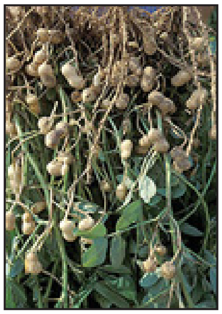
Matter cycles through both living and nonliving things.

You can observe decomposers in action by making a compost pile. *Compost* is a mixture of soil and decaying organic matter you can use as fertilizer in a garden. Decomposers, such as earthworms, are important parts of any compost pile. They break down the matter, releasing its carbon, nitrogen, and other nutrients.

what do you think?

Predict the outcome of the following experiment. A student collects leftover food scraps from one day's worth of her family's meals. Then she divides the scraps in two equal portions. She places one portion in a tightly sealed, black trash bag. She covers the other portion with soil. If the student leaves both sets of scraps side by side for a week, what do you predict will happen? How will each set of scraps look? Will they be the same?

What do you know?
Use clues from each image to name the matter being cycled (water, carbon, or nitrogen). Then, write a short description of the process represented in each image. The first row has been completed for you.

Image	Name of Cycle(s)	Description of process represented
	water cycle	The transpiration of water from soil happens through plant roots. This water evaporates back into the atmosphere when it exits through pores in the leaves.
		
		
		

CYCLING OF MATTER

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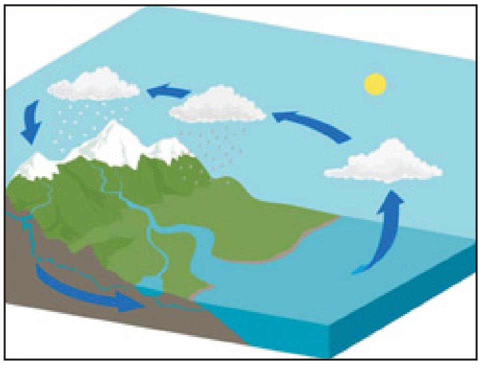		

connecting with your child

Make Compost
Have your child research methods for composting kitchen and yard waste. If you do not already use a composting method in your home, consider working with your child to begin one. If you already have a method, have your child analyze its effectiveness and make suggestions about ways to improve it.

Here are some questions to discuss with your child:

- What everyday waste materials can be composted at home? What materials should not go into a compost pile?
- What are the different methods people use for composting their kitchen and yard waste? What method would work best for our home?
- Why is it a good idea to compost kitchen and yard waste rather than to throw it in the trash?