ACTIVITY 3 - Cycling of Water through Earth's Systems

Overview

Strand 6.3: EARTH'S WEATHER PATTERNS AND CLIMATE

All Earth processes are the result of energy flowing and matter cycling within and among the planet's systems. Heat energy from the Sun, transmitted by radiation, is the primary source of energy that affects Earth's weather and drives the water cycle. Uneven heating across Earth's surface causes changes in density, which results in convection currents in water and air, creating patterns of atmospheric and oceanic circulation that determine regional and global climates.

Standard 6.3.1 Develop a model to describe how the cycling of water through Earth's systems is driven by energy from the Sun, gravitational forces, and density.

Standard 6.3.3 Develop and use a model to show how unequal heating of the Earth's systems causes patterns of atmospheric and oceanic circulation that determine regional climates. Emphasize how warm water and air move from the equator toward the poles. Examples of models could include Utah regional weather patterns such as lake-effect snow and wintertime temperature inversions.

Scientific and Engineering Practices Utilized:

- Developing and using models
- Analyzing and interpreting data
- Constructing explanations and designing solutions
- Obtaining, evaluating, and communicating information

Crosscutting Concepts:

- Cause and effect: mechanism and explanation
- Systems and system models
- Stability and change

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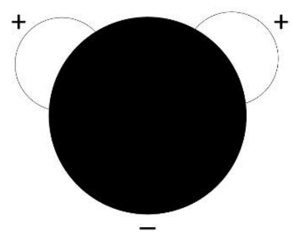
Teacher Background

In order to provide additional information for Standard 6.2.2, this background information on the cycling of water through Earth's systems will describe many of the processes in terms of what is happening at the molecular level (omitting some complex details). This is different from descriptions and explanations given in many other sources. We will begin with important information about water molecules.

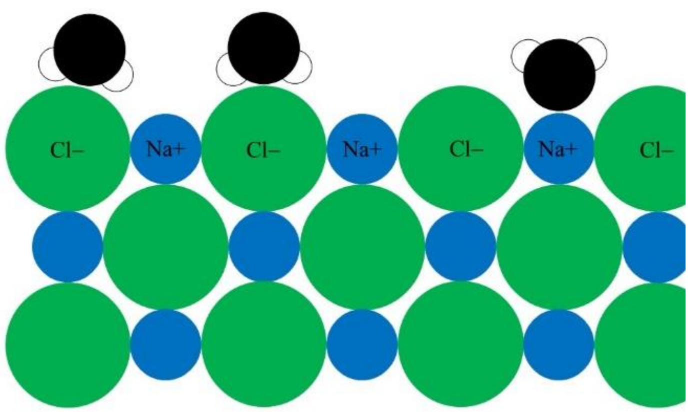
Water Molecules

The attraction of water molecules to each other and to other objects is the result of electric forces. In a water molecule, electrons are shared between the oxygen atom and the hydrogen atoms. On average, the shared electrons are more likely to be found closer to the oxygen atom than the hydrogen atoms. Because of this, a water molecule has, on average, a slight negative charge on the side of the oxygen atom and a slight positive charge on the side of the hydrogen atoms. Objects with opposite charges attract each other, so the negative sides of water molecules attract the positive sides of other water molecules. So, water molecules are attracted to other water molecules.



Simplified diagram indicating the average charge possessed by each side of a water molecule.

Water molecules are also attracted to the surfaces of other objects. One example is table salt. Table salt is made up of an arrary of chlorine atoms that each have an extra electron (giving each atom a negative charge) and sodium atoms that are each missing an electon (giving each atom a positive charge). Water is stongly attracted to salt because the positive side of a water molecule is attracted to the negatively charged chlorine atoms and the negative side of a water molecule is attracted to the positively charged sodium atoms.



Simplified diagram of water molecules attracted to chlorine (Cl) and sodium (Na) atoms in salt.

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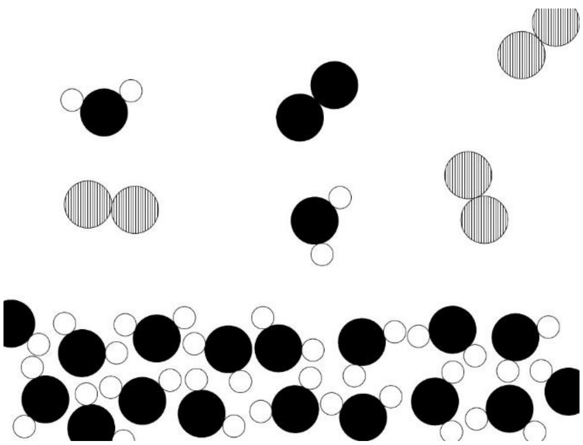
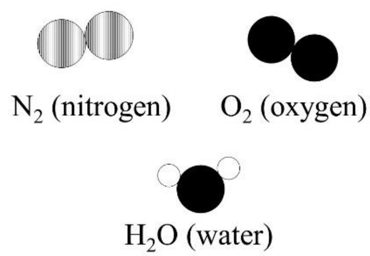
The Water Cycle

Earth's weather patterns and climate are caused by the flow of energy. In the water cycle, the energy originates from the Sun. Energy from the Sun absorbed by liquid water on Earth's surface causes water molecules to increase their motion to a point to where some of them gain enough speed to change state from liquid to gas, a process called **evaporation**. An individual water molecule will evaporate into the air when it randomly gains a little bit more energy than average from collisions with other molecules (the other molecules lose energy during the collision). That extra speed allows it to break away from the electrical attractions of its neighboring molecules. Since the molecules that evaporate have more energy than average, molecules that are left behind as liquid have less average motion than they had before. So when water evaporates from the surface of the Earth, the surface cools. When water in the form of sweat evaporates from your skin, your skin cools. About 80% of Earth's evaporated water comes from the oceans and about 20% comes from inland water and vegetation.



Water evaporating in air.

This diagram shows molecules of air above the surface of liquid water. The water molecules in the air have received enough energy from collisions with other water molecules in the liquid to escape into the air.



> **Air Parcel**: A small volume of air that has approximately the same meteorological properties (e.g. temperature, pressure, humidity) throughout the volume.

If a parcel of air with these gaseous water molecules is hotter than the surrounding air (due to unequal heating), the volume they occupy will increase. These hotter molecules push surrounding cooler air molecules outward because they are moving faster and collide with more force. This decreases the density of this particular parcel of air. Gravity pulls the colder, denser regions of air downward and underneath the warm air, pushing the warm air upward. Thus, hot air rises.

Air pressure decreases with altitude. As the parcel of moist air rises, the decrease in air pressure will allow our parcel of air to expand even more. This expansion is not the result of increased motion of the molecules, but due to a decrease in inward forces from surrounding air molecules. As molecules in our rising air parcel slowly expand into a larger space, some of them will lose speed as they collide with other molecules that are also moving outward. You can demonstrate this by bouncing a ping-pong ball off a backward-moving paddle. You will find that after striking the paddle, the ball has less speed than before. This means that when a gas expands slowly, the molecules lose speed and the temperature of the gas decreases.

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Air also contains many extremely small, light particles of dust, clay, soot, and salt from ocean spray or other substances. These tiny particles are called cloud condensation nuclei. (The average diameter of condensation nuclei is 0.0002 mm.) As the air cools, water molecules within our air parcel will stick to the surface of these particles if their speed is not high enough to escape the pull of the electrical forces between the surface of the particle and the molecule. As one of these water molecules approaches close to the particle's surface, electrical attraction suddenly increases between the water molecules and the particles. The increased attraction speeds up the incoming water molecule; when it hits and sticks, the energy of the water molecule's motion is transferred into the particle as heat (increased vibrations of the particle's atoms). When a slower moving air molecule subsequently collides with the same particle, the slower moving air molecule's speed can increase as a result of the collision which also decreases the vibrations of the particle's atoms. So, heat will move from the particle into the air. Because billions of air molecules collide with the particle each second, this happens very quickly.

Once a particle is covered by water molecules, other water molecules will also stick to water molecules already attached to the particle. This changes the water from a gas to a liquid, a process called **condensation**. If there are enough water molecules in the air and the temperature is low enough (called the dew point), the rate of condensation will be greater than that of evaporation and the volume of water surrounding the particle will increase a million times or more and create cloud droplets. (The average diameter of a cloud droplet is 0.02 mm.) If it is cold enough, water molecules can also form into crystals of ice (solid water). The many tiny droplets of liquid water or ice crystals created by condensation form a cloud.

For another perspective on the process of cloud formation see: https://www.weather.gov/jetstream/formation

When condensation occurs, cloud droplets are heated by the same process that heats cloud condensation nuclei particles (described above). Because air molecules other than water molecules do not undergo condensation at these temperatures, energy lost by water molecules in condensation (that heats the droplets) is quickly transferred to the surrounding air molecules during collisions with cloud droplets. The energy acquired by the air molecules increases their motion and temperature. **While evaporation cools its surroundings, condensation heats its surroundings**. This heating causes the air around the water droplets to expand, decreasing its density. This heated air within the cloud rises (this upward movement of air is called an updraft). These rising air molecules exert an upward force on the liquid water drops and ice crystals and keep them aloft even though they are denser than the air. Because cloud droplets are so small, only a small updraft is needed to keep them from falling.

Temperature differences due to unequal heating by the Sun cause pressure variations in the atmosphere. Air molecules move from regions of higher pressure to regions of lower pressure creating winds. Clouds are pushed along by winds high the atmosphere. As cloud droplets collide they merge to form larger drops. If the drops become large enough, the force from the rising air is no longer strong enough and the drops will fall to the ground as rain, snow or hail. This process is called **precipitation**. Some of the water falling on land will seep into the ground (a process called infiltration). Water unable to seep into the ground will move across the surface from higher to lower elevation (from mountains to valleys etc.)

because of gravity and eventually will flow into streams and rivers and then into lakes or the ocean. Water in the ground may remain there for long periods of time. (Ground water is a primary source of water for communities in Utah). It may also travel long distances through the ground before returning to the surface or seeping into other bodies of water, such as streams and the oceans. Once this water is again on Earth's surface, energy from the Sun will cause this cycle of evaporation, condensation and precipitation to repeat.

Ocean Currents

The movement of ocean currents is caused by many factors that include both global wind patterns and the rotation of Earth. Earth receives more solar radiation at the equator than it does at the poles; this uneven distribution of heat creates pressure differences, which in turn cause the movement of air, or wind. Because the poles are either north or south of the equator, winds have a northward or southward flow. Earth's rotation causes fluids — both air and water — to be deflected to the side as they move across our planet's surface. This is known as the Coriolis Effect. In addition to winds' northward or southward flow, the Coriolis Effect causes winds to move in an eastward or westward direction. The combination of the uneven heating of Earth with Earth's rotation causes winds to rotate and form three separate bands in each of the northern and southern hemispheres.

Ocean currents mirror these wind patterns to some extent. However, continents impede the flow of water. When currents encounter a landmass, they are deflected and ultimately form circular patterns, called gyres, around the perimeter of Earth's oceans and seas. The Coriolis Effect acting on these currents causes northern hemisphere gyres to move in a clockwise direction and southern hemisphere gyres to move in a counterclockwise direction.

The Gulf Stream

The Gulf Stream forms the western edge of the North Atlantic Gyre. Originating near the southern tip of Florida, this swift, warm current travels along the east coast of the United States and across the North Atlantic. South of Greenland, the Gulf Stream widens and slows, becoming a vast, slow-moving, warm current known as the North Atlantic Drift. Further on, the North Atlantic Drift splits. One part continues north as the Norway Current. The other, the Canary Current, heads south toward the northwest coast of Africa, where its waters are warmed again by the intense solar radiation in the tropics.

The Gulf Stream reaches depths of up to several hundred meters (a thousand feet) below the surface and travels up to 10 kilometers (6.2 miles) per hour. It moves as much as 100 million cubic meters (3.5 billion cubic feet) of water per second. By comparison, the Mississippi River moves about 15,000 cubic meters (530,000 cubic feet) per second.

Even more important than the volume of water moved by the Gulf Stream is the heat it carries and the effect of that heat on climate. Living at 51 degrees north latitude, Londoners might expect their winters to resemble those in Calgary, Alberta. At 60 degrees north latitude, the west coast of Norway should look very much like Siberia in January. Instead, the Gulf Stream delivers a steady flow of heat to the atmosphere near the North Atlantic. As a result, London sees plenty of rain but very little snow. And the west coast of Norway remains ice-free all winter, not at all like Northern Saskatchewan or Siberia.

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Resources

- Exploring the Water Cycle – NASA
    - https://pmm.nasa.gov/education/lesson-plans/exploring-water-cycle
    - This lesson plan is intended for teachers to use with their middle school students to learn about the water cycle and the forces that drive it. The emphasis in this lesson will be on having students understand the processes that take place in moving water through Earth's system.
- Summary of the Water Cycle – USGS
    - https://water.usgs.gov/edu/watercyclesummary.html
    - This page includes a summary of the water cycle with graphics and pictures.
- Parts of the Water Cycle – USGS
    - https://water.usgs.gov/edu/watercycleatmosphere.html
    - The left column of this page has links to individual pages with more detailed information on parts of the water cycle.
- How Clouds Form – National Weather Service
    - https://www.weather.gov/jetstream/formation
    - This page has additional information and graphics on the formation of clouds.

Activity Outline

Student Performance Outline

Phenomenon: Water Cycle Animation

- Group Discussion
    - Review what students observed during the two density tank activities to refresh their memories.
- Individual Performance
    - Watch the video and complete the worksheet based on what they observe and can infer from their observations.
- Group Discussion
    - Watch the water cycle video one more time and use it as a springboard to help students combine all their knowledge to understand the lake effect that is experienced in Utah.
- *Group Discussion (optional)*

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- *As a class watch the Gulf Stream NOVA video and discuss the role of atmospheric circulation in ocean currents. Use the discussion questions to relate it to the students' prior knowledge about temperature, density, and movement of water.*

Materials

- Water Cycle Video
- *Gulf Stream NOVA Video (optional)*
- Water Cycle Worksheet (1 per person)

Set up

Prepare to show the water cycle video and print a copy of the Water Cycle Student Worksheet for each student. *Optional: Prepare the Gulf Stream NOVA video so that it is ready for use later in the lesson.*

Procedure

- Group Discussion
  - Begin this lesson by engaging students in a discussion about what they know about temperature, heat energy, density, and gravity based upon their experiences in the two density tank activity lessons.
  - Ask the following questions to help students review:
    - Think about the past two activities we have done with the density tank. Based on those, what do you know about the relationship between temperature and density? (Higher temperature means lower density)
    - What force causes materials of different density to move and arrange themselves in layers from most to least dense if left to settle? (Gravity)
    - What is the main source of heat energy on Earth? (The Sun)
- Individual Performance
  - After the discussion, pass out the Water Cycle Student Worksheet and show the video. Play the video through once and have the students watch it without writing anything. Have them look for the movement of water (either as a liquid or a gas) and for water changing from a liquid to a gas and from a gas to a liquid.
  - Play the video again and instruct them, based on what they see happening in the video, to write a brief description on the worksheet, in every location where water is moving, that explains how or why the water is moving. Their description should also indicate where water is changing from a gas to a liquid or a liquid to a gas.
    - The goal of this portion is not to have students label the diagram with vocabulary words. The goal is to have them describe the processes they see happening in the video.
  - Discuss with the students what they saw happening in the video and have a class discussion about the phenomenon. As the students describe the different things they saw, write short descriptions on the board until all parts of the water cycle are described.
    - The goal of the discussion is to have everyone notice the distinct parts of the water cycle.

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- Have students turn the worksheet over and answer the two questions on the back. As they answer the questions it may be helpful to remind them of what they know about the relationship between temperature and density and the effects of gravity.
  - The goal of these questions is to help students develop a model to describe how the cycling of water through Earth's systems is driven by energy from the Sun, gravitational forces, and density.

- Group Discussion
  - After students have answered these questions and developed their models to explain the water cycle come back and have a class discussion about the models they came up with. Make sure students properly identified the role of the sun, gravity, and density in their models.
  - To make a connection between the water cycle and something students may be familiar with, play the video one more time asking students to pay particular attention to the clouds over the mountains.
  - Ask:
    - What happens to the mountains when the clouds reach them? (They get covered in snow)
    - What happens in the valley after lots of clouds have built up? (Rain storm)
    - Can this process occur in places besides near the ocean? Where? (Yes, by big lakes)
    - What big lake do we have in Utah? (The Great Salt Lake)
    - What is in the mountains near the Great Salt Lake? (Ski resorts)
    - Why do the ski resorts get so much snow? (Because of the evaporation from the lake)
  - This is called the "lake effect" and it is one of the reasons why there is sometimes increased amounts of precipitation in particular locations along the Wasatch Front during a rain or snow storm and why the snow in the Wasatch Mountains can be so heavy.
  - This discussion allows students to take the somewhat abstract concept of moving air and water and connect it with something they should have some familiarity with.
- Group Discussion (optional)
  - Watch the Gulf Stream NOVA video and have a class discussion about the following questions.
    - Why is Earth heated unevenly? (Intensity of light is different—Remind students of Angle of Incidence activity and Reason for the Seasons activity)
    - Based on Density Activity 2 what do we know about the effects of uneven heating on density? (Causes circular swirling of water and currents)
    - What is the principal cause of surface currents in the ocean? (Uneven temperatures and therefore uneven densities)
    - Where do the warm air and water start? (The equator)
    - Where do the warm air and water move toward? (The poles)
    - What do the differences in air and water temperature cause? (Differing regional climates and weather patterns)