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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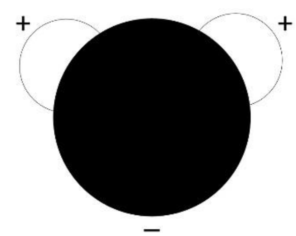
Teacher Background

This background provides additional information that connects Standards 6.2.2 and 6.3.1 by describing the cycling of water through Earth's systems with a focus on processes occurring at the molecular level (omitting some complex details). We will begin with important information about water molecules.

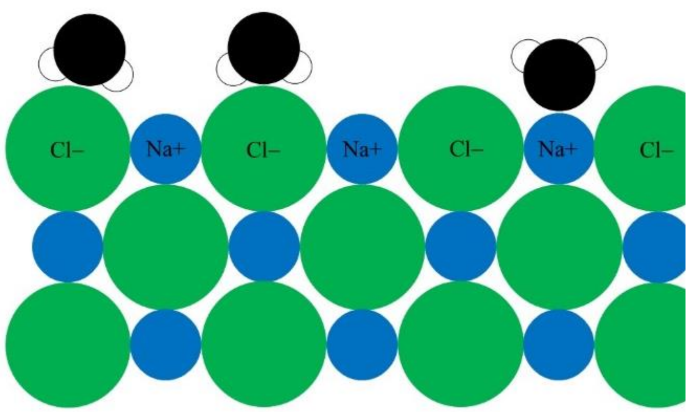
Water Molecules

Water molecules are attracted to each other and to other objects by 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 to the hydrogen atoms. Because of the position of the electrons, 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.



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

Objects with opposite charges attract each other. When water molecules are next to each other, the negative sides of water molecules attract the positive sides of other water molecules.



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

Water molecules are also attracted to the surfaces of other objects. For example, table salt is made up of an array of chlorine and sodium atoms. Each chlorine atom has an extra electron giving it a negative charge. Each sodium atom is missing an electon giving it a positive charge. Water is stongly attracted to salt because the two charged sides of a water molecule are attracted to the two oppositely charged atoms in salt.

The Water Cycle: Evaporation

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 is absorbed by liquid water on Earth's surface. This energy causes water molecules to increase their motion. As energy is transferred into the liquid, some of the molecules gain enough speed to change state from liquid to gas, a process called **evaporation**.

As water molecules move and collide with each other, they lose or gain energy from each collision. If an individual water molecule gains enough energy in a collision, it will fly into the air. The extra energy increases its speed enough to escape the electrical attractions of its neighboring molecules. Other molecules involved in the collision lose energy.

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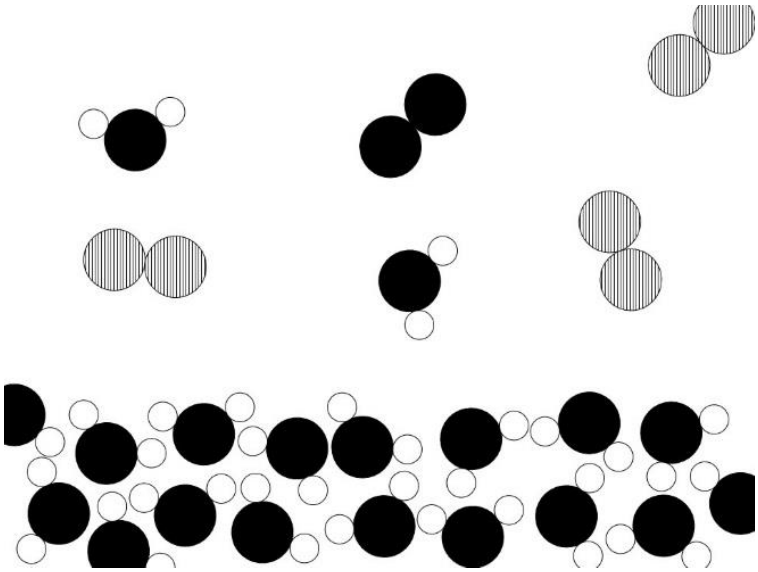
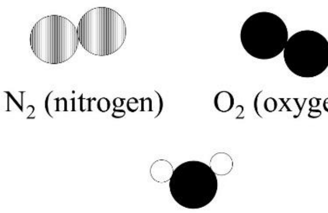


Water evaporating in air.

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



Molecules that evaporate have *more* energy than average, while molecules that are left behind as liquid have *less* average motion than they had before. In other words, evaporation is a cooling process. When water evaporates from the surface of the Earth, the surface cools. An example of this process is when water in the form of sweat evaporates from your skin, cooling your skin.

About 80% of Earth's evaporated water comes from the oceans and about 20% comes from inland water and vegetation.

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

Hot Air Rises, Expands, and Cools

In the air, hotter molecules are moving faster than cooler air molecules. These hotter molecules push surrounding cooler air molecules outward because they collide more often and with more force.

If a particular parcel of air with these gaseous water molecules is hotter than the surrounding air (due to unequal heating), the volume they occupy will increase. This decreases the **density** of this parcel of air. Gravity pulls the colder, denser regions of air downward and underneath the warm air. As the colder air is pulled downward, it pushes the warm air upward. Thus, hot air rises.

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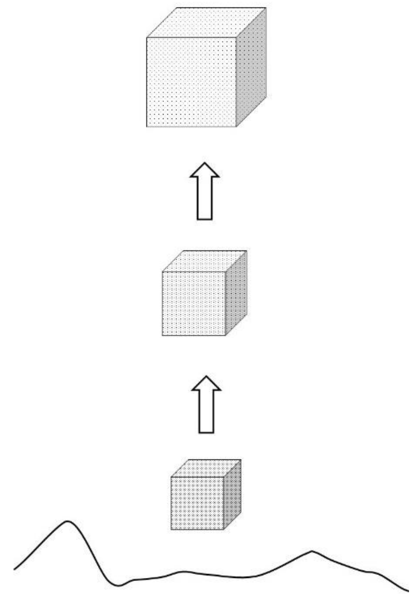

A rising parcel of air expands as air pressure decreases with altitude.

Air Pressure Decreases with Altitude

As this parcel of moist air rises, the decrease in air pressure will allow it to expand even more. This expansion is due to a decrease in inward forces from surrounding air molecules, *not* the result of increased motion of the molecules.

As molecules in our rising air parcel slowly expand into a larger space, some of them 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.) So, when a gas expands in this way, the molecules lose speed and the temperature of the gas decreases.

The Water Cycle: Condensation

As the air cools, some water molecules within our air parcel will stick to the surface of larger particles that float around in the air. 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**.

These particles are called cloud condensation nuclei. They are extremely small, light particles of dust, clay, soot, and salt from the ocean and land. (The average diameter of condensation nuclei is 0.0002 mm. Despite this tiny size, they are still about 700 times wider than a water molecule!)

Electrical forces attract water molecules to these particles. Condensation occurs as airborne water molecules collide with a cloud condensation nucleus. If a water molecule's speed is high enough, it will bounce off and remain in the air. But if its speed is too low, the electrical forces will cause it to stick to the particle.

Condensation Heats the Surrounding Air

The force of electrical attraction dramatically increases as the distance between objects with charge decreases. As one of these water molecules approaches close to the particle's surface, electrical attraction greatly increases between the water molecules and the particle. 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).

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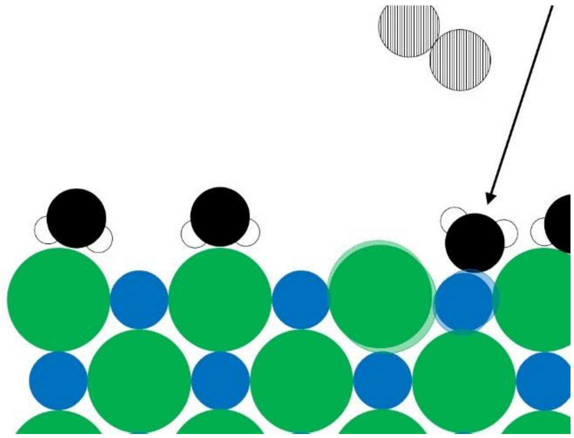
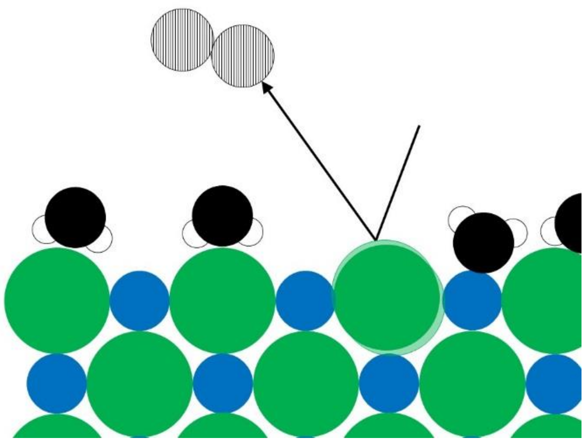


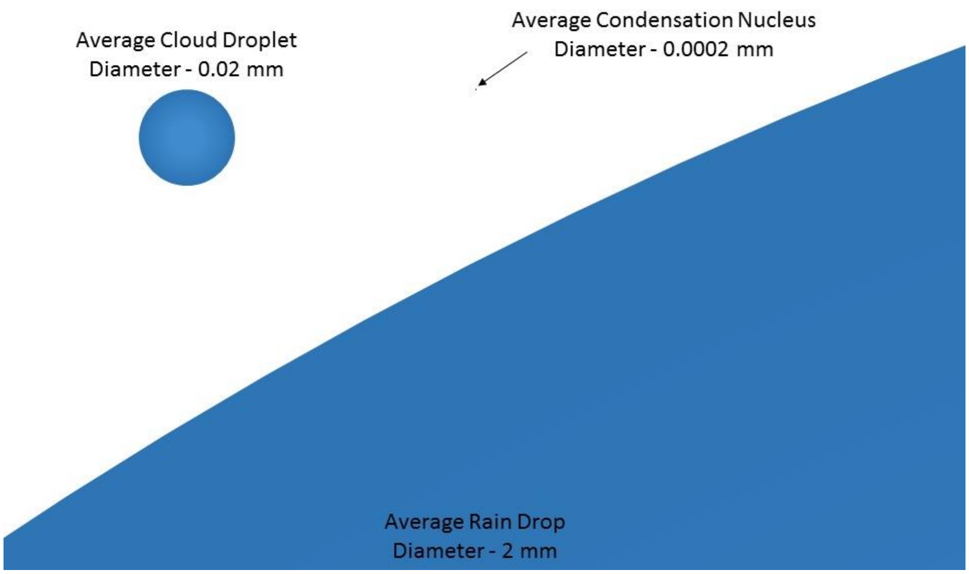
(Figure 1)
A water molecule collides with and sticks to a salt particle. The energy of motion of the water molecule is transferred into the salt, increasing the vibrations of the atoms in the salt.



(Figure 2)
When an air molecule collides with the salt particle, some of that energy is transferred to the air molecule, increasing its speed which heats the air.

Then, when an air molecule that is moving more slowly collides with the same particle, the collision can increase that slower moving air molecule's speed. This decreases the vibrations of the particle's atoms. So, heat will move from the particle into the air. Billions of air molecules collide with the particle each second, causing the heat transfer to happen very quickly.

If the air's temperature is low enough, the rate of condensation will be greater than that of evaporation. This temperature is called the **dew point**, and it varies based on the amount of water in the air. If the air is below this temperature, 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, 100 times the diameter of the condensation nuclei.)



This illustration shows the relative (average) sizes of a condensation nucleus, a cloud droplet, and a rain drop.

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If it is cold enough, water molecules can also freeze into crystals of ice (solid water). Clouds can be composed of many tiny droplets of liquid water or ice crystals created by condensation.

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

Evaporation Cools Its Surroundings, Condensation Heats Its Surroundings

When condensation occurs, cloud droplets are heated by the same process that heats cloud condensation nuclei particles (described above). Other molecules in the air (non-water molecules) do not undergo condensation at these temperatures. So, energy lost by water molecules in condensation is quickly transferred to air molecules as they collide with cloud droplets. The energy acquired by these molecules increases their motion and temperature.

The heat released from the condensation process causes the air around the water droplets to expand. This increases the air's volume and decreases its density. Because it has lower density, the heated air rises within the cloud. This upward movement of air is called an updraft. These rising air molecules exert an upward force on the liquid water droplets and ice crystals. The updraft keeps the cloud particles 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.

Wind is the Movement of Air Molecules

The Sun heats the Earth's surface and atmosphere unequally. The resulting temperature difference 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.

The Water Cycle: Precipitation

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. Eventually it 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.

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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)*
  - *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)

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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.
  - 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.

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  - 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)