Water Cycle
Content Background Document

Introduction: Matter, Molecules, and the Water Cycle

As we start our content exploration of matter, molecules, and the water cycle, take a moment to consider what you already know about these science topics.

Most likely you know that matter, such as water, exists in three states—solid, liquid, and gas. You may also have heard the terms *evaporation* and *condensation* used in relation to the three states of matter and the water cycle. Specifically, evaporation has something to do with water drying up or seeming to disappear. You might also know that evaporation is a process involving a change of state: Water goes from a liquid state to a gas state. Condensation is the reverse process: Water goes from a gas state to a liquid state. Water in a gaseous state is called *water vapor*. Good! You have some background knowledge about evaporation and condensation. But what do you *really* know?

- Do you know why evaporation happens?
- What about condensation?
- Can you identify everyday examples of evaporation and condensation?
- Can you explain what's happening at the molecular level?
- Can you connect evaporation and condensation to the water cycle?
- Why is it important for kids to learn about these processes?
- Why is it important for *you* to learn about them?

In this reading, you'll be challenged to broaden and deepen your understanding of matter, molecules, and the water cycle (including evaporation and condensation) based on what you already know. This document has been written to support and further your own content learning about these topics, including ideas about water, states of matter, energy, and molecules. The goal is for you to develop a more conceptual understanding of these ideas so you will be able to more effectively teach elementary students. The content was written with you, the teacher, in mind. The subject-matter knowledge is tied to teaching examples and is presented at a higher level than the level at which you'll be teaching your students. This is important because a rich conceptual understanding will help you better listen to your students' ideas and figure out how to best help them move forward in their understanding. It will also help you make good decisions about how to respond to students' unexpected questions.

Part 1. Evaporation and Condensation

In this section, we'll study how water changes states and what happens to water molecules as they gain or lose thermal energy. These ideas will serve as a foundation for learning about the water cycle in Part 2. The concept map in figure 1 provides a conceptual framework for part 1.

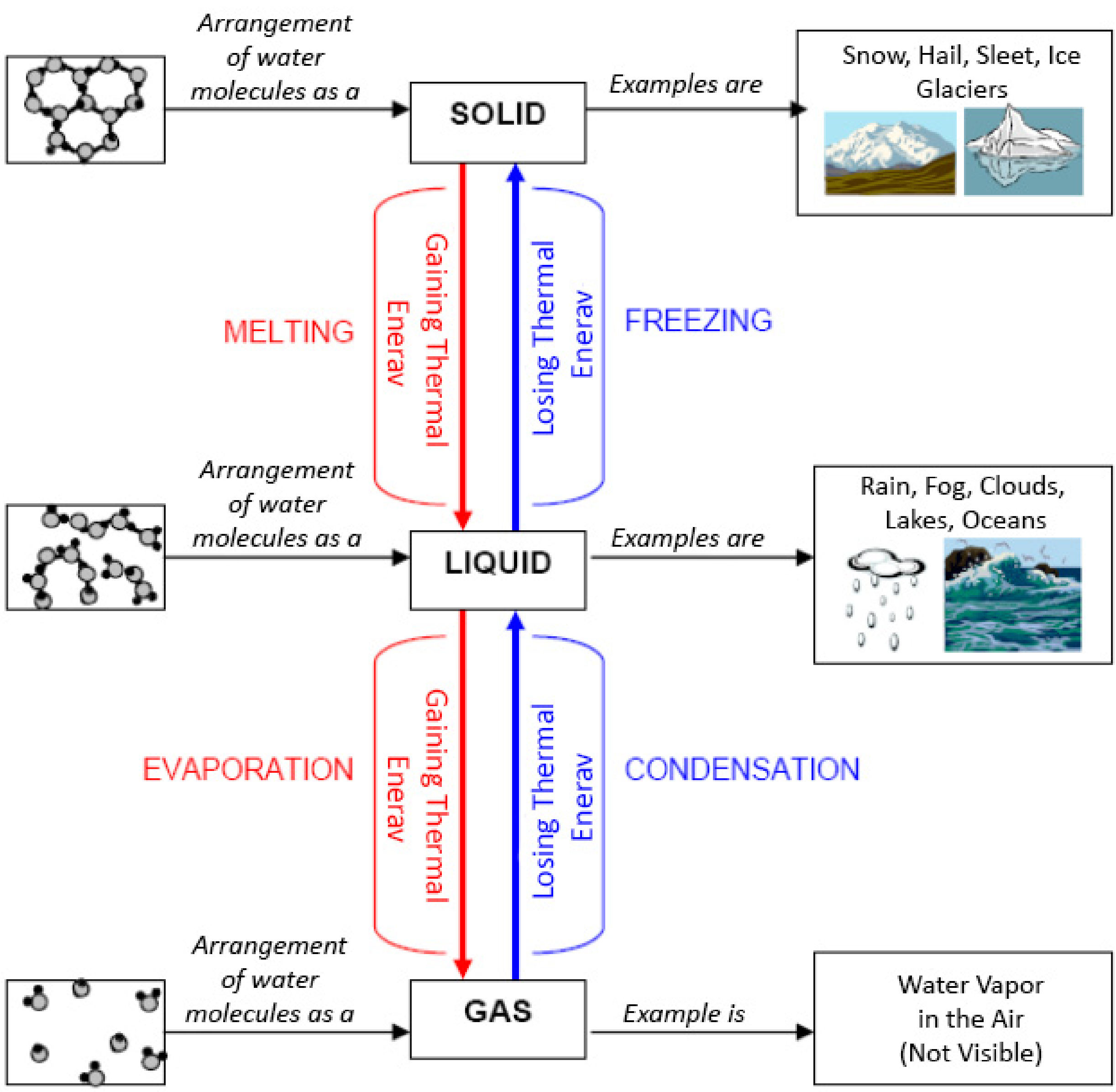


Figure 1. Evaporation and condensation concept map

1.1 Getting Started: A Molecular View

To get us started learning about evaporation and condensation, let's take a closer look at water. All matter is made up of small particles. Water is made up of small particles called *molecules*. You probably already know that the molecular formula of a water molecule is H_2O. This symbol means that each molecule of water contains two hydrogen atoms and one oxygen atom. The oxygen and hydrogen atoms connect in a specific arrangement to form a water molecule (see figure 2).

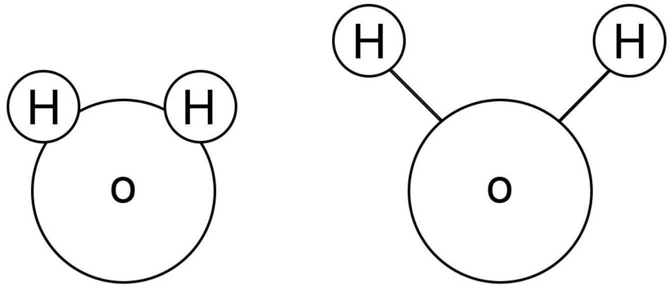


Figure 2. Molecular structure of water

Now imagine a single *drop* of water, not just one molecule.

STOP AND THINK

How many molecules are in a drop of water? Can you compare the number of molecules to other things to help you understand the scale?

As of March 2018, more than 300 million people were living in the United States.[1] There are about 300 *billion* times as many molecules in a drop of water as there are people living in the United States! That's 1,000,000,000,000,000,000,000 molecules of water in a single drop! Can you draw other comparisons?

To understand how water changes from solid to liquid to gas, we need to be able to describe what water is like in each of those states or phases. Figure 3 provides an overview of the different states of water. The first state is *liquid water*. Liquid is overwhelmingly the most common state of water on Earth and in our bodies. In fact, we human beings are mostly liquid water. And the majority of Earth is covered with liquid water.

Imagine a large raindrop (about 4 mm in diameter). The drop lands on your car and is running down the window. What would you see the water molecules doing if they were visible? (It's worth noting that no microscope is able to do this.) You probably know that molecules of H_2O are moving around inside that drop of liquid water. The molecules are attracted to one another but slide past each other. When compared to either ice or water vapor (see figure 4), the molecules are close together. (The drawings in figure 4 are not to scale.)

Water is unusual in that the solid form (ice) is less dense than liquid water. For almost all other substances, the solid form is denser than the liquid form because the molecules in a solid are packed more closely together. If you compare the drawings showing water molecules in liquid and in solid states, you can see the reason why water is different: The arrangement of the molecules in solid ice crystals creates a structure with more space between molecules than in liquid water. *In what other ways does ice differ from liquid water?*

[1] The US Populations clock updates its estimate of the US population every second. For the current estimate, go to http://www.census.gov/popclock/.

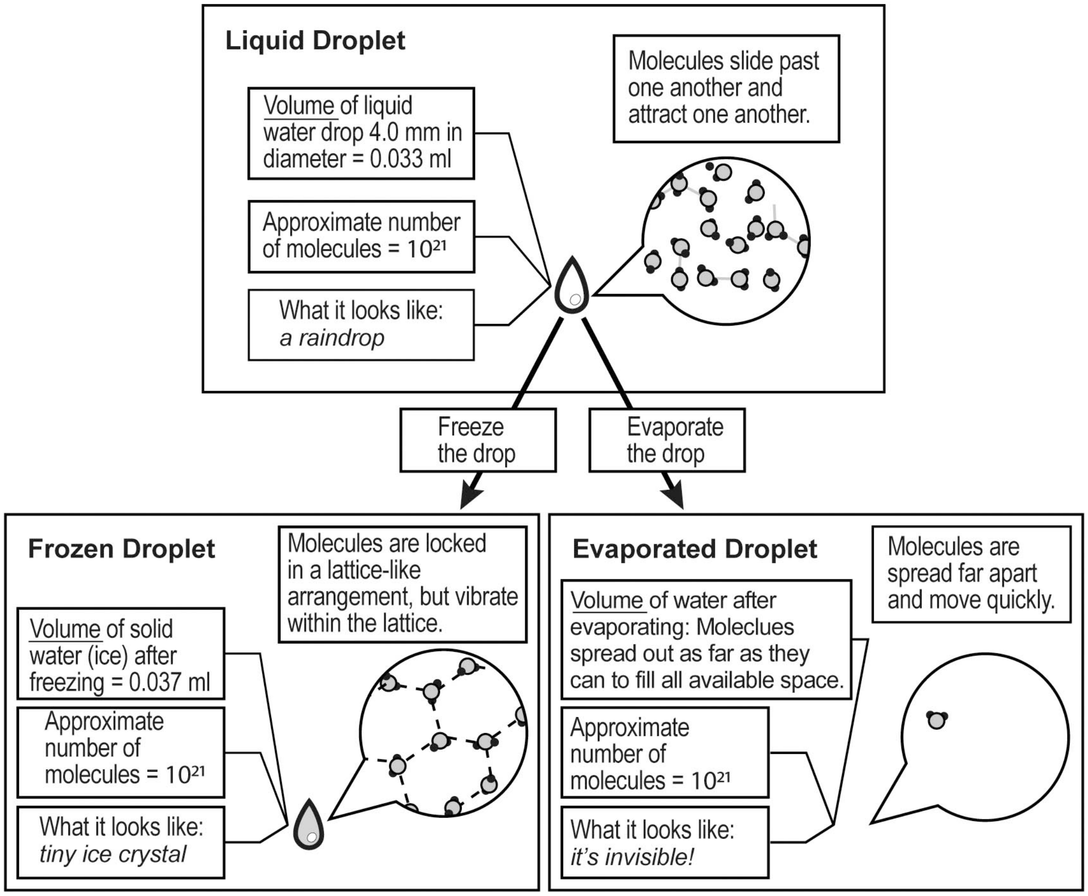


Figure 3. Molecular structure of different states of water

After you've compared the drop of water as a liquid to what it's like after freezing, compare both of these states to what the water is like in its gaseous state. Consider the volume differences especially.

Water vapor in the air is just that—water vapor in the air. This means that water molecules in the gaseous state (water vapor) mix with other gases in the air. A water molecule that evaporates from that drop of liquid water goes from being surrounded by other water molecules in close proximity to being surrounded by molecules of nitrogen gas and oxygen gas as well as water molecules. And the distance between all of these molecules is much greater.

All molecules move, whether they are in the solid, liquid, or gaseous state. The slower they move, the easier it is for molecules to attract one another, and they will line up with one another in rigid patterns. The faster they move, the harder it is for them to come close enough to attract one another, and the more spread out they will be.

Take a look at figure 4, which shows how water molecules are organized when they are in solid, liquid, and gaseous states. What do you notice?

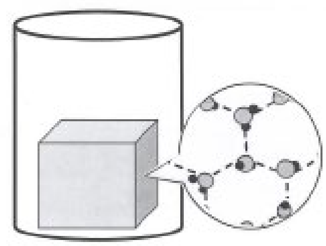
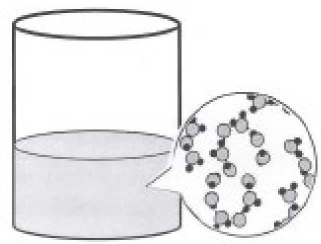
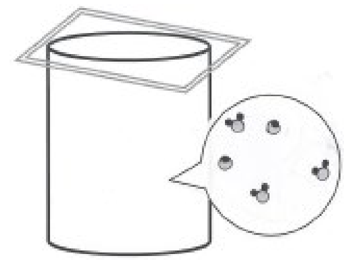
Solid (*Ice*)	Liquid (*Water*)	Gas (*Water Vapor*)
		

Figure 4. Arrangement of water molecules

STOP AND THINK

When liquid water changes to water vapor, what happens to the water molecules?

The organization and type of molecules and the relative amount of movement are characteristic of a given state of matter.

As a *solid*, water molecules are arranged in a lattice-like structure that allows for space to exist between molecules. The molecules still move, but they move by vibrating in fixed positions. It is important to note that the lattice-like space makes water an unusual substance, *expanding* when it freezes. Other liquids shrink when they freeze because molecules line up more closely in the solid phase than the molecules moving around in the liquid phase.

However, a *liquid* does swish around in a cup. Take a look at figure 4 again to see how water molecules are arranged in the liquid state. Notice that they're closer together and sometimes attracted to one another, but there is not a rigid structure as in ice. Water molecules in the liquid state can actually slide past one another and change their positions.

Water molecules as *gas* are called *water vapor*. Rather than joining together, they exist as individual water molecules that move all over the place. Imagine water vapor in a sealed container. The water molecules are not at the bottom of the container. Instead, they are moving so they disperse evenly throughout the container.

The molecules in a particular state of matter don't move at the same speeds; rather, they have a range of speeds. That is, not all molecules in a glass of water are moving at the same speed. Some are moving faster and some slower than others. But if we compare the movement of molecules in the three states of matter for a substance like water, we find that on average the molecules in the solid state are moving slower than the molecules in the liquid state. Comparing the motion of molecules in the liquid state and gaseous states is a little more complex. Generally, we can say that the molecules of water in the gaseous state have the ability to move faster than molecules in the liquid state. We'll learn more about this later.

An important aspect of matter is that it can undergo physical changes or chemical changes (see table 1). A *physical change* means matter is changing form, but the molecules that comprise the matter don't change.

The molecules remain intact; a new substance isn't created. In the case of water, H_2O molecules remain as H_2O molecules in the solid, liquid, and gas states.

On the contrary, a *chemical change* is when new substances are created. The atoms in a molecule break apart from each other and rearrange themselves to form new molecules. In the case of water, a chemical change would mean that the hydrogen and oxygen atoms separate from one another and form new arrangements with other atoms.

Table 1. Physical and chemical changes of matter

Examples of Physical Changes	Examples of Chemical Changes
• Cutting paper • Boiling water • Crushing ice • Breaking glass	• Burning wood • Combining vinegar and baking soda • Photosynthesis • Baking a cake

Changes of state (i.e., melting, freezing, boiling, evaporating, and condensing) are examples of physical changes. This can happen when a substance gains or loses enough thermal energy. Gaining thermal energy is more commonly referred to as *warming*, and losing thermal energy is often called *cooling*.

Why do scientists talk about gaining thermal energy instead of saying that something is heating up? For scientists, heating (used as a verb) refers to a process where thermal energy (heat energy) is transferred from an object with a higher temperature to an object with a lower temperature. When a substance gains thermal energy, its molecules move faster, and as long as the substance is not changing state, its temperature rises. If a substance is heated enough (to melting- or boiling-point temperatures), the thermal energy it gains causes the molecules to move apart, and the substance changes state. Its temperature remains the same during a change of state even when heat energy is being added.

Therefore, heating a substance can have two effects: (1) If a substance is heated, the thermal energy transferred to it increases the kinetic energy (and motion) of its molecules, and the substance's temperature increases (it warms up); and (2) If a substance is heated enough (to melting- or boiling-point temperatures), the thermal energy transferred actually causes changes in the arrangement of molecules with respect to each other (it changes state).

But scientists' definitions are even more complicated. They also define heat as a noun and make a clear distinction between heat and temperature. While it isn't reasonable to expect your elementary students to make these distinctions, you should know about them so that you don't slip into using the words *heat* and *temperature* in ways that might contribute to student misconceptions.

Scientists define *thermal energy* as "a measure of the *total amount* of kinetic energy of all molecules (and atoms) in a given volume of a substance." *Temperature* is a measure of the *average* kinetic energy of molecules in a substance. *Heat* is the energy that flows into or out of a system because of a temperature difference. The average molecule in a cup of warm water moves faster than the average molecule in a bathtub of cool water, but the bathtub water has more thermal energy because it has more molecules. So the cup of warm water has a higher temperature, but the bathtub of cool water has more thermal energy. Can you think of a similar example?

In everyday language, we often use the words *heat* and *temperature* as if they mean the same thing. We say things like "This heat is really getting to me. What's the temperature supposed to be today?" But now we see that heat and temperature have very different meanings. It's important for us as teachers to understand these terms not only for our own benefit but also to address students' comments or questions. For example, classroom investigations should focus on the idea that the molecules of a substance, such as water, move differently in different states of matter. Generally, we're satisfied if students understand four primary ideas related to heat and temperature:

1. If we heat liquid water, the temperature will increase until the water boils.
2. If we heat an ice cube, the solid water will melt to form liquid water. If we continue to add heat, the liquid water will evaporate to become water vapor—water in its gaseous state.
3. The higher the temperature of a substance, the faster the molecules move in that substance. So the molecules in liquid water move faster than the molecules of water in ice.
4. As heat is added to water, the molecules gain energy.

It is *not* necessary to address the following ideas:

1. Temperature is a measure of the average kinetic energy of the molecules of a substance.
2. Sometimes when water gains heat energy, the speed of the molecules of water increases, making them move faster and thus increasing their kinetic energy. The result is an increase in temperature.
3. Sometimes the heat energy increases the distance between the molecules of water, thus increasing their potential energy. The result is a change of state, but not an increase in temperature.
4. When water vapor is present in the air around us, these molecules of water are at the same temperature as the air. If a glass of liquid water is also at this same temperature, then the molecules of water in the air—water in its gaseous state—have the same average kinetic energy as the molecules in the glass of liquid water.
5. One of the reasons it takes a relatively large amount of heat energy to raise the temperature of water—especially liquid water—and to change its state is because water is a polar molecule.

If we put all these ideas together, we can imagine heating an ice cube. The molecules of water in that ice cube move faster as the temperature of the ice cube increases from –10 degrees Celsius to 0 degrees Celsius, and the ice cube begins to melt. We continue to add heat energy, but the temperature doesn't increase. All the heat energy actually goes into moving the molecules farther apart, but they don't move faster. The temperature remains constant during a change of state, in this case during melting. When the ice cube has melted, the water is in its liquid state. If we continue to heat the liquid water, the molecules move faster, and the temperature of the water increases. This happens until—you guessed it—the liquid water reaches its boiling point. At that time, as we continue to add heat energy, the energy goes into moving the molecules farther apart, but they don't move faster. The temperature remains constant during a change of state; in this case, during boiling. If we continue to heat the water in its gaseous state, the molecules of water vapor will move faster, and the temperature of water will increase. Remember how we said earlier that the molecules of water in its gaseous state have the ability to move fastest of all. Now you know a little more about why.

However, molecules of water in its gaseous state don't necessarily move fastest of all. The molecules of water vapor in the air around you right now are moving no faster or slower than the molecules of liquid water in the bottle that's been sitting on your desk since yesterday at the end of class. Since the water in its liquid state and water vapor in the air are both the same temperature, they have the same average kinetic energy and are basically moving at similar speeds.

Throughout this content background document, we refer to *thermal energy*. This phrase may be foreign and distracting for elementary students, so we advocate that you not use it with them. However, most elementary students are able to meaningfully connect to the ideas of heat and energy because these terms are in common use. For elementary students, it's suitable to use phrases like "gaining or adding heat energy" and "losing heat energy" when referring to the processes of heating and cooling (regardless of whether the result is a change in temperature or a change in state, according to the fourth primary idea stated earlier).

There is a specific way water molecules are attracted in liquid and solid states when they are in close proximity. A process occurs in which the oxygen atom of one water molecule is attracted to a hydrogen atom of another water molecule. The name of this process is *hydrogen bonding*. It is important to note that hydrogen bonding refers to the attractions *between* water molecules (see figure 5). The bonds between the hydrogen and oxygen atom *within* a water molecule are called *covalent bonds*.

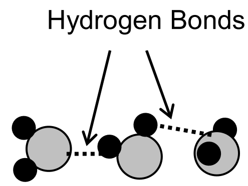


Figure 5. Hydrogen bonds between water molecules

We said earlier that water molecules are unique because of the crystalline pattern they make in the solid state. This has to do with the fact that water molecules are *polar*. This polarity also explains other unique properties of water, such as its tendency to bead up and its high melting and boiling points. What do we mean when we say that an H_2O molecule is a polar molecule? The oxygen atom is slightly negative with respect to the hydrogen atoms, which are slightly positive. So the negative charge of the oxygen atom of one H_2O molecule is attracted to the positive charge of a hydrogen atom from another H_2O molecule. Even though we often say that molecules in the liquid state are loosely attracted so they can slip and slide past one another, the effect of the hydrogen-bond attractions explains why water has a high boiling point and takes a relatively large amount of heat energy to boil. You may have even heard someone use the colloquialism “A watched pot never boils,” which refers to this phenomenon.

The hydrogen bonds of water molecules are relatively strong compared to attractions between molecules that loosely connect other liquids. Think about when you’ve spilled rubbing alcohol or nail-polish remover. These substances don’t bead up like water because they aren’t made of polar molecules

Although hydrogen bonding is an important concept that could help students simulate the different states of water more accurately, it is generally not introduced until high school. Therefore, it’s acceptable for students to show that water molecules are joined together without having to show the exact configuration (e.g., the attraction of an oxygen atom of one water molecule to a hydrogen atom of another water molecule).

The good news is that these ideas will be addressed in their entirety later in a student’s science education. Students will learn about bonding and the polar nature of the water molecule. They’ll also learn about thermal energy as a total amount of energy, temperature as a measure of the average kinetic energy of the molecules of a substance, and heat as a noun and as a verb. These aren’t learning goals for elementary students; however, understanding these ideas would be extremely helpful if questions or comments arise when students measure water temperature while a pot of water is being heated on a stove. They can easily see that the water boiled when heat is added, but the temperature of the water doesn’t increase.

1.2 Common Student Activities for Learning about Atoms, Molecules, and Matter

The water molecule is one of the smallest molecules, much too small, in fact, to be seen by the microscopes typically used in classrooms. At about 10^{-10} meters, it’s even too small to be seen by the high-powered microscopes scientists use. Therefore, all of our pictures of water molecules are just models to help us visualize something too small to see.

To help students visualize the water molecule, you can have them build their own models using consumable products like gumdrops or marshmallows. For example, you can use two different-colored gumdrops or two different-sized marshmallows to represent the hydrogen and oxygen atoms. Students can "bond" their atoms together using toothpicks or plastic coffee stirrers. Once students have built their individual water molecules, they can use their models to represent water in each of the different states by working together in small groups.

Another way to help students understand how water molecules are arranged in different states of matter is engaging them in a role-play. Three students can form one water molecule by linking their arms together. This "water molecule" can represent water vapor. Other students can join as water molecules to represent liquid water and solid water. Don't forget that molecules move! Make sure students demonstrate how water molecules move in each of the three states of matter. Taking this activity outside to the playground might alleviate some space issues.

Now that we've reviewed some background information about atoms, molecules, and matter, we can proceed with learning about evaporation. First, let's think about the following Stop and Think questions.

STOP AND THINK

What ideas do you have about how to answer these questions?

- Why does water evaporate in direct sunlight?
- Why can water still evaporate in the dark?
- Where does evaporated water go? Does all of it end up in a cloud?

All of these questions have something to do with evaporation. To answer them, we'll first need to gather more information about atoms, molecules, and matter.

1.3 Evaporation

We've learned that water molecules are always moving. As a solid, water molecules vibrate in fixed positions. However, if you heat a solid (remember, scientists call this "gaining thermal energy"), at some point the water molecules vibrate with enough energy that the hydrogen bonds holding the molecules in the lattice-like structure are disrupted. When this happens, the water molecules are still in close proximity and loosely connected but are slipping and sliding past one another. This type of arrangement and motion is characteristic of the liquid state. The process of going from a solid to a liquid state is called *melting* (see figure 6).

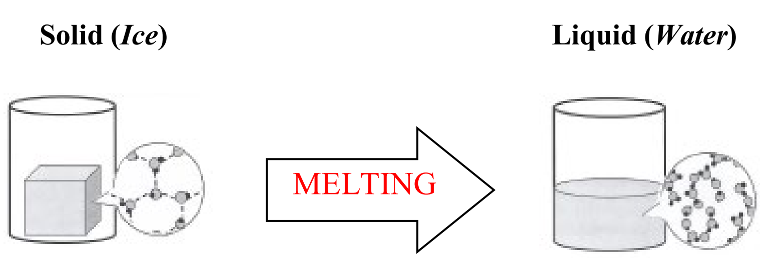


Figure 6. Melting

Another process that involves a change of state is *evaporation* (see figure 7). Evaporation occurs when a liquid changes to a gas. During evaporation, molecules gain enough thermal energy to escape from the liquid surface into the air as water vapor. Water-vapor molecules spread out, breaking completely free of each other, and then disperse or spread out among the other gas molecules in the air.

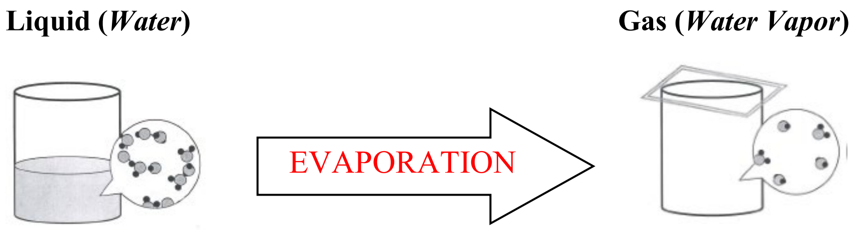


Figure 7. Evaporation

Remember that all molecules move. If we looked at a collection of molecules, some have more energy and move quickly, while others have less energy and move slowly. The temperature of a substance tells us about the *average* kinetic energy (or average motion) of all the molecules in the substance. In a sample of liquid water, the molecules are bumping into and sliding past one another. Sometimes when fast-moving molecules get near the surface, they are able to break through the loosely connected molecules and escape. When they escape the liquid surface, they become water vapor.

Think about the children's game Red Rover. A group of children stand in a line holding hands. Imagine that they represent the loosely connected water molecules at the liquid surface. When a slow runner tries to break through the line, he doesn't have the energy to do it, so he joins that line of children. This runner represents a less energetic, slow-moving molecule that ultimately joins other liquid molecules near the surface. When a fast runner tries to break through the line of children, she has enough energy to make it through the line and beyond. This runner represents a more-energetic, fast-moving molecule that escapes the surface, or evaporates, as a water-vapor molecule.

Heating liquid water makes evaporation happen faster. Heating the liquid increases the kinetic energy (motion) of all the liquid molecules, so there are more fast-moving molecules that can escape the surface. When the water is not being heated and isn't already warm, this process still takes place, but it happens more slowly because there are fewer fast-moving molecules in the water.

STOP AND THINK

What happens to the *average* kinetic energy of the molecules in a liquid if the fastest ones leave the liquid?

As the faster-moving molecules escape the liquid surface, the average kinetic energy of the liquid molecules decreases. Since temperature is a measure of the average kinetic energy of molecules, we observe a decrease in temperature in the liquid water. This process is called *evaporative cooling*. You have likely felt cool sensations when sweat evaporates from your skin, when rubbing alcohol evaporates from a wound, when hand sanitizer evaporates from your skin, and when you air-dry after a dip in the pool. This is evaporative cooling!

Water vapor is made of individual water molecules. Notice in figure 8 that the individual water molecule itself does not break apart during evaporation, meaning it does *not* break into separate hydrogen and oxygen atoms. This supports our understanding that evaporation is an example of a *physical change*. Liquid water changes to water vapor, but the molecules stay the same. A molecule of water is always H_2O whether it's in its solid, liquid, or gaseous state (see figure 4).

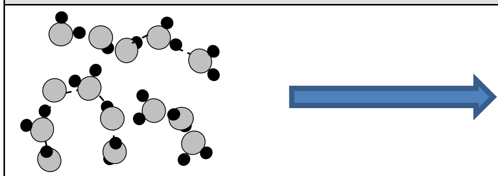
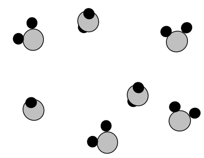
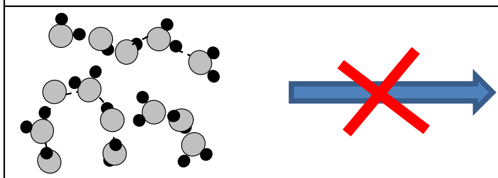
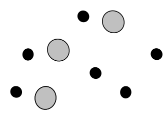
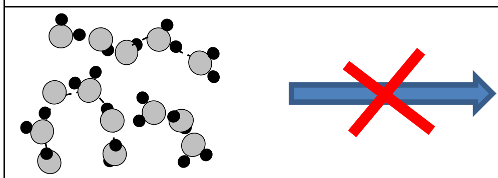
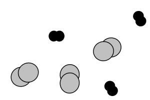
Different Ideas about Water Molecules during Evaporation		
Liquid (*Water*)	**Gas (*Water Vapor*)**	**Idea**
		Water remains as H_2O molecules.
		Water **does not** break apart into H and O atoms.
		Water **does not** break apart and form H_2 and O_2 molecules.

Figure 8. Different ideas about water molecules during evaporation

A common misconception is that water molecules break apart during evaporation so that the hydrogen atoms and oxygen atoms move separately around in the air. This is not correct. The attractions *between molecules* (called hydrogen bonds) are much weaker than the bonds or connections (called *covalent bonds*) holding oxygen and hydrogen atoms together *within a single water molecule*. It takes a great deal of energy to break apart a water molecule into hydrogen and oxygen atoms. Scientists are able to do this with a direct current, for example (i.e., through electrolysis). But it takes much less energy to simply separate water molecules from *other* water molecules, as in evaporation.

But what if you wanted to speed up this process? Let's say you wanted to demonstrate to your students that evaporation is taking place. Instead of waiting a couple of days to see the water level go down in a cup of liquid water in your classroom, what could you do? How could you make evaporation happen faster?

1.4 Making Evaporation Happen Faster

There are a few ways to make evaporation happen faster in the classroom. For example, you could put the cup of liquid water in direct sunlight. Water absorbs energy from the Sun (visible light, invisible UV light, and infrared energy), which increases its thermal energy. The liquid-water molecules near the surface move faster, eventually escaping from the surface as water-vapor molecules. Let's examine this more closely by thinking about a puddle of water on a sunny day.

The puddle of water absorbs light energy from the Sun and warms, which makes the water molecules move faster and evaporate into the air as water vapor (see figure 9). Younger students often think that the water disappears or is absorbed into the ground regardless of the material (e.g., grass, cement, asphalt). But you know this isn't the case! Although some of the water may get absorbed, most of it is changed to water vapor. It doesn't disappear; you just can't see it.

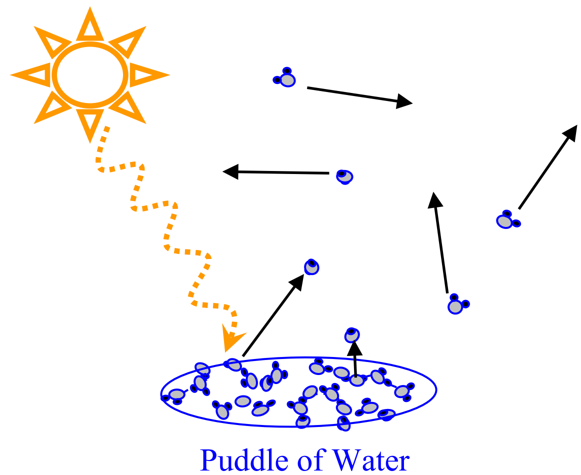


Figure 9. Sun shining on a puddle

Another way to make evaporation happen faster is by boiling liquid water. When liquid water is boiled, evaporation occurs faster at the surface. But boiling water also makes the water molecules move faster throughout the liquid, especially when they are near a hot surface (e.g., near the bottom surface of a pot or glassware that is in contact with a burner or hot plate). Bubbles begin to appear when the temperature of the water reaches 100 degrees Celsius. These bubbles are filled with water vapor that forms in the microscopic grooves and valleys of the container's heated surface. Because gas is less dense than liquid, the bubbles rise to the surface of the liquid. When the bubbles reach the surface of the liquid water, they pop and the water vapor escapes into the air.

Remember, you can't see water vapor. Some people mistakenly think that steam is water vapor (or gas) because it looks wispy or smoky. This is not the case. What most people call steam is actually condensed liquid water.[2] The liquid water in steam is in small droplets moving through the air. These droplets are what we see when we see steam. If you move a piece of paper through the steam, it will get wet. That means some water molecules are still joined together.

Every once in a while, a molecule of water vapor in the air will move to the surface of liquid water, join with other water molecules, and become liquid water. Remember, the process of changing from a gaseous state to a liquid state is called *condensation*. If you had a closed system, such as a closed bottle of water that you are neither heating nor cooling, the two processes—evaporation and condensation—would be happening at the same rate: Some liquid-water molecules would evaporate into the air, and some would condense.

What if the bottle were open? If that were the case, the water molecules that evaporate would rise into the air. Now the water in the bottle could completely evaporate over time (see figure 10).

[2] Scientists and engineers refer to steam as "condensed water vapor," which is water vapor condensed into liquid-water droplets.

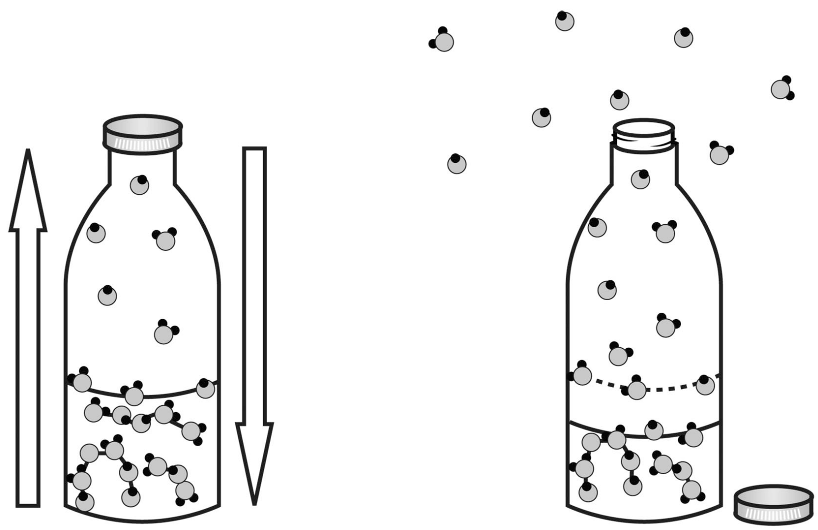
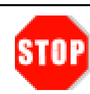


Figure 10. Evaporation in a closed system (left) and an open system (right)

On windy days, the air contains a lot of water-vapor molecules that are being moved around. The molecules are less likely to rejoin the liquid water on windy days, which means it's easier to dry things, such as laundry on a clothesline.

Of course, if it's a very humid day, with lots of water vapor in the air, then even the wind won't help evaporation much. The water vapor that the wind blows away is replaced by more water vapor that comes into contact with the surface of the clothes and becomes liquid water. This is why it can be hard to dry clothes on a warm summer day if it's humid; even though the Sun warms up the clothes and speeds up evaporation, the humid air keeps the clothes damp.

Let's summarize what we've learned so far: Evaporation can happen faster when water is heated or gains enough thermal energy to change states (such as putting water in direct sunlight or boiling it). Natural factors (e.g., wind and humidity) influence the rate of evaporation. Does this knowledge help us understand why there aren't lakes in the desert?



STOP AND THINK

Based on this reading, why do you think there are generally no lakes in the desert?

If there were lakes in the desert, would there automatically be clouds? A common belief when students learn about the water cycle is that water evaporates from lakes, for example, and travels straight into the clouds. From this perspective, the clouds are the destination point for the water vapor. Students tend to think that the water from lakes somehow "knows" to rise up to the clouds, or the clouds have some sort of invisible mechanism to pick up the water. Water-cycle drawings, such as the one in figure 11, may propagate this idea.

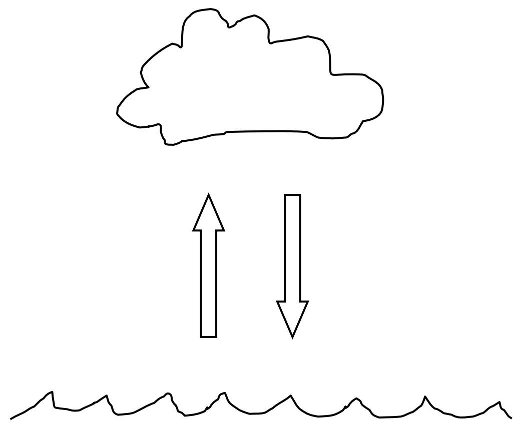


Figure 11. Common water-cycle diagram

In a drawing such as this one, the upward arrow denotes water evaporating from the lake and rising toward the cloud. Does all the evaporated water end up in a cloud? The answer is no. The evaporated water goes all over the place. Most of the water in the atmosphere is invisible water vapor—not clouds—and less than 1% of the mass of water in the air falls as precipitation!

As water vapor, *the water molecules move in random directions*. Because they move randomly, all over the place, not all of the evaporated water winds up in a cloud. In fact, some of the water molecules may even return to the lake and rejoin other molecules in the liquid state (see figure 12).

What's happening to water molecules when clouds are formed? Do the water molecules go inside the clouds? Do they make up the clouds? In what state of matter is the water in clouds? We'll learn more about cloud formation in the next section about condensation.

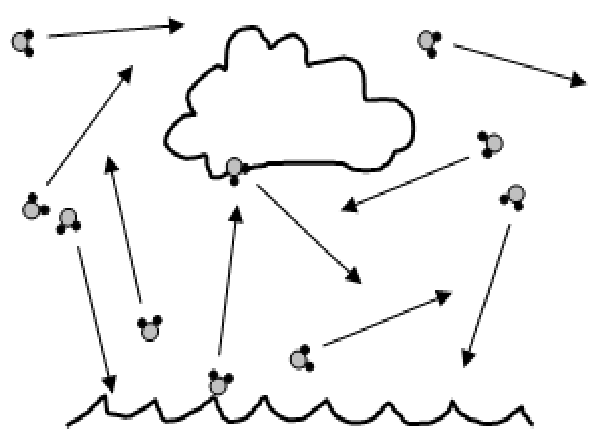


Figure 12. Appropriate diagram of evaporating water

STOP AND THINK

What new ideas do you have about the questions you considered at the beginning of this section?

- Why does water evaporate in direct sunlight?
- Why can water still evaporate in the dark?
- Where does evaporated water go? Does all of it end up in a cloud?

1.5 Condensation

Think back to what you learned in the previous section about the movement of water molecules and the addition of thermal energy. Now we're going to build on those ideas and apply them in answering the following Stop and Think questions, which all relate to condensation.

STOP AND THINK

Consider these questions:

- If you put a cold glass of lemonade on the table, why doesn't a cloud form right above the glass?
- How do clouds form?
- Why do you see dew on the grass on some mornings?
- How do you get rid of the "fog" on your car windshield?

We learned in the previous section about evaporation that adding thermal energy (by heating) causes water molecules to change from liquid to water vapor. This change of state takes place because heating causes water molecules to move faster so that more of them escape the surface and disperse into the air as water vapor.

What happens when you cool water or take thermal energy away? When you cool water, you remove thermal energy so that the molecules slow down. This is sometimes a difficult concept for students to understand. Students view cold or coldness as a *trait* of a material object (a thing) rather than as a *result* of heat transfer occurring between two objects of different temperatures. For example, a student may state that "a refrigerator has coldness" or "the condensation on the outside of the cup is due to the coldness coming out." However, *coldness* is everyday language used to describe the amount of heat an object has. When an object is cold, it simply means it doesn't have a lot of heat—or put another way, it doesn't have a lot of thermal energy.

Do We Measure Cold?
To scientists there is no such thing as "cold." There is simply more or less heat. When we describe something as cold, it's usually in comparison to some other physical thing (for example, when we say the pool or lake water is cold, we're comparing it to ourselves or the outside air). If we aren't comparing one object to another object of a different temperature, then we talk about cold in the same way we talk about heat. If you (or your students) talk about how cold something is, you're referring to how much heat is *not* in the object or material. If cold is a reflection of temperature and temperature is a measure of average kinetic energy of molecules, then cold objects have less-energetic, or slower-moving, molecules than warm objects.

Cooling liquid water to 0 degrees Celsius causes the water molecules to slow down so much, they can arrange themselves in a rigid, lattice-like structure. Once they lock into this structure, the molecules can no longer move past one another; they only vibrate in place. This process of changing from a liquid to a solid is known as *freezing* (see figure 13).

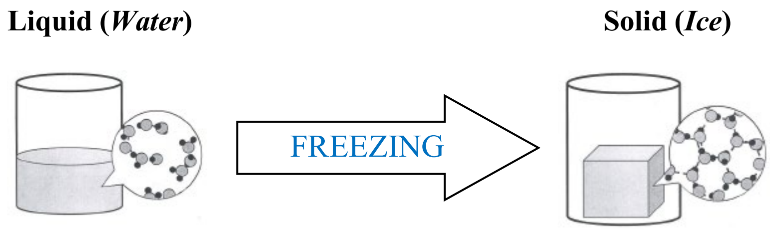
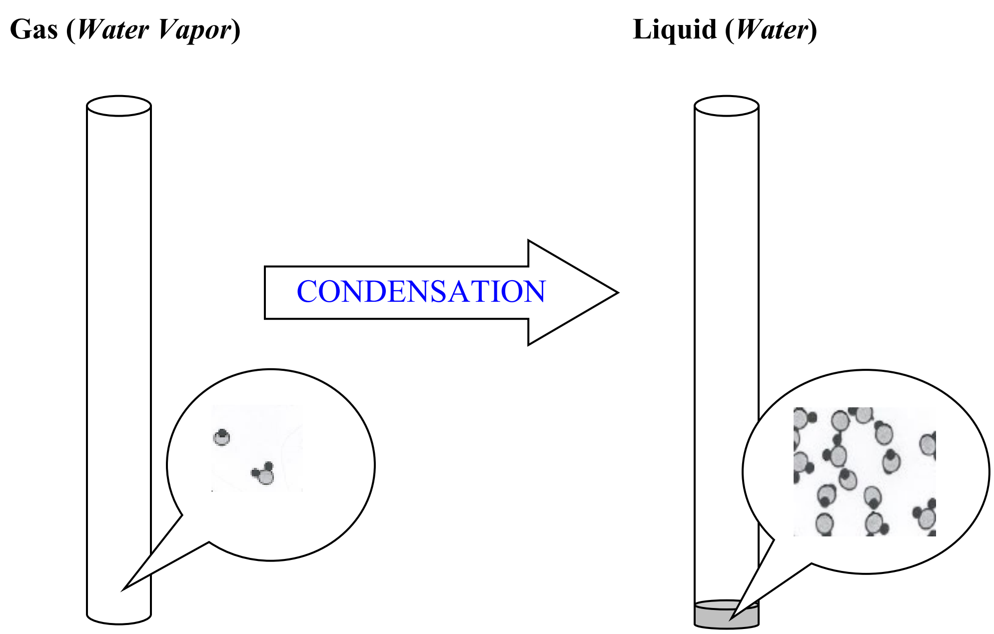


Figure 13. Freezing

Students probably have prior knowledge about freezing from making ice cubes or ice pops. What other common examples of freezing can you think of to help students make connections to everyday experiences?

Another process that involves a change of state with the loss of thermal energy is called *condensation* (see figure 14). Condensation is when gas changes to liquid. In the case of water, water vapor changes to liquid water. What's happening in condensation is very similar to what's happening in freezing. The molecules of water vapor slow down, move closer, and are loosely attracted through hydrogen bonds. They aren't locked in place (meaning, they didn't cool to 0 degrees Celsius), so in the liquid state, they can still slide past one another and change their positions.



(Not to scale)

Figure 14. Condensation

Liquid water is about 1,500 times denser than water vapor when both are the same temperature and volume. We couldn't easily represent in a diagram how much more space a given amount of liquid water (a liter, for example) would take up as a gas. But we do want to show that it would take up a lot more space. So paint a picture in your mind of a liter bottle of liquid water. (Imagine half a 2-liter soft-drink bottle). Now picture that liter of water spread out over 1,500 times the space—that's what it does when it evaporates.

We learned earlier that water molecules as water vapor move in random directions. The more energy they have, the faster they move. The opposite is also true. The less energy they have, the slower they move. As the water vapor cools, the molecules in the air slow down. When they slow down, they move closer and are loosely attracted through hydrogen bonds between the molecules, forming liquid water.

Some students, however, don't think that water-vapor molecules form the liquid water. Instead, they may mistakenly believe that hydrogen and oxygen atoms combine to form liquid water. This is a common misconception among students (see figure 15). But this is not correct, because water changing states is an example of a *physical change*; the individual water molecules remain intact.

Scientists often refer to the liquid water that forms during the process of condensation as *condensation*. That is, they use the same word in reference to the *process* and the *liquid* that forms during the process. Listen carefully to how your students use the word *condensation*. Ask questions that probe their thinking to better understand whether they're referring to the process or the liquid that forms. It's worth noting that the same is not true with evaporation. Evaporation is the *process*, and *vapor* results from the process.

Different Ideas about Water Molecules during Condensation

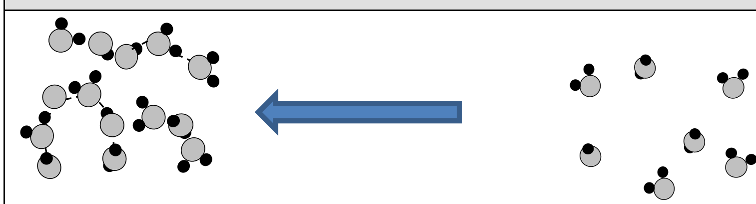
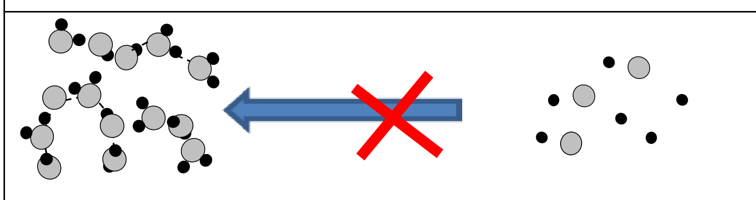
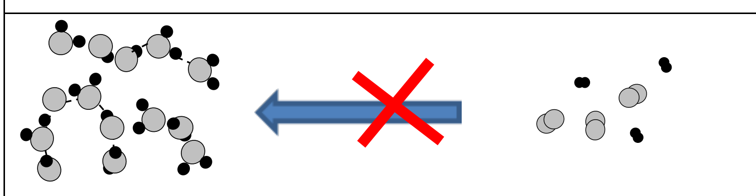
Liquid (*Water*)	**Gas (*Water Vapor*)**	**Idea**
		Individual H_2O molecules connect loosely to form liquid water.
		H and O atoms **do not** combine to form water.
		H_2 and O_2 molecules **do not** combine to form water.

Figure 15. Different ideas about water molecules during condensation

1.6 Everyday Examples of Condensation

Did you know that clouds and dew form in much the same way? Clouds form in the sky through the process of condensation. The ocean and land absorb most solar radiation, which increases their thermal energy. As the oceans and ground warm, they warm the air next to them, and this air warms the air a little higher up, and so on. In other words, our atmosphere is warmed from the ground up through a process called *conduction*. But higher up in the atmosphere, the air gets colder because there is less thermal energy to transfer.

Warm air also rises because it is less dense than cooler air. As warm air rises, it cools, which slows the water-vapor molecules in the air. Slowing the water-vapor molecules causes them to condense into liquid water (or sometimes, in very cold conditions, ice). This happens most often if there are particles in the sky called *condensation nuclei*, which may appear in the form of dust, ash, smoke, or salt. The water molecules condense onto these particles. As more and more water molecules combine around more and more of the condensation nuclei, a cloud is formed.

You might be wondering, *Why can we make what looks a little like a cloud in the classroom? Why do we see what we sometimes call a cloud of steam above a pot of boiling water?* Condensation nuclei aren't necessary for condensation to occur. However, when condensation nuclei are not present, condensed liquid water (steam) is very short lived. Just as in clouds, condensation and evaporation occur simultaneously to form and dissipate steam. The droplets of condensed liquid water in steam are extremely small, and evaporation occurs extremely fast. So steam is present only for a moment or two until the condensed water droplets have completely evaporated and dispersed in the air as invisible water vapor. If you hold an object in the steam, condensed liquid water forms (and lingers) on the object because the object acts as a condensation nuclei.

The visible parts of clouds are liquid water. Students often think that visible clouds are made of water vapor. When asked why, they often respond with such reasons as "They float," "Because you can put your hand through them (like steam)," and "They're puffy and wispy." These observations make sense to students and influence their thinking, but only because they are unaware of the properties of water.

Imagine a teakettle of boiling water (see figure 16). In some instances, there is no steam right at the tip of the spout. The steam appears slightly above the spout. Why does that happen?

Figure 16. Photos of steam above teakettle spout

Think about the changing states that are occurring. The liquid water in the teakettle is boiling, and some of the liquid water is evaporating as water vapor. Some of the water vapor escapes the teakettle through the spout and, for a short time, stays in the gaseous state. We can't see water vapor, so we see an empty space just above the spout. But the temperature of the air outside the teakettle isn't as high as the temperature of the water vapor coming from the spout. As the temperature of the water vapor decreases, the molecules slow. As they slow, some of them condense to form tiny droplets of liquid water that we can see. We call this "cloud" of tiny liquid-water droplets *steam*.

Ideally you'll be able to show this to your students. Ask them to draw a picture of what's happening as the water boils. Drawing can help a scientist look more closely at something. Your students are likely to notice things from their drawings that they wouldn't pick up on by simply looking at the teakettle. Having students pay close attention to what is happening to water molecules and heat energy helps them better understand the process of condensation.

Let's revisit the simple water-cycle diagram we examined earlier (see figure 17). Knowing what you know now about condensation, what do you find problematic about this diagram?

After careful examination, you may have noticed that the diagram gives no clear indication of the condensation process. You might argue that the upward arrow indicates evaporation, and the downward arrow represents precipitation, but where's condensation happening? Condensation is happening in and around the clouds. We now know that the water-vapor molecules are moving fast and randomly, but the molecules that rise higher in the sky (where the temperature is cooler) will slow down and condense around some particles to form a cloud. But evaporation is happening in and around clouds too. In fact, clouds are a mix of liquid water we can see and water vapor we can't see. The processes of condensation and evaporation occur simultaneously in clouds, which is one reason clouds are so dynamic (e.g., moving, changing shape and size, here one minute and gone the next).

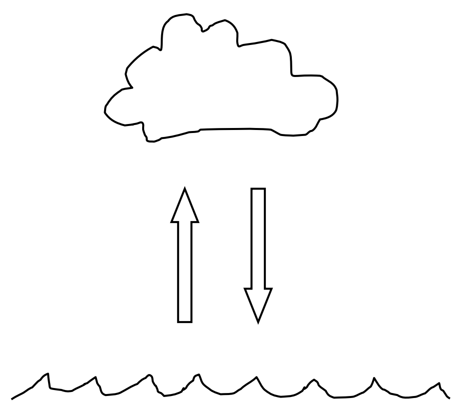


Figure 17. Simple water-cycle diagram

STOP AND THINK

How could you change the water-cycle diagram to show that condensation occurs to form clouds?

Fog is another natural example of condensation. Think about all the times you've been in or seen fog. Have you ever driven from the top of a hill into a foggy valley or river bottom? Fog is often viewed as a cloud close to the ground. It's actually more like an upside-down cloud. Instead of warm air being cooled as it rises into cooler air, the warm air is cooled from below, from the ground, because the temperature of the ground is lower than the temperature of the air above it. One way fog forms is when warm, moist air flows over a cold surface. The water vapor in the warm air cools near the ground and condenses to form fog.

Let's think about other scenarios where you can apply your developing understanding of condensation, water molecules, and thermal energy. Have you ever noticed condensation on the outside of your car's windshield? This usually happens when you leave your car parked outside in the late evening or early morning. Why do you think condensation forms?

Have you ever seen condensation on the *inside* of your car windshield? What do you do? Most of you probably set the ventilation system to defrost/defog, but how does this work? It's actually a little more complicated than you might think. The defrost/defog function actually uses the air-conditioning system to cool and remove moisture from the air. This drier air can then be forced onto the windshield. In the wintertime, the drier air may be warmed before being forced onto the windshield.

Have you ever walked through the grass early in the morning and found your shoes wet, even though it didn't rain? Where did the water come from? Under the right conditions, moisture from the air condenses on the surface of the grass, and we call this *dew*. You might be surprised to know that dew is most likely to form on triple-C nights: cool, calm, and *clear*. If the topic of this document were heating and cooling, we'd spend more time figuring out why clear nights are more likely to have dew than cloudy nights. But the short story is that clear skies allow more heat to escape from Earth's surface than cloudy skies do. The temperature simply falls more rapidly, and rapid cooling can lead to dew formation.

1.7 Common Student Activities for Learning about Evaporation and Condensation

There are many activities you can use to teach your students about evaporation and condensation. As previously described, you can have students use gumdrop- or marshmallow-molecule models or role-play being water molecules themselves to simulate what happens when water gains or loses thermal energy (or, as we suggest, heat energy). For example, you can first have them act like liquid-water molecules, making sure they're all moving together and able to change positions (sliding past one another but still close together). Then tell them you're heating them, and they're gaining thermal energy. Students should know to move faster. Next, tell them you've heated them so much that they are beginning to evaporate. Students should move from loosely connected liquid-water molecules to individual water-vapor molecules moving in all directions. Each time you give them more information, ask students what is happening. You can do a similar role-play activity to demonstrate condensation.

It's worth discussing with your students that unlike water molecules moving from a liquid to a gaseous state, they can't float through space. Moving around the room or playground, they'll make a two-dimensional model of a three-dimensional process. This model would be more realistic if the evaporating molecules floated above the ones still in the liquid. How else does a model made of kids differ from the real phenomenon? Make sure to call on a few students to share their explanations. This will help make their thinking visible.

1.8 More Evaporation Activities

Before introducing ideas about evaporation and water molecules, you might engage students in thinking about evaporation phenomena with activities like the following:

a. Have your students fill a clear plastic cup with water and mark the water level with a permanent marker. Ask them to predict what will happen to the water level if the cup sits for a couple days. Make sure they include their reasons. Then set the cup in a protected spot in the classroom. After a couple of days, students will see that the water level went down. This should spark a good discussion about where the water went, possibly leading to other investigations about evaporation (e.g., placing the cup of water in the shade or covering the cup with cellophane wrap). You can ask questions to probe student ideas about thermal energy and what is happening to water molecules.

b. Use artwork to engage students in learning about evaporation phenomena. Have them paint with watercolors mixed with kosher salt. When the water evaporates, what remains is paint with beautiful salt-crystal patterns. This activity can serve as an introduction to evaporation, getting students to think about what happened to the water.

After students have been introduced to the ideas related to evaporation and water molecules, you might challenge them to use these ideas in one or more of the following activities:

a. Have students simulate weather conditions that would influence the rate of evaporation. For example, you could have students work at three different stations and test how long it takes for water to evaporate using these items:

    1. A lamp to represent the Sun
    2. A fan to represent the wind
    3. A hair dryer to represent the Sun and wind

    Students can record the time and conduct multiple trials. The class can then pool their data to calculate averages, make interpretations about their data, and use the ideas about evaporation and water molecules to explain their results.
b. Use student understandings to explain various situations, such as the following:

    1. Why they feel cold when they get out of a swimming pool and hit the air
    2. Comparing the effectiveness of drying clothes in a dryer as opposed to a clothesline
    3. Why a puddle dries faster if it's spread out
    4. How air-drying their wet hair works

c. Have a towel-drying contest in which students develop and write down the strategy they will use to dry a saturated towel the fastest (without wringing). They must include the reasoning for their strategies, using ideas about evaporation and water molecules. You might have them weigh the towels at the beginning and end of the contest to see which towels lost the most water.

1.9 More Condensation Activities

Before introducing ideas about condensation and water molecules, you might engage students in thinking about a condensation phenomenon with an activity like the following:

a. Have students observe droplets of water form on the outside of a cold beverage container. This can be a very productive activity if you're aware of common student misconceptions and how to address them. When students observe condensation on the outside of a cold beverage container, they often think the liquid came from the inside and "somehow" went through the walls of the container, regardless of the material (e.g., plastic, glass, aluminum). Sometimes, students will compare this phenomenon to people sweating; condensation on cans is often called *sweating* in everyday conversation. The line of reasoning goes something like this:

    → Sweat is moisture that comes from inside the body.
    → There is moisture on a cold beverage container.
    → Therefore, the moisture must have come from inside the container.

    Humans sweating and condensation forming on a cold beverage are both more noticeable on hot, humid days, reinforcing this misconception.

    Being aware of this common misconception can help you—the teacher—better plan your activities. For example, you can present students with ice water in clear plastic cups. Then ask students, "Where did the water on the outside of the cup come from?" When students claim that the moisture came from inside the cup, you can challenge their ideas by putting food coloring in the ice water (see figure 18). If the water really leaked through the cup wall from the inside, like sweat in humans, then the moisture on the outside of the cup should be colored when the cup is wiped with a paper towel or napkin. Students will have evidence that this is not the case. Something else must be going on.

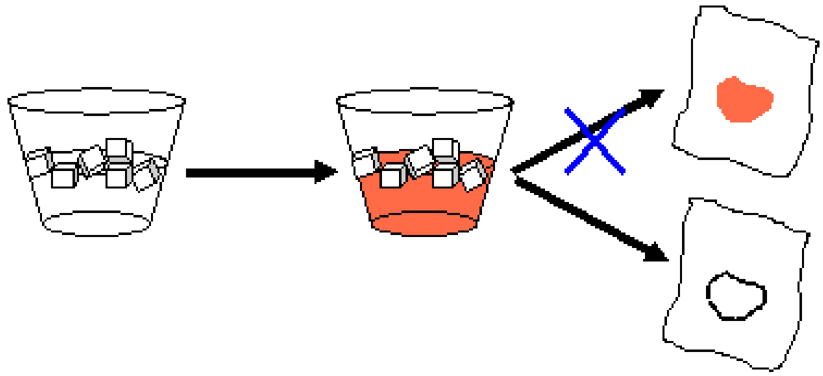


Figure 18. Ice water in a plastic cup, with and without food coloring

Perhaps other students think that the moisture came from inside the cup, but not through the container wall. Some students believe that the liquid "escapes" from the top of the cup and falls down the side as moisture. Again, knowing that students may think this way, you can have them observe cold soda cans that are unopened. Students will soon see that moisture still forms on the outside of the can even though there is no opening at the top for the liquid to escape. Again, something else must be going on.

After students have been introduced to the ideas related to condensation and water molecules, challenge them to use these ideas in the following activity:

b. Make a cloud in a jar. This activity requires a clear glass container (such as a fishbowl), warm water, matches, and an aluminum pie pan with ice (see figure 19). You will create a cloud by placing warm water in a clear container, putting ice cubes in a pie pan to cover the top of the container, and blowing out a lighted match inside the container. Why do we need the smoke from the match? Remember that for clouds to form, condensation nuclei must be present to provide something for the liquid-water molecules to adhere to. In this case, the condensation nucleus is the smoke from the blown-out match.

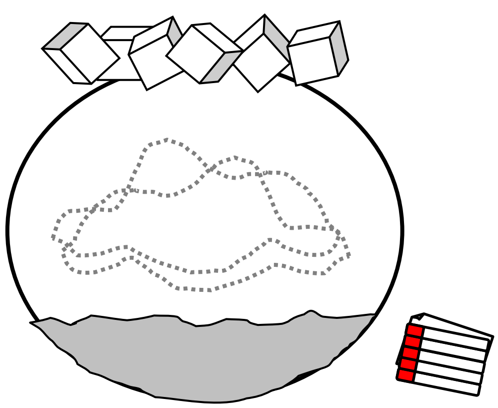


Figure 19. Setup for making a cloud

A tricky part of this activity is that students often hold the misconception that a cloud is smoke, so they may think the smoke from the match *is* the cloud, thus reinforcing the misconception. To challenge this idea, start the activity by placing a blown-out match in an empty container. Cover the container with an empty pie tin. Then have students make observations. They should see that the smoke eventually dissipates, and they won't be able to see anything. By starting the activity with an example of what smoke looks like in an empty container, students are more likely to accept that the later setup is actually a cloud and distinguish it from smoke.

Next, tell students that you'll put warm water in the container and cover the opening with ice cubes in an aluminum pie tin. You will then add smoke from a match to the container. Challenge students to think about what they've learned about evaporation, condensation, and water molecules to predict what they think will happen. You can do this through a Think-Pair-Share session, for example. Hopefully, students will consider that the water molecules in the warm water are moving faster because they have more thermal energy, and that some molecules escape and evaporate as water vapor. They should also predict that the water-vapor molecules at the top of the container will lose heat energy because of the ice and condense to form liquid droplets of water. They will probably be confused about the purpose of the match. Wait until after they've observed the cloud to clarify the purpose of the smoke.

Finally, fill the container with warm water. Drop another blown-out match into the container. Cover the container with a pie tin filled with ice. Have students make observations. They should see a cloud! You'll need to help them distinguish between this cloud and the smoke they saw earlier. Make sure they understand the point of adding the smoke: Emphasize that the cloud they are seeing is made of tiny droplets of liquid water that are forming on pieces of dust or smoke. Without the smoke, they would only observe condensation on the inside surface of the container or the bottom of the pie pan. In order to create a cloud in the air in the container, there needs to be something in the air for the water vapor to condense onto, and the smoke particles serve this purpose.

These are just a few of the activities you can use to help students learn about evaporation and condensation. In the next section, we'll learn more about water molecules and thermal energy as they are connected to weather. You've already learned some aspects of this—for example, about the Sun in providing thermal energy, and condensation forming clouds. In addition to learning more about how to teach these ideas, you'll continue to develop and refine your knowledge about evaporation and condensation while applying it to the water cycle.

Part 2. The Water Cycle

Thus far we've learned about water molecules and, more specifically, what happens to water molecules during evaporation and condensation. In this section, you'll continue to deepen your understanding about these two processes while making connections to what happens in nature. In nature, water is recycled in the water cycle (also called the *hydrologic cycle*). Figure 20 illustrates the water cycle and how water molecules are arranged in different states as a result of either the gain or loss of thermal energy.

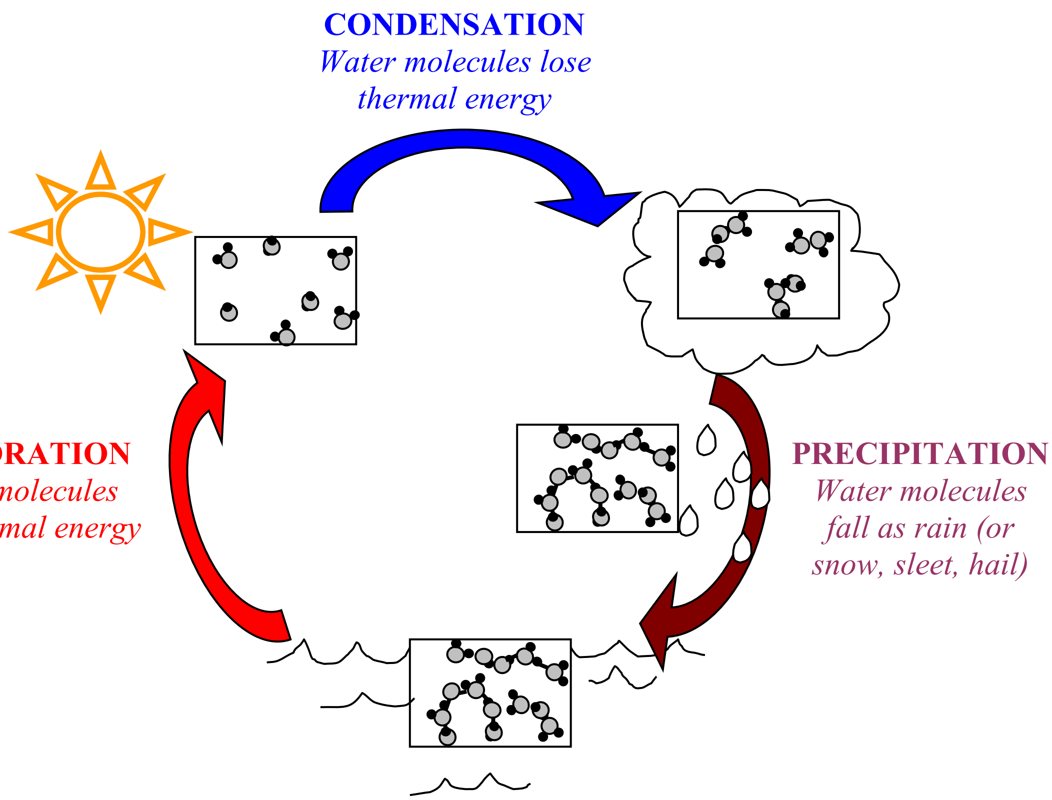


Figure 20. The water cycle

Why is this concept so important? The water cycle is an essential example of one of the biggest crosscutting ideas in all of science: *The flow of energy drives the cycling of matter.* There are many different foci you can take and many more opportunities for making connections to previous and later teachings. In this regard, the water cycle serves as an excellent context for learning different science topics, such as water, states of matter, evaporation, condensation, precipitation, humidity, dew point, conservation, recycling, and more. The multitude and variety of topics offer exciting possibilities for teaching about the water cycle. However, stop and think what students are actually learning. Students often learn *what* happens (e.g., "Water changes states from liquid to gas in a process called *evaporation*," or "The water cycle is evaporation, condensation, and precipitation"). However, they are seldom afforded opportunities to go beyond the descriptive to a more conceptual understanding of *why* it happens (i.e., why evaporation happens at the molecular level, the role of energy in the water cycle, or how the water cycle can be explained from a mechanistic point of view). Later in their educational careers, students should be provided opportunities for making connections to other kinds of matter cycles, such as the nitrogen cycle and the carbon cycle. Understanding the nature of these cycles is essential to understanding science more broadly.

In this section, you'll apply your knowledge about evaporation and condensation to the water cycle. You will also connect other ideas about precipitation, states of matter, water molecules, and thermal energy to build a fuller, more conceptual understanding.

2.1 Putting It All Together: The Water Cycle

Let's consider the following questions to get us started thinking more deeply about the water cycle:

- Does the water cycle still happen on cloudy days?

- What happened to the water that dinosaurs drank?
- Why can you feel wet outside when it's not raining?

Asking the question "What happened to the water that dinosaurs drank?" is a way some teachers engage students with ideas about the water cycle. A simplified answer to this question is that we could be drinking the same water as dinosaurs once did, because water is constantly being recycled in the water cycle. Water evaporates from the ocean, condenses into clouds, and precipitates back onto Earth, where it gets used again and again. What does this really mean? Why does it matter? Let's find out.

Water covers about 71% of Earth's surface. To make this idea more prominent, you can toss around an inflatable globe. Each time a student catches the globe, she or he should count the number of fingers that touch "blue" (or water). Tally up the number of blue touches versus the total number of touches. In the end, the numbers should roughly come out to 71% (statistically speaking, the more trials you collect, the closer you'll get). Finding out about water through this activity engages students, integrates mathematics, and helps students begin to quantify the amount of liquid water present on Earth.

2.2 Evaporation from the Ocean

Earlier in this reading, we thought about how we experience evaporation on a daily basis—clothes drying, the evaporation of sweat from our bodies, and water boiling. Think back to what you learned about evaporation: Evaporation is the process in which liquid water changes to water vapor. Heating liquid water makes evaporation occur faster. In this section, we'll think about evaporation on a larger scale as we consider the evaporation of water from the oceans (and other bodies of water). How does this happen?

Most of the energy for evaporation everywhere on Earth ultimately comes from the Sun. Bodies of water continually absorb solar radiation (even on cloudy days), which increases the thermal energy of water. So why don't oceans and lakes get warm enough to completely evaporate or boil? The answer is complex, having to do with currents and convection in and above oceans. But it's important to know that most solar radiation can penetrate and warm only the surface of the water. Other cooling mechanisms—evaporation and transfer of thermal energy from warmer water to cooler air, land, and water—continually decrease the thermal energy of water at the surface. But overall, the Sun maintains some balance of thermal-energy transfer to and from bodies of water.

Thermal energy can be stored. We know this is the case for water because scientists observe only slight changes in surface water temperature from day to night or from sunny days to cloudy days. In fact, ocean temperatures have a relatively narrow temperature range from season to season compared with other places of comparable latitudes. So like soup that stays warm and keeps evaporating for some time after being removed from the stove, bodies of water on Earth do the same.

Remember, molecules of water have different energies and motion—more-energetic molecules move faster and less-energetic molecules move slower. Evaporation occurs when higher-energy, faster-moving molecules near the surface of liquid water eventually escape from the surface into the surrounding air as water vapor. Maintaining the thermal energy of the water (through the continual absorption of solar radiation) is important in that it continually provides high-energy, fast-moving liquid molecules that can escape the surface. But as we learned earlier, evaporation is only part of the story. Condensation is another important part.

2.3 Condensation and Cloud Formation

Water vapor is everywhere in the air. Individual water molecules, as water vapor, are moving in random directions. As they move higher in the sky where the temperature is cooler, they lose thermal energy and slow down. Eventually, some molecules will slow down and condense with one another to form liquid droplets. If there are dust particles in the sky, they can attach to those particles and form a cloud.

Sometimes, if the temperature is cold enough, the cloud will be made of ice crystals. We already learned about the formation of clouds, so hopefully this will be a quick review.

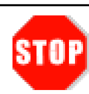
What happens to clouds? As they grow bigger (which means that condensation is happening faster than evaporation), bigger drops of water form that eventually fall from the clouds because of gravity. These drops of water can be in the form of rain. Many students think that a cloud picks up water from the ocean and drops it elsewhere in the form of rain, similar to a construction crane lifting objects from one place, swinging around, and dropping them in another place.

But we know better! The cloud doesn't pick up the water. The cloud doesn't *already* exist. Remember, water evaporates and then condenses to *form* clouds. It's a two-step process: (1) evaporation and then (2) condensation. Students often forget about condensation, even after formally learning about it. Or they're unclear about condensation being a separate process from evaporation. For example, if you ask a student who has learned about evaporation and condensation the question "How does a cloud form?" the student will typically respond with something like "The water evaporates from the ocean and goes into the sky where it becomes a cloud." In this example, it is unclear how the water becomes a cloud. If you were this child's teacher, what could you do to determine whether this student understands condensation?

Some students believe that if clouds already exist, then they're always in the sky. You just can't see them on certain days because of the way Earth rotates. What do you think about this idea? Is this true? What happens to the clouds? Where do they go?

Although the wind may carry clouds to other locations, they don't travel intact across Earth. A cloud you see in Corvallis, Oregon, is probably not the same cloud you might see in Beijing, China, if you went on vacation there the next day. As we saw with the cloud-in-the-bottle activity in the condensation section, clouds in the atmosphere are dynamic. They appear and disappear and change size and shape as water condenses and evaporates. When you see a cloud grow in the sky, you know that the rate of condensation is faster than the rate of evaporation. Put another way, the cloud is being built faster than it is being taken apart.

You probably knew before beginning this reading that at least a few different factors influence the rates of evaporation and condensation. You may well have known that a hotter clothes dryer dries clothes faster than a cool one. You probably also knew that things dry more quickly on sunny days than on cloudy ones. You could state those things but perhaps couldn't *explain* them or relate them to other observations you have made. How can you take the previous knowledge you had about evaporation and condensation in certain specific instances (like the drying of clothes, for example) and connect it to the conditions necessary for clouds to appear or disappear?



STOP AND THINK

What conditions are needed for clouds to form? When a cloud disappears, what happens to whatever it was that the cloud was made of?

So how did you answer the Stop and Think questions? Can you connect cloud formation to moisture forming on a cold can? For a cloud (or moisture on a cold can) to form, you need

1. plenty of water vapor in the air,
2. condensation nuclei—something in the air for the water to condense upon, and
3. cooling of the air to facilitate the condensation of the water vapor on the condensation nuclei.

If any of those three elements is missing, clouds will not form. You might consider these the essential ingredients for clouds. In what ways do the activities of humans alter the conditions for cloud formation? In what ways do we alter the water cycle? Let's consider the examples in table 2.

Table 2. Things that affect cloud formation and the water cycle

Cloud Ingredient	How Humans Alter the Recipe	A Guess or a Question about Why It Makes a Difference
Water in the atmosphere	Local or regional irrigation of crops and the watering of lawns and golf courses spray water into the air, making more water available for evaporation.	Does this make cloud formation more likely in areas that have been arid? Can we look at data from the National Weather Service and see any changes as irrigation practices have changed?
Condensation nuclei	Jet exhaust adds particles to the atmosphere.	Contrails, the clouds we often see behind jets, are clouds. Will these new clouds make Earth warmer or cooler?
Cooling air to the dew point	Pavement contributes to the formation of "heat islands" in cities.	Patterns of precipitation may change in ways that both help and hurt agricultural production.

Each of these examples affects the water cycle in more than one way. Pavement, for example, not only changes the way a particular place warms up and cools down, but it also changes the way water runs off when it precipitates.

Think back to the big idea mentioned above: *The flow of energy drives the cycling of matter.* How does understanding cloud formation help us understand that idea?

Consider this idea as part of the answer: As energy flows or transfers into and out of matter, changes occur. The changes depend on the direction of these energy transfers. As energy transfers into liquid water, it promotes evaporation. As energy transfers out of water vapor, it promotes condensation. In a cloud, energy transfers out of water vapor as it cools and condenses into liquid water to form a cloud.

2.4 Precipitation as an Atmospheric Phenomenon

Precipitation, like condensation, can refer to either a process or a thing. The process of precipitation is the falling of water (in either solid or liquid form) from clouds (see figure 21). *Precipitation* is also the name we give falling water, whether it is rain, sleet, hail, or snow.

Precipitation—as rain—mostly originates from clouds as ice. As ice begins to fall from clouds, it melts and turns into rain. Rain is the liquid form of precipitation. Some of this rain reaches Earth. However, much of the rain never does because the speed at which the raindrops fall isn't great enough to overcome the updrafts (upward-moving wind) that support the cloud. Remember, we learned in the evaporation section that wind is an important factor that influences the rate of evaporation. Therefore, having a lot of upward-moving wind causes the downward-falling precipitation to evaporate faster. The drops evaporate before they hit the ground.

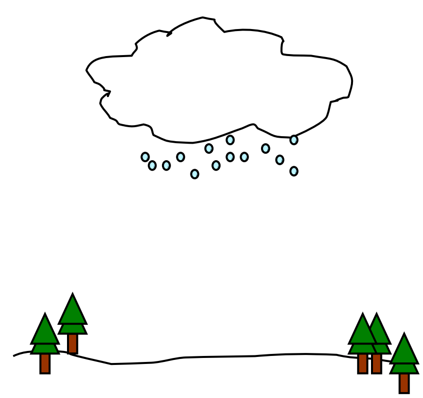


Figure 21. Precipitation

In some cases (for example, in clouds over tropical regions or low, "warm" clouds), rain starts as liquid from the clouds and ends as liquid when it reaches the ground. However, other forms of precipitation undergo changes in state. Sleet, for example, goes through many transitions. Sleet starts as falling snow that partially melts but then refreezes and turns into ice pellets. Similarly, hail forms when water droplets continuously collide and cool during thunderstorms, resulting in balls or lumps of ice (also known as hailstones). When the hail gets too heavy for the updrafts, it falls to the ground. Snow forms when water vapor changes directly into ice. This process of going from the gaseous state to the solid state is called *deposition*. Not all gaseous substances need to turn into a liquid before becoming a solid. The opposite is also true. Not all solids need to turn into a liquid before becoming a gas. Dry ice, or solid carbon dioxide, is a very common example of this phenomenon that teachers like to use in the classrooms. If you take a block of dry ice and put it on a table (in room temperature), you'll see carbon-dioxide gas coming from the solid. This is because the solid is changing directly into a gas, a process called *sublimation* (see table 3).

Table 3. Deposition and sublimation

Process	Change of State	Example
Deposition	Gas → Solid	Snow
Sublimation	Solid → Gas	Dry ice

Thermal energy affects both deposition and sublimation. Which process do you think occurs when thermal energy is gained? What about when thermal energy is lost?

Of course, you would expect to see the solid forms of precipitation occur in places with colder temperatures (e.g., mountains, New England, the Arctic). Mountains are often included in water-cycle diagrams. These diagrams show precipitation (as either liquid or solid) falling onto mountains, forming in rivers and streams that run down the mountains, and flowing into a lake or ocean. The water cycle continues in this way. Other times, however, the water-cycle diagrams exclude mountains and simply show water going up and coming down. Such is the case in the diagram we examined earlier on evaporation and condensation. Let's revisit this diagram now (see figure 22).

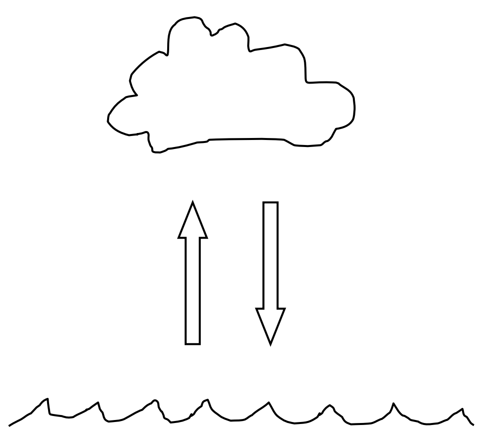


Figure 22. Simple water-cycle diagram

As we discussed, this diagram is problematic. The upward arrow is misleading because it appears that water evaporating from the ocean rises straight into the clouds. This is not the case. Instead, the water that evaporates goes all over the place. The individual water molecules move fast and randomly. We also recognized that the process of condensation is missing from this diagram, or at the very least is unclear.

The presence of the cloud makes it seem as though the water vapor goes into the cloud rather than *forming* the cloud. Now take a look at the diagram again and pay attention to the downward arrow that is supposed to represent precipitation. Do you recognize any problems here?

There are two points to make about this diagram. First, it accurately represents precipitation falling from the clouds; however, it presents a simplified view of what actually happens. Not all precipitation falls directly into the ocean. Precipitation can fall onto mountains, rivers, trees, the ground, and even your head! The second point is that the diagram doesn't include the Sun. The Sun is the main source of energy and the driving force behind the water cycle. Without solar energy and the resulting changes in the thermal energy of Earth's surface and atmosphere, the water cycle would not happen.

2.5 Water Is Recycled

An important point to emphasize about the water cycle is that it has no beginning or end; the water cycle is continuous. That means water is always evaporating, always condensing, and always precipitating. It is neither created nor destroyed. Since Earth is a closed system for water, water molecules can never escape the system. Water on Earth is always conserved, which means that water molecules can change states, but they can never disappear or lose mass. So the water that existed when Earth was first formed is the same water that exists today. That means we *do* drink the same water dinosaurs once did!

When thinking about the water cycle in molecular terms, we have to remember that they don't change into other substances as they move from place to place and change from state to state. The H_2O molecules remain as H_2O molecules. Depending on the amount of thermal energy they gain or lose, water molecules move at different speeds as a result of how they're clustered or arranged together. Therefore, the *same* water molecule moves around Earth almost forever, sometimes as a solid, sometimes as a liquid, and sometimes as water vapor.

Let's take a more careful look at the same diagram we used to introduce part 2 (figure 23).

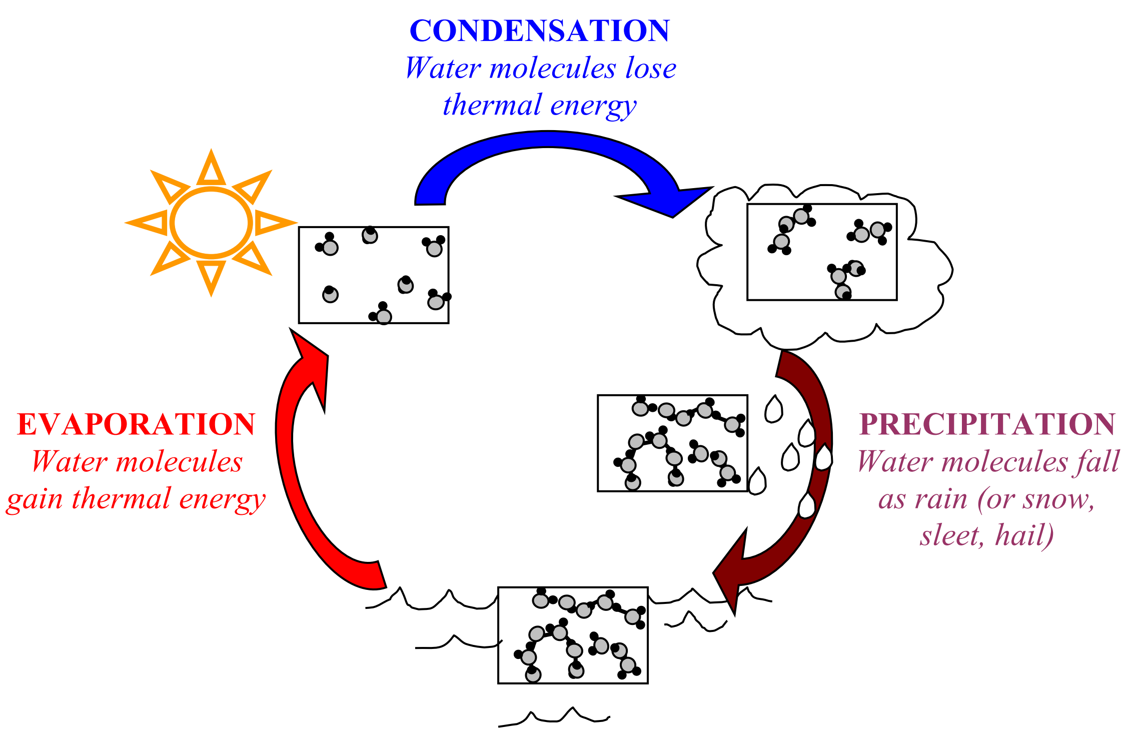


Figure 23. The water cycle

In summary, the water cycle is a process by which water moves about Earth's surface and atmosphere. The Sun is the power source that drives the water cycle; it ultimately provides water molecules with thermal energy. When water molecules are in the liquid state (e.g., an ocean), they move faster because they are heated by the Sun. Some of the water molecules will escape from the liquid surface into the air as water vapor. This is called *evaporation*. As the water molecules rise, however, they begin to lose thermal energy and slow down because the temperature of the atmosphere is cooler. When the water molecules cool, they slow down and connect loosely, forming liquid water. This is called *condensation*. If a *nucleating agent* (i.e., condensation nuclei such as dust particles) is available, the water molecules attach to these particles, and a cloud develops. This cloud will change size and shape depending on the rates of evaporation and condensation. If evaporation is faster than condensation, the cloud will decrease in size (and eventually disappear). If condensation is faster than evaporation, the cloud will grow bigger and probably release some of its water molecules as *precipitation* (e.g., rain, snow, sleet, hail). Once the precipitation falls back onto Earth, the water molecules can evaporate and continue through the water cycle indefinitely.

2.6 Additional Information about the Water Cycle

Although the water cycle is typically taught at the elementary level as evaporation, condensation, and precipitation, a lot more is actually going on that might be useful for you to know if you don't already. Once the precipitation lands on Earth, it can be moved or stored. *Stored* means the water is collected in its current state for long periods of time. The two major natural storage units on Earth are oceans and glaciers (and ice caps). Oceans cover about 71% of Earth's surface, and glaciers and ice caps cover about 11%. If you're thinking about world geography, realize that Antarctica and Greenland account for most of the glacial ice.

Water that isn't stored gets moved around. For example, water that lands on the ground can flow as *surface runoff* into rivers, lakes, and oceans. But water from surface runoff can also be absorbed into the ground as *infiltration*, seeping back into rivers, lakes, and oceans, as well as coming out of the ground as freshwater springs. Of course, any of the precipitated water can also evaporate back into the air. Did you know that evaporation occurs in plants, too? Water gets absorbed in the roots and travels throughout the plant. When it reaches the leaves, it changes into water vapor and is released through tiny holes (*stomata*). The release of water vapor into the atmosphere is called *transpiration*, which is essentially evaporation in plants.

This is a simple overview of just some aspects of the water cycle. As you can see, there's a lot going on with water! If you're interested in learning more, we recommend visiting the US Geological Survey (USGS) website at https://water.usgs.gov/edu/watercyclesummary.html.

2.7 Common Student Activities for Learning about the Water Cycle

There are a number of ways you can teach students about the water cycle. Two ways involve the order in which you sequence the content. For example, do you first want to teach about the water cycle as an introduction to what happens in evaporation and condensation? In this way, you can give students a context for learning about the processes of evaporation and condensation before digging deeper into these topics later. Or do you want to teach about evaporation and condensation first and then present the water cycle to give students a bigger picture? The bigger picture will allow them to pull all the pieces together and apply their understanding of evaporation and condensation to a new but related context. Regardless of the order in which you eventually decide to teach this content, there are a number of activities you can use to highlight ideas about the water cycle. These activities are merely suggestions to get you started; you may find or develop other activities that match your particular learning goals.

Water Bottle

Have you ever left a partially filled water bottle in your car? What did you notice? A clear plastic water bottle can provide students with a good visual of the water cycle. It's a closed system in which water can evaporate from the liquid in the bottom of the bottle, condense as visible liquid-water droplets on the inside of the bottle, and then roll back down the side of the bottle to the bottom, mimicking precipitation. This visual serves as an especially nice introduction or an assessment tool depending on when you use it in your lesson sequence. If you use it as an introduction, you can ask students to make predictions about what they think will happen if you put the water bottle outside in the sunlight (keeping the bottle sealed with a cap). Some students might say nothing will happen. Others may say the water will get hotter or will form drops on the inside of the bottle. Ask students questions to probe their thinking. The information you gather will help you determine next steps in your teaching. For example, students may be thinking the water needs to be warm for droplets to form. If this is the case, they are incorrectly associating *heating* water with condensation. You would want to challenge this idea by presenting other activities that show *cooling* water vapor resulting in condensation.

The water-bottle observations can also serve as either a *formative* assessment or a *summative* assessment. You can ask students the same question about what they think will happen if you put the sealed water bottle outside in the sunlight. Ideas about evaporation, condensation, thermal energy, and water molecules should be represented.

Water-Changes Demonstration

Another activity you can use in your classroom is a teacher demonstration on water changes (figure 24).

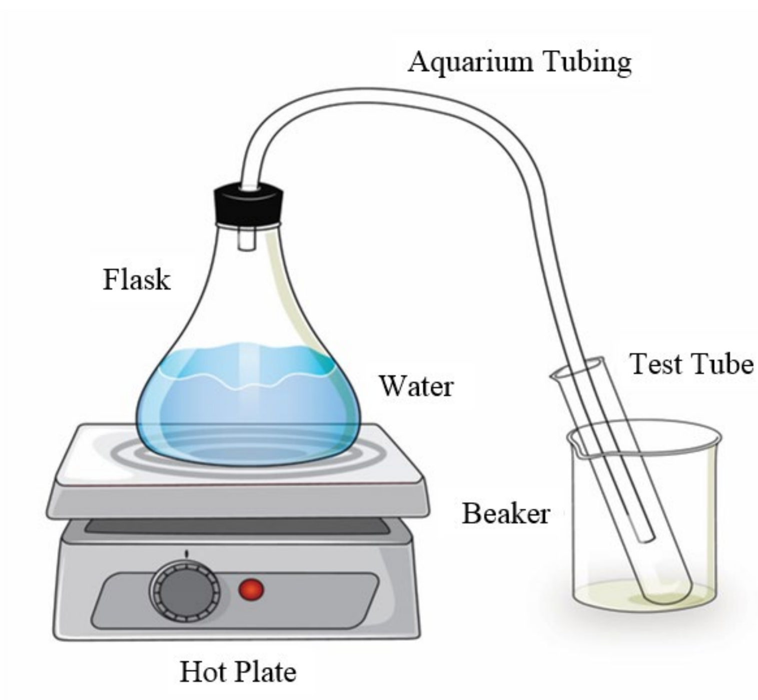


Figure 24. Water-changes-demonstration apparatus

This water-changes apparatus includes some specialized science equipment (e.g., a one-hole stopper, flask, and hot plate), along with other basic materials (e.g., water, aquarium tubing, test tube, beaker) that you can easily obtain. The demonstration shows the water cycle in its representative parts. At one end of the setup, water will change from a liquid to water vapor through evaporation; this occurs in the flask. However, since the flask is not entirely sealed (i.e., the stopper has aquarium tubing in it), the water vapor is allowed to travel through the tubing in the middle section of the apparatus. As the water-vapor molecules travel farther from the heat source, they will gradually cool and slow down. Students will begin to see water droplets forming in the aquarium tubing, which will fall into the test tube at the other end of the apparatus. The water that falls and collects in the test tube is like precipitation. Consequently, this demonstration (also known as a *distillation activity*) depicts the water cycle in its entirety.

An interesting point to discuss is whether all the water will transfer (or move) into the test tube. Rather than waiting for the entire flask of water to evaporate (which is not only time consuming but also somewhat dangerous, since you run the risk of cracking the flask), you can mark the water level on the flask at the beginning of the demonstration and then pour the test-tube water back into the flask after only a few minutes. (**Caution:** Use a potholder; the tube is hot!) Do you think the combined water will reach the original water level?

If you do this demonstration, you'll see that the final water level is *lower* than the original mark. This is because some of the water escaped as steam and water vapor on the other end of the test tube, which wasn't sealed or closed. If you want students to make connections between this demonstration and the water cycle, have them draw the apparatus and label the parts that represent elements of the water cycle. Water molecules should be included in their drawings. (See figure 25 as an example.)

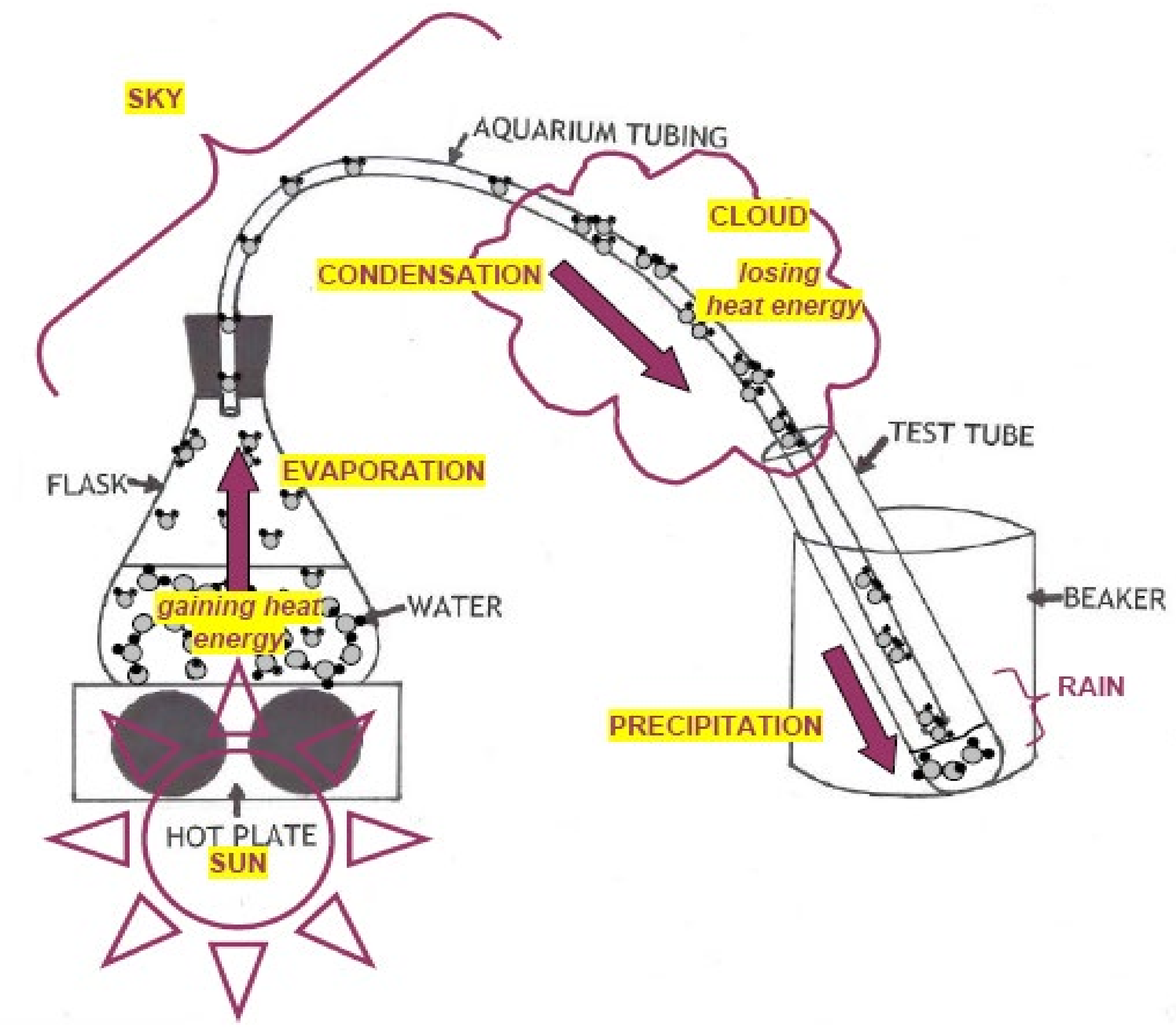


Figure 25. Ideal sample of a student diagram

Terrarium

Another common student activity that teachers like to use when teaching about the water cycle involves a simple terrarium. In figure 26, notice that a plant and a small dish of water are placed inside a terrarium, with a lamp outside that provides light and heat.

This activity is designed to show the water cycle. The lamp heats the water in the small dish, causing the water molecules to move faster. Some of the water molecules will escape from the liquid surface into the air as individual water molecules and become water vapor. As the water vapor rises higher in the container, it will cool and condense into liquid droplets that form on the underside of the lid and on the sides of the container. Eventually, when enough water molecules combine, the liquid droplets will get big and fall like precipitation, watering the plant.

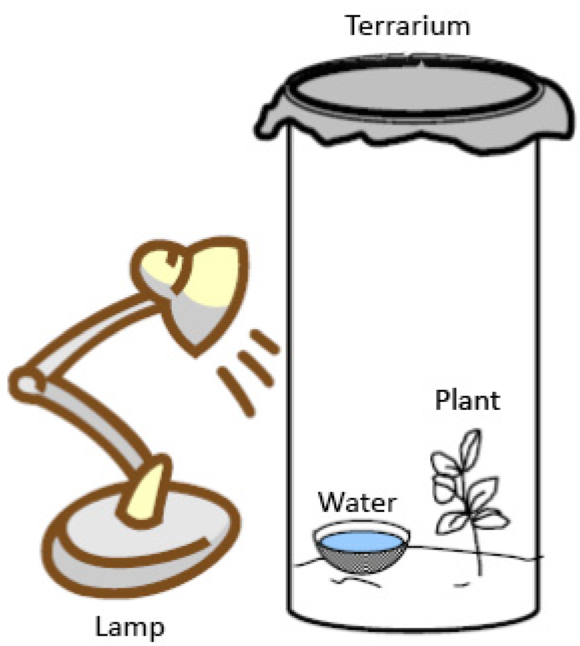


Figure 26. Simple terrarium setup

2.8 Concluding Remarks

Why do we care about the water cycle? Earth operates in cycles, and the water cycle plays a significant role in maintaining life and ecosystems. Since Earth holds a finite amount of water that is continuously recycled, it's an important and valuable resource. We talk about aspects of the water cycle nearly every day as we discuss the weather. We think about components of the water cycle when we pay attention to watering our lawns or house plants. We think casually about the water cycle when we wipe the moisture from the outside of a cold can of soda or replace water that has evaporated from an aquarium. And we may take for granted the water cycle when we take a drink of water. Through this reading, our hope is that you'll not only be able to more fully describe the water-cycle phenomena but will also be more prepared to help your students understand and describe it.