Investigation2 – What happens to the energy of water molecules during hurricanes?

Table of Contents:

INVESTIGATION 2: What happens to the energy of water molecules during hurricanes?

Overview

In the previous investigation, students developed a model to explain what holds water molecules together in the liquid state. In this investigation, students will analyze evidence to make claims about what happens to water molecules during phase changes. They will then analyze a simulation to develop a model of the relationship between potential energy, phase changes of water, and decomposition of water. Students will use the relationship between changes in energy and phase changes to explain where the energy for a hurricane comes from in order to answer the unit driving question: What powers a hurricane?

The Performance Expectations (NGSS)

HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

Elements from NGSS (NGSS Lead States, 2013, p. 97–98)	**Connections to this investigation**
Elements of Disciplinary Core Idea	
Elements of the core idea from the NGSS Performance Expectation	How this investigation builds toward the core ideas

Overview

Definitions of energy: • Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. • These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.	When opposite charges are moved farther apart, the potential energy stored in the electric field between those charged object is increased. In Unit 2, students analyzed the changes of energy due to interactions between charged subatomic particles when atoms form bonds. In this investigation, students analyze the changes of energy when molecules interact. Students compare the energy changes associated with breaking chemical bonds within molecules to the energy changes associated with. breaking the interactions between molecules.
Crosscutting concept	
Crosscutting concept from the NGSS Performance Expectation	How this investigation builds toward the crosscutting concept
Energy and matter: • Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems.	Students relate changes in energy to changes in molecular and atomic arrangements. Students track the flow of energy during phase changes, noting that if the energy of the system changes, energy must be transferred to or from the surroundings. Also, students use the ideas of conservation of energy and changes in potential energy to explain how water temperature can remain constant while water is boiling even when energy is transferred into the system from the surroundings.
Science and engineering practice	
Science and engineer practice from the NGSS Performance Expectation	How this investigation builds toward the science and engineering practice

Overview

Developing and using models: • Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). ○ Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.	Throughout this investigation, students draw models that represent what happens to atoms and molecules during various atomic and molecular rearrangements, how those rearrangements relate to changes in energy, and how those relationships can be used to explain observations.

HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

Elements from NGSS (NGSS Lead States, 2013, pp. 92–93)	**Connections to this investigation**
Elements of Disciplinary Core Idea	
Elements of the core idea from the NGSS Performance Expectation	How this investigation builds toward the core ideas
Structure and properties of matter: • The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.	Students use the atomic and molecular properties they have explored in previous units and investigations to explain observations of phase changes. They use the interactions between charged subatomic particles to explain interactions between molecules. Students then use these molecular interactions to explain changes in energy associated with phase changes.
Crosscutting concept	
Crosscutting concept from the NGSS Performance Expectation	How this investigation builds toward the crosscutting concept
Patterns: • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.	In the previous investigation, students noticed patterns related to the properties of polar and nonpolar molecules. In this investigation, students are using those patterns to explain and make predictions about the behavior of various substances.
Science and engineering practice	

Overview

Science and engineering practice from the NGSS Performance Expectation	How this investigation builds toward the science and engineering practice
Planning and carrying out investigations: • Planning and carrying out investigations in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. ○ Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.	Students do not plan their own investigations, but they do carry out investigations to collect data. Students compare their data with other groups so they can identify patterns in the data rather than relying on individual observations. Collecting data and comparing results with other groups provides experience using real data and motivates the need for considering the precision of measurements when designing investigations (for example, why it is important to include multiple trials).

Target Model: *What should the students' conceptual model include?*

- *Students will develop a model that explains how intramolecular and intermolecular interactions result in arrangements that lower potential energy.*
- *Intramolecular interactions (such as the formation of chemical bonds) and intermolecular interactions (such as the formation of hydrogen bonds) involve similar kinds of electrostatic interactions. However, the former involve interactions between full charges, and the latter involve interactions between partial charges. Therefore, the magnitude of each type of interaction is different; the interaction is stronger for chemical bonds and weaker for intermolecular interactions.*

Background Knowledge

Molecules interact with other molecules through intermolecular forces. These forces are similar to the forces that hold atoms together in bonds, but the magnitude of intermolecular forces is significantly smaller. Intermolecular forces are due to interactions between partial charges. When the charge of interacting particles is stronger, the interaction between those particles is stronger. The distance between atoms involved in intermolecular interactions is greater than the distance between bonded atoms within a molecule. The greater the distance, the weaker the interaction. Though the magnitude of the interactions in intermolecular forces is smaller, the forces and energy involved behave the same way as the forces that hold atoms together in bonds. When molecules are closer together, oppositely charged particles are closer, so the potential energy in the field between those particles is reduced. Separating molecules causes the charged particles to be moved farther apart, increasing the potential energy associated with the electric field.

Activities

Activity 3.1	*What does boiling do to water molecules?*	*280 min.*
Activity 3.2	*How hot can water get?*	*110 min.*
Activity 3.3	*How does energy change when evaporation is reversed?*	*60 min.*

Activity 2.1: What does boiling do to water molecules?

SUMMARY

The driving question for this unit is, *what powers a hurricane?* By the end of the unit, students should be able to explain the source of the energy that is released during a hurricane. In the previous investigation, students evaluated evidence about what makes water and other polar molecules stick together. In this activity, students will evaluate multiple sources of evidence to determine what happens to water molecules when water boils. In the next activity, students will look at changes in energy associated with boiling or evaporating water. Students will eventually use this information to explain why large amounts of energy are released during a hurricane.

LEARNING GOAL

Students will use evidence to determine that water molecules remain intact during boiling.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Structure and properties of matter: The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (NGSS Lead States, p. 92)	*Scale, proportion, and quantity:* Students understand that the significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. They recognize that patterns observable at one scale may not be observed or exist at other scales and that some systems can only be studied indirectly as they are too small, too large, too fast, or too slow to observe directly. (NGSS Appendix G p. 84)	*Constructing explanations and designing solutions:* • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. • Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. • Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. (NGSS Appendix F p. 61)

POINTS FOR CONSIDERATION

- Students often believe that the gas created when water boils is a mixture of hydrogen and oxygen gases. Students need to evaluate evidence that contradicts this idea. They also need time to process the evidence and what it tells them about the changes that occur when water boils.

PREPARATION

Class Time: 280 min.

Materials (for each group)

- 100 mL or 150 mL beaker
- tap water
- cobalt chloride test strips
- tongs
- hot plate
- watch glass
- For the teacher: heat resistant gloves

Materials (for the whole-class demonstration)

- 2 rubber stoppers with holes
- short glass tubing
- tap water
- Erlenmeyer flask
- balloon
    - ***Note:*** Cheap or low-quality balloons will weaken when heated and will be more likely to pop. Make sure you purchase decent quality latex balloons.
- heat resistant gloves

Activity Setup (for the whole-class demonstration)

- Connect the two rubber stoppers using the glass tubing so that the smaller end of one stopper is facing the larger end of the other stopper. See an example of the setup in the picture below.

- Optional: As part of this demo, you will compare what happens when a balloon filled with water vapor is touched by a flame to what happens when a balloon filled with a mixture of hydrogen and oxygen is touched by a flame. If you would like to make your own hydrogen/oxygen balloon instead of showing the video, see Preparing the Balloons for the Explosion Demo.
- Print out the instructions for Testing Boiling Water experiment.

SAFETY ISSUES

Hot plates are used in both the student lab and the teacher demo. Explain to students that the hot plates must be handled with care to avoiding burning. Make sure the area around each hot plate is clear of combustible materials and flammable liquids/vapors. Also, explain that any glassware or other equipment that has been sitting on a hot plate will be hot even though there may be no visual indication of this.

Activity 2.1 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY
Use this space to make notes to prepare for your lesson

1) Introduction
    a) Questions

    b) Discussion

2) Testing Boiling Water

    a) Discussion

3) Interpreting Evidence for Boiling Water

    a) Question

4) Boiling Water: Additional Tests

    a) Demonstration

    b) Questions

5) Boiling Water Model

    a) Questions

6) Conclusion

Activity 2.1 (Student materials): What happens to water molecules when water boils?

DQ	**Introducing the Lesson** Revisit the unit driving question: *What powers a hurricane?* Review the conclusions from Investigation 1, and identify questions that still need to be answered. *Possible questions:* • *Early in the last unit, we discussed that hurricanes only happen near oceans and that water might have a role in hurricanes. What do you think happens to water during a hurricane? Can some characteristics of a substance change while it still remains the same substance? Can you think of any examples?* • *Do hurricanes happen near all bodies of water? If you lived in Alaska, would you be worried that a hurricane might occur near you? Why or why not? (Draw out that hurricanes only occur where water is warm.)* • *What happens to water when it is heated up? What happens at the molecular level (i.e., to the water molecules) when water is heated and evaporates or boils?* The goal of this discussion is to elicit a range of student ideas, so be sure to ask for additional thoughts from students who have not already contributed. *Possible questions:* • *How are your ideas similar to those that have been expressed? How are your ideas different?'* • *How can you build from what the previous student said?* • *What do you think about the ideas that have been shared?*

Page title:
Introduction

In the last investigation, you observed some properties that make water special. In Unit 2, you also observed how substances can change into new substances. For example, you saw that water can be broken down into hydrogen and oxygen gas. In this investigation, you will test to see if all changes create new substances.

1. [prediction question] [drawing prompt] Heating water can make it evaporate more quickly or boil. Draw a diagram to show what you think happens to water molecules when they are heated up and boil.

Student responses: Since this is an initial ideas question, student diagrams might show two different processes:

- water molecules breaking to form hydrogen and oxygen gas
- water molecules moving farther apart

[text prompt] Describe what is happening to the water molecules when they are heated up and boil.

Student responses: This is an initial ideas question, so students' answers will vary. Their answers may fall into two basic categories:

- The water turns into hydrogen and oxygen gas.
- The water molecules move apart.

Some students may combine these two ideas or have different ideas.

Discussion: Display and discuss students' initial ideas about what happens when water boils. The purpose of this discussion is only to identify initial ideas; students do not need to agree at this point.

Possible questions:

- *What do you notice?*
- *Any similar ideas?*
- *Different ideas?*

Page title:
Testing boiling water

In this experiment, you will investigate what happens to water molecules when water starts to boil. You will use cobalt chloride strips to test the composition of water vapor.

Cobalt chloride paper is initially blue because it contains cobalt chloride, which has a blue color when not in combination with water molecules. When encountering water molecules, cobalt chloride combines with water to form a new compound that has a pink color.

Lab Instructions: Testing Boiling Water

Note: Hot plates are used in both the student lab and the teacher demo. The hot plates must be handled with care to avoiding burning. Make sure the area around each hot plate is clear of combustible materials and flammable liquids/vapors. Also, any glassware or other equipment that has been sitting on a hot plate will be hot even though there may be no visual indication of this. Make sure to use heat resistant gloves when handling hot glassware.

2. Copy your observations into the table below, then take a snapshot of your table.

Observations of cobalt chloride strip with water	
Observations of cobalt chloride after it is heated on hot plate	
Observations of cobalt chloride strip with liquid on watch glass	
Observations of cobalt chloride strip above water	
Observations of cobalt chloride strip in other liquids **(Note: Cobalt chloride testing with other liquids will be done by your teacher in class. Wait for the demonstration to fill out this row of the table.)**	

Discussion: After students have collected data, discuss their observations and what the cobalt chloride strips indicate.

Possible questions:

- *What happened when you dipped the cobalt chloride paper in water?*
- *Cobalt chloride paper is a type of indicator. What makes it change color? What is it telling you when it changes color?*
- *Do you think any liquid would make the cobalt chloride paper change color? Or do you think water is the only liquid that does this?*

After students begin to speculate about what it means when the cobalt chloride strip changes color, use the test strips to test some liquids that do not have any water in them (for example, acetone, hexane, or ethanol).

Discussion: Collect and display a class data set. Point out whether the cobalt chloride strip was blue or light pink/white after each test.

Possible questions:

- *What did you observe?*
- *How many groups had the same observation?*

Leave the class data set displayed so students can refer to it while answering questions.

Page title:
Interpreting evidence of boiling water

3. What causes the cobalt chloride strip to change color?

Supplemental content: Cobalt chloride paper is initially blue because it contains cobalt chloride compound ($CoCl_2$), which has a blue color when not in combination with water molecules. When encountering water molecules, cobalt chloride combines with water to form cobalt chloride hexahydrate, $CoCl_2 \bullet 6H_2O$, which has a pink color.

> *Clarification - Students should only be recording their observations; they don't need to explain why cobalt chloride changes color upon reaction with water. They also don't need to specify the color.*

Student responses: Coming into contact with water causes the cobalt chloride strip to change color. It changes from blue to light pink (or white).

Note: Some sources of evidence to support this are as follows:

- *The other liquids do not cause the cobalt chloride strip to change color.*
- *When the cobalt chloride strip is dried on a hot plate, it returns to its original color, which is blue.*

If students do not connect the change in color with an indication that water is present, ask them about these sources of evidence and what they tell us about the cobalt chloride strips.

4. What is the liquid that formed on the watch glass? Support your claim with evidence.

Supplemental content: When the water starts boiling, water vapor condenses on the watch glass to form liquid water. When dipped into the liquid on the watch glass, the cobalt chloride strip turns pink because the liquid on the watch glass is water.

> *Clarification - Students don't need to explain why the liquid on the watch glass is water; they only need to support their answer by observing the color change of the cobalt chloride strip.*

Student responses:

- The liquid is water. The cobalt chloride strip changed color from blue to light pink (or white) when it was dipped in water, and the strip again changed color from blue to light pink (or white) when it was placed in the watch glass.

5. Based on what happened to the cobalt chloride strip when it was held just above the boiling water, what can you conclude about the molecules that were in the air above the boiling water?

Supplemental content: Water vapor consisting of water molecules formed in the region just above the boiling water. Water molecules don't break apart upon boiling because the amount of energy supplied via boiling is not enough to break the bonds that hold oxygen and hydrogen atoms together in the water molecule. Instead, energy supplied during boiling increases the motion of water molecules, causing intermolecular forces that hold water molecules close together in the liquid form to break. Breaking intermolecular forces causes water molecules to move farther apart from each other. When water molecules move farther apart from each other, they convert from a liquid phase to a gas phase. Water vapor is made up of water molecules in the gas phase. These molecules interacted with the cobalt chloride strip, causing it to change color from blue to pink.

Clarification - Students should only be recording their observations; they don't need to explain why the liquid on the watch glass is water.

Student responses:

- Because the cobalt chloride strip changed color to light pink (or white), water vapor must have been above the boiling water. This observation also supports the idea that the water molecules remain as H_2O and do not break apart into H_2 and O_2 molecules, and that there are water molecules in the air above the boiling water.

Note: Students may not agree on the interpretation of the evidence at this point. For example, students could argue that the water molecules are breaking apart in the air but reforming on the edges of the strip.

Page title:
Boiling water: Additional tests

Demonstration
Follow these steps to fill a balloon with water vapor.

- Attach two rubber stoppers with a glass tube.
- Add some water to an Erlenmeyer flask, and place one of the rubber stoppers in the opening of the flask. Pull the balloon over the second stopper.
    - *Note: It is helpful to use your breath to blow up the balloon first, and then let it deflate, in order to stretch it out.*
- Place the flask on a hot plate and boil the water. Using heat resistant gloves, make sure the stoppers remain sealed as the balloon starts to inflate.
- Once the balloon is inflated, quickly seal the "tail" of the balloon with a clamp and remove the stopper from the flask. NOTE: The balloon will be hot, so keep the heat resistant gloves on to complete this part.
- When the balloon has cooled, pass it around to have students observe the puddle of water that has formed in the balloon.
- The following video provides some tips for conducting this demonstration: balloon water vapor demo.

After students have made observations of the balloon, try igniting the balloon by touching it with a flaming splint. Since the balloon is mostly filled with water vapor, touching the balloon with a flame will just pop the balloon. This is in contrast to the large explosion that occurs when a balloon filled with a mixture of hydrogen and oxygen gas is ignited, as shown in the video linked to the student question below. The goal is to compare igniting a balloon filled with water vapor and a balloon filled with oxygen and hydrogen gas to help students understand that boiling water doesn't produce hydrogen and oxygen gas.

Possible questions:

- What did you observe in this demonstration?
- Why did the balloon expand when placed above boiling water?
- What do you think water vapor consists of?
- What do you notice about the balloon when it shrinks?
- What happens when the balloon is touched with flame?

6. Record your observations of the balloon that is filled by placing it over boiling water.

Student responses: Answers will vary. Students' observations may include the following:

- The balloon shrinks when it is removed from the flask.
- A puddle of water forms inside the balloon when it shrinks.
- The balloon does not explode when touched with a flame.

Students may record additional observations.

7. Watch the video and record your observations of the balloon that is filled with hydrogen and oxygen gas.

[Link to video of balloon filled with hydrogen and oxygen gas]

Student responses: Students may record a variety of observations.

- The balloon explodes
- There is a big fire
- There is a loud boom

8. Compare the balloon filled with hydrogen and oxygen gas in the video with the balloon filled by placing it over boiling water in the demonstration. Could the two balloons be filled with the same gas? Support your answer with evidence. Be sure to include what this tells you about the gas that is formed when water is boiled.

Student responses:

- No, the two balloons cannot be filled with the same gas because they react differently when touched by a flame. This tells me that the gas formed when water is boiled is not oxygen or hydrogen gas.

Discussion

Have students compare their observations of the balloon filled with water vapor to their observations of the balloon filled with hydrogen and oxygen gas from Unit 2 and the video.

Possible questions:

- *Could the two balloons be filled with the same thing?*
- *What evidence do you have to support that?*
- *What was in the balloon that filled when placed over boiling water?*
- *Does our evidence indicate that boiling water breaks the water molecules into hydrogen and oxygen gas, or that the water molecules remain intact?*
- *What do you think is happening to water when it boils?*
- *In Unit 1 Investigation 5, we sealed some air in a syringe and were able to compress the gas. What did that tell us about gases? How would that apply to what is happening to water molecules when we boil water?*

Page title:
Boiling water model

9. [drawing prompt] Draw a model that shows what happens to water molecules when water boils.[text prompt] How does your model account for your observations of the cobalt chloride strip placed over boiling water and your observations of the balloon filled by placing it over boiling water?

Supplemental content: Water vapor consisting of water molecules is formed in the region just above the boiling water. Water molecules don't break apart upon boiling because the amount of energy supplied via boiling is not enough to break the bonds that hold oxygen and hydrogen atoms together in the water molecule. Instead, energy supplied during boiling increases the motion of water molecules, causing intermolecular forces that hold water molecules close together in the liquid form to break. Breaking intermolecular forces causes water molecules to move farther apart from each other. When water molecules move farther apart from each other, they convert from the liquid phase to the gas phase. Water vapor is made up of water molecules in the gas phase. When water molecules in water vapor interact with a cobalt chloride strip, the strip changes color from blue to pink.

When a balloon is placed over water vapor, water molecules in the gas phase fill the balloon. Since the distance between water molecules in the vapor phase is greater than in the liquid phase, the balloon filled with water vapor is larger. When water vapor is tested with a glowing splint, no explosion happens because water molecules are not explosive, unlike hydrogen and oxygen gases. Once the balloon is taken off the flask with boiling water, the water vapor inside cools down (loses energy to the surroundings) and water molecules go back to the liquid phase. Since water molecules in the liquid phase take up much less space, the volume of the balloon decreases and you can observe a puddle of water in the balloon.

Clarification - Students don't need to talk about phase change. They only need to use observations to support their model that water molecules remain intact but move farther apart from each other during boiling.

Student responses: At this point, students should have come to a consensus that the water molecules remain intact but separate from each other when they boil. Water molecules do not turn into hydrogen and oxygen, or other gases.

- The cobalt chloride strip turns light pink (or white) when held above boiling water because there are individual water molecules filling the space above the boiling water, which affects the cobalt chloride strip. When trying to ignite the balloon filled with water vapor, no explosion happened, which suggests that the balloon is not filled with hydrogen and oxygen gas. Therefore, the water vapor in the balloon contains water molecules. This evidence suggests that water molecules remain intact during boiling.

10. Why were the observations of igniting a balloon filled with hydrogen and oxygen, shown in the video, so different from the observations of igniting a balloon filled with water? Justify your answer.

Student responses:

- Hydrogen and oxygen are explosive. but since the balloon that was filled with water contained water molecules, not hydrogen and oxygen molecules, it did not explode.

11. Based on your understanding of what happens at the molecular level when water boils, what do you think happens at the molecular level when hexane boils?

Student responses:

- The hexane molecules probably stay intact but move apart from each other. Students may also predict that the temperature will be lower than water.

Concluding the Activity

Discuss students' models, introduce the term *water vapor*, and revisit the unit driving question.

Possible questions:

- *What do you notice in your models?*
- *What happens to water molecules when water boils? What evidence do we have to support that?*
- *Does anything else happen?*

Students should come to the consensus that water molecules stay intact when they boil but move apart from each other. Once students have agreed that this is what happens, introduce the term *water vapor*. Water vapor is the term for water molecules in the gas phase. Water vapor is made up of water molecules that are spread apart from each other.

Possible questions:

- *Do any of these models represent water vapor? Where? How?*
- *Is boiling water the only way to get liquid water to change to water vapor?*

Add about 100 mL of water to a beaker and set it out on the counter. You will return to this beaker at the end of the next activity.

Possible questions:

- *What do you think will happen to the water in this beaker?*
- *If we come back and check it in two days, how much water do you think will be in here?*
- *Any other predictions?*

After students agree about what happens to water when it boils and are comfortable with the term *water vapor*, revisit the unit driving question, *What powers a hurricane?* and discuss what the evidence from this activity has added to the answer to this question.

Possible questions:

- *Earlier we noted that water seems to be related to hurricanes. Based on the evidence from this activity, what do you think is happening to the water molecules in the ocean before and during a hurricane? NOTE: Students may disagree on the answer to this question at this point.*
- *What additional questions do we need to answer before we can explain what powers a hurricane?*

Activity 2.2: How hot can water get?

SUMMARY

This activity will continue to focus on water. Students will investigate how energy changes when water is heated and then boils, and relate that to the intermolecular forces that hold water in a liquid state. In the next activity, students will use the relationship between energy and intermolecular forces to explain where the energy that powers a hurricane comes from. In this activity, students will perform a heating curve experiment and explore a simulation to gather evidence about energy and phase changes.

LEARNING GOAL

Students will collect and analyze evidence to support a description of how energy changes when heating water to a boil.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Definitions of energy: • Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. • These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). (NGSS Lead States, pp. 97–98)	*Systems and system models:* Students investigate or analyze a system by defining its boundaries and initial conditions, as well as its inputs and outputs. They use models (e.g., physical, mathematical, computer models) to simulate the flow of energy, matter, and interactions within and between systems at different scales. (NGSS Appendix G, p. 85)	*Analyzing and interpreting data:* • Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations. • Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. (NGSS Appendix F, p. 57)

POINTS FOR CONSIDERATION

- Students often think that the longer you boil something, the hotter it will get. In the heating curve experiment, they will observe that the temperature of water stays constant during boiling.

PREPARATION

Class Time: 110 min.

Materials (for each group)

- room-temperature water
- 250 mL Erlenmeyer flask or beaker (whichever is available)
- thermometer
- rubber stopper with two openings: one for the thermometer and one for letting water vapor out (if using an Erlenmeyer flask)
- clamp to hold the thermometer in place (if using a beaker)
- hot plate
- boiling stones (if available, see note below)
- stopwatch
- For the teacher: heat resistant gloves

Materials (for the whole-class demonstration)

- tap water
- 250 mL Erlenmeyer flask
- thermometer
- rubber stopper with two openings: one for the thermometer and one for letting water vapor out (if using an Erlenmeyer flask)
- clamp to hold the thermometer in place (if using a beaker)
- hot plate

Activity Setup

- For the whole-class demonstration, place a thermometer in the rubber stopper with two openings. The thermometer should be set to a height for measuring the temperature of the water vapor above the boiling water in the flask.
- Print out the instructions for the Water Heating Curve Lab.

SAFETY ISSUES

Hot plates are used in both the student lab and the teacher demo. Explain to students that the hot plates must be handled with care to avoiding burning. Make sure the area around each hot plate is clear of combustible materials and flammable liquids/vapors. Also, explain that any glassware or other equipment that has been sitting on a hot plate will be hot even though there may be no visual indication of this.

HOMEWORK

Reading for Activity 2.2: Why Is Temperature Constant During Boiling?

Activity 2.2 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introduction
    a. Discussion
    b. Questions
    c. Discussion
2. Heating Curve Lab
    a. Lab
    b. Discussion and Water Vapor Demonstration
    c. Questions
    d. Discussion
3. Breaking Molecules vs. Pulling Molecules Apart
    a. Simulation and Questions
    b. Discussion
    c. Questions
    d. Discussion
4. Compare Electrolysis and Boiling Water
5. Conclusion

Activity 2.2 (Student materials): How hot can water get?

Introducing the Lesson

Revisit the previous activity, in which students tested the gas produced by boiling water. Review the conclusions made based on the tests involving the cobalt chloride strips and the observations of igniting a balloon filled with the gas from boiling water. , Ask students to predict how energy might be involved in the process of boiling water.

Possible questions:

- *Based on the results of testing water vapor, what is it made of?*
- *Recall the activity from Unit 2 in which you timed how long it takes for dye to mix with water at different temperatures. What do your conclusions from that activity tell you about what happens to water molecules when you heat water on a hot plate?*
- *What does temperature measure?*
- *How does heating influence water molecules?*
- *Do you think molecules in liquid water or water vapor have more energy? Why?*
- *When liquid water is heated, do you think its temperature keeps rising indefinitely? Why or why not?*

The goal of this discussion is to elicit a range of student ideas, so be sure to ask for additional thoughts from students who have not already contributed.

Possible questions:

- *What do you think about the ideas that have been shared?*
- *How are your ideas similar to what has been discussed?*
- *How are they different?*

Page title:

Introduction

In the previous activity, you started talking about what happens to water molecules when water boils. You tested water vapor to evaluate whether the water molecules stay together or break into separate atoms. In this activity, you are going to discuss what happens to energy when water boils.

1. **[prediction question] Suppose you have two pots of boiling water: one has been boiling for 1 minute, and the other has been boiling for 15 minutes. How do you think the temperature of the water in each pot will compare? Justify your answer.**

Student responses: Answers will vary. Possible answers include:

- The water in the pot that just started boiling will have a lower temperature than the water that has been boiling for 15 minutes. This is because the water molecules that have been heated longer will have more kinetic energy and therefore a higher temperature.
- The water in both pots will both be 100°C because water boils at 100°C.

Students who provide an answer similar to the second example response will most likely be relying on past experience or prior knowledge.

Discussion: Ask students to share their ideas about how the temperature of water changes when it is boiled for different amounts of time.

Possible questions:

- *Do you think the temperature of water that has been boiling for 1 minute will be different from the temperature of water that has been boiling for 15 minutes? Why or why not?*
- *Any similar ideas?*
- *Different ideas?*

Page title:

Water heating curve lab

In this experiment, you will investigate how the temperature of water changes when it is boiled. Your observations will help you answer some of the questions that have been discussed in class, including questions about how energy changes when water boils.

Experiment Instructions: Water Heating Curve Lab

Tip: If you have digital temperature probes, you could have the computer capture and plot the data rather than have students complete this lab manually.

2. [drawing prompt] Draw the shape of the temperature curve you created when doing the boiling water experiment.

Student responses:

- The curve should indicate temperature rising till it gets to 100°C and then leveling off after that

Discussion: Ask students to share their heating curve graphs and discuss the results of the lab.

Possible questions:

- *What do you notice about the heating curve?*
- *How did the temperature of the water change when you were heating it up?*
- *Did anything about the liquid water change as you were heating it up?*
- *Why do you think the temperature stayed constant after the water started boiling?*
- *Based on our earlier evidence, what happens to water molecules when water boils?*
- *Based on what we discovered about bonding in Unit 2, what happens to energy when atoms move farther apart?*
- *When we looked at simulations involving the separation of atoms in Unit 2, what happened to the potential energy of the field?*
- *What do you think would happen to the temperature of water vapor if you monitored it for some time after water started boiling? Explain your prediction.*

Demonstration

As a demonstration, measure the temperature of water vapor.

- Add some water to an Erlenmeyer flask and bring it to a boil on a hot plate.
- Allow the water to boil for at least 3 minutes, and then hold a thermometer in the water vapor above the water level (using a clamp or a stopper with two holes to secure the thermometer).
- You can also add a second thermometer to measure the water temperature at the same time. (SAFETY NOTE: If you add a second thermometer and are using a stopper, use a three-hole stopper so that you have at least one empty hole to allow the water vapor to vent, so pressure does not build up inside the flask.)

Possible questions:

- *How do you think the temperature of the water vapor is going to change?*
- *How do you think the temperature of the water vapor will compare with the temperature of the boiling water?*

Once the water in the beaker starts boiling, record the temperature of the water vapor for some time so that students notice patterns in how the temperature changes. Discuss the demonstration.

Possible questions:

- *What did you notice about the temperature of the water vapor?*
- *What do you think are some differences in behavior between water molecules in liquid water and in water vapor?*

3. What happened to the water molecules in the heating curve experiment above that could help explain the resulting graph?

Supplemental content: When water is heated up from room temperature, the energy transferred to the water molecules increases their molecular motion, so there is an increase in temperature. The energy transferred to the water increases the kinetic energy of the water molecules. Once the water starts boiling, the temperature stays constant because the energy transferred to the water is now used to overcome the intermolecular forces holding the water molecules together. The energy transferred to the water and used to overcome the intermolecular forces increases the potential energy of the molecules.

> *Clarification* - Students are starting to put these ideas together, so their answers may be incomplete at this point. They might not recognize that once water starts boiling, energy is used to overcome intermolecular forces, or that this process increases the potential energy of the water molecules

Student responses:

- Heating the water transferred energy to the molecules of water, causing them to move faster. As they started moving faster, the temperature increased. As the water molecules were moving faster, the molecules had enough energy to break free of the intermolecular forces holding them together.
- Heating the water transferred energy to the molecules of water, causing them to move faster. As they started moving faster, the temperature increased. Once the water started boiling, the kinetic energy of the molecules stopped changing. Therefore, the temperature was constant. The energy transferred in the form of heat provided enough energy to the molecules in the liquid state to cause them to break free of the intermolecular forces holding them together.
- Heating the water transferred energy to the molecules of water, causing them to move faster. As they started moving faster, the temperature increased. Once the water started boiling, the kinetic energy of the molecules stopped changing. Therefore, the temperature was constant. The energy transferred in the form of heat provided enough energy to the molecules in the liquid state to cause them to break free of the intermolecular forces holding them together. So the molecules formed water vapor, and the potential energy of the water molecules increased.

4. How can your observations of the temperature of the water vapor be explained using ideas involving energy?

Student responses:

- The temperature of the water vapor we measured was constant. This means that the kinetic energy of the water molecules in the water vapor stayed constant. The potential energy of the molecules increased because the energy transferred from the hot plate was used to overcome the intermolecular forces that were holding the water molecules together, increasing the distance between water molecules.
- The temperature of the water vapor we measured was constant. This means that the kinetic energy of the water molecules in the water vapor stayed constant. The potential energy of the molecules increased because the energy transferred from the hot plate was used to heat up the surrounding air molecules (increasing their motion).

Discussion: Revisit chemical bond formation from a force and energy perspective (see Unit 2 Investigation 3). Discuss what happens to attractive and repulsive forces between atoms when they form a chemical bond and how the energy of the system changes when a chemical bond is formed. Then discuss how the energy of the system changes when the process is reversed and a chemical bond is broken.

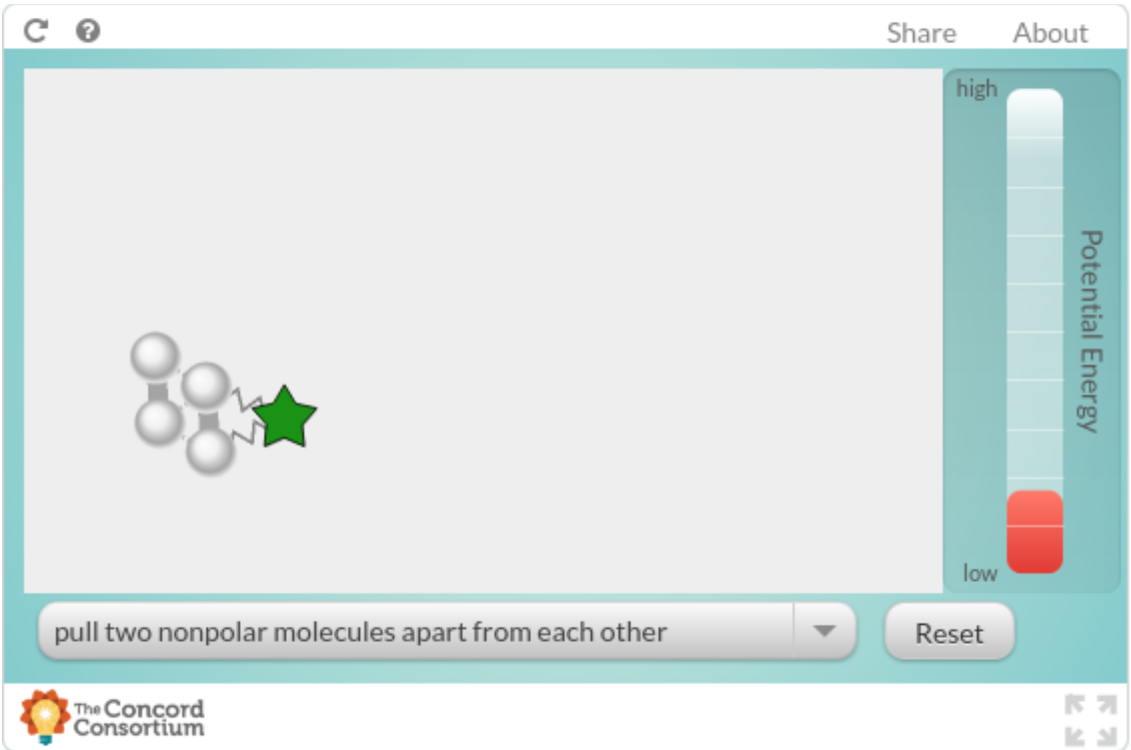
Possible questions:

- *Describe the state of the attractive and repulsive forces between atoms that have formed a bond.*
- *What happens to energy when a chemical bond is formed?*
- *What happens to energy when a bond is broken?*

Page title:

Breaking molecules vs. pulling molecules apart

Explore the simulation. Notice how the energy change differs depending on whether you are pulling two molecules apart or pulling two atoms in a single molecule apart (breaking a bond).



http://lab.concord.org/interactives.html#interactives/interactions/comparing-potential-energy-of-bond.json

5. How does the change in energy when two polar molecules are pulled apart compare with the change in energy when two atoms in a polar molecule are pulled apart?

Student responses:
- The change in energy is greater when you pull two atoms in a polar molecule apart than it is when you pull two polar molecules apart.

6. How does the change in energy when two nonpolar molecules are pulled apart compare with the change in energy when two atoms in a nonpolar molecule are pulled apart?

Student responses:
- The change in energy is greater when you pull two atoms in a nonpolar molecule apart than it is when you pull two nonpolar molecules apart.

7. Which interactions are stronger, the forces holding atoms together in a polar molecule or the forces holding polar molecules together? Support your answer with evidence from the simulation.

Student responses:
- The forces holding atoms together in a polar molecule are stronger than the forces holding polar molecules together because it takes more energy to pull two atoms apart in a polar molecule than it takes to pull two polar molecules apart.

8. Which interactions are stronger, the forces holding nonpolar molecules near other nonpolar molecules or the forces holding polar molecules near other polar molecules? Support your answer with evidence from the simulation.

Student responses:
- The forces holding polar molecules close to each other are stronger than the forces holding nonpolar molecules close to each other because it takes more energy to pull apart polar molecules than it takes to pull apart nonpolar molecules.

9. Rank the following interactions in order of decreasing strength, starting with the strongest interaction:

A. forces that hold atoms together in a polar molecule
B. forces that hold atoms together in a nonpolar molecule
C. forces that hold nonpolar molecules together
D. forces that hold polar molecules together

Support your answer using evidence from the simulation.

Student responses: The interactions are ordered by decreasing strength, starting with the strongest interaction, as follows:

A, B forces that hold atoms together in any molecule (polar or nonpolar)
D forces that hold polar molecules together
C forces that hold nonpolar molecules together.

The ranking reflects the decreasing amount of energy needed to break each type of interaction.

- A & B are strongest because it is hardest to pull them apart in the simulation. C is the weakest because it is not hard to separate two nonpolar molecules in the simulation.

Discussion: Ask students to share their observations of the simulation. Make sure to connect the simulation to why the temperature remains constant during boiling. Discuss the differences in energy change when pulling polar and nonpolar molecules apart from each other. Connect these energy changes to energy changes during boiling for polar and nonpolar molecules.
Possible questions:

- *What happens to the potential energy when you pull two polar molecules apart?*
- *What happens to the potential energy when you pull two atoms in a polar molecule apart?*
- *What happens to the potential energy when you pull two nonpolar molecules apart?*
- *What happens to the potential energy when you pull two atoms in a nonpolar molecule apart?*
- *Which situation do you think reflects what happens when water boils: pulling two polar/nonpolar molecules apart or pulling two atoms in a polar/ nonpolar molecule apart?*
- *How can this simulation help you explain why the temperature stays constant during boiling?*
- *How is the energy change different when you pull two polar molecules apart than it is when you pull two atoms apart in a polar molecule? In a nonpolar molecule?*
- *How is the energy change different when you pull two polar molecules apart than it is when you pull two nonpolar molecule apart?*
- *How is the energy change different when you pull two atoms apart in a polar molecule than it is when you pull two atoms apart in a nonpolar molecule?*

Revisit the ideas of electronegativity and polarity that were discussed in the previous investigation. Relate these ideas to the intermolecular forces between polar and nonpolar molecules.
Possible questions:

- *How do polar molecules stick together?*
- *Why do polar molecules stick together?*
- *How do nonpolar molecules stick together?*
- *How do the forces that hold the atoms in a polar molecule together compare with the forces between polar molecules?*
- *What do you think happens to the forces between two polar molecules when you heat water? Between two nonpolar molecules?*
- *What do you think happens to the forces that hold atoms in polar molecules together when you heat water?*
- *What do you think happens to the forces that hold atoms in nonpolar molecules together when you heat water?*

10. Based on your observations of the simulation, explain what happened to the water molecules in the heating curve experiment you did earlier that could explain the resulting temperature graph.

Supplemental content: When the water was heated up from room temperature, the energy transferred to the water molecules increased their molecular motion, so there was an increase in temperature. The energy transferred to the water increased the kinetic energy of the water molecules. Once the water started boiling, the temperature stayed constant because the energy transferred to the water was now used to overcome the intermolecular forces holding the water molecules together. The energy transferred to the water and used to overcome the intermolecular forces increased the potential energy of the molecules.

Clarification - At this point, students might not mention that the potential energy of the water molecules increased during boiling, but they should relate increase in temperature to increase in kinetic energy and overcoming intermolecular interactions.

Student responses:

- The energy transferred from the heat source increased the kinetic energy of the water molecules. Therefore, the temperature of the water increased. Once the water started boiling, the the temperature remained constant, which means that the kinetic energy of the water molecules stopped increasing. At this point, the energy being transferred from the heat source is used to cause the molecules to break free of the intermolecular forces holding them together, resulting in an increase in the potential energy of the water molecules.

11. Recall that hexane is a nonpolar molecule. Do you think the boiling point of hexane would be higher or lower than the boiling point of water? Support your prediction using your understanding of what happens to molecules during boiling and your understanding of polar and nonpolar molecules.

Supplemental content: The boiling point of hexane (68°C or 154°F) is lower than the boiling point of water (100°C or 212°F) because the interactions between the molecules of hexane are weaker than the interactions between the molecules of water. This is because hexane molecules are nonpolar, and because the intermolecular forces that hold hexane molecules together are due to instantaneous electron density fluctuations that cause temporary partial charges in different regions of the molecule. The interactions between these temporary partial charges attracts nonpolar molecules to each other. Since these partial charges are the result of temporary random fluctuations in electron density, these interactions are weaker than the interactions between partial charges in polar molecules. Because the interactions between hexane molecules are weaker than the interactions between water molecules, hexane molecules do not require as much energy to be moved apart from each other, so hexane starts to boil at a lower temperature than water does.

> *Clarification - Students don't need to explain what kinds of interactions hold nonpolar molecules like hexane together. At this point, students can either assume that interactions between nonpolar molecules are very weak or that they are absent. Either is fine at this stage.*

Student responses:

- Because hexane is a nonpolar molecule, it takes less energy to pull two hexane molecules apart than it does to pull two water molecules apart. SInce molecules move farther apart from each other during boiling, it will take less energy and, therefore, a lower temperature to pull apart two hexane molecules.

Discussion: Discuss the similarities and differences between intermolecular forces and bonds in polar and nonpolar molecules.

Possible questions:

- *Based on what we explored in Unit 1, what are the factors that affect the strength of interactions between charged objects?*
- *Based on what we explored in Unit 2, what are the interactions that hold atoms together in a bond?*
- *How are the interactions that hold two atoms in a molecule together similar to the interactions that hold two molecules together? How are the interactions different?*
- *Which are stronger, the interactions that hold two atoms in a molecule together or the interactions that hold two molecules together? What evidence do you have to support your answer?*

By the end of the discussion, students should come to the consensus that atoms and molecules are both held together by interactions between oppositely charged particles, but bonds are stronger. The evidence for this is that it takes more energy to break bonds (example: water electrolysis) than to break intermolecular interactions (example: water boiling). Bonds within molecules are generally strong whether the molecule is polar or nonpolar in nature.

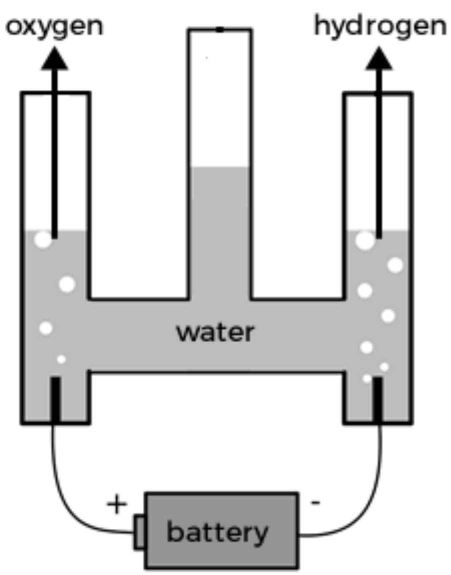
Keep in mind that students should be refining these ideas. If needed, point out evidence they have collected that supports these ideas.

Page title:

Compare electrolysis and boiling water

Recall from Unit 2 that electrolysis is a process of running an electric current through water. In Unit 2, you observed that as the electric current runs through the water, small gas bubbles are formed. After a very long time, all the water would be used up and only gas would be left. To completely change 10 mL of water into oxygen and hydrogen gases using electrolysis requires about 131,738 joules of energy. (A joule is a unit of energy.) By comparison, heating 10 mL of water from room temperature and boiling it until the entire sample has been converted to water vapor requires about 25,000 joules of energy.

ELECTROLYSIS



Converting 10 ml of water to hydrogen and oxygen takes **131,738 joules of energy**.

BOILING

Converting 10 ml of water to steam (water vapor) takes **25,000 joules of energy**.

12. Based on the above information and the illustration on the right, which interactions do you think are stronger— the interactions that form the bonds between hydrogen and oxygen atoms within water molecules or the interactions between water molecules? Justify your answer.

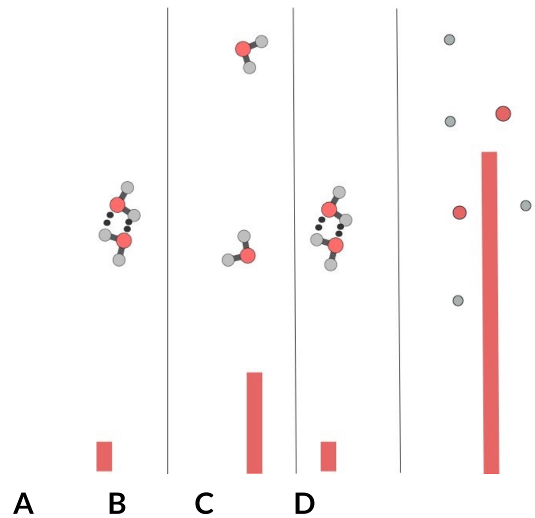
Student responses:

- The bonds between hydrogen and oxygen atoms within water molecules are stronger because it takes more energy to break them apart, which is what happens during electrolysis.

13. [drawing prompt] Draw a model that compares the changes that occur at the atomic level during electrolysis to the changes that occur at the atomic level when water boils. Add bar graphs to your model to show the relative change in potential energy for each process.

[text prompt] Compare the process of electrolysis to the process of boiling water.

Student responses:



The model should indicate that when water boils, the intermolecular interactions holding water molecules together are overcome, and water molecules move farther apart from each other. This change is accompanied by a change in energy (graph A and B). Further, the model should indicate that during electrolysis, chemical bonds that hold oxygen and hydrogen atoms together in a water molecule break, and atoms separate, destroying the water molecules (graph C and D). The energy change associated with breaking a chemical bond is much greater than the energy change associated with overcoming an intermolecular interaction.

- During boiling, increased energy causes water molecules to break free from the intermolecular forces holding them together, and water molecules move farther apart from each other. During electrolysis, bonds that hold oxygen and hydrogen atoms together in the water molecules break. To break bonds much more energy is required than to break intermolecular forces, as shown in the graph above.

Concluding the Activity
Display and discuss students' energy graphs for electrolysis and boiling water.

Possible questions:

- *Which electrical forces are stronger, the forces between atoms in a water molecule or the forces between molecules of water?*
- *Temperature also remains constant during melting just as it does with boiling? Why does temperature remain constant during boiling/melting?*
- *How is the energy transferred from the heat source used when boiling/melting water?*
- *Does boiling break bonds between atoms in water molecules? Why or why not?*

Discuss the similarities and differences between evaporation at room temperature and boiling.

Possible questions:

- *What happens to a puddle of water over time?*
- *How can water change from a liquid to gaseous state without boiling?*
- *Remember that temperature is a measurement of the average kinetic energy of atoms and molecules. In water that is 80°C, do you think some of the molecules could be moving fast enough to separate from the other molecules? What about in water that is 20°C?*
- *What is the difference between boiling and evaporation?*
- *How are boiling and evaporation similar?*

NOTE: Students do not need to develop a precise definition for the difference between boiling and evaporation, but they should recognize that some water molecules can change state without heat being added.

Revisit the driving question for the unit: *What powers a hurricane?*

Possible questions:

- *What do you think happens to ocean water before a hurricane occurs?*
- *Does ocean water boil before a hurricane?*
- *Are there other ways for liquid water to change into water vapor?*
- *What do you think causes ocean water to evaporate?*

Homework: Reading for Activity 2.2
Why Is Temperature Constant During Boiling?

Activity 2.3: How does energy change when evaporation is reversed?

SUMMARY

In the previous activity, students looked at what happens to energy when molecules of water move apart (boiling and evaporation). In this activity, they will investigate how energy changes when the process is reversed and water condenses from vapor to liquid. Understanding these energy changes will help students answer the driving question for the unit, *What powers a hurricane?* by defining where the energy that powers a hurricane comes from.

LEARNING GOAL

Students will construct a model that explains the relationship between the condensation of water molecules and changes in energy.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Definitions of energy: • Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. • These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). (NGSS Lead States, pp. 97–98)	*Energy and matter:* Students learn that the total amount of energy and matter in closed systems is conserved. They can describe changes of energy and matter in a system in terms of energy and matter flows into, out of, and within that system. They also learn that energy cannot be created or destroyed. It only moves between one place and another place, between objects and/or fields, or between systems. Energy drives the cycling of matter within and between systems. (NGSS Appendix G, p. 86)	*Developing and using models:* • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. • Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. (NGSS Appendix F, p. 53)

POINTS FOR CONSIDERATION

- Keeping track of energy when a process is reversed can be difficult for students. In the previous activity, students established that energy is needed to convert molecules in the liquid state to molecules in the gaseous state, but it may be hard for them to then establish that energy is released when water molecules condense.

Activity 2.3 - Teacher Preparation

PREPARATION

Class Time: 60 min.

Materials

- No materials needed.

HOMEWORK

Reading for Activity 2.3: How does breaking apart ATP molecules produce energy for the cell?

Activity 2.3 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introduction

    a. Questions

    b. Discussion

2. Simulation “Pulling molecules apart”

    a. Questions

    b. Discussion

    c. Questions

3. Conclusion

Activity 2.3 (Student materials): How does energy change when evaporation is reversed?

Introducing the Lesson
Revisit the conclusions drawn from the previous two activities and identify what additional questions need to be answered to address the driving question for the investigation, "*What powers a hurricane*?"

Possible questions:

- *Recall the process of electrolysis from Unit 2. What happened to energy when chemical bonds in water were broken?*
- *What happened to energy when H_2 and O_2 reacted to form water ?*
- *What happened to energy when water changed from liquid to gas (vapor)?*
- *How would the energy change that occurs when reversing evaporation (forming intermolecular interactions) compare with the energy change that occurs when forming water from H_2 and O_2 (forming a chemical bond)?*
- *We have been talking about how hurricanes only happen near water. What do you think happens to water molecules during a hurricane?*

The goal of this discussion is to elicit a range of student ideas, so be sure to ask for additional thoughts from students who have not already contributed.

Possible questions:

- *What other ideas do you have? What do you think about the ideas that have been shared?*

Page title:
Introduction

In the previous activity, you looked at how energy changes when water goes from a liquid state to a gas state—a process called *boiling (or evaporation)*. As you may remember, it took much more energy to break bonds than to change water from a liquid to a gas. In this activity, we will look at energy changes that occur during the reverse process, when water changes from a gas state to a liquid state. This process is called *condensation*.

1. [prediction question] When water vapor condenses to liquid water, do you think energy is transferred into or absorbed from the surroundings?

Student responses:

- Energy is transferred into the surroundings when water condenses. Water molecules move closer to each other and form intermolecular interactions through interactions between partial charges. Energy is released and transferred to the surroundings when these interactions are formed.
- It takes energy to boil water. Since condensation is the reverse process, energy is transferred into the surroundings during the process.

2. [drawing prompt] Draw a diagram to show what happens to water molecules during condensation. [text prompt] Describe what is happening to the water molecules shown in your diagram.

Student responses: Water molecules that are in the form of a gas should be far apart from other water molecules, but they should still be shown as H_2O molecules. In the liquid state, the water molecules are close to each other. The diagram should indicate that as molecules are condensing, water molecules are coming closer to each other and forming intermolecular interactions through partial charges on oxygen (partial negative charge) of one molecule and hydrogen (partial positive charge) on the adjacent water molecule.

- Condensation is the transition from a gas to a liquid. As water molecules are condensing from gas to liquid, they are moving closer to each other and forming intermolecular interactions between the partially positive hydrogen atom from one molecule and the partially negative oxygen atom of another molecule.

Discussion: Discuss students' predictions about what happens to energy when water condenses.

Possible questions:

- *Did you predict that energy is transferred into or absorbed from the surroundings during condensation? Why?*
- *Does anyone have any similar ideas?*
- *Different ideas?*

3. During a hurricane, water vapor in the air forms raindrops. When raindrops form, what is happening to water molecules at the atomic level?

Student responses:

- Water molecules move closer to each other and condense to form liquid.

Page title:

Pulling molecules apart

Explore the simulation. Notice how the energy change differs depending on whether you are moving polar water molecules close to each other or away from each other.

Simulation link: http://lab.concord.org/interactives.html#interactives/interactions/comparing-potential-energy-of-bond.json

4. In the simulation, what happens to the potential energy of the polar molecules when they are moved closer together?

Student responses:

- The potential energy of the polar molecules decreases when they are moved closer together.

5. Use the simulation to compare what happens to the potential energy of polar and nonpolar molecules when they are moved closer together and explain your observations.

Student responses:

- The potential energy of polar molecules decreases more than potential energy of nonpolar molecules when they are moved closer together. This is because the amount of energy stored in the system depends on the magnitude of charge and distance between charges. Since we are moving molecules by approximately the same distance, in this case the amount of energy stored in the system is only affected by the amount of charge. The amount of charge in the system of polar molecules is larger because of the permanent charge separation within polar molecules as a result of difference in electronegativity of atoms that make up the molecule. The amount of charge in the system of nonpolar molecules is smaller because temporary induced partial charges resulting from the movement of electrons are smaller than charges in polar molecules.

6. Recall that energy can be neither created nor destroyed. If the potential energy changes when water molecules are brought closer together, what else must happen in order for the total amount of energy to be conserved?

Student responses:

- When water molecules are brought together, the energy has to transfer to the surroundings.

7. What happens to the surroundings (the air around the water molecules and the energy of the molecules in the surroundings) when the water molecules condense to form a liquid?

Student responses:

- The surroundings gain energy from the condensing water. The air molecules are moving faster, and the air warms up.

Discussion: Discuss students' observations of the simulation and ask them to share their answers.

Possible questions:

- *What happens to the potential energy of the system and the surroundings when water molecules move close together?*
- *What other ideas do you have that are similar to what has already been discussed? What ideas do you have that are different?*

Ask students to think about how their refrigerator works at home.

Possible questions:

- *You have concluded that energy is released into the surroundings when water condenses from vapor to liquid. Do you think this energy flow would be true for other substances? Why or why not?*
- *What happens to the temperature of the surroundings when substances condense from vapor to liquid?*
- *If you ever touch the back of your refrigerator, you will notice that it is warm. Why do you think the back of the refrigerator is warm?*
- *Why is the inside of the refrigerator always cold?*

Discussion: Revisit the unit driving question, *What powers a hurricane?* and discuss how the evidence from this activity adds to the answer to that question.

Possible questions:

- *What happens to energy when water vapor forms raindrops in a hurricane?*
- *In a hurricane, there is a lot of wind, which causes destruction. Wind means there is a lot of kinetic energy in the air. Where does this kinetic energy come from?*

Page title:
What powers a hurricane?

8. [drawing prompt] Draw a model to explain what powers a hurricane. Your model should include what happens to water molecules and energy during a hurricane. Draw energy bar graphs to represent how energy changes during a hurricane.
[text prompt] How does your model explain what powers a hurricane?

Student responses: Students' models should focus on water molecules condensing from vapor to liquid and releasing energy in the process. Models should indicate that as water condenses, water molecules are coming closer together, forming intermolecular attractions. Students' energy bar graphs should indicate an energy flow from water molecules to the surroundings. They should show that energy is released and transferred into the surroundings when intermolecular interactions are formed. The total amount of energy should be conserved.

- When water molecules are condensing to form liquid water, they form intermolecular interactions through partial charges on oxygen and hydrogen atoms in adjacent water molecules. The formation of these interactions decreases the energy of the system, and excess energy is released and transferred into the surroundings. This energy is what powers a hurricane.

9. Since the change in energy when water molecules interact is smaller than the change in energy associated with forming bonds, why is so much energy released and transferred into the surroundings during a hurricane?

Student responses:

- There are a lot of water molecules all condensing into water drops during a hurricane, so even though one water molecule interacting with another does not add much energy, all of the interacting molecules add up to a lot of energy.

10. Imagine that in a hurricane, instead of water molecules condensing to form water drops, hydrogen and oxygen gas reacted to form the same number of water drops. What would happen?

Student responses:

- The hurricane would be much more destructive because it would have much more energy. This is because the energy released and transferred into the surroundings when a chemical bond between oxygen and hydrogen forms is much greater than the energy released into the surroundings when water condenses to form liquid.

11. In Unit 1, you did several labs to explore the interactions between electrically charged objects. For example, you pulled pieces of tape apart and rubbed balloons and rods with fur. These labs do not work as well on humid or rainy days. On humid or rainy days, when a lot of moisture is in the air, objects tend to lose their charge quickly. Use your explanations of what was happening in the labs and your understanding of water molecules and water vapor to predict why charged objects lose their charge quickly on humid or rainy days.

Supplemental content: On a humid day, there are a lot of water molecules in the air. Since water molecules are polar, partial charges on water molecules can interact with charged objects. These interactions (water molecules bumping into charged objects) might knock electrons off charged objects. If all, or a significant amount, of an object's excess electrons are lost to water molecules in the air, the object loses charge and becomes neutral. This is why some experiments do not work as well on humid days.

Clarification - Students' answers will vary, but students should try to connect the following ideas: 1) water molecules are polar, 2) on humid days there are water molecules in the air, and 3) charge can be transferred when objects interact.

Student responses:

- Water molecules are polar, so water molecules in the air would be attracted to a charged object. If a water molecule in the air bumps into a charged object, some of the electrons could be transferred, which would decrease the charge on the object.

Concluding the Lesson
Ask students to share their answers about what would happen if oxygen and hydrogen reacted to form water in a hurricane.

Possible questions:

- *What did you predict would happen if oxygen and hydrogen reacted during a hurricane? Why?*
- *How does the energy change that occurs when oxygen and hydrogen react compare with the energy change that occurs when water condenses from gas to liquid?*
- *What ideas do you have that are similar? What ideas do you have that are different?*

Revisit the unit driving question, *What powers a hurricane?* and ask students to share their models of what powers a hurricane.

Possible questions:

- *According to your model, how is water involved in producing hurricanes?*
- *What is the energy source for the powerful winds in a hurricane?*
- *What happens to water molecules during a hurricane?*
- *What if the ocean was made of hexane? How would that affect the power of the hurricane? Include ideas of polarity and electronegativity in your answer.*

Connect Unit 3 to previous units by discussing how water molecules in the air could impact charged objects.

Possible questions:

- *Why might water molecules interact with charged objects?*
- *How do objects get charged?*
- *How might water molecules in the air cause objects to lose their charge?*

HOMEWORK

Reading for Activity 2.3: How does breaking apart ATP molecules produce energy for the cell?