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INVESTIGATION 1: Why is water special?

Overview

In Unit 2, students analyzed interactions between atoms and changes in energy as the distance between atoms changed. In this unit, students will analyze interactions between molecules and the changes in energy that occur as the distance between molecules changes. The driving question for this unit is, *What powers a hurricane?* Students will start by looking at the properties of different liquids to identify patterns related to the structure of the molecules that make up the liquids. . Investigation 1 begins with a demo showing that a thin stream of water will bend toward a charged rod but that not all liquids have this property. Throughout Investigation 1, students will explore the properties of water and try to determine how the structure of water molecules can be used to explain and predict the properties of water. In Investigation 2, students will look at the relationship between energy, the structure and properties of molecules, and interactions between molecules in order to explain why hurricanes are so powerful.

The Performance Expectations (NGSS)

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, p. 92 - 93)	**Connections to this investigation**
Elements of Disciplinary Core Idea	
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 start by analyzing data about various liquids, their molecular structure, and their properties. From this, students notice that molecules that contain oxygen tend to have different properties than similar molecules without oxygen. Students use electron distribution and interactions between charges to explain why molecules with oxygen (or other atoms that have high electronegativity) have higher boiling points, melting points, and viscosity, and will attract charged objects. Students use their understanding of interactions between charged subatomic particles and of atomic structure to explain specific properties of liquids.

<table>
<tr><th colspan="2">Crosscutting concept</th></tr>
<tr><td>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.</td><td>Students analyze data about properties of substances and data from simulations to identify patterns connecting the structure of the molecules that make up a substance and the properties of that substance. Students also identify patterns connecting the atoms within a molecule and the properties of that molecule (e.g., electron distribution and polarity).</td></tr>
<tr><th colspan="2">Science and engineering practice</th></tr>
<tr><td>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.</td><td>Students do not plan their own investigation, but they do analyze a large amount of data, reflect on how the data help them answer the driving question for the unit, and identify other information they need in order to answer the driving question. Students need support and practice with planning their own investigations, but using increasing amounts of data to make claims and reflecting on what else is needed to answer questions help prepare them for designing their own investigations.</td></tr>
</table>

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

- *Given an atom's electronegativity, students will make and support claims about the polarity of molecules. (Clarification: Molecules for which the geometry is an important contributor to the cancellation of the dipole moment will be avoided.)*
- *Predict how electron distribution within molecules affects the way molecules interact with each other.*
- *Predict and explain the effect that differences in polarity of molecules of a substance have on observable phenomena.*

Overview

Background Knowledge

Atoms that make up molecules in different substances are held together in chemical bonds. Chemical bonds are formed by the sharing of electrons between the atoms, and these electrons are shared differently depending on the properties of the atoms in the bond. Some atoms have a higher affinity for electrons than others. This property of attracting electrons is called electronegativity. If atoms with similar or identical electronegativity values form a bond, electron density will be equally distributed between the atoms in the bond. However, if atoms with different electronegativity values are involved in forming a bond, electron density between atoms in the bond will shift toward atoms with higher electronegativity. This unequal electron cloud distribution occurs in polar bonds. These electron density shifts create partial charges in polar molecules, and these partial charges affect how molecules interact with each other. In particular, molecules with polar bonds will have a higher affinity toward each other due to the partial charges, and therefore will require more energy to break them apart. This results in certain patterns in observable macroscopic properties, including higher boiling points, longer evaporation times, and higher viscosity values.

Activities

Activity 1.1	*How are water and other liquids similar and different?*	*120 min.*
Activity 1.2	*Why is water different from other liquids?*	*150 min.*
Activity 1.3	*Is oxygen really that special?*	*70 min.*
Activity 1.4	*How does electron distribution impact our observations?*	*60 min.*

Activity 1.1: How are water and other liquids similar and different?

SUMMARY

In this activity, students are introduced to the driving question for Unit 3: *What powers a hurricane?* Students then make observations and ask questions about water and how it powers hurricanes. In Units 1 and 2, students developed and used a model that includes interactions between charged pieces of atoms to explain phenomena. In this activity, students will observe that a thin stream of water and acetone both bend toward a charged rod but that a stream of hexane does not. Students will ask questions to see if their model of atomic interactions could be used or modified to explain these new observations, keeping in mind that the most useful models are able to explain a wide variety of observations. In the following activities, students will analyze data on properties of substances to look for patterns and note that compounds that have oxygen do not follow the same patterns as compounds that do not have oxygen. Then they will apply the ideas they used previously for explaining bonding to also explain interactions between molecules (intermolecular forces).

Note on the driving question for Unit 3:

In the question, *What powers a hurricane?* we are using the term *power* colloquially. This is different from how the term *power* is used in physics. In physics, power is the rate of energy transfer per unit time. In this unit, students are not calculating the amount of power associated with a hurricane. Instead, students are describing the energy transfers that occur during a hurricane. In particular, students develop a model for the changes of energy due to the interactions between water molecules as the water changes phases. This is an initial piece of calculating the power associated with hurricanes, but students do not analyze the rate per unit time.

Activity 1.1 - Teacher Preparation

LEARNING GOAL

Students will make observations of properties of liquids and ask questions about those observations.

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)	*Cause and effect:* Students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena. They recognize that classifications or explanations used at one scale may not be useful or may need revision using a different scale, thus requiring improved investigations and experiments. (NGSS Appendix G, p. 82)	*Asking questions and defining problems:* • Ask questions ○ that arise from careful observations of phenomena, or unexpected results, to clarify and/or seek additional information and relationships. ○ to clarify and refine a model, an explanation, or an engineering problem. • Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory. (NGSS Appendix F, p. 51)

POINTS FOR CONSIDERATION

- Part of this investigation involves developing a model to explain the differences between liquids and gases. The particles in liquids, like in solids, are packed tightly together. The particles in gases are spread apart. However, students often imagine that the particles in solids are tightly packed, the particles in liquids are somewhat spread out, and those in gases are very spread out. The misunderstanding of these different states as a continuum is often represented in textbook images of liquids, solids, and gases, making it even more important to clarify in the classroom. In reality, the particles in liquids are also tightly packed, but are moving more freely than the particles in solids.

PREPARATION

Class Time: 120 min.

Materials (for each group)

- syringe filled with water and sealed (1 per group)
- syringe filled with air and sealed (1 per group)

Materials (for the whole-class demonstration)

- 4 burettes
- 3 large beakers
- 4 burette clamps
- 4 ring stands
- 2 pieces of parafilm wax or stoppers the size of the burette

- water (50–100 mL)
- acetone (50–100 mL)
- hexane (50–00 mL) **Note:** Any nonpolar liquid can be used, such as toluene or odorless mineral spirits
- Teflon rod
- balloon
- fur
- glass rod
- silk

Activity Setup

- Attach the burette clamps to the four ring stands and use the clamps to hold the burettes.
- Pour water into two of the burettes, pour acetone into the third burette, and pour hexane into the last burette.
- Label the burettes.
- Cover the tops of the burettes containing acetone and hexane with parafilm wax or a stopper to minimize evaporation while not in use.

SAFETY ISSUES

Hexane and acetone are flammable and volatile liquids. They should not be used near open flames or near equipment that could cause sparks. Additionally, the fumes can be hazardous if inhaled. Hexane and acetone should only be used in a fume hood or well-ventilated area. Additionally, all containers should be tightly capped when not in use.

Activity 1.1 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Liquid versus gas
    a. Hurricane video & discussion
    b. Initial ideas
    c. Lab
    d. Driving question and discussion
2. Observations of liquids
    a. Demonstration
    b. Questions
3. Models of liquids
    a. Initial ideas
4. Conclusion

Activity 1.1 (Student materials): How are water and other liquids similar and different?

Introducing the Lesson

Students have spent time developing a model of atomic interactions and used that model to explain observations of various materials after charging them and of materials that cause explosions. Does this model of atomic interactions work to explain other interactions as well? Remind students that the most useful models can be used to explain a range of phenomena. Let students know we will pose a new question to see if our model can be useful in new situations as well.

Possible questions:

- *We started by looking at why some clothes stick together when coming out of the dryer, and then we looked at what causes explosions. What model have we developed to explain these phenomena?*
- *Explosions cause a lot of damage to objects around them. From what we discussed in the last unit, how can we explain why explosions cause so much damage? What else can we add to that?*
- *Remember that the most useful models can explain a range of phenomena. Can you give examples of additional phenomena you think our model of atoms could explain?*

Set the context for the driving question for Unit 3 by discussing hurricanes. You could use a video that shows the destructive forces of hurricanes. This is a good example from NOAA: http://oceantoday.noaa.gov/hurricanestormsurge/ If you use a different video that you found online, try to use one that shows the powerful winds as well as the storm surge but does not include an explanation of how hurricanes form or where the powerful winds come from. After setting the context, ask students about how their model explains this type of destruction.

Possible questions;

- *What about hurricanes? Do you think the structure of atoms could explain why hurricanes are so powerful? Do you think a chemical reaction is occurring during storms like hurricanes? Does anyone disagree?*

Note: At this point, students do not need to agree on whether or not an atomic model is useful for explaining the powerful force of hurricanes.

Keep in mind that throughout the discussion, the goal is to elicit a variety of student ideas. Ask follow-up questions to get students to explain their thinking and to elicit ideas from a range of students.

Possible questions:

- *What do you mean by that?*
- *Can you elaborate?*
- *Does anyone have a different idea?*
- *[Student's name], what do you think of that idea?*
- *What can you add to that idea?*

Introduce students to the driving question for Unit 3: *What powers a hurricane?* Ask students what they know about hurricanes. Through the discussion, draw out the idea that water plays a large role in hurricanes. This will help lead to the activity-level question: *How are water and other liquids similar and different?*

Possible questions:

- *What do you know about hurricanes?*
- *What patterns do you notice about where hurricanes occur? Would you expect to have a hurricane in, for example, Nebraska? Why or why not? What about in Florida? Why or why not?*
- *What happens during a hurricane? What happens to water during a hurricane?*

Note on the driving question for the unit:
As noted at the beginning of this Investigation, we are using the term *power* colloquially in the driving question for Unit 3, *What powers a hurricane?* In physics, power is the rate of work per unit time—in other words, the rate of energy transfer per unit time. In this unit, students will not actually be calculating power or discussing the rate with respect to time. Students will be identifying the energy transfers that occur during a hurricane.

Page title:
Liquid versus gas

1. **[drawing prompt] During a hurricane, water in the air condenses into drops of liquid water. How does water in liquid form compare with air? Draw a diagram to show what you think the difference is between molecules of water in liquid form and molecules of water in gas form.**

Student responses: The questions in this first activity are provided to elicit students' ideas. Students' answers will vary. It is good to review and discuss these answers, but do not evaluate them. At this point, students do not have enough evidence to decide if some answers are better than others.

- Students may draw water molecules farther apart in the gas phase.
- Students may draw hydrogen and oxygen molecules or atoms in the gas phase.

Materials

- sealed syringe filled with water
- sealed syringe filled with air

Record the position of each syringe in the first column of the table below. Then test how far you can compress the materials in each syringe.

2. Record the measurement on the syringe before you compress the plunger and when it is being compressed.

	Before compression	During compression
Water		
Air		

https://interactions-resources.concord.org/unit3/saving-html-state/syringe-compression.html

Tip: Students may believe they are able to compress the water a small amount (see Points for Consideration above for more information). You may need to remind them to pay attention to the scale on the syringe rather than to their assumptions or interpretations. They may be feeling the stem of the plunger flexing a bit under the pressure from their hand and interpret that as the particles of water being compressed more tightly together. In fact, the water molecules are already packed tightly together and cannot be compressed at all by the plunger.

[snapshot prompt] Take a snapshot of your data table.

Student responses: Students' data tables should show the same volume of water before and during compression, but a significant difference in the volume of air.

3. [drawing prompt] Draw an atomic-level model of liquid water and air that could explain your observations.

[text prompt] Describe how your model explains your observations.

Student responses: Students' models should show a particle-level or atomic-level representation. The model should be able to explain why the air could be compressed but the water could not be compressed. For example, students could use the distance between particles to explain why it is possible to compress air (the particles are far apart) but not liquid (the particles are already packed together).

Discussion: Display students' models and discuss how well the models can explain their observations of the syringes.

Possible questions:

- *How are liquid water and air shown in this model?*
- *How does this explain our observations of the syringes in the two conditions?*
- *If the molecules in the water/air were actually arranged as shown in this model, would you predict that you could compress the water/air?*

Discussion: Return to the driving question: *What powers a hurricane?* Discuss what the activity adds to students' understanding about what happens during a hurricane and add some additional questions. Through the discussion, gather students' predictions about whether water is special or whether using any liquid would lead to similar observations.

Possible questions:

- *Where does all the water in a hurricane come from?*
- *In Unit 1, we observed ethanol and what happens when water and ethanol mix. What if the oceans were full of ethanol instead of water, do you think we would still observe powerful hurricanes near the oceans? Why or why not?*
- *Is there something special about water or could any large body of liquid lead to storms like a hurricane?*

Add the activity-level driving question to the driving question board: *How are water and other liquids similar and different?*

Page title:
Observations of liquids

Demonstration
Have students observe what happens when a charged rod and charged balloon are brought close to streams of water, acetone, and hexane (or an alternative to hexane: toluene or odorless mineral spirits). Use a burette to get a thin stream of each liquid. Run the three streams of liquid one at a time. For the acetone and hexane, be sure to remove the seal on the top of the burette while the stream is running and then replace the seal when done. Charge the teflon rod using fur to make the teflon rod negatively charged. Bring the rod near each stream of liquid. Make sure to recharge the rod before bringing it to each liquid. The water should bend noticeably, the acetone may bend slightly, and the hexane should not be affected at all (or very little). Then, charge the balloon using fur to make the balloon negatively charged. Bring the balloon near each stream of liquid. Make sure to recharge the balloon before bringing it to each liquid. Just like with the charged rod the water should bend more than acetone, but the overall magnitude of bending should be more for both water and acetone due to the fact that balloon is larger than rod and therefore has more charge. The hexane should now bend slightly towards the balloon, because the interaction is amplified by the larger charge on the balloon. To see the demo, watch the following video: Bending solvents.

Note: If you use a substitute for hexane, let the students know that you have substituted a different substance, but that it has a similar molecular structure to hexane.

Discuss students' observations and what may have caused the phenomena and the difference in observations for the rod and the balloon.

Possible questions:
- *What did you observe?*
- *How were the liquids similar or different?*
- *What did you notice about the behavior of the liquids when we tested them with the balloon and the rod?*
- *Why did the balloon and the rod cause the liquids to behave differently?*
- *Which object has more charge: the rod or the balloon? Why?*
- *Why might water behave the way it did?*
- *Why might hexane behave in a different way with the rod than with the balloon?*

As students identify possible causes, test their ideas as appropriate. For example, if students speculate that water has a charge, conduct some additional demos to test this.

Possible questions:

- *How could we test that?*
- *If water is charged, what should happen when two streams of water are near each other?*

Test the idea that water is charged by filling a second burette with water. Show that water does not attract or repel when two streams are placed near each other. Try testing the water with a positively charged object as well (such as glass after it has been rubbed vigorously with silk or a plastic bag).

Possible questions:

- *Does our evidence indicate that the water is charged or neutral?*
- *What questions could we ask to help us develop an explanation of why water behaves differently than hexane and acetone?*
- *What questions could we ask to help us develop an explanation of why hexane behaves differently with the rod and the balloon?*

Note: By the end of this activity, students should come to the conclusion that water and acetone are neutral

The following video provides some examples of these demos: Testing streams of water.

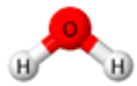
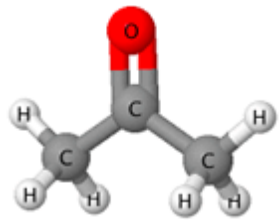
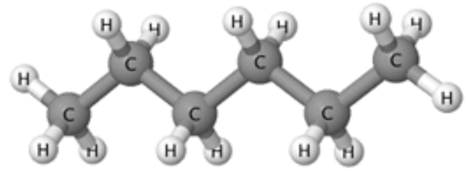
4. Record your observations of the demonstration involving a charged rod and charged balloon and the streams of liquid.

Potential answers: Make sure students record all observations from the demonstration.

- The water bends more toward charged balloon than towards the charged rod. Acetone bends slightly, but not as much as water. The magnitude of bending is larger when tested with the balloon than the rod. Hexane does not bend when tested with the rod and bends slightly when tested with the balloon. Two streams of water near each other do not bend.

Note: If the ideas that were brought up during the discussion lead to additional tests with the streams of liquid, emphasize to students that they should record all their observations of the various tests in their answer above.

The table provides ball-and-stick models for water, acetone, and hexane.

Compound	Water	Acetone	Hexane
Formula	H_2O	C_3H_6O	C_6H_{14}
Ball-and-stick model			

5. Based on the models, what do you think might affect whether or not a liquid bends toward a charged object?

Supplemental content: The water and acetone molecules are both polar molecules - meaning the oxygen atom in the molecule tends to have a small negative charge leaving other regions of the molecule with a small positive charge. These small, or "partial", charges interact with the electric field of the charged rod. Students will be developing this model throughout this investigation. At this point, they should just see any differences they notice between the hexane molecule and the water and acetone molecules.

Clarification - students are not expected to know polar or partial charges at this point.

Student responses: Answers will vary. Students may note that the two liquids that were affected by the charged rods both have oxygen, but it is not really enough data at this point to determine if this is a consistent pattern.

- Water and acetone both bent towards the rod and both have oxygen.
- Hexane did not bend or only bent a little and it is a lot bigger than the other molecules.

6. What questions do you think need to be answered in order to be able to explain why the water and hexane behaved differently during the demonstration?

Student responses: Students will develop a range of questions. Students may record questions that were raised but not answered in the discussion or vague questions. Push students to think of what evidence they would need to help them develop more specific questions.

- How is the rod different from the balloon?
- How can we compare amount of charge on the rod and the balloon?
- Why does the amount of charge on the rod and the balloon effect behavior of liquids?
- Why are water molecules charged and hexane molecules not charged or only charged a little?
- How do you charge a molecule?
- Why does having oxygen on a molecule make it interact more with a charged object?

Conclusion
Review student’s answers to the previous two questions. Add some of them to the driving question board. Indicate that students will be exploring some of these questions as the unit progresses.

Activity 1.2: Why is water different from other liquids?

SUMMARY

In the previous activity, students observed some properties of different liquids, focusing on charges. They observed demonstrations and concluded that water and acetone are neutral. They also looked at ball-and-stick models of liquids and started discussing how structure might relate to properties. In this activity, students will continue to investigate how the structure of molecules might be connected to their properties. Students will compare the viscosity, boiling point, and speed of evaporation of various liquids. Based on these comparisons, they will make predictions about the properties of oxygen-containing molecules. This will help students further investigate what effect oxygen has on the structure and properties of oxygen-containing molecules, including water. Eventually, students will use these properties to explain why water molecules stick together, and what happens during a hurricane.

LEARNING GOAL

Students will analyze data to identify patterns in properties of substances based on the composition of molecules of the substance.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Types and properties of interactions: The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (NGSS Lead States, p. 92)	*Patterns:* Students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena. They recognize that classifications or explanations used at one scale may not be useful or may need revision using a different scale, thus requiring improved investigations and experiments. (NGSS Appendix G, p. 82)	*Analyzing and interpreting data:* • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. • 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

- In this activity, we are using oxygen-containing molecules as an example of polar molecules. Therefore, in their explanations, students might equate the presence of oxygen in a molecule with polarity. To avoid this over-simplification, make sure to emphasize that polarity is related to differences in the electronegativity values of the atoms making up a molecule, and that oxygen-containing molecules are examples of polar molecules because oxygen has higher electronegativity than the other atoms in the molecules being discussed.
- Students often have difficulty relating structure to properties. When they are explaining their answers about properties of substances, make sure they explicitly relate properties

to the structure of molecules, which in this activity will mostly be focused on structure containing oxygen.

PREPARATION

Class Time: 150 min.

Materials (for the first whole-class demonstration)

- 2 beakers
- honey
- water

Materials (for the second whole-class demonstration)

- plastic sheet
- pipette
- hexane
- stopwatch

Materials (for each group)

- plastic sheet
- 2 pipettes
- acetone
- water
- 2 stopwatches

Activity Setup

- Prepare containers of water and acetone for the groups. Make sure the acetone is in a container that can be capped or sealed.

SAFETY ISSUES

Hexane and acetone are flammable and volatile liquids. They should not be used near open flames or near equipment that could cause sparks. Additionally, the fumes can be hazardous if inhaled. Hexane and acetone should only be used in a fume hood or well-ventilated area. All containers should be tightly capped when not in use.

Activity 1.2 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes for your lesson

1. Why is water different from other liquids?
    a. What makes honey different from water?
    b. Demonstration
    c. Discussion
    d. Introduce “viscosity”
2. Why do some liquids evaporate faster than others?
    a. Demonstration
    b. Lab
    c. Data analysis
    d. Discussion
3. Comparing boiling points and viscosities of different liquids
    a. Data analysis
    b. Discussion

Activity 1.2 (Student materials): Why is water different from other liquids?

Introducing the Lesson

In the previous activity, students looked at properties of different liquids when they interact with a charged rod. They concluded that water, hexane, and acetone are neutral, but interact with charged rod in different ways. They also started looking at the chemical structure of those compounds to help determine why their properties might be different. In this activity, students will further explore connections between the structure and properties of different compounds, including water. They will continue to investigate what makes water properties special to help explain how water is involved in powering hurricanes.

Possible questions:

- *Why do you think a stream of water might bend toward a charged object?*
- *Why do you think a stream of hexane might bend towards a charged object?*
- *What other properties of liquids can you think of?*
- *Do you think the chemical structure of liquids might relate to their properties? Explain your answer.*
- *Do you think molecules of water interact with each other? Explain your answer.*

Page Title:
What makes honey different from water?

Watch your teacher conduct the demonstration involving honey and water. Observe the demo carefully because your observations will help you ask and answer questions during the discussion.

Demonstration
Pour the honey and water into two different beakers. Have students observe how pouring honey is different from pouring water.

Ask students to share what, in their opinion, makes honey different from water. Point out that the thickness of honey can be described by a scientific term: *viscosity.* Therefore, another way of saying "Honey is thicker than water" would be "Honey is more viscous than water."

Possible questions:

- *What do you observe when honey is being poured and when water is being poured?*
- *How did the honey and water compare?*
- *What are examples of other liquids that are more viscous than water?*
- *Can you think of liquids that are less viscous than water?*
- *How can you tell that something is viscous?*
- *What do you think makes a liquid viscous?*

1. **Based on your observations, what is different about honey being poured than water being poured?**

Student responses:

- The honey pours more slowly.
- The honey is thicker

Page title:

Why do some liquids evaporate faster than others?

Materials (for each group)

- plastic sheet
- 2 pipettes
- acetone
- water
- 2 stopwatches

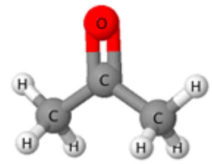
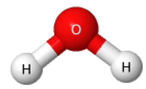
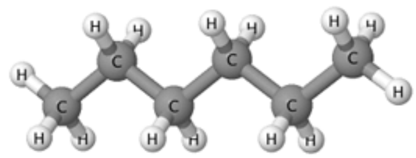
In the table, record the time it takes for hexane to evaporate when your teacher tests it. Then conduct the following test to see how long it takes acetone and water to evaporate.

Use a pipette to place five drops of water on one spot on the plastic sheet. Start one of the timers. As you are waiting for the water to evaporate, repeat with acetone by using the other pipette to place five drops of water on a different spot on the plastic sheet, and then start the other timer. Watch carefully to see when each liquid dries up, and at that time, stop the appropriate timer. Record the results in the table.

Demonstration

Students will test how long it takes for acetone and for water to evaporate. First, demonstrate the evaporation of hexane for the class.

Use a pipette to place five drops of hexane on the plastic sheet and time how long it takes for the hexane to evaporate. It would be best to do this in a fume hood, if possible. Have students test acetone and water using the same procedures you used to test hexane. To avoid building up too many hexane vapors in the classroom, students should not test hexane in their groups.

Type of Liquid	Molecular Shape	Time to Evaporate (minutes)
Acetone		
Water		
Hexane		

https://interactions-resources.concord.org/unit3/saving-html-state/evaporation-table-save-state.html

2. Take a snapshot of your data table.

3. Compare the evaporation times of the three different liquids.

Student responses: Students should compare all three liquids.
- Hexane evaporates faster than acetone, and acetone evaporates faster than water.
- Hexane is the fastest
    - *Push students to compare all of the liquids by asking how the acetone and water compare.*

The table below provides some data about the liquids we have tested. For each liquid, the table shows:
- heat of evaporation (the amount of energy it takes to transform a particular liquid into gas)
- molar mass (a way to measure the mass of a molecule),
- boiling point, and
- viscosity.

Use this table to answer the questions.

Molecular Formula	**Heat of Evaporation** (kJ/mol)	**Molar Mass** (g/mol)	**Boiling Point**	**Viscosity** (mPas)
C_3H_6O Acetone	31.3	58.08	56°C (132.8°F)	0.32
H_2O Water	40.7	18.02	100°C (212°F)	0.89
C_6H_{14} Hexane	28.5	86.18	68°C (154.4°F)	0.30

4. [drawing prompt] Draw bar graphs for the time of evaporation and heat of evaporation for the three liquids.

Student responses: Students' graphs should indicate that the heat of evaporation is highest for water and the water took the longest to evaporate. Similarly, the hexane has the lowest heat of evaporation and took the shortest amount of time to evaporate.

5. Describe any patterns you can identify from your graphs.

Student responses:

- Yes. As heat of evaporation increases, the time of evaporation also increases.

6. Based on your observations and the data provided in the table, what are the differences between water, acetone, and hexane?

Student responses: Students are not expect to explain the data at this point, just identify patterns.

- Hexane has a really low boiling point, fast evaporation time, and low viscosity. The chemical formula for hexane doesn't contain oxygen. Acetone and water both contain oxygen as part of their chemical structure. Acetone and water have higher viscosities than hexane.

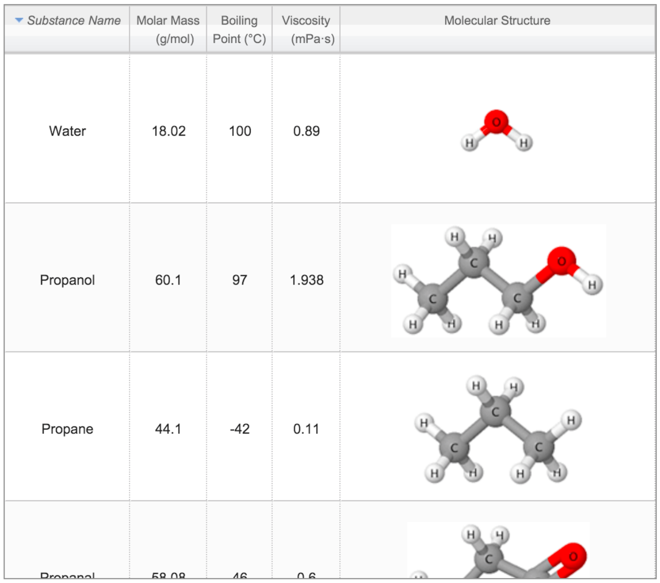
Discussion: Ask students to share their explanations of the observed patterns from the previous question. Encourage them to think of what happens at the molecular level during evaporation.

Possible questions:

- *What happens to (the distance between) molecules as they change from liquid to gas?*
- *What patterns do you notice about the different molecules and how quickly they go through this change?*
- *What might be a reason that some molecules evaporate more slowly than others?*
- *Is evaporation similar to any other process we have talked about in this class?*

Page title:
Comparing boiling points and viscosities of different liquids

The table shows the boiling point, viscosity, and molecular structure for different substances. Look through the table and try to find some patterns that would connect molecular structure to these properties. NOTE: you can click on the column titles to sort the data using that property.



Substance Name	Molar Mass (g/mol)	Boiling Point (°C)	Viscosity (mPa·s)	Molecular Structure
Water	18.02	100	0.89	
Propanol	60.1	97	1.938	
Propane	44.1	-42	0.11	
Propanal	58.08	46	0.6	

Here's a link to the table that can be embedded: https://interactions-resources.concord.org/unit3/sortable-table/examples/sorting-properties.html

8. Compare propane and propanol, which both have three carbons. What do you notice about the boiling points and viscosities of these two substances?

Student responses: Students are not expected to explain or understand the differences, just notice and compare the properties.

- Even though the substances have similar formulas (C_3H_8O for propanol and C_3H_8 for propane), their boiling points and viscosities are very different.

9. Select at least two other pairs of compounds with similar formulas and describe how their properties compare.

Student responses: Possible pairs that students may choose include: hydrogen sulfide (H_2S) and water (H_2O), isopropanol (C_3H_8O) and propane (C_3H_8), propanal (C_3H_6O) and butane (C_4H_{10}). Students' answers should include that oxygen-containing compounds tend to have higher boiling points and viscosities when compared with similarly structured compounds that don't contain oxygen. For example:

- Hydrogen sulfide and water have the same shape and both have two hydrogens. water has an oxygen where hydrogen sulfide has a sulfur. Water has a smaller mass but higher viscosity and boiling point.

Tip: You may want to check to make sure students are choosing a variety of pairs, so the class can share and discuss the different combinations that were selected.

10. Describe any patterns that show a relationship between the molecular structure of the compound and its properties.

Student responses:

- If the molecular structure contains oxygen, the boiling point and viscosity are significantly higher than if the structure does not contain oxygen.

11. Based on the data, predict whether propane, propanol, or both will bend toward a charged rod. Support your answer with evidence.

Student responses:

- Propanol will bend toward a charged rod. It has a high boiling point, has a high viscosity, and contains oxygen, which makes it similar to water. Therefore, it will bend toward a charged rod. Propane will not bend toward a charged rod or bend just a little because it has properties similar to hexane, including a low boiling point and an absence of oxygen.

Discussion: Ask students to share their conclusions about properties of compounds based on the two pairs of compounds they chose for the question above. See if students notice any patterns and ask them to share ideas about what might explain those patterns. Suggest that oxygen might be involved in explaining the different properties. Ask them whether they think energy might be involved in explaining the observed patterns.

Possible questions:

- *What is similar about the molecular structures of molecules with high boiling points and viscosities?*
- *What is it about oxygen that might cause molecules containing oxygen to have higher boiling points and viscosities?*
- *How do you think oxygen-containing liquids would interact with a charged rod?*
- *How do you think molecules that don't contain oxygen would interact with a charged rod?*

Activity 1.3: Is oxygen really that special?

SUMMARY

In the previous activities of this investigation, students identified patterns in the relationships between the molecular structure of a substance and the observable properties of that substance. Students noted that molecules containing oxygen seem to have different properties than similar molecules that do not contain oxygen. In this activity, students will explore simulations as an introduction to the ideas of electronegativity and polarity. Students will use these ideas to begin developing an explanation for the patterns they noted in the previous activities, and for what is happening when water molecules interact with each other. In the next investigation, students will add the idea of energy to this explanation in order to answer the driving question about what powers a hurricane.

LEARNING GOAL

Predict how electrons are distributed within molecules and, based on this distribution, the polarity of the molecule. (Clarification: Students will not be asked to explain why a symmetrical molecule with polar bonds can be non-polar overall.)

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Types 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)	*Cause and effect:* Students suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems. They recognize changes in systems may have various causes that may not have equal effects. (NGSS Appendix G, p. 83)	*Obtaining, evaluating, and communicating ideas:* Communicate scientific and/or technical information or ideas (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, mathematically). (NGSS Appendix F p. 65)

POINTS FOR CONSIDERATION

- The terms *electronegativity* and *polarity* refer to abstract ideas since we cannot see these processes. Electronegativity is a measurement of the tendency of an atom to have a stronger attraction with electrons in a bond. Atoms that have higher electronegativity will have a higher electron density around them. Polarity is an unequal distribution of electrons across an atom due to differences in electronegativity. Students may have a tendency to say the reason for an observation is “because of the polarity” or “because of the electronegativity.” Make sure to push students to fully explain what is happening and how that connects to the observation rather than accepting the term as a complete answer.
- Some molecules, while being made of polar bonds, may be nonpolar overall. For example, carbon dioxide has two polar bonds (since oxygen has a higher electronegativity than carbon). However, since the two oxygens are on opposite sides of the carbon, the polar bonds “cancel each other out,” leaving the molecule nonpolar overall. Molecules like this, in

which the polarity of the molecule depends on its geometry as well as the bond polarity, are not used as examples in this curriculum since students have not been asked to predict the geometry of molecules.

PREPARATION

Class Time: 70 min.

Materials

Handout for Activity 1.3: Periodic Table with Electronegativity Values

Activity Setup

- Print a copy of the periodic table with electronegativity values for each student.

HOMEWORK

Reading for Activity 1.3: Electronegativity, Polarity, and Partial Charges

Activity 1.3 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Simulation
    a. Simulation
    b. Discussion
    c. Questions
    d. Revisit the Driving Question discussion
2. Electronegativity
    a. Questions
    b. Revisit the Driving Question discussion
3. Electronegativity and larger molecules
    a. Simulation
    b. Questions
    c. Discussion

Activity 1.3 (Student materials): Is oxygen really that special?

Introducing the Activity

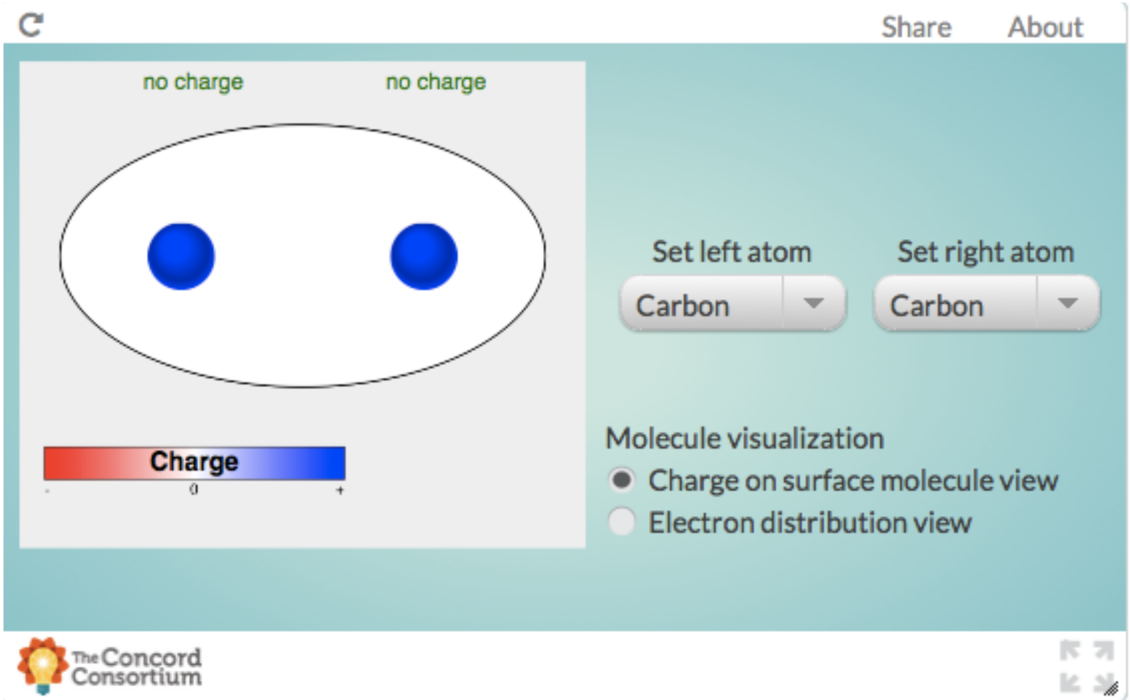
Review the patterns relating properties and molecular formulas from Activity 1.2 and ask questions about what might make molecules with oxygen behave differently than other molecules.

Possible questions:

- *What pattern did we see in the last activity when we compared different molecules and their properties?*
- *Do you think oxygen is really that special?*
- *What do you think is different about oxygen?*
- *What questions could we ask to figure out what makes molecules with oxygen behave differently?*

Page title:
Simulation

Explore the simulation. Notice how the distribution of electrons changes as you change atoms.



Simulation link: http://lab.concord.org/interactives.html#interactives/interactions/polarization.json

Discussion: Display and discuss the simulation.

Possible questions:

- *What do you notice in this simulation?*
- *What do you think it means when it says an atom has a partial negative or partial positive charge? Does anyone have something to add? Does anyone agree or disagree?*
- *Could there be more or less partial charge on an atom in different instances? What affects the partial negative or partial positive charge? Does anyone have something to add?*

Be sure to introduce and define the terms *partial positive, partial negative,* and *partial charge*, and use student's ideas expressed during the discussion when talking about these terms.

1. **How do the kinds of atoms in the bond affect the electron distribution?**

Student responses: Students should note that if the two atoms are different, the electrons density is higher around one of the atoms. If the two atoms are the same, the electron density is evenly distributed across the bond. Students may also note that oxygen tends to have a higher density around it.

- When you have different atoms, the electrons are more on one side.

Compare the following pairs of atoms using the simulation. Identify which atom has a partial negative charge for each pair.

2. Chlorine and Sulfur

A. Chlorine always has a partial negative charge.
B. Sulfur always has a partial negative charge.
C. It depends on which atom is on the left and which atom is on the right.

Student responses:

- **A. Chlorine always has a partial negative charge.**
- B. Sulfur always has a partial negative charge.
    - *Ask student to show you on the simulation and compare chlorine and sulfur.*
- C. It depends on which atom is on the left and which atom is on the right.
    - *Ask student to test chlorine on the right with sulfur on the left and vise versa.*

3. Carbon and Oxygen

A. Carbon always has a partial negative charge.
B. Oxygen always has a partial negative charge.
C. It depends on which atom is on the left and which atom is on the right.

Student responses:

- A. Carbon always has a partial negative charge.
    - *Ask student to show you on the simulation and compare carbon and oxygen.*
- **B. Oxygen always has a partial negative charge.**
- C. It depends on which atom is on the left and which atom is on the right.
    - *Ask student to test carbon on the right with oxygen on the left and vise versa.*

4. What is the relationship between the electron distribution and the charge of the atom?

Student responses:

- The atom with the higher electron distribution is always partially negative. The atom with the lower electron distribution is always partially positive. Students may also note that if the two atoms have similar electron distribution, both atoms have no partial charge.

Revisiting the driving question: Discuss the patterns students noticed in the simulation and how these patterns connect to students' earlier observations. Revisit the activity-level driving question, *Is oxygen really that special?* and the investigation-level driving question, *What makes water special?* Introduce the term *electronegativity*—the tendency for an atom to pull on electrons when bonded with other atoms. When atoms are bonded with each other, there will be a higher probability of finding electrons around those that have a higher electronegativity.

Display the simulation. Use the evidence from the simulation to reach the consensus that some types of atoms are more likely to have higher electron density around them.

Possible questions:

- *What patterns do you notice about how electrons are distributed around ~~across~~ the atoms that are bonded together? What else can we add?*
- *This property of atoms is called "electronegativity" and refers to how strongly atoms pull on electrons. Atoms with higher electronegativity will tend to pull more on electrons around them. Which atoms in the simulation seem to have higher electronegativity? Which ones seem to have lower electronegativity?*
- *What happens when an atom with higher electronegativity is bonded to an atom with lower electronegativity?*

Page title:
Electronegativity

Table of Electronegativity Values

H 2.1																
Li 0.98	Be 1.57											B 2.04	C 2.55	N 3.04	O 3.44	F 3.98
Na 0.93	Mg 1.31											Al 1.61	Si 1.9	P 2.19	S 2.58	Cl 3.16
K 0.82	Ca 1.0	Sc 1.36	Ti 1.54	V 1.63	Cr 1.66	Mn 1.55	Fe 1.83	Co 1.88	Ni 1.91	Cu 1.9	Zn 1.65	Ga 1.81	Ge 2.01	As 2.18	Se 2.55	Br 2.96
Rb 0.82	Sr 0.95	Y 1.22	Zr 1.33	Nb 1.6	Mo 2.16	Tc 1.9	Ru 2.2	Rh 2.28	Pd 2.2	Ag 1.93	Cd 1.69	In 1.78	Sn 1.96	Sb 2.05	Te 2.1	I 2.66
Cs 0.79	Ba 0.89	La 1.1	Hf 1.3	Ta 1.5	W 2.36	Re 1.9	Os 2.2	Ir 2.2	Pt 2.28	Au 2.54	Hg 2.0	Tl 2.04	Pb 2.33	Bi 2.02	Po 2.0	At 2.2
Fr 0.7	Ra 0.89	Ac 1.1														

NOBLE GASES DON'T BOND

5. Given the electronegativity data displayed in this periodic table, why did oxygen often have a partially negative charge in the simulation on the previous page?

Student responses:

- Oxygen has a high electronegativity.

6. Is oxygen the only atom that is likely to often have a partially negative charge in a molecule? Support your answer using the electronegativity data from the table.

Student responses:

- No. Other atoms also have high electronegativity values, for example: fluorine, nitrogen, and chlorine are all above 3.

Revisiting the Driving Question

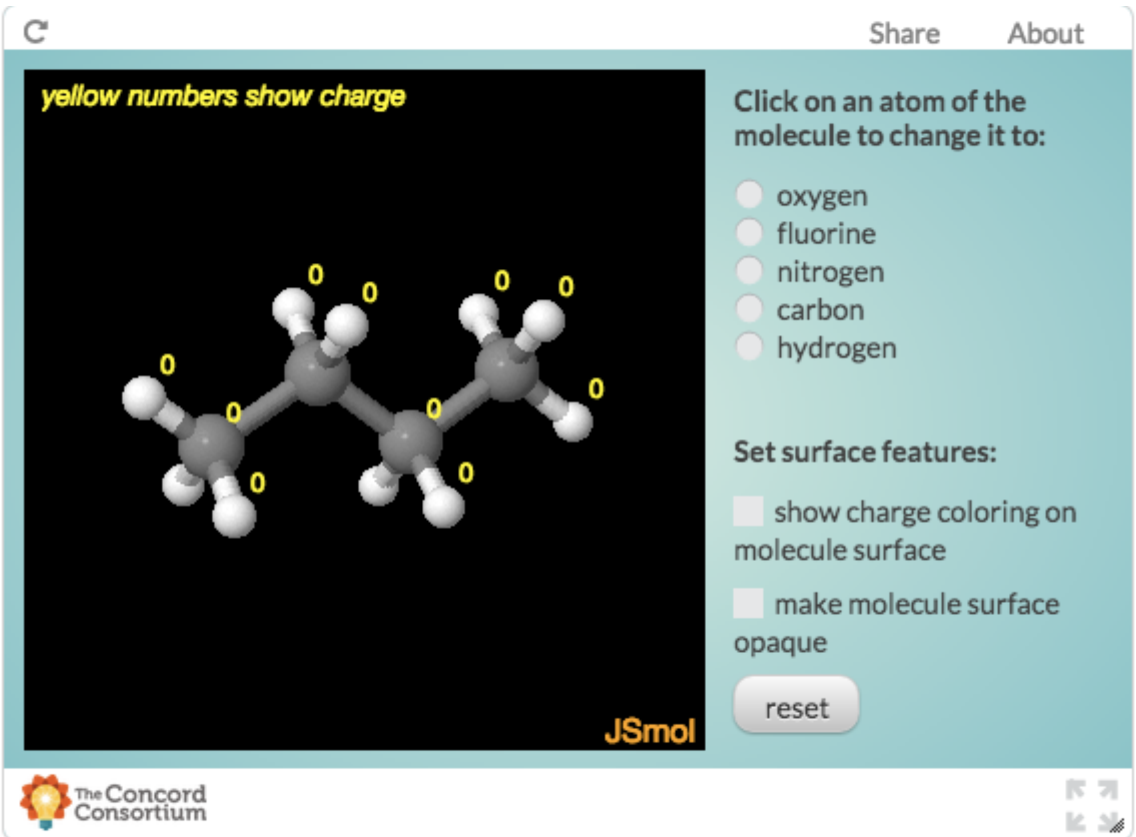
Refocus attention on the activity-level driving question: *Is oxygen really that special?*

Possible questions:

- *Does oxygen have high or low electronegativity?*
- *Is oxygen the only atom with high electronegativity?*
- *How does oxygen compare with the other atoms in the simulation and in the table?*

Page title:
Electronegativity and larger molecules

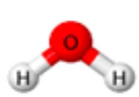
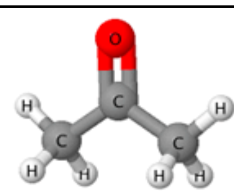
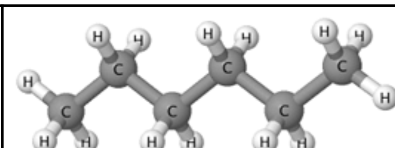
You saw that if two atoms with different electronegativities are bonded together, one will be partially positive and one will be partially negative. Use this simulation to explore electronegativity and partial charges in molecules that are made of several atoms.



Simulation link: http://lab.concord.org/interactives.html#interactives/interactions/buildMoleculesPartialCharge.json

7. [drawing prompt] On the models of hexane, water, and acetone, indicate which areas would have higher electron density, and which areas would have lower electron density.

[insert in drawing background]

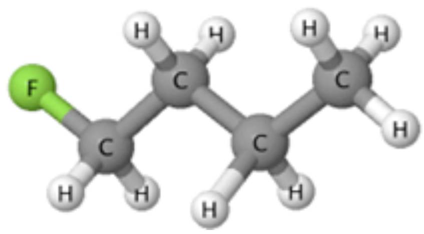
 water	 acetone	 hexane

[text prompt] How could this model explain your earlier observations that water bent toward the charged rod, acetone bent slightly, and hexane barely moved?

Student responses: Students should indicate that there would be higher electron density around the oxygen atoms in water and acetone. They may do this by adding different circles or shapes on the images, or by simply adding notes on the picture.

- The molecules that have partial charges or an uneven distribution of electrons bend toward the charged rod, but hexane does not bend much toward the charged rod because it does not have an area of higher electron density or partial charges.

8. Based on the electron distribution across molecules and the patterns you observed, predict if a stream of the molecule below would bend toward a charged rod. Be sure to support your prediction using the evidence and patterns you have seen.



1-fluorobutane

Student responses: Students should predict that it will bend toward the charged rod.

- Fluorine has a high electronegativity, so the electrons would likely be closer to the fluorine atom and the fluorine would have a partially negative charge. Water and acetone also have partially negative charges in the molecule, and they both bent toward charged rods.

Discussion: Display students' models of water, acetone, and hexanes. Try to reach a consensus about where electrons would most likely be found. Use the images to introduce the terms *polar* and *nonpolar*.

Possible questions:

- *What do you notice in the models of water, acetone, and hexane? What else can we add?*
- *How are acetone and water different from hexane?*
- *Water is called a* polar *molecule, meaning that the electron density is built up in one area and that the molecule has partial positive side and a partial negative side. Where would the partial negative side be?*
- *The opposite of a polar molecule is a* nonpolar *molecule. Nonpolar molecules have electrons evenly distributed throughout the molecule without any partial charges. Would acetone be a polar or nonpolar molecule? Explain your choice. Would hexane be a polar or nonpolar molecule?*

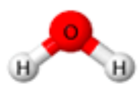
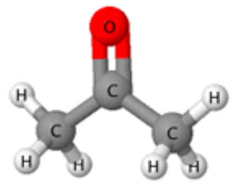
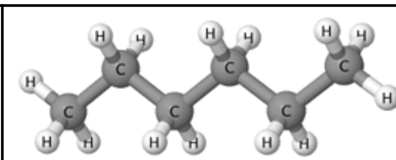
Display the 1-fluorobutane molecule shown in the previous question, or make the molecule using the simulation. Try to reach a consensus about where the electrons are likely to be in the molecule and whether the molecule is polar or nonpolar.

Possible questions:

- *Where do you think electrons are most likely to be found in this molecule?*
- *Do you think this molecule is polar or nonpolar? Support your answer.*
- *Does anyone agree or disagree?*

Page title:
Polar and nonpolar

Water and acetone are polar molecules. Hexane is nonpolar because there is an equal probability of finding the electrons across all the carbon and hydrogen atoms.

 water	 acetone	 hexane

9. What makes water and acetone polar molecules?

Student responses: Students answers may vary; there are several reasons students could draw upon.

- Electrons are more likely to be found around the oxygen atoms.
- The oxygen atoms have a stronger pull or higher electronegativity than the other atoms.
- The oxygen atoms have a partially negative charge.

10. Could molecules with atoms other than oxygen also be polar? Support your answer using the simulation.

Student responses:

- Yes, other atoms also have high electronegativity, as shown on the periodic table and in the simulation. To support their answer, students may refer to specific atoms or molecules that they used in the simulation or make a general statement that atoms other than oxygen have high electronegativity as well.

Concluding the Lesson
Revisit the activity-level driving question, *Is oxygen really that special?* and the investigation-level driving question, *Why does a stream of water bend toward a charged rod?*

During the discussion, encourage students to use the terms that were introduced in this activity (electronegativity, polar, nonpolar) while also pushing them to describe what is meant by these terms. In other words, don't accept something like "Because water is polar" as a complete answer.

Possible questions:

- *How would you answer the driving question for this activity:* Is oxygen really that special?
  Note: Keep in mind that while the driving question for this activity is a yes-or-no type question, the answer is not that simple because both of the following are true:
  - *Yes, oxygen is that special because molecules that have oxygen have very different properties than other molecules.*
  - *No, oxygen is not that special because there are other atoms with high electronegativities that have similar impacts on molecules.*
- *What is special about oxygen? What is not special about oxygen?*
- *How does this activity help answer our driving question for the investigation:* Why does a stream of water bend toward a charged rod?
- *How might these ideas apply to hurricanes?*

Homework: Reading for Activity 1.3
Electronegativity, Polarity, and Partial Charges

Activity 1.4: How does electron distribution impact our observations?

SUMMARY

In the previous activities, students identified patterns in the relationships between the properties of a substance and the structure of its molecules. Students then developed the ideas of electronegativity and polarity to support explanations of the differences between molecules based on their structure. In this activity, students will connect the ideas of electronegativity and polarity at the atomic level to observations of substances at the macroscale. Throughout Unit 3, Investigation 1, students are building an understanding of how water molecules interact with each other. Changes to water are a key process during a hurricane (evaporation and condensation). At this point, students really do not have much of an answer to the unit driving question: *What powers a hurricane?* In the next investigation, students will add the idea of energy to what they have already discovered in order to explain what powers a hurricane. Remember, we are treating "power" colloquially here. By the end of Investigation 2, students will be able to use the interactions between water molecules and the changes in energy that accompany those interactions to provide a causal account of the transfers of energy that accompany a hurricane.

LEARNING GOAL

Students will predict and explain the effect that differences in polarity of molecules have on observable phenomena.

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 observable 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)	*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. (NGSS Appendix F, p. 53)

POINTS FOR CONSIDERATION

- It is often difficult for students to connect their observations (macro scale) to changes at the atomic level. Support students in connecting what is happening at the atomic level with what we can observe.

Activity 1.4 - Teacher Preparation

PREPARATION

Class Time: 60 min.

Materials

- No materials needed.

HOMEWORK

Reading for Activity 1.4: Walking on Water

Activity 1.4 - Teacher Preparation

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

1. Introducing the activity discussion

2. Pulling apart molecules

    a. Simulation

    b. Questions and discussion

3. Properties of molecules and observations

    a. Simulation

    b. Discussion

    c. Questions

    d. Concluding the activity discussion

Activity 1.4 (Student Materials) How does electron distribution impact our observations?

Introducing the Activity

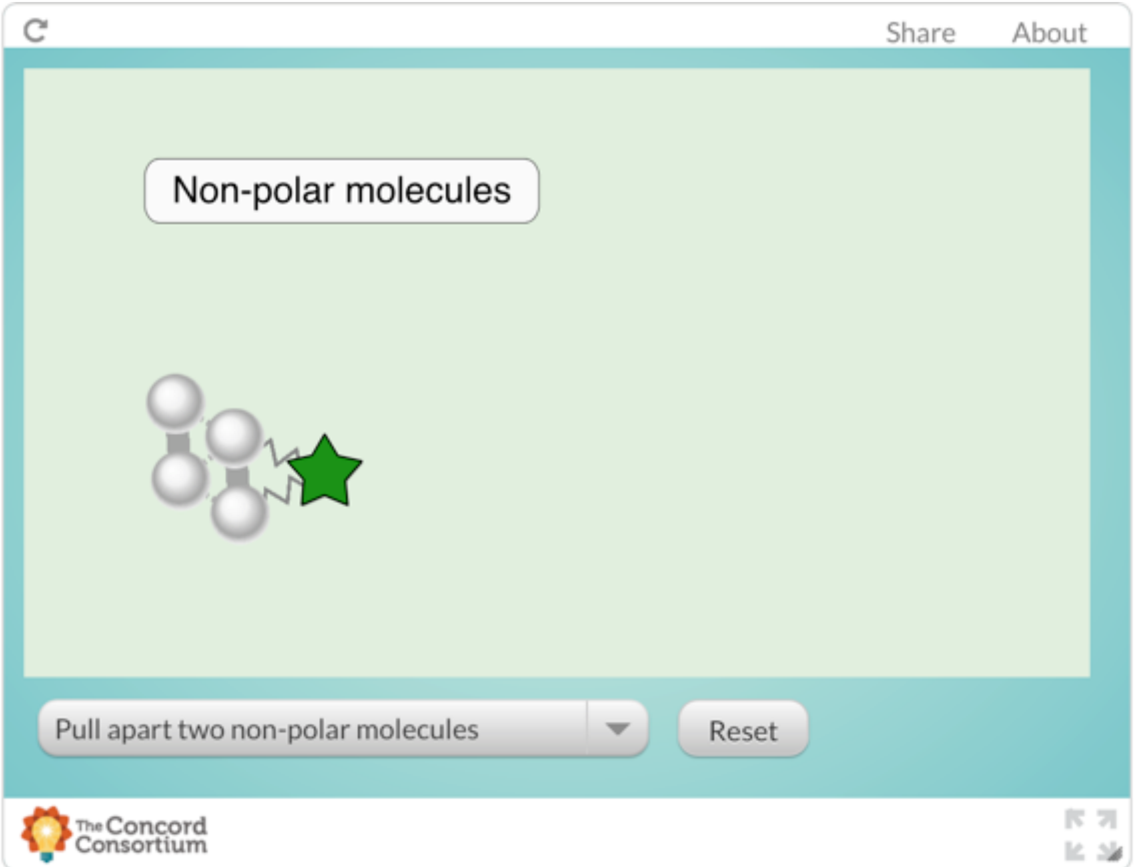
Review Activity 1.3, *Is oxygen really that special?* and ask how the ideas from that activity can help explain our observations of the liquids (bending toward a charged rod, viscosity) and their different properties, (boiling points, heat of evaporation).

Possible questions:

- *In the last activity, we saw that some atoms have a stronger pull on electrons in a bond or molecule than other atoms in the molecule. How could this help explain some of our earlier observations?*
- *Earlier we noticed that molecules that have oxygen seem to have higher boiling points. What do you think explains this?*

Introduce the driving question for this activity: *How does electron distribution impact our observations?*

Page title:
Pulling apart molecules



Simulation link: https://lab.concord.org/interactives.html#interactives/interactions/comparing-polar-non-polar.json

1. **When the simulation is set to "Pull apart two polar molecules," notice that the partial positive end of one molecule is close to the partial negative end of the other molecule. Use your understanding of charges to explain why this arrangement makes sense.**

Student responses:
- Opposite charges attract, so the positive end of one molecule will be attracted to the negative end of the other molecule.

2. Use the idea of electronegativity and partial charges to explain how polar molecules are different from nonpolar molecules.

Student responses:

- In a polar molecule, one atom has a higher electronegativity, so the electrons are more likely to be near that end of the molecule. This means the charges within the molecule are not evenly distributed and there are small partial charges in the molecule.

3. Based on the simulation, how do the interactions between two polar molecules compare with the interactions between two nonpolar molecules? Be sure to cite evidence from the simulation and include reasoning about the polarity of molecules and how charges interact to support your answer.

Students responses:

- The attraction between two polar molecules is stronger than the attraction between two nonpolar molecules. In the simulation, you had to pull on the star with more force to separate the two polar molecules, which shows it is harder to overcome the attraction between polar molecules. Polar molecules have partial charges. The partial positive of one molecule is attracted to the partial negative of the other molecule.

Discussion: ask students to share their answers to the questions above. Push them to think about how interactions between polar molecules are different from interactions between nonpolar molecules.

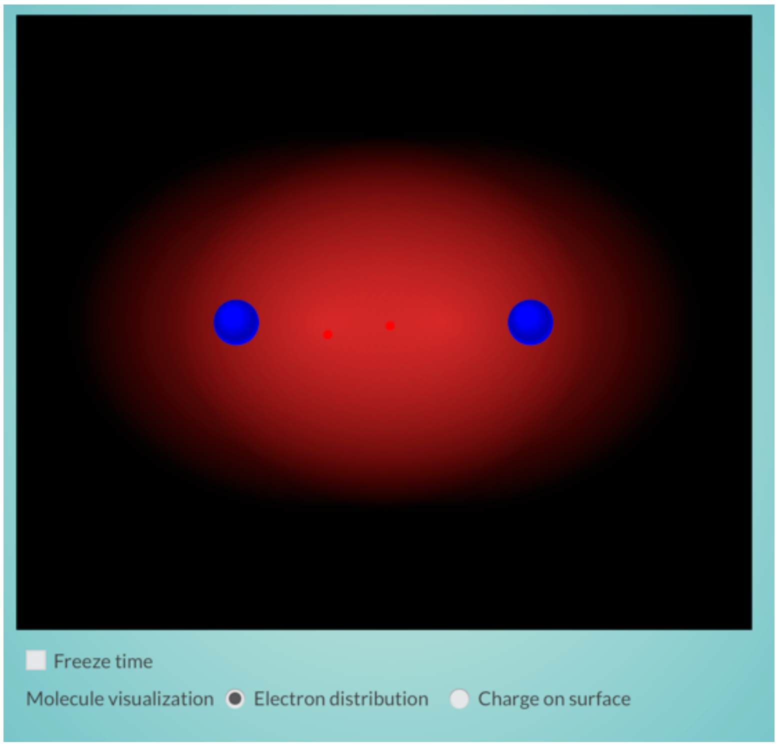
Possible questions:

- *Based on the simulation, which molecules are harder to pull apart: polar or nonpolar? Why?*
- *What is it about the interactions between polar molecules that make them harder to pull apart?*
- *What is it about the interactions between nonpolar molecules that makes them easier to pull apart?*
- *Why do you think two non-polar molecules stick together at all?*

Page title:
How do nonpolar molecules attract?

In the simulation on the previous page you saw that polar molecules attract to each other because of opposite partial charges. You also saw in activity 1 that hexane, consisting of nonpolar molecules, is a liquid at room temperature. This means that non-polar molecules of hexane must also be attracted together. Use the simulation below to explore how nonpolar molecules can have attractive forces between them.

Here is a simulation with a two atom molecule made by bonding together two atoms of hydrogen. Because the atoms are identical they will have identical electronegativities causing them to pull on the electrons equally.



https://lab.concord.org/embeddable.html#interactives/interactions/instantaneous-dipole-one-molecule.json

4. {drawing prompt] Use the "Molecule visualization" control to see different ways to look at the distribution of electrons. Then take a snapshot showing how the electrons are distributed. [text prompt] Describe what your snapshot shows regarding electron distribution.

Student responses: The electrons are distributed evenly between the two atoms. the molecule is nonpolar.

5. Now use the "Freeze time" control and try looking for the electrons at various points in time. Describe what you see when you "Freeze time" several times. Is the molecule always nonpolar?

Student responses: The electrons seem to move randomly between the two nuclei. Sometimes the molecule is polar and sometimes not.

6. [drawing prompt] Take a snapshot that shows how a nonpolar molecule might be able to briefly attract to another nonpolar molecule, and add labels to show why.
[text prompt] Describe how your snapshot shows a way for a nonpolar molecule to briefly attract to another nonpolar molecule.

Student responses: Snapshots should show that electrons are randomly distributed between the two atoms. Labels should indicate partial negative charge in the spot where electrons are found at a given moment in time. possible descriptions include:

- Since electrons are randomly distributed between the two atoms, negative charge will also be randomly distributed with no permanent negative charge on a particular part of molecule.
- When electron cloud instantly shifts to one of the atoms, that atom will have partial negative charge. the location of partial negative charge will constantly change since electrons are equally attracted to both atoms.

Discussion: Ask students to share their answers to the questions above. Push them to think about how nonpolar molecules become temporarily polar as a result of constantly moving electrons.

Possible questions:

- *Based on the simulation, how are electrons distributed in the nonpolar molecule?*
- *How are the partial charges distributed in the nonpolar molecule?*
- *Can a nonpolar molecule become polar? How?*
- *How are charges on nonpolar molecule different from those on polar molecule?*

7.**Predict what would happen to another hydrogen molecule nearby at the moment you indicated in your snapshot of the hydrogen molecule? Justify your prediction.**

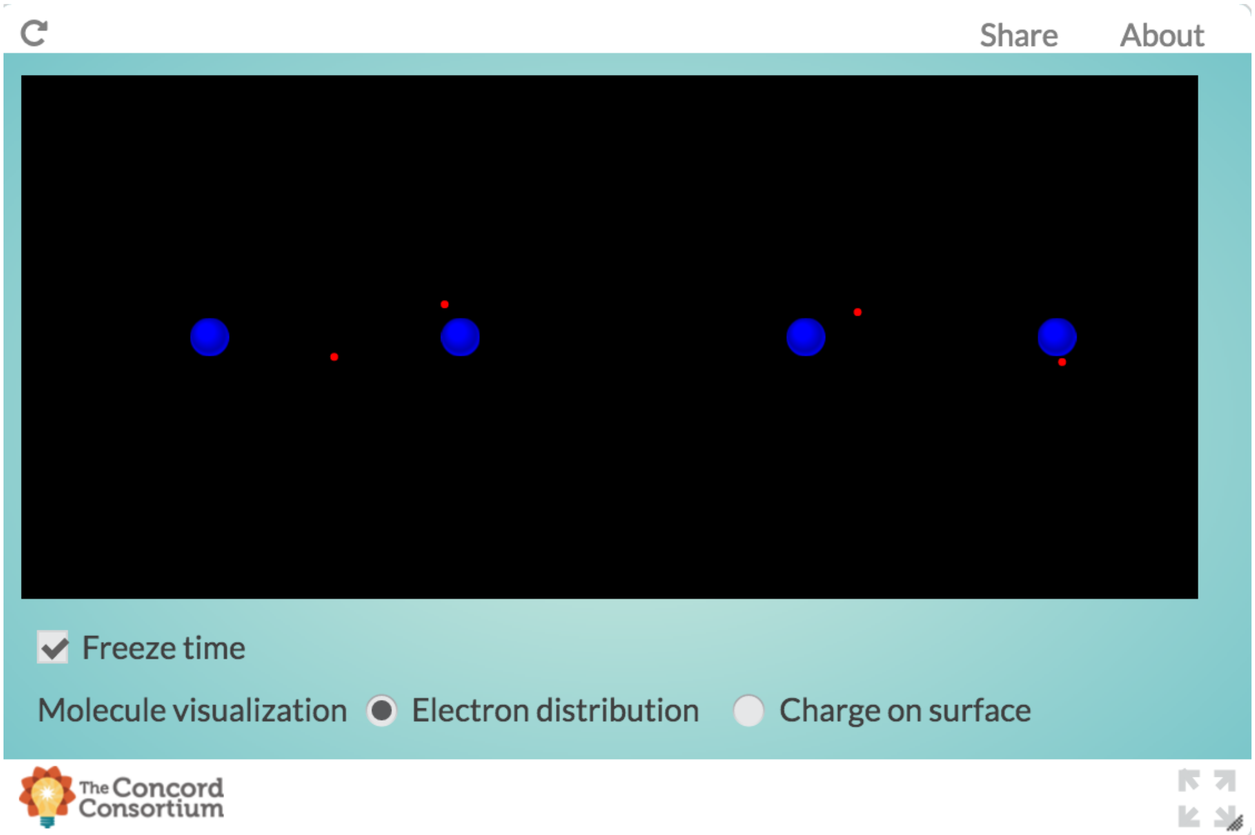
Supplemental content: The temporary partial charge separation within hydrogen molecule will induce charge separation within another hydrogen molecule that comes close to it because the electron cloud of the adjacent molecule will shift as a result of interaction with the induced partial charge. These temporary induced partial charges are what holds nonpolar molecules together. Since electrons constantly move, interactions formed as a result of these temporary partial charges are constantly broken and formed, but are still strong enough to hold nonpolar molecules together. Since polar molecules consist of atoms with similar electronegativity values, there will not be any significant permanent electron cloud shift within the molecule because all atoms within polar molecules have similar affinity for electrons. Therefore, polar molecules have no permanent change separation within them. Permanent charges in polar molecules cause stronger interactions between polar molecules than temporary induced charges between nonpolar molecules.

Clarification - students are not expected to give a very detailed or accurate answer at this point.

Student responses: The electron cloud of the nearby molecule will shift as a result of interaction with the temporary partial charge on the hydrogen molecule indicated in the snapshot. This will cause temporary charges on both molecules, causing them to stick together.

Page title:
Why is hexane a liquid?

In the previous simulation you explored how electrons are distributed in a simple nonpolar molecule. In the simulation below you are going to continue investigating how nonpolar molecules can interact with each other.



https://lab.concord.org/embeddable.html#interactives/interactions/instantaneous-dipole-two-molecules.json

8. [drawing prompt] Explore the simulation and take a snapshot to show the scenario where the two molecules will attract.
[text prompt] Explain your choice.

Student responses: Snapshots should indicate instantaneous partial charge on one or both molecules. When both molecules are partially charged the two molecules will attract via opposite charges. when one of the molecules is partially charged, it will cause electron shift in the nearby molecule causing it to be partially charged, and therefore attract the other molecule.

9. Use ideas discussed above to explain how hexane molecules attract to form a liquid.

Student responses: The electrons in hexane molecules move all the time and can occasionally create areas with higher electron density. That area will have a partial negative charge for as long as the electrons are slightly more concentrated in that spot. This partial charge causes electrons in the adjacent molecule to move away causing partial positive charge at the site of interaction and creating a temporary interaction between hexane molecules.

Discussion: ask students to share their answers to the questions above. Push them to think about how temporary induced partial charges in nonpolar molecules can cause the molecules to stick together.

Possible questions:

- What do you think would happen if another hydrogen molecule is brought near the hydrogen molecule you showed in your snapshot? Why?

Recall simulation with the balloon from unit 1. You can project it to remind students about the details. The simulation can be found here.

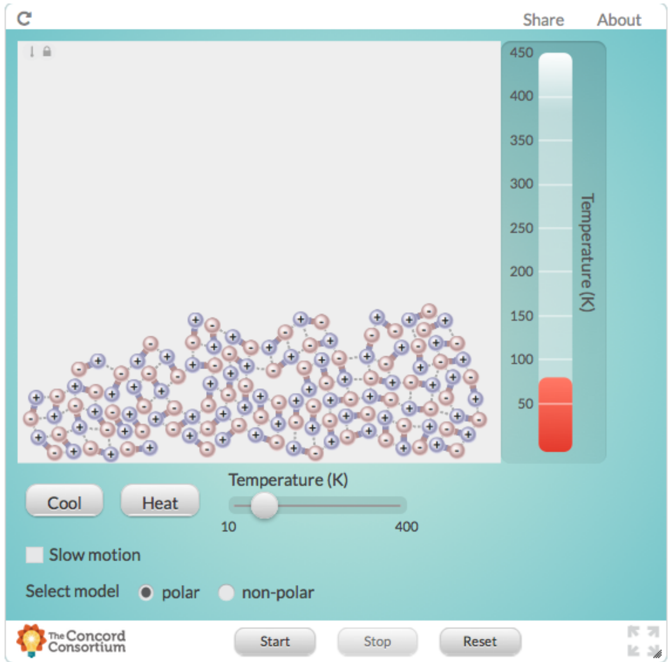
Possible questions:

- Based on the balloon and the wall simulation, how would charge distribution change in a nearby nonpolar molecule if it's brought close to the hydrogen molecule you took a snapshot of on the previous page?
- How would the fluctuating charge distribution in nonpolar molecules affect interactions between them?

Possible questions:

- Based on the simulation above, why is hexane a liquid?
- Based on the discussion so far, how does the magnitude of polar and nonpolar interactions compare?
- Why do you think the magnitude of polar and nonpolar interactions differ?
- How do charges affect the magnitude of polar and nonpolar interactions?

Page title:
Properties of molecules and observations



Simulation link:
https://lab.concord.org/interactives.html#interactives/interactions/boiling-point-polar-nonpolar.json

Discussion: Project the simulation and discuss students' observations.

Possible questions:

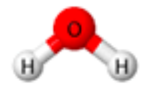
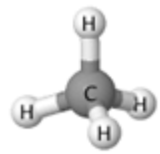
- *What relationships do you see in the simulation?*
- *Why do you think the polar and nonpolar molecules behave so differently? Who can add to that?*
  - *For this question, push kids to include a lot of details. Make sure they are drawing on the ideas from the previous simulations involving polarity, partial charges, electronegativity, and the strength of interactions between polar and nonpolar molecules.*

10. Describe how the arrangement and motion of molecules is different in a solid, liquid, and gas.

Student responses:

- In a solid, the molecules are close together and stay in one place. In a liquid, they move around but are still close together. In a gas, they move all over the place and are far apart from each other.

Use the data in the table below to answer Question 5–7.

Substance and Molecular Formula	Molar Mass (g/mol)	Boiling Point (°C)	Viscosity (mPas)	Molecular Structure
Water (H_2O)	18	100	0.89	
Methane (CH_4)	16	-162	0.02	

11. Compare the strength of the attraction between two water molecules and two methane molecules.

Student responses:

- Two water molecules are more strongly attracted.

12. Use the ideas of polarity, charges, and electronegativity to support your answer to the previous question.

Student responses:

- Water molecules have oxygen, which has a high electronegativity, so the oxygen end of the water molecule has a partial negative charge. The partial negative end of one water molecule is attracted to the partial positive end of a nearby water molecule. Opposite charges attract, so the two water molecules are attracted to each other. Methane molecules consist of hydrogen and carbon, which have similar electronegativity values, so there is no permanent partial charge within methane molecules because electrons are evenly distributed. However, there are attractions between methane molecules but the forces are weak, so at room temperature methane is a gas.

13. Water and methane molecules are very similar in size and mass, but they have very different boiling points. Why is the boiling point of water so much higher than the boiling point of methane?

Supplemental content: The attraction between molecules of water is higher than the attraction between molecules of methane. The higher attraction means that the molecules have to be moving more to separate from each other. Note: students may bring in the idea of energy at this point; that is okay but not necessary. The next investigation will focus on bringing energy into the idea of attraction between molecules.

Clarification - Students are not expected to connect all the ideas together at this point. They are just being asked to connect some of the ideas of liquids versus gases, electronegativity, and molecular interactions.

- **Student responses:** Push students to use the ideas they have developed to analyze the differences between methane and water and use those properties to speculate about boiling point.
- When we timed the evaporation of liquids, we saw that liquids with oxygens took longer to evaporate. Water has an oxygen and methane does not. Taking longer to evaporate could be connected with a higher boiling point.

14. Explain why polar molecules have higher boiling points.

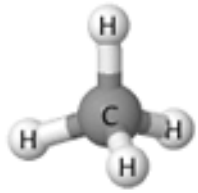
Supplemental content: Polar molecules have a positive end and a negative end. The opposite charges in different molecules are attracted. More force (or energy, effort, etc.) is needed to pull the molecules apart. Nonpolar molecules are held together by temporary induced charges formed as a result of fluctuations in the electron cloud due to the motion of electrons. These interactions are much weaker than interactions between polar molecules because charges involved are smaller and not permanent. Therefore, it takes less energy to overcome those attractions resulting in lower boiling points for nonpolar substances.

Clarification - Students may have an incomplete understanding of boiling at this point, but they should be able to speculate about the polarity and interactions between molecules.

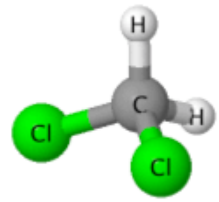
Student responses:

- Polar molecules have permanent partial charges, which means there are stronger attractions between polar molecules. Nonpolar molecules are held together by temporary weaker attractions. These attractions could affect what temperature a liquid boils at.

15. The molecular structures of methane and dichloromethane are shown in the figures. Predict which substance has a higher boiling point. Support your answer using the ideas of electronegativity and polarity.



methane



dichloromethane

Student responses: Students may have different ideas about what happens when molecules boil, so they may not agree on an answer. However, students should agree that dichloromethane is polar while methane is not and that will lead to different observable properties.

- Dichloromethane has a higher boiling point because the chlorine atoms have a different (higher) electronegativity than carbon and hydrogen. One end (the end with the chlorines) will have a partially negative charge and the other end will be partially positive. Because the molecule is polar (or because the molecule has partial charges) and opposites attract, the partial positive end of one molecule will be attracted to the partial negative end of another atom.

Concluding the Activity

Review students' answers and discuss how polarity affects the properties of molecules. Make sure students are using the ideas of charges and attraction in their explanations. Revisit the investigation-level and unit-level driving questions.

Note: Students will not have a complete answer to the unit-level driving question at this point, and may in fact have more questions than answers. However, students should be able to explain how water molecules interact with each other. We know water plays a role in hurricanes since they only happen near large bodies of water. But at this point, students have not yet developed the connection between water molecule interactions and the destruction during a hurricane.

Possible questions:

- *Why does water have a higher boiling point than other molecules of similar size? Who can add to that?*
    - *Push students to include charge in their answer: How is a water molecule different from other molecules? What holds the water molecules together as a liquid?*
- *Will molecules with higher boiling points also tend to have higher viscosity? Why? Anyone disagree?*
- *What can we say now about why water bends toward a charged rod?*
- *Why does hexane only bend slightly toward a charged rod?*
- *How does this information help us answer our driving question:* What powers a hurricane?
- *What might be happening to water molecules during a hurricane?*
- *What questions do we still have about what powers a hurricane?*

Homework: Reading for Activity 1.4: Walking on Water