Investigation 3: How can a small spark start a huge explosion?

Table of Contents:

INVESTIGATION 3: How can a small spark start a huge explosion?

Overview

In previous investigations, students learned about energy and systems. Energy can convert between the energy of motion (kinetic energy) and energy due to position (potential energy). Energy can also be transferred between objects, and energy is conserved. To be able to explain how a small spark can start a huge explosion, students need to connect this knowledge of energy to chemical reactions, which involve the breaking and forming of chemical bonds in the molecules of substances.

In this investigation, students will explore how energy is related to molecules. The investigation starts by having students identify properties of substances in order to distinguish between them. Students are introduced to molecules, including their composition, and how scientists represent them in multiple ways. Then students explore various simulations to build an understanding of the relationships among electric forces, energy, and the relative distance between two separate atoms. Based on this understanding, students build models to explain why separate atoms form a molecule, using the concepts of electric force, atomic structure, and potential energy. They also explain the energy transfer and conversion that occur when a molecule forms and breaks using the concept of conservation of energy.

In the next investigation, students will use their models of energy and intramolecular interactions to explain various observable chemical reactions. Understanding what molecules are and why they form in terms of electric forces, energy, and the relative distance between two separate atoms will help students build toward answering the driving question for the unit.

The Performance Expectations (NGSS)

MS-PS1-1 Develop models to describe the atomic composition of simple molecules and extended structures.

Elements from NGSS (NGSS Lead States, 2013, p. 56)	**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

Structure and Properties of Matter: • Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. • Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.	In this investigation, students will explore the structure and composition of various molecules to be able to explain what molecules are. They will also build models of molecules showing the atomic composition of molecules using different types of representations.
Crosscutting concept	
Crosscutting concept from the NGSS Performance Expectation	How this investigation builds toward the crosscutting concept
Scale, Proportion and Quantity: • Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.	This investigation focuses on introducing what molecules are and how they are formed. This will help students to use atomic-level interactions to explain observable phenomena by connecting various scales.
Science and engineering practice	
Science and engineering practice from the NGSS Performance Expectation	How this investigation builds toward the science and engineering practice
Developing and using models: • Develop model to predict and/or describe phenomena	In this investigation, students will use both physical models and computer simulations to build a deeper understanding of molecules. They will also learn how to represent molecules using different types of models.

HS-PS1-4 Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.

Elements from NGSS (NGSS Lead States, 2013, p. 56)	**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

<table>
<tr><td>Structure and Properties of Matter:
A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart.
Chemical Reactions:
Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.</td><td>In this investigation, students will link the ideas of energy and electrostatic forces to explain the formation of molecules. Bond formation always releases energy, whereas bond breaking always requires an input of energy. Understanding this phenomenon is a step towards building understanding of the changes in energy that occur in a chemical reaction.</td></tr>
<tr><td colspan="2">Crosscutting concept</td></tr>
<tr><td>Crosscutting concept from the NGSS Performance Expectation</td><td>How this investigation builds toward the crosscutting concept</td></tr>
<tr><td>Energy and Matter:
Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.</td><td>This investigation helps students understand how energy is transferred between the potential and kinetic forms when bonds form and break.</td></tr>
<tr><td colspan="2">Science and engineering practice</td></tr>
<tr><td>Science and engineering practice from the NGSS Performance Expectation</td><td>How this investigation builds toward the science and engineering practice</td></tr>
<tr><td>Developing and using models:
Develop a model based on evidence to illustrate the relationships between systems or between components of a system.</td><td>This investigation provides computer simulations to help students explore the relationship between energy and electrostatic forces and to help them connect the ideas of energy transfer and conservation to explain what happens when a molecule forms from and breaks into individual atoms. Students will also develop their own models to explain why atoms form a molecule and what happens when a bond is formed and broken.</td></tr>
</table>

Objective: Target Model

What should the students' conceptual model include?

- *Students will develop a model that a molecule is formed when different atoms combine because the electric field energy is lower for the molecule than for the individual atoms.*
- *Students will provide an explanation of a chemical bond in a molecule using attractive and repulsive interactions at the atomic level.*

Background Knowledge

Traditionally, teaching materials have used isolated factors or rules (e.g., memorizing types of bonds and the octet rule) to "explain" the interactions between atoms and molecules. In these materials, we are connecting the underlying concepts of electric interactions to provide a more robust and useful way to explain how and why molecules form and break.

A molecule is a collection of two or more atoms that are linked together by chemical bonds. In the chemical bonds of a molecule, the balance between attractive and repulsive electric forces maintains the existence of the bound state.

Bonds form when atoms occupy positions that lower the electric field energy. The electric field energy is lower for a molecule compared with the individual atoms because the atoms within a molecule are at positions that balance the attractive and repulsive forces between them, which stem from the positively charged protons and negatively charged electrons. When atoms bond together to form a molecule, the electric potential energy of the individual atoms is released to the surroundings. Often light or heat can be observed as evidence of this energy transfer.

In order to break a molecule apart, one must provide an amount of energy equal to or greater than the binding energy—the difference between the potential energy of the molecule and the potential energy of the separate atoms. Breaking bonds requires transferring energy to a molecule, causing the atoms to move faster and separate, which in turn increases the potential energy stored in the electric field between the atoms. This energy, often electric or thermal, overcomes the attractive forces, separating the molecule into individual atoms or smaller molecules.

Activities

Activity 3.1	*Why are some materials explosive, while other materials are not?*	*80 min.*
Activity 3.2	*What holds the atoms of a molecule together?*	*120 min.*
Activity 3.3	*When atoms get close to each other, what happens to their potential energy?*	*120 min.*
Activity 3.4	*Why is a spark needed to start an explosion?*	*60 min.*

Activity 3.1: What makes substances different from each other?

SUMMARY

In this activity, students will learn more about molecules, including their composition, chemical formula, and structure. In the following activities, students will use ideas of attractive and repulsive interactions between charges to to explore how atoms can form a molecule and also what happens to the potential energy of the system when two atoms form a molecule.

LEARNING GOALS

- Students will measure and use properties to characterize and distinguish between substances.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Structure and properties of matter: Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it. (NGSS Lead States, p. 56)	*Structure and Function:* Students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal a system's function and/or solve a problem. (NGSS Appendix G p.87)	*Analyzing and interpreting data:* Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. (NGSS Appendix F p. 57)

- Students will use models to explain how substances are different from each other.
    - A molecule is a collection of two or more atoms that are linked together.
    - Molecules of the same substance have the same composition and ratio of atoms
    - At this time, we don't expect students to know about chemical bonds—how and why atoms are held together.
    - Clarification: although the arrangement of atoms is also an important factor in defining a molecule of a substance, molecular geometry and the arrangement of atoms within a molecule is outside the scope of this investigation.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Structure and properties of matter: Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms. Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it. (NGSS Lead States, p. 56)	*Structure and Function:* Students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal a system's function and/or solve a problem. (NGSS Appendix G p.87)	*Developing and using models:* Students will develop and/or use model to predict and /or describe phenomena (NGSS Appendix F p. 53)

POINTS FOR CONSIDERATION

- Some students cannot clearly state the difference between an atom and a molecule.
- Students may think that chemical reactions produce individual atoms rather than molecules (e.g., that electrolysis of water yields one oxygen atom and two individual hydrogen atoms).

PREPARATION

Class Time: 80 min.

Materials (for the whole-class testing gases demonstration):

- Bunsen burner
- wooden sticks
- match or lighter
- six test tubes with stoppers for gas collection
- large beaker or bowl
- 1–2 L of tap water
- three large test tubes and stoppers with a hole for a gas tube
- solid $CaCO_3$
- 5M HCl
- granulated Zn
- $MgSO_4$ (Epsom salt)
- solid $KMnO_4$

Materials (for the whole class electrolysis demonstration using Hoffman Apparatus):

- Hoffman tube
- column stand
- 2 electrodes
- 1 L of 1M Sodium Sulfate
- DC power supply with clip leads

- ruler
- 2 test tubes marked X and Y
- wooden splint
- matches or lighter
- candle

Materials (for each group):

- clear plastic cup
- two metal thumbtacks
- 9-volt battery
- distilled water (for electrolysis; see preparation instructions under "Activity Setup" below)
- large beaker or bowl
- tap water
- two 10 ml Pyrex graduated test tubes or graduated cylinders
- two small pieces of paper
- wooden sticks
- lighter or match

Activity Setup

- Prepare Test Tubes X (x2 per class), Y (x2 per class) and Z (x2 per class) (for the whole-class demonstration).
    - Test Tube X will be filled with CO_2.
      Prepare the CO_2 gas by adding 5M HCl to 5–10 g of $CaCO_3$. Collect the carbon dioxide gas using the upward displacement of air.
    - Test Tube Y will be filled with H_2.
      Prepare the H_2 gas by adding 5M HCl to 5–10 g of granulated Zn. Collect the hydrogen gas from the inverted displacement of water.
    - Test tube Z will be filled with O_2.
      Prepare the O_2 gas by heating 5 g of $KMnO_4$ in a test tube. Collect the oxygen gas from the inverted displacement of water. There are many procedures you can use to collect oxygen gas. Use one you are familiar and comfortable with.
    - Prepare TWO of each test tubes per class; one for the flame test and one for the glowing splint test.
- Prepare Hoffman Apparatus for electrolysis demonstration.. You can refer to Bassam Z. Shakhashiri (1992) *Chemical Demonstrations: A Handbook for Teachers of Chemistry*,Vol.4. p156. available on-line here for additional details on the procedure.
    - Insert the electrodes into the Hoffman apparatus and place the apparatus on a column stand.
    - Close the stopper on the top of the Hoffman apparatus and pour sodium sulfate solution through the bulb until full.

        - Open one of the stoppers on the apparatus and allow the solution to fill that arm of the apparatus. Make sure the arm is completely full. Add more solution if necessary.
        - Conduct the same procedure to fill the other arm.
        - At the beginning of class attach the negative end (black) of the power supply to the cathode on the Hoffman Apparatus (marked +). Attach the positive end (-) of the power supply to the other end of the Hoffman Apparatus (anode, marked -). Turn on the power supply. Bubbles should form on both electrodes. Adjust the power supply to about 15-20 volts and 1.5 amperes. Make sure the process is not too vigorous, adjust the voltage accordingly. Let the electrolysis proceed during class.
    - Prepare water for electrolysis (for each student group).
        - Add about 2 tablespoons of $MgSO_4$ to 250 mL of distilled water.

SAFETY ISSUES

- Prepare and collect all gases in a fume hood.
- Oxygen and hydrogen mixtures are explosive, make sure to handle with care and burn off the gases completely to avoid explosion.
- Concentrated hydrogen peroxide, hydrochloric acid and sodium sulfate solutions can cause severe irritation or burning of the skin, eyes, and mucous membranes. Students and teachers should wear goggles and gloves when working with hydrogen peroxide.

WORKSHEET

Handout for Activity 3.1: Water Electrolysis

HOMEWORK

Reading for Activity 3.1: Molecules and Their Representations

Activity 3.1 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introduction
    a. Introducing the lesson
    b. Testing gases with flame demonstration
    c. Testing gases with splint demonstration
    d. Discussion
2. What are substances made of
    a. Discussion
    b. Electrolysis and testing gases demonstration
    c. Discussion
3. Electrolysis and testing gases hands-on experiment
4. What is water made of?
    a. Discussion
    b. Questions
    c. Discussion - introduce term "molecule"
5. What makes substances different?
    a. Discussion
    b. Questions
    c. Discussion
6. Concluding the lesson

Activity 3.1 (Student materials): What makes substances s different from each other?

Introducing the Activity

Review what has been learned so far about energy and matter. Review the reading from the end of Investigation 2 “How does the lightning happen?” and discuss how energy changes relate to changes in matter.

Possible questions:

Recall the reading from the end of Investigation 2. How is energy involved in producing lightning?

How are charges involved in producing lightning?

Return to the driving question for the unit and discuss what else needs to be learned in order to answer “How does a small spark start a huge explosion?”

Possible questions:

- *What is the driving question for the unit?*
- *What have we answered so far?*
- *What else do we need to study more fully in order to answer this question?*
- *What causes the spark?*
- *Does everything explode when hit by a spark?*

Page title:

Introduction

In the previous investigation, you explored energy and how changes in the energy of the system lead to different phenomena. In this investigation, you will continue to learn about energy and to investigate how energy changes relate to changes in matter. You will explore what makes substances different, and then investigate the relationship between changes in energy and changes in the structure of different substances.

Page title:
How can we tell the difference between substances that look the same?

Different substances have different properties that can be used to identify them. Test Tubes X, Y, and Z are filled with gas. Can the properties of the gas in each test tube be used to tell whether the gases are the same or different?

1. **What do you think might happen when a gas is exposed to a small flame? List as many possible results as you can think of.**

Student responses: Students might not have an answer at this point, this is just a prediction question to elicit their ideas. Their responses do not need to be correct at this point.

- an explosion will occur
- the flame will go out or get brighter

Page title:
Investigate

- Watch the demo to see what happens when a small flame is placed inside each of the test tubes.

Demo: Testing gases with a small flame

Materials
- Test Tube X (containing CO_2)
- Test Tube Y (containing H_2)
- Test Tube Z (containing O_2)

Instructions: For each test tube, perform the following steps.
1. Hold the test tube in a horizontal position.
2. Carefully and quickly open the stopper. Then immediately put the small flame inside the test tube
3. Observe.

Watch the following video to help you prepare to conduct the demo successfully in your classroom: Flame test demo.

- Watch the demo to see what happens when a glowing splint is placed inside each of the test tubes.

Demo: Testing gases with a glowing splint

Materials
- Test tube X (containing CO_2)
- Test tube Y (containing H_2)
- Test tube Z (containing O_2)

Instructions: For each test tube, perform the following steps.
1. Hold the test tube in a horizontal position.
2. Carefully and quickly open the stopper. Then immediately put the glowing splint inside the test tube.
3. Observe.

Watch the following video to help you prepare to conduct the demo successfully in your classroom: Glowing splint test demo.

2. Fill in the table to record your observations of what happened when a small flame or glowing flint was placed inside each test tube. If you want to see the demonstrations again, watch the following videos:

- Flame test demo
- Glowing splint test demo

Test Tube	What happened when a small flame was placed in the test tube?	What happened when a glowing splint was placed in the test tube?
X		
Y		
Z		

http://lab.concord.org/interactives.html#interactives/interactions/gases-table-U2-Inv3.json

Supplemental content: Burning or combustion is a chemical reaction between oxygen in the air and some type of material it is reacting with (wood in the case of a splint or fuel in the case of a lighter). When you place the flame or the glowing splint into the tube with carbon dioxide (test tube X), CO_2 displaces oxygen therefore eliminating one of the reagents in the chemical reaction. As a result, the flame is extinguished. For the same reason, when you place the flame or the glowing splint into the test tube with oxygen (test tube Z), the flame becomes brighter because there is now additional oxygen to react. Finally, hydrogen gas is explosive and the energy transferred to the molecules of hydrogen gas in test tube Y by the flame that you introduce will break the bonds between hydrogen atoms, which react with oxygen to form water.. The "pop" sound is evidence that energy is transferred to the surroundings when the product bonds form.

Clarification - students do not need to make predictions about the types of gases, they only should record their observations at this stage.

Student responses:

What happened when a small flame was placed in the test tube?

X - *The flame was extinguished.*

Y - *A "pop" sound occurred.*

Z - *The flame became brighter.*

What happened when a glowing splint was placed in the test tube?

X - *The glowing splint was extinguished.*

Y - A "pop" sound occurred, and the splint kept glowing.

Z - The glowing splint was reignited.

3. Each test tube contained a gas. Was the gas in each test tube the same or different? Use evidence to support your answer.

Student responses:

- The gas in each test tube was different because each gas has properties that differed from the others. The gas in Test Tube X caused the flame and glowing splint to be extinguished. The gas in Test Tube Y caused a "pop" sound to occur when either the flame or glowing splint was placed inside, and the splint kept glowing. The gas in Test Tube Z caused the flame to become brighter and the glowing splint to reignite.

Discussion

Start by asking, *What are gases made of?* Previously, students explored the particle nature of matter and learned that the particles that make up matter can be made of one atom or a group of atoms. Refer back to this idea and help students make a connection to this demo, with the goal of helping them understand that substances are made of different types of atoms and groups of atoms.

Possible question:

- *How can we distinguish between 3 unknown gases using flame and glowing splint test?*
- *What do you think makes the gases inside Test Tubes X, Y, and Z different from each other?*
- *Does our particle/atomic model help explain why different gases would have different properties? If so, how?*

Page title:
What are substances made of?

Discussion

Students most likely know that water can be written as H_2O. Use the example of water to build the discussion about what substances are made of. The purpose of this discussion is to encourage students to explore their prior knowledge. So at this point, do not tell them whether their answers are right or wrong. They will be able to better evaluate their answers as they complete this activity.

Possible questions:

- *What makes water different from other substances?*
- *How do scientists know the composition of water?*
- *What evidence do scientists have about the composition of water?*

One way scientists learn about substances is by breaking them down chemically to see what types of atoms they are made of. One such technique is called *electrolysis.* You will now use electrolysis to separate water into its components. Follow the procedure outlined in the Water Electrolysis handout. Make sure to record your observations. If you have any difficulties, you can also check out the following videos to see the procedure:

- How to insert the tacks (Step 1)
- How to submerge the test tubes and position the battery (Steps 3–11)

4. When you have collected the gases, compare the amount of gas in the test tubes over each electrode.

Supplemental content: the ratio of the volumes of collected hydrogen and oxygen gases is very close to 2:1. Since electrolysis is the decomposition of water molecules into its components, oxygen and hydrogen gas, the observed ratio is indicative of the ratios of those atoms in a water molecule, H_2O. The electrolysis experiment carried out by the students might not be as accurate in terms of showing the 2:1 ratio, and you should point out during discussion that they will further observe the electrolysis using Hoffman apparatus, which should show ratios that are more accurate than their procedure.

Clarification - students answers might not be exactly 2:1, but they should be fairly close.

Student responses: The volume of gas in the test tube that was over the negative electrode terminal is about two times the volume of gas in the test tube that was over the positive electrode terminal.

5. Using the results of your observations from the testing gases demonstration at the beginning of the activity, predict what gas was collected in test tube X. Justify your prediction.

Student responses: Test tube X contained the same gas as test tube Y in the testing gases experiment because when the splint was placed into the test tube, it made the same "pop" sound.

6. Using the results of your observations from the testing gases demonstration at the beginning of the activity, predict what gas was collected in test tube Y. Justify your prediction.

Student responses: Test tube Y contained the same gas as test tube Z in the testing gases experiment because when the splint was placed into the test tube, it was reignited just like when testing gas in test tube Z.

Discussion

Ask students to share their ideas about which gases were collected in tubes X and Y. At this point they don't need to agree. They will conduct electrolysis themselves to further confirm their predictions..

Possible questions:

- What happened when the splint was placed in test tube X?
- What can you conclude about the gas in test tube X based on the demonstration at the beginning of class?
- What happened when the splint was placed in test tube Y?
- What can you conclude about the gas in test tube Y based on the demonstration at the beginning of class?
- Does anybody have a different idea?

Note: in the following activity students will collect gases themselves and test the collected gas with either glowing splint or small flame. Make sure to assign each group one test because they don't have enough gas to do both tests.

Page title:
Testing the gases

Continue to investigate by testing the gas in each tube to detect its properties. You will test both tubes with either a small flame **or** a glowing splint. Make sure to get your teacher's permission before proceeding. Then follow Steps 13, 14, and 15 in the chart.

Fill in the table to record what happened when a small flame or a glowing splint was placed inside each test tube.
Note: *Since some groups tested the small flame and other groups tested the glowing splint, you will need to share results with another group before you can complete this chart.*

Test	Gas from negative (-) terminal	Gas from positive (+) terminal
Small flame		
Glowing splint		

http://lab.concord.org/interactives.html#interactives/interactions/electrolysis-table-U2-Inv3.json

Student Responses

Small flame	*A "pop" sound occurs, and the flame goes out.*	*The flame gets brighter.*
Glowing splint	*A "pop" sound occurs.*	*The glowing splint reignites or gets brighter.*

Note: When using a glowing splint to test the gas from the positive electrode, the results may vary depending on the amount of gas collected and the amount that has leaked out. With a small amount of gas, the glowing splint will get brighter. With a larger amount of gas, the splint may reignite.

7. Use the results of the previous experiment to make a claim about which Test Tube(s) used in the demonstration (X, Y, and/or Z) contained a gas that could be a component of water. Be sure to support your claim with evidence.

Supplemental content: A particular compound always has certain unchanged properties that are determined the molecular composition. By comparing observations of properties of different substances it is possible to conclude if substances are in fact the same or different based on whether they exhibit the same properties under the same conditions. One of such properties brought to the student's attention in this experiment is the reaction of these three gases with flame.

Clarification - students do not need to know that molecular composition determines properties at this point. They also don't need to know and/or use the term "molecule". It will be introduced later in the activity.

Student responses:

- Test Tubes Y and Z each contained a gas that could be a component of water. This is because the gas from the positive electrode terminal and the gas in Test Tube Y had a property in common—both caused a "pop" sound to occur. Also, the gas from the negative electrode terminal and the gas in Test Tube Z had a property in common—both caused a glowing splint to reignite.

You will further observe electrolysis performed by your teacher using a slightly different procedure. Notice the ratios of gases produced in this demonstration, as they will be more accurate than what you found. This will help you more accurately determine what gas ratios are for decomposition of water during electrolysis.

Demo: Follow the instructions provided at the beginning the the activity to set up and start electrolysis at the beginning of class.

- In about 45 minutes, you should have about 22 cm of hydrogen and 11 cm of oxygen collected at the corresponding electrodes.
- Measure the gas amount with the ruler and record the numbers on the board.
- Light the candle and place the splint near it. Open the cathode stopper on the Hoffman Apparatus and collect hydrogen gas into the test tube marked X. Close the test tube with your finger and light the splint from the candle. Place the splint into the test tube. It should make a soft pop.
- Conduct the same procedure with the anode on the Hoffman Apparatus and collect oxygen gas into the test tube marked Y. While holding a finger over the test tube with oxygen, light the splint from the candle and blow it out so it is still glowing. Place the splint into the test tube and watch the oxygen to re-ignite it.

Page title:
What is water made of?

Different substances have different properties. Thus, properties can be used to identify substances. The table lists some substances that are commonly found in air, as well as some of their properties.

Substance	Boiling Point (°C)	Density (g/L)	Reaction with a glowing splint	Reaction with a small Flame
Oxygen	-183	1.429	Glowing split becomes brighter or is reignited	Flame is brighter
Carbon dioxide	-78	1.977	Glowing splint is extinguished	Flame goes out
Water (vapor)	100	0.804	Glowing splint is extinguished	Flame goes out
Helium	-269	0.179	Glowing splint is extinguished	Flame goes out
Hydrogen	-259	0.089	“Pop” sound occurs	“Pop” sound occurs

10. Use the data in the table to determine the identities of the two gases that you found could be components of water. Provide evidence to support your claim.

Student responses:

- The identities of the two gases that could be components of water are hydrogen (Test Tube Y) and oxygen (Test Tube Z). When we did the electrolysis of water, two types of gas were produced. One made a flame brighter and caused a glowing splint to reignite, which matches properties of oxygen. When the other gas that was produced by electrolysis was brought near a flame or glowing splint, a “pop” sound occurred, which matches properties of hydrogen.

Discussion
Have students use the evidence from their water electrolysis experiment to help answer the question, *What are substances made of?*

From their electrolysis of water, students will know that water is made of oxygen and hydrogen. This provides evidence that some substances are made of different types of atoms.

Students may already know that substances can be made of one type of atom or different types of atoms, but the discussion should lead into how the evidence that they collected supports this.

Possible questions:
- *What are substances made of?*
- *Are all substances made up of atoms?*
- *Are all substances made up of only one type of atom? What is your evidence?*
- *Are all substances made up of more than one type of atom?*

11. Compare the volumes of the two gases produced by electrolysis. What does their ratio tell you about the ratio of the atoms that make up water?

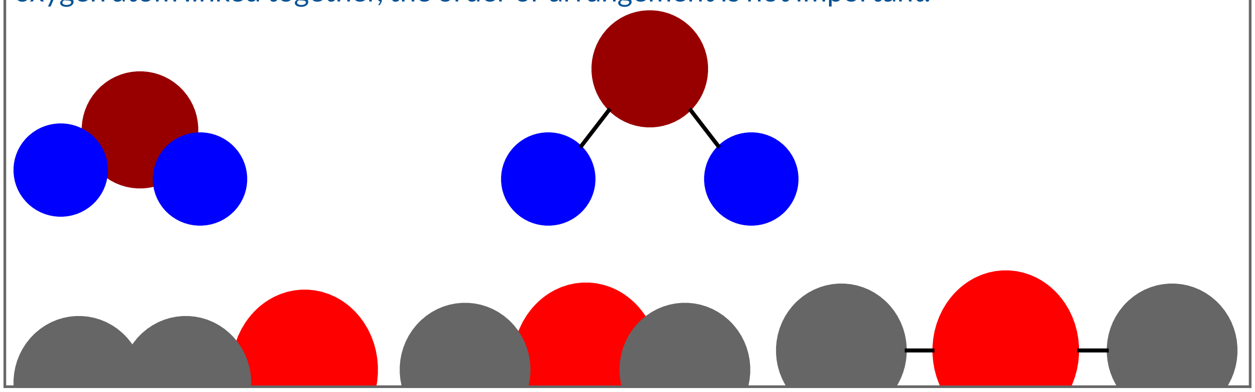
Student responses:
- Water has a ratio of two hydrogen atoms to one oxygen atom.
- The ratio of hydrogen atoms to oxygen atoms in water is 2:1.

12. Water is often represented using the symbol H_2O. Based on your identification of the gases and their ratio, what do you think the symbols mean?

Student responses:
- the symbols represent hydrogen (H) and Oxygen (O)
- The numbers mean there are two atoms of hydrogen for every atom of oxygen.

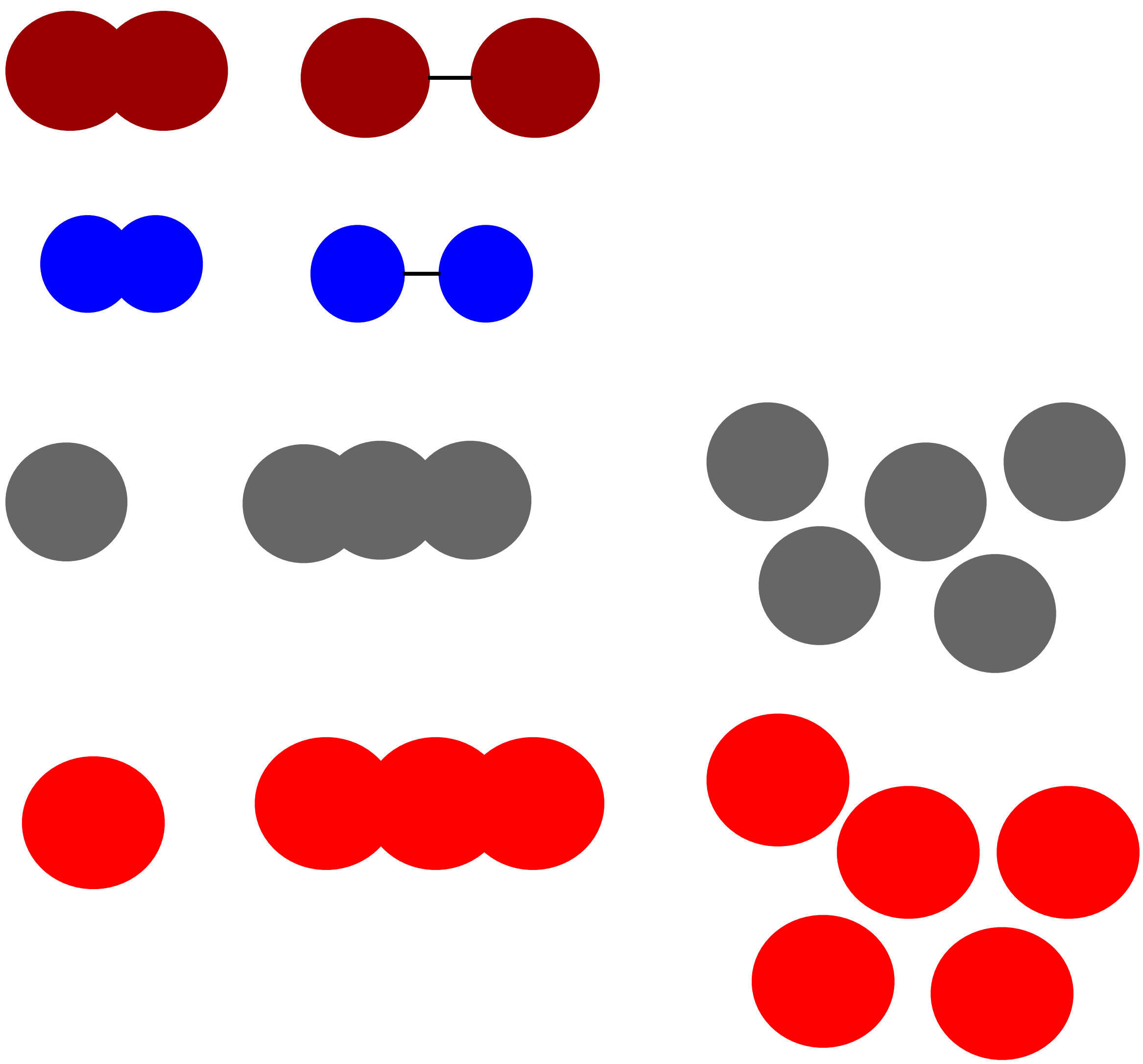
13. [drawing prompt] Draw a model to show what you think water would look like if you could see the atoms that make it up.

Student responses: Drawings may vary. Students should include two hydrogen atoms and one oxygen atom linked together, the order or arrangement is not important.



14. [drawing prompt] For each of the gases produced by the electrolysis of water, draw what you think the gas would look like if you could see the atoms that make it up.

Student responses: Drawings may vary. Students' drawings don't have be correct at this point. However, their drawings should show that the two gases are made up of different types of atoms and/or have different numbers of atoms. Also, there should no longer be a link between the hydrogen and oxygen atoms.



Discussion

At this point, students know that water is made of two hydrogen atoms and one oxygen atom. Discuss how scientists communicate with others when they talk about water molecules. This will introduce students to chemical formulas. During the discussion, point out that a chemical formula tells us about the composition of a molecule.

Possible questions:

- *Why do the two gases have different properties?*
- *What makes water different from the two gases?*
- *Based on the evidence you have, which do you think is the best representation of water? Which models best explain our observations?*
- *Do H_2O and H + H + O mean the same thing?*
- *Do H_2O and O_2 + H_2 mean the same thing?*
- *What does H_2O tell us?*
- *Hydrogen gas is composed of two hydrogen atoms linked together. So what do you think the chemical formula of hydrogen gas could be?*
- *The chemical formula of oxygen gas is O_2. What does O_2 tell us?*

Use student's' representations of water and product of water electrolysis (oxygen and hydrogen gas) to introduce the word *molecule.* Note that most substances are made up of particles consisting of a group of atoms linked tightly together. Those atoms can be the same or different types. A group of atoms that stays together is called a *molecule.*

Page title:
What makes substances different?

You know that water is different from the two gases that resulted from electrolysis. What makes water different from other substances? What makes any substance different from others?

Discussion
Refer back to the periodic table used in Unit 1, Investigation 5, and point out that there are only about 120 different types atoms. Of these 120, only about 20 atoms make up most of the materials that exist in the world. Guide students to think about how there can be so many different substances, what those substances are made of, and what makes them different from each other.

Possible questions:

- *How can there be so many different substances in the world even though there are so few different types of atoms?*
- *What makes one substance different from others?*
- *Could two or more substances be made from same types of atoms?*

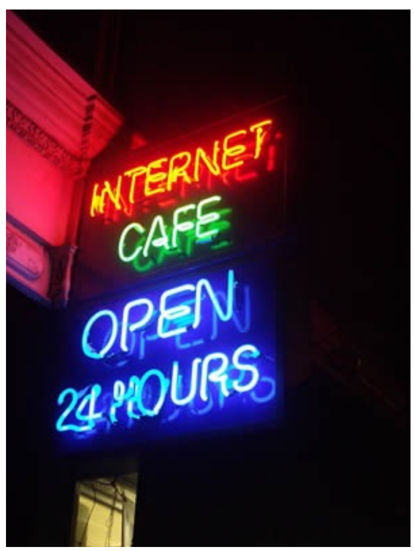


Figure 1: Neon signs are made from glass tubes that are filled with neon gas.
Credit: Justin Cormack
License: CC BY-SA 2.0
Image source: http://commons.wikimedia.org/wiki/File:Neon_Internet_Cafe_open_24_hours.jpg

15. [drawing prompt] Neon gas is composed of many single neon (Ne) atoms. Draw a model to show what you think neon gas would look like if you could see the atoms that make it up.

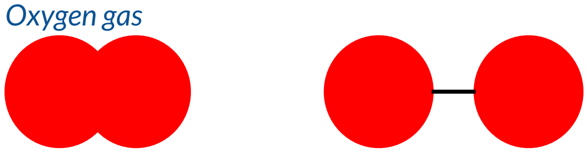
Student responses: Students may draw one atom or many atoms. There should not be bonds between the atoms.

Oxygen gas and ozone gas are both composed of oxygen atoms, but their properties are very different. Oxygen is a transparent gas that has no smell. It is essential to many life-forms on earth. Ozone is a pale blue gas with a distinctively strong smell. High concentrations of ozone can damage respiratory tissues in animals.

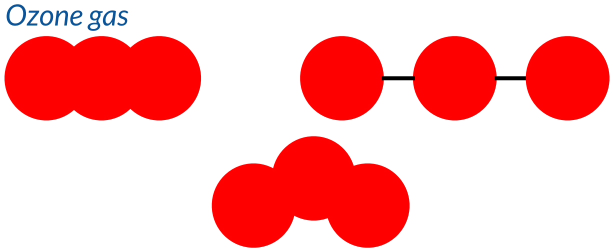
16. [drawing prompt] Oxygen gas (O_2) is composed of two oxygen atoms; ozone gas (O_3) is composed of three oxygen atoms. What are some possible representations of oxygen gas and ozone gas?
[text prompt] What do you think causes oxygen gas and ozone gas to have different properties?

Student responses:

Oxygen gas



Ozone gas

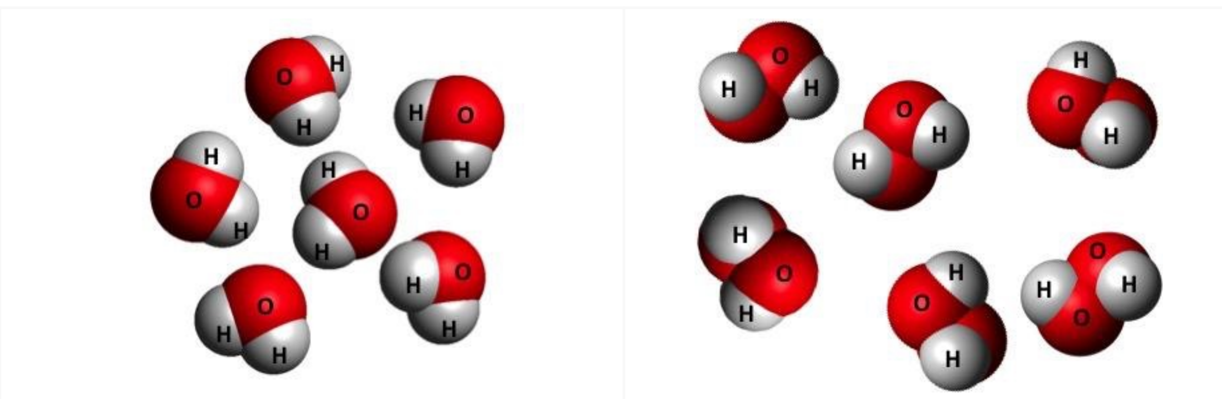


- Different substances have different properties and are made of different types and/or

Hydrogen peroxide is used in hair dye to bleach out the natural color of hair, usually in preparation for giving hair a new color.

Figure 2: Hydrogen peroxide is used in hair dye to bleach out the natural color of hair, usually in preparation for giving hair a new color.
Credit: Jhayne
License: CC BY-NC-SA 2.0
Image source: https://www.flickr.com/photos/foxtongue/8400505873/in/photolist-

Water molecules always consist of two hydrogen atoms and one oxygen atom (H_2O). This chemical composition makes water different from other substances. Hydrogen peroxide also consists of hydrogen and oxygen, but in a different number--two atoms of hydrogen and two atoms of oxygen. The figure below show the water and hydrogen peroxide molecules.



Molecules of water (H_2O)	Molecules of hydrogen peroxide (H_2O_2)

Figure 3: Comparing molecules of water and hydrogen peroxide.

This table describes some properties of water and hydrogen peroxide.

Property	**Water**	**Hydrogen Peroxide**
Corrosive	No	Yes
Boiling Point	100.0°C	150.2°C
Density	1.000 g/cm^3	1.135 g/cm^3

17. Why are water and hydrogen peroxide different substances even though they are both made up of hydrogen and oxygen atoms?

Student responses:

- Water and hydrogen peroxide have different properties because they are different substances. The water molecules consist of one oxygen and two hydrogen atoms, but the hydrogen peroxide molecules consist of two oxygen and two hydrogen atoms. The molecules of the same substances must have the same types and number of each types of atoms. Even though water and hydrogen peroxide both consist of oxygen and hydrogen atoms, the number of oxygen and hydrogen atoms is different so that water and hydrogen peroxide are different substances.

Discussion

Use students' representations of substances to discuss the following information about different configurations of molecules:

- Some substances are made of one atom, such as Neon gas.
- Some different substances are made of molecules consisting of the same type of atom, but a different number of those atoms—such as oxygen gas and ozone.
- The molecules of some substances are made of more than one type of atom, such as water and hydrogen peroxide.

Possible questions:

- *How is neon gas different from oxygen gas?*
- *What makes oxygen gas different from ozone?*
- *What makes hydrogen peroxide different from water?*
- *How can molecules account for so many different kinds of substances in the world, given that there are only about 100 elements?*
- *If two different materials are made up of molecules with the same type of atoms but different numbers of atoms, will the materials have the same or different properties? Why?*

Concluding the Activity

Ask students to think about the driving question for the activity: *Why are some materials explosive, while other materials are not?* Help students connect this question to the driving question for the unit: *How can a small spark start a huge explosion?*

Possible questions:

- *Do all substances explode when they come in contact with a spark?*
- *Why are some materials explosive, but others are not?*
- *Why do different substances have different properties?*

Homework: Reading for Activity 3.1 [Molecules and Their Representations]

Activity 3.2: What holds the atoms of a molecule together?

SUMMARY

In this activity, students will develop ideas about how attractive and repulsive interactions between atoms lead to formation of a chemical bond. In this activity we emphasize the ideas of balance between attractive forces originating from interactions between electrons of one atom and nuclei of the other atom and repulsive forces originating from interactions between the nuclei as well as shifts in electron density as a result of those interactions that lead to bond formation. In the next activity, students will explore how energy changes when interactions between atoms occur and how energy is involved in the process of forming a chemical bond.

LEARNING GOALS

- Students will use a model to explain what happens when two atoms get close to each other in terms of changes in the electric forces and changes in the electron probability map between the atoms.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Types of Interactions: Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. (NGSS Lead States, p. 93)	*Cause and Effect:* Cause and effect students suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems (NGSS Appendix G p.83)	*Developing and using models:* Students will develop and/or use model to predict and /or describe phenomena. (NGSS Appendix F p. 53)

- Students will construct a model to explain how atoms are held together in a diatomic molecule.
    - In a stable molecule, the repulsive force between the positive nuclei is balanced by the attractive force between the positive nuclei and the negatively charged electrons.
    - When the attractive and repulsive forces between two atoms are balanced, and the electron probability distribution of the atoms overlaps significantly between them, a bond forms between the atoms.
    - Atoms in a stable molecule are held together by the sharing of electrons.

Activity 3.2 - Teacher Preparation

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:* Cause and effect relationships may be used to predict phenomena in natural and designed systems (NGSS Appendix G p.83)	*Developing and using models:* Students will develop and/or use model to predict and /or describe phenomena (NGSS Appendix F p. 53)

POINTS FOR CONSIDERATION

- Students previously explored atomic structure and the characteristics of subatomic particles. However, they have not yet connected electric interactions between subatomic particles with why or how chemical bonds are formed.
- Often when students explain bonding, they rely on rules but cannot express any reasoning behind those rules (for example, "Atoms want eight electrons"). In this activity, the focus is on why atoms are attracted to each other instead of specific rules about how atoms bond. Therefore, we are not asking students to predict how many bonds will form, but rather to explain why any bonds form. In particular, you should not discuss the octet rule or how to use it to determine the structure of molecules. Instead, focus on comparing relative strength of interactions between components of atoms. In particular, point out that electron interactions are weaker than interactions generated by protons. This is because electrons are more spread out due to their probabilistic nature and therefore the electron charge is more spread out, which leads to a weaker field generated by the charge. In contrast to an electron, a proton's positive charge is concentrated in the small nucleus of an atom. This high concentration of charge leads to a stronger electric field generated by protons. The strong repulsive force between protons prevents overlap of nuclei, but the weaker field generated by the diffuse electrons permits overlapping of the electron clouds and bonding through electrons being attracted to both nuclei. It is through the balance of all these attractive and repulsive interactions that a chemical bond is formed.

PREPARATION

Class Time: 80 min.

Materials

- rod
- fur
- two balloons

HOMEWORK

Reading for Activity 3.2: Same Molecules but Different Representations

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

1. Introduction

2. Review of Atomic Model

    a. Questions

    b. Discussion and Balloon and Rod Demonstration

3. What holds oxygen atoms together when they form oxygen molecule?

    a. Simulation

    b. Discussion

    c. Questions

    d. Discussion

    e. Questions

    f. Discussion

    g. Questions & models

    h. Discussion

4. How do scientists represent atoms that are bonded together?

    a. Simulation

    b. Questions

c. Discussion and conclusion

Activity 3.2 (Student materials): What holds the atoms of a molecule together?

Introducing the Activity

Review the reading from the previous activity "Molecules and their representations". Ask students to share their answers for naming the compounds in the table.

Possible questions:

- *What information do molecular models provide?*
- *What are they different kinds of molecular models that you read about?*
- *What information do chemical formulas provide?*
- *Why are molecular models useful?*

Select and share some student representations of molecules from the previous activity that show different ways of connecting atoms. (At this point, various representations showing connections between atoms can be used—not just "correct" ones.) Ask students what holds the molecules together. If there are any representations that show a chemical bond, ask what the bond represents. Do not use the term *bond* or *chemical bond* yet unless students bring it into the discussion. If students mention one of these terms, ask them what they think the term means.

Possible questions:

- *Why did you draw these two (or three) atoms connected together?*
- *What does this "stick" represent in your molecule?*
- *(If students mention the term* bond or chemical bond*) What do you know about bonds? What is the meaning of the word* bond*? (Do not correct students' ideas at this point.)*
- *What ties hydrogen and oxygen together in a water molecule?*
- *What is between the atoms? What is connecting them?*
- *Why do atoms connect (or bond) together?*

Page title:
Introduction

In the previous investigations, you explored the idea that matter is made up of positive and negative particles that can attract or repel each other depending on whether their charges are alike or opposite. Could this electric nature of matter help to explain what connects the atoms of a molecule?

Page title:
Review Atomic Model

Recall the model of an atom you saw in Unit 1. You concluded that an atom has both positive and negative charges arranged as shown in the model depicted in Figure 1 below. Depending on the identity of the atoms, their nuclei can have different number of protons and neutrons. For example, the model below shows a helium atom that has two protons and two neutrons.

Review the model and answer the following questions.

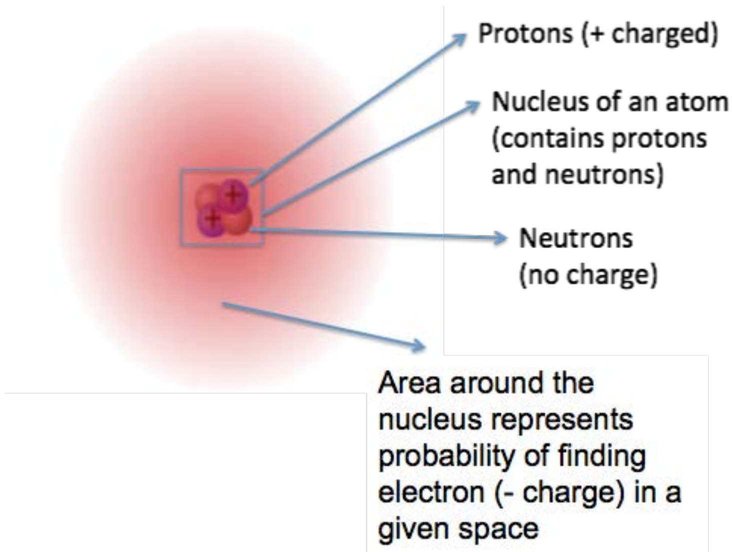


Figure 1. Probabilistic model of an atom.

1.**Using the model of an atom shown in Figure 1, describe the types of forces involved in holding the atom together**.

Student responses:

- negatively charged electron is attracted to the positively charged protons in the nucleus. The area around the nucleus shows the probability of finding the electron.
- While not important for the answer, students might mention strong force holding nucleus together.

2. Predict how two atoms will interact as they come close to each other. Support your prediction based on your model of electric forces and your model of atoms.

Student responses: Answers may vary. Do not correct students' responses at this point.

- Atoms will always repel each other, due to negatively charged electrons repelling
- Nothing because the atoms are neutral overall
- It depends on the charge of the atoms

Discussion and Demonstration

Revisit the model of atomic structure. Have students share their answers to the questions above. Ask students to think about how the electric nature of matter can help explain what is between the atoms that form a molecule, what holds molecules together, and why atoms may form a molecule instead of remaining separate.

Possible questions:

- *What happens when two neutral atoms get close to each other?*
- *How do you think the positive nuclei and negative electrons of two atoms would interact as the atoms come close together?*
- *Do you think electrons care about which proton they are attracted to: same atom or the proton in the atom near it?*

Demonstration

Show the demonstration below and discuss whether objects care about which charged object they interact with.

Hang two neutral balloons next to each other. They should be about 10 inches apart so that when you bring the charged rod between them they don't touch. The string should be between 10-15 inches long. Charge the rod with fur and place the rod between the two balloons. Since the two balloons are neutral, they both will attract towards the rod when you bring it between the two balloons.

Possible questions:

- *What did you notice about how the balloons interact with the charged rod?*
- *Does the rod pick a balloon to interact with?*
- *Do you think electrons pick a nucleus to interact with?*

Review the factors that affect the strength of the interaction between objects. Continue with the following demonstration and discussion.

Using the same set-up as above, move the charged rod closer to one of the balloons. Allow students to observe the interaction.

Possible questions:

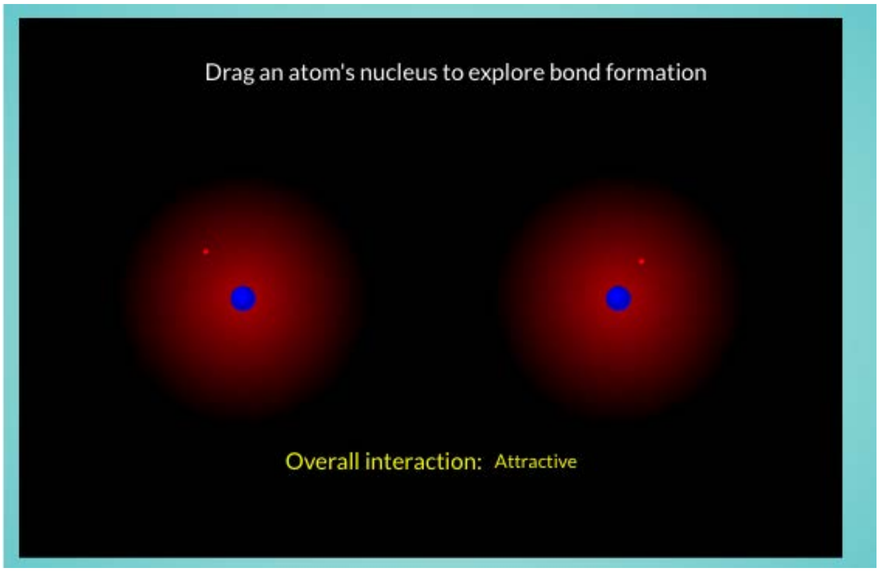
- *How are the interactions between the rod and each of the balloons different?*
- *How are they similar?*
- *Why does one of the balloons interact differently with the rod than the other one?*
- *What did you notice about how the distance of the balloons affects interact with the charged rod?*
- *How does this experiment help you describe interactions between two atoms?*

Page title:
What holds oxygen atoms together when they form an oxygen molecule?

You saw that electrons can be represented by a **probability map**, which shows where electrons are likely to be found. Based on the model of the interaction between the rod and balloons that your teacher just demonstrated, you made some predictions about how electrons and atoms might interact with each other. You will continue to explore what happens to electrons when two atoms approach each other.

Investigate

Explore the simulation by dragging the atoms closer to each other or farther apart. Notice how the distance between the two atoms influences the force between the atoms and the electron probability map of each atom.



Simulation link: http://lab.concord.org/interactives-dev.html#interactives/interactions/forming-molecule.json

Discussion

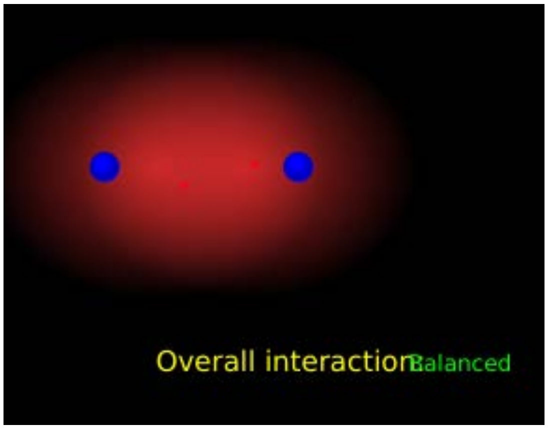
First, let students explore the simulation. Allow them to ask their own questions before they answer the questions in the activity. The following questions may help stimulate student questions.

Possible questions:

- *What do you notice about the simulation? What do you observe?*
- *What does the red area around each atom represent?*
- *How might these interactions between atoms help you explain why molecules form?*

3. [drawing prompt] Starting with the simulation in it’s initial state, move the atoms closer together, and take a snapshot when interactions are balanced.
[text prompt] Describe how the likely location of electrons changes when the interactions are balanced.

Student responses: When the atoms are moved closer together, finding an electron between the two atoms becomes more likely.



4. What causes the electron density to change as the two atoms get closer together?

Supplemental content: As the two atoms move closer together, the electrons of one atom are attracted to the nucleus of the other atom through the electric field. Consequently, the electron density shifts from being uniformly distributed around the atom to being closer to the nucleus of the other atom. The same thing happens to the electron cloud of the other atom. As a result of these interactions the electron density shifts to the area between the two approaching atoms. Theoretically, if there were only two atoms in the entire universe, no matter how far apart they were they would still be attracted to each other. This is always true, just more pronounced as the atoms get closer and the interactions get stronger. At the same time, the electrons from one atom repel the electrons from the other atom and the nucleus of one atom repels the nucleus of the other atom. When the atoms are far apart and as the atoms approach each other, attractive forces between the electron clouds and nuclei are stronger than the repulsive forces between the electron clouds of each atom and the nuclei of each atom. This is because the electrons are able to shift around to maximize the attractions and minimize the repulsions. At a certain point, these attractive forces become equal to the repulsive forces between electron clouds of each atom and their nuclei. At this point, the interactions are balanced.

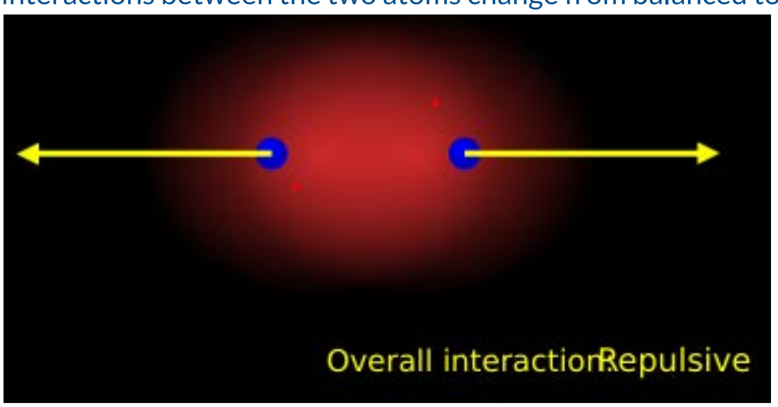
Clarification - students don't need to mention electric fields or repulsive forces between electron clouds and nuclei in this question. The following question gets at the repulsive interactions.

Student responses:

- When the atoms are moved closer together, electrons of one atom start to get close to the adjacent nucleus/protons, they start attracting because opposite charges attract. The attraction leads to a greater electron density between the positively charged nuclei.

5. [drawing prompt] Move the atoms closer than the point at which the interactions are balanced.
[text prompt] How do the interactions between the two atoms change when the atoms get closer than the balanced point?

Student responses: When the atoms are moved closer together than the balanced position, the interactions between the two atoms change from balanced to repulsive.



6. What causes the interactions between the atoms to change when they move closer together than the balanced position? Make sure to specify which parts of the atom are involved in the observed in interactions.

Supplemental content: As the two atoms continue moving towards each other, the repulsive forces become stronger than the attractive forces. The repulsions are always there, but as they get closer, the repulsion gets stronger since forces are larger at smaller distances and since the electrons are not as spread out as they were when the atoms were farther apart. Electrons also start repelling more when the two atoms get closer together since they are similarly charged and have less space to spread out between the nuclei. The main contributor to the repulsive interaction is the repulsion between positively charged nuclei.

Clarification - students might point out that both electron clouds and the nuclei start repelling. This answer is acceptable. You should however point out that repulsion between the nuclei is more significant than repulsion between electron clouds.

Student responses:

- When the atoms are moved from balanced position closer together, nuclei of the two atoms start getting too close to each other and therefore repel because similar charges repel.

Discussion Ensure students understand the representation in the simulation.

Possible questions:

- *What is meant by the term* probability map?
- *How do atoms interact when they are far apart?*
- *How do atoms interact when they are very close together?*
- *How do atoms interact when the interactions are balanced?*
- *Do you think attraction and repulsion is always present between two atoms? Why?*

The following sequence of questions and discussion addresses some of the important aspects of the bond formation process that students often have difficulty with. When going through the rest of the activity, make sure you emphasize the following points that students will likely to have difficulty understanding:

- Why would two neutral atoms be attracted to each other? Make sure you emphasize that as atoms get closer together, the electron clouds don't care which nucleus to attract to, so electron density shifts towards the center between the two atoms, which is where the bond forms.
- How do the interactions change as the two atoms get closer? Make sure to emphasize the parts of the atoms responsible for each type of interaction that occurs when atoms approach: attraction between electrons of one atom and nucleus of the other atom, repulsion between nuclei and electron-electron repulsion. Since electrons are more spread out, the repulsion between them is much weaker than repulsion between nuclei and attraction between nuclei and electrons.
- Where does the bond form? Make sure to point out that the distance at which the attractive and repulsive interactions are balanced is the distance where the chemical bond will form because at that point, atoms don't move closer or further away.
- It is also important to realize that the simulation only represents the overall interaction between the atoms. Students need help breaking down what is going into that interaction at the different distances. They should realize that there is always an attraction and repulsions, but at a given distance which are stronger and why?

7. [draw prompt] Draw a model to compare the interactions between two atoms when the overall force between the two atoms are: attractive, balanced, and repulsive.
[text prompt] What causes the attractive and repulsive forces in your model and how do they change as the atoms interact?

Supplemental content: Negative electrons are attracted to positive protons, while positive protons repel other positive protons and negative electrons repel other negative electrons. All these interactions are always present; however the relative strengths of the various interactions depends on the distance between them. Also, since electrons are in constant motion, the electron probability map can shift to maximize the attractions. As the two atoms get closer together the attractive interactions between the nuclei of one atom and the electron cloud of the other atom are larger than the repulsive interactions between the two nuclei and the repulsive interactions between the two electron clouds. At a certain point, these attractive and repulsive interactions balance out. If atoms continue moving towards each other, repulsive interactions between nuclei become larger than attractive interactions between nuclei and electrons. The chemical bond forms at the distance where attractive and repulsive interactions are balanced. At this point , the electrons are attracted to both nuclei, or, in other words, shared by both nuclei. This sharing of electrons is the essence of a chemical bond.

Clarification - at this point students don't need to know what a chemical bond is. They should however describe the difference types of interactions and the parts of the atoms that are involved in those interactions.

Student responses:

- Protons are attracted to electrons, but protons repel other protons and electrons repel other electrons. When the atoms are far apart the attractions are strongest because the electrons can move to be closer to the other atom. When the atoms are too close, the repulsions are stronger because the electrons no longer have as much room between the protons and are not able to shift in a way to maximize attractions while reducing repulsions.

8. Using the simulation, explain how attractive and repulsive interactions between atoms contribute to holding the two atoms together and ensure that the two atoms stay together and not drift apart.

Student responses:

- When the two atoms interact, electrons of one atom attract to the nucleus of the other atom. The nuclei of the two atoms repel. At a certain distance between the atoms, attractive and repulsive interactions balance out. This is where the two atoms are held together. If they start drifting apart, attractive interactions bring them together.

9. Using the simulation, explain how the electron density shift resulting from changing relative position of the atoms contributes to holding the two atoms together.

Student responses:

- When atoms are attracting, electron density shifts towards the space between the atoms. Atoms are held together by sharing electron density between the two nuclei. If the atoms move away from the balanced position, electron density of one atom starts attracting to the nucleus of the other atom and brings the two atoms together.

Discussion

Share students' snapshots and models to stimulate a discussion of how the magnitude of force changes when atoms are at different distances and how that relates to the location of the electrons. Encourage students to think about why the electron probability map changes, focusing on the attractive force between atoms. Help students talk about where the attractive and repulsive forces between the atoms come from:

- The electron of one atom and the nucleus of the other atom attract each other.
- The nuclei of both atoms are positively charged, so they repel each other.
- The electrons of both atoms are negatively charged, so they also repel each other.
- At the balanced point, the electrons are attracted to both nuclei and are shared between them.

Possible questions:

- *What types of charge do electrons and nuclei have?*
- *How does an electron of one atom interact with the nucleus of the other atom?*
- *Why don't the negative charges of the electron clouds always force the atoms apart?*
- *How do atoms interact when they are far apart?*
- *How do atoms interact when they are very close together?*
- *How do atoms interact when the interactions are balanced?*
- *Do you think atoms can continue moving towards each other until the nuclei touch? Why?*
- *What happens to the electron clouds when atoms get too close together?*
- *At what point do you think a molecule forms? Why?*
- *What questions do you still have about what you observed in the simulation?*

Now you will apply what you've learned from the simulation to develop a model that explains how oxygen atoms form an oxygen molecule.

10. Using your understanding of atomic structure and electric forces, explain what is happening when an oxygen molecule is formed from two separate oxygen atoms. Make sure to explain the following:

- **the cause of the forces between the atoms**
- **the effect of the distance on the forces between the atoms**
- **what holds the molecule together**

Student responses: Student explanation should specify which parts of the atom are involved in attractive and repulsive interactions and explain why at a certain distance the interactions are balanced. The explanation should also reflect that electron density is shared by both atoms involved in the interaction.

- The two atoms come closer together, the electron clouds of one atom are attracted to the nuclei of the other atom and shifted towards the space between the two atoms. As the two atoms continue attracting towards each other, the distance between them gets smaller. At a certain distance the attractive forces become equal repulsive forces between the nuclei of the two atoms and electrons are shared between the nuclei of the two atoms. This is where a chemical bond forms. If atoms continue moving closer, they repel because repulsive forces become larger than attractive forces.

Discussion

Ask students to share their models for explaining how an oxygen molecule forms. Discuss different types of interactions shown in the models and components of the model responsible for those interactions. Point out the following ideas:

- Interactions between electron clouds and atomic nuclei are responsible for attraction between atoms.
- At distances where attractive interactions between nuclei and electrons are larger than repulsive interactions between nuclei, atoms continue attracting and distance between them gets smaller.
- Electron density shifts towards the space between the atoms as they attract because electrons of one atom are attracted to the nucleus of adjacent atom.
- At a certain distance attractive and repulsive interactions are balanced. At this point a chemical bond forms between the two atoms.
- If atoms are pushed beyond the point where the attractive and repulsive forces are balanced, their nuclei start repelling and they are pushed away from each other, which leads to increasing the distance between the atoms till the forces are balanced out again.
- Through sharing electron density atoms are able to form a molecule.

Possible questions:

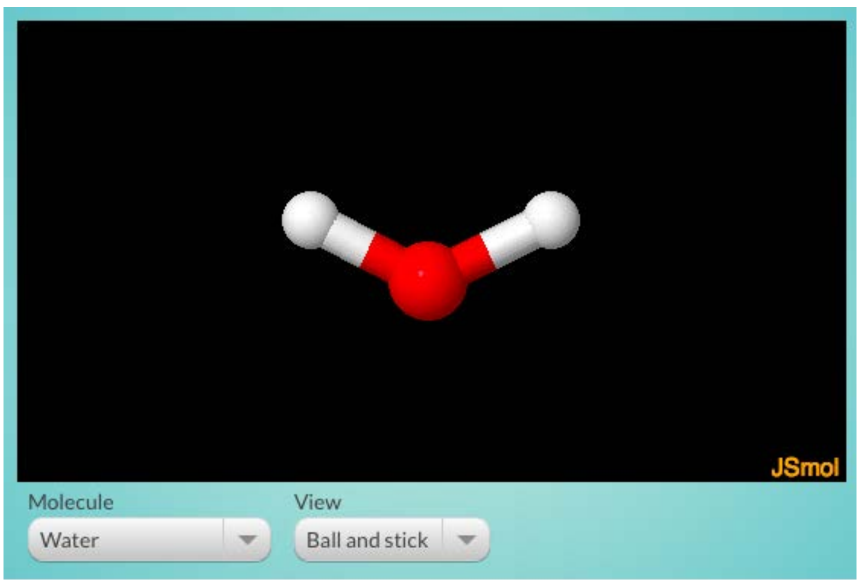
- *How does your model explain the cause of attractive forces between the two atoms?*
- *What components of your model are involved in generating attractive forces between the two atoms?*
- *How does your model explain the cause of repulsive forces between the two atoms?*
- *What components of your model are involved in generating repulsive forces between the two atoms?*
- *How does your model explain the effect of attractive and repulsive forces on the distance between the two atoms?*
- *How does your model explain what causes the molecule to form?*
- *How does your model explain what causes the molecule to stay together?*

Page title:
How do scientists represent atoms that are bonded together?

Think back to the discussion from the beginning of this activity about different ways that molecules can be represented. In the next simulation, you will explore two different types of models that scientists use to represent how the atoms are connected to each other in molecules.

Note: The purpose of this page is to introduce the two types of models and explain how to interpret them. As homework, a reading about space-filling and ball-and-stick models will also help students to think more about the different features of molecules that each model emphasizes.

At this point, students are not expected to give the composition of a molecule or the accurate relative positions of the atoms in a molecule.



Simulation link: http://lab.concord.org/interactives.html#interactives/jsmol/exploring-views.json

11. How are the two types of representations (ball-and-stick and space-filling) similar? Tip: *Click and drag on the molecule to view it in 3D.*

Student responses:

- In both types of representations, the atoms are shown in 3-D. Also, in both types of representations, a sphere represents an atom, and different colors represent different types of atoms.

12. How are the two types of representations (ball-and-stick and space-filling) different?

Student responses:

- The ball-and-stick model has sticks or tubes connecting the spheres that represent the atoms, but the space-filling model has no lines connecting the spheres. Instead, in the space-filling model, the spheres touch each other and overlap.

13. Compare the way that the sharing of electrons in a chemical bond is represented in the space-filling and ball-and-stick models.

Student responses:

- The ball-and-stick model uses sticks to represent the sharing of electrons in a chemical bond. The space-filling model shows the spheres of the atoms overlapping to represent the sharing of electrons in a chemical bond.

Discussion

Based on students' responses to the models, lead a discussion to compare different representations and their usefulness, as well as their limitations. The consensus of the class should be that there are different ways of representing the same molecule, each of which can emphasize different aspects.

- Discussing the ball-and-stick model provides an opportunity to check students' ideas about what holds atoms together.
- Make sure students understand that stick bonds are not real; they are only a representation of chemical bonds. In reality, there are no physical objects linking the atoms in a molecule together.

Possible questions:

- *What is shown in a space-filling model?*
- *What do you think the overlapped part of a space-filling model represents?*
- *What do you think the stick in a ball-and-stick model represents?*
- *If you could see an actual molecule, how do you think these representations would compare with what you would actually see?*
- *Which representation is better at showing or explaining chemical bonds or forces between atoms? Why?*
- *Which representation do you think is more close to the shape of real molecules? Why?*

Homework: Reading for Activity 3.2
Same Molecules but Different Representations

Activity 3.3: When atoms get close to each other, what happens to their potential energy?

SUMMARY

The previous activity was about how electric forces between two individual atoms are associated with molecule formation. The purpose of this activity is to help students use the idea of potential energy, which they learned about in the previous investigation, to explain why atoms in molecules are more stable when bonded together than when separate. This activity also introduces the *binding energy* of molecules. This activity helps students answer the driving question, *How does a small spark start a huge explosion?* by connecting potential energy and the composition of various substances. The next activity will help students explain what happens, in terms of energy transfer and conversion, when a molecule is formed from or broken apart into individual atoms.

LEARNING GOAL

Students will use their conceptual model of atoms to explain, in terms of relative potential energy due to electric interactions, why a molecule forms.

- A molecule has lower potential energy than the same set of individual atoms.
- *Binding energy* is the difference in potential energy between the "optimal distance" where atoms form a molecule and a "too far distance" where no interaction occurs between them.
- Atoms in a stable molecule are held together by the sharing of electrons.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Structure and properties of matter: A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart. (NGSS Lead States, p. 92)	*Cause and Effect:* Cause and effect students suggest cause and effect relationships to explain and predict behaviors in complex natural and designed systems (NGSS Appendix G p.83)	*Developing and using models:* Students will develop and/or use model to predict and /or describe phenomena (NGSS Appendix F p. 53)

POINT FOR CONSIDERATION

- Students may have difficulty relating force and potential energy when two atoms interact because interactions between both similar and opposite charges are involved. When two atoms approach each other, the electron cloud of one atom is attracted to the nucleus of the other atom. While the atoms are attracted, the distance between them decreases and the potential energy of the system decreases. At a certain distance the attractive interactions between atomic nuclei and electrons are equal to repulsive interactions between their nuclei and between their electrons. At this point the energy of the system is minimal and the system is at it's most stable state. If atoms get closer, repulsive interactions between nuclei and electrons become larger than attractive interactions and the potential energy of the system increases dramatically. Therefore, a chemical bond forms at the distance where attractive and repulsive interactions between atoms are balanced because this is where the energy of the system is minimal and the system is at it's most stable state.

- The formation of a chemical bond between the two atoms is achieved by sharing electrons and driven by the principle of achieving higher stability within the system through minimizing potential energy of the system. For some atoms (for example, noble gases like helium, argon etc.), the potential energy of the system for two separate atoms is almost equal to the potential energy of the system of the atoms when they are at the distance where the attractive and repulsive forces are balanced. At this distance electrons are still shared by the two atoms, but the change in energy is not big enough to keep the atoms bonded It is therefore important to point out to students that any pair of atoms won't necessarily form a chemical bond even if they interact at a distance where attractive and repulsive forces between them balance out. If the potential energy of the system is not significantly minimized as a result of bond formation, the bond will not form.
- One of the most common misconceptions is that bonds store energy. This idea for the most part stems from the way a chemical bond is viewed in the context of a biological system.. This is analogous to the ball falling from the top of the hill to a well. It requires energy to get the ball out of the well which is the position of minimal energy. Similarly, it takes energy to ensure that molecules overcome the minimum energy well that they exist in when they are bonded together. Some bonds require higher energy input to break than others, but all bonds require energy to break. There is no way to have a bond that does not require some energy to break. By definition and laws of physics all bonds require energy to break always. Students likely already heard this idea in middle school, so you might need to address this directly to ensure that students sort through the details.

PREPARATION

Class Time: 80 min.

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introduction

2. Simulation

    a. Questions

    b. Discussion

3. Are all molecules more stable than separate atoms?

    a. Discussion: introduce binding energy

    b. Simulation

    c. Questions

    d. Discussion

    e. Questions

4. Discussion

5. Conclusion

Activity 3.3 (Student materials): When atoms get close to each other, what happens to their electric potential energy?

-

Introducing the Activity
Review the reading from the previous activity "Same molecules but different representations."

Possible questions:

- *What are the different models used to represent molecular structure?*
- *How are they the same/different?*
- *How does each model represent what holds atoms together in a molecule?*

In this activity, students connect the concept of potential energy to the molecular-level phenomenon of bond formation. To help them make this connection, refer back to the activities involving potential energy and the tendency of systems to move toward a more stable state (e.g., the pencil-drop and spring activities in Investigation 2). Remind students of the need to define a system, and that a system always acts in a way that minimizes potential energy of the electric field.

Possible questions:

- *What is defined as the system in the pencil-drop (or spring) activity?*
- *What did the pencil-drop (or spring) activity tell us about potential energy?*
- *How do you think potential energy could be related to atoms and molecules?*
- *What is defined as the system when atoms form a molecule?*
- *What happens to the energy of the system when atoms get close to each other?*
- *How do you think energy changes when the distance between atoms changes?*

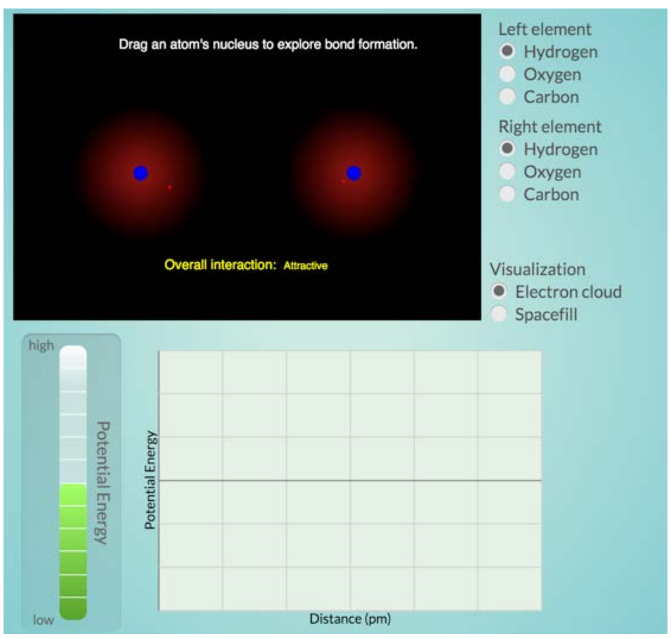
Page title:
Introduction

In previous investigations, you explored simulations of changes in the potential energy of a spring and a pendulum. Now you will explore a simulation to investigate how the potential energy between two atoms changes when they come together to form a bond.

1. **People often think bonds store or hold energy. If that is true, should the energy be high or low when a bond forms?**

Student responses:
- If that was true, energy at the bonding point should be high.

Investigate
In this simulation, you will change the distance between two atoms, just as you did in the simulation in Activity 3.2. This time, notice how the atoms' potential energy changes as you move them.



Simulation link: http://lab.concord.org/interactives.html#interactives/interactions/forming-molecules-graph-no-axes.json

Note: Before students answer the following questions, remind them that the system consists of two atoms.

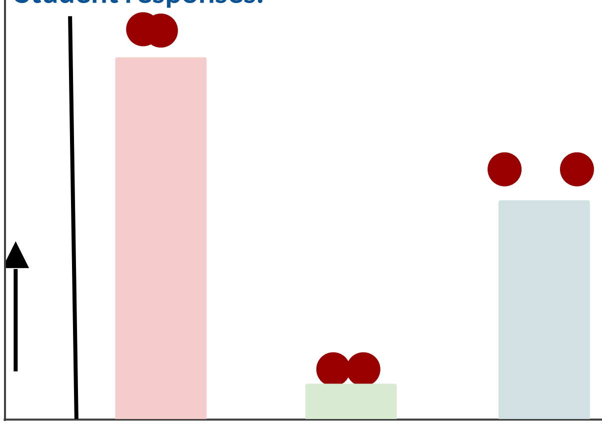
2. **Using the simulation, find a pattern in how the potential energy of the system changes when the relative distance between two atoms changes. Describe the pattern.**

Student responses:
- As two atoms get closer to each other, the potential energy of the system decreases until it reaches the minimum. If the atoms get too close to each other, the potential energy increases as the atoms get closer. There is an optimal distance between two atoms at which the potential energy is lowest.

3. [drawing prompt] Draw a series of bar graphs of potential energy that show when the atoms
- **are very close together**
- **form a stable bond**
- **are too far apart to form a bond**

Make sure to label your graph.

Student responses:



4. Using the simulation, select three different pairs of atoms. For each pair, find the distance between the two atoms at which the potential energy is lowest. Is the distance the same for all three pairs?

A. yes
B. no

Student responses:

A. yes
B. **no**

5. What patterns do you notice when comparing the points where the potential energy is lowest for different pairs of atoms?

Student responses:

- The potential energy is lowest when the distance between the two atoms balances the attractive and repulsive forces.

6. Use ideas of energy, stability and attractive and repulsive forces to explain why two separate atoms form a bond.

Supplemental content: Once the atoms start moving towards each other (in real life atoms constantly move and therefore the probability of encountering another atom in the vicinity is not equal to zero) the electric field of their electron clouds starts interacting with the electric field of the nuclei (attractive interactions) and electric field of the nuclei interact with each other (repulsive interactions). While atoms are close enough for the attractive forces between electron clouds and nuclei to overcome the repulsive forces between their nuclei, atoms will continue moving towards each other. As was discussed in unit 1 energy of the field between two opposite charges decreases as the distance between the two charges decreases. The same thing happens to energy between negatively charged electron clouds and positively charged nuclei. They continue moving towards each other as the energy of the system decreases. However, at certain distance between the atoms, repulsive forces between nuclei become larger than attractive forces. Potential energy of similar charges decreases as the distance between the two charges increases. Therefore atoms continue repelling each other and the potential energy of the system decreases until the interactions are balanced again. As discussed in the previous investigation, systems tend to move towards states of lower potential energy because those states are characterized by highest stability. Therefore, since energy of the system of two interacting atoms is minimal when the attractive and repulsive interactions are balanced, this is also energetically the most stable state for the system.

Clarification - students don't need to mention electric fields. they should relate energy and stability to balanced attractive and repulsive interactions

Student responses:

- Systems tend to move towards more stable states. When potential energy is lowest, the system is at its most stable state. The potential energy is lowest at the distance between the two atoms that the attractive and repulsive forces are balanced. If the atoms get too close, the repulsive forces between nuclei become larger than the attractive forces between electrons and nuclei, which causes atoms move apart. If atoms get too far away, attractive forces between nuclei and electrons are higher than the repulsive forces drawing atoms closer together.

Note: Students don't need to compare the distances quantitatively. At this point, all they need to know is that different types of atoms are at relatively different distances when they have the lowest potential energy. Remind students that this is when the bond forms.

Discussion
Display some student responses. As a class, discuss how the potential energy of two atoms changes when the distance between them changes. Ask students to explain the relationship between electric force and potential energy when two atoms are at different distances from each other. When making the connection between force and potential energy, reminding students of a hands-on activity such as the toy car and spring activity may be helpful.

Possible questions:

- *What happens to the force and the potential energy as two atoms start to get closer to each other?*
- *Why would the potential energy of the atoms increase when the atoms get closer?*
- *What happens to the potential energy when the forces are balanced? Why?*

Page title:
Are all molecules more stable than separate atoms?

Many substances, such as oxygen gas (O_2), water (H_2O), and ammonia (NH_3), are made up of molecules. However, some substances, such as helium gas (He), are made up of single atoms. Why is helium made up of single atoms rather than molecules?

To answer this question, you need to compare the potential energy of the separate atoms with their potential energy when they are together in a molecule. In the figure, the difference in the potential energy between Point 1 (stable molecule) and Point 2 (individual atoms staying separate) is called the *binding energy* of the molecule.

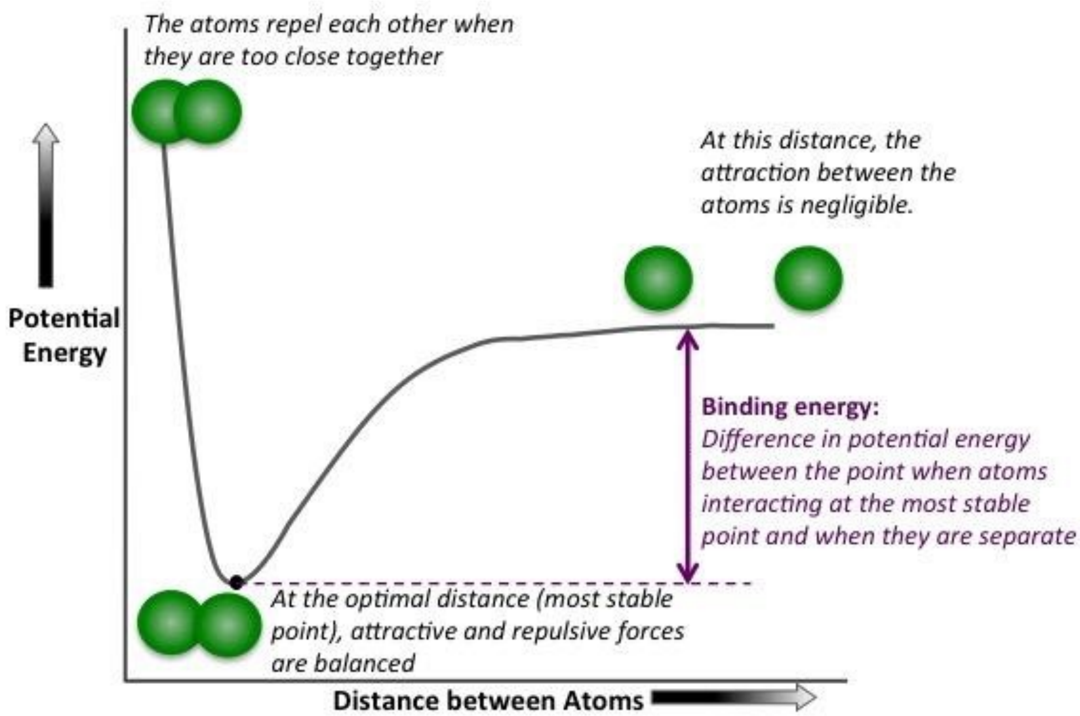
Discussion

Introduce the term *binding energy*.

- The potential energy of two atoms is lowest when they form a molecule. This means that the molecule is more stable than the separate atoms.
- The difference between the potential energy of a stable molecule and the potential energy of its separate atoms is called the *binding energy* of the molecule.

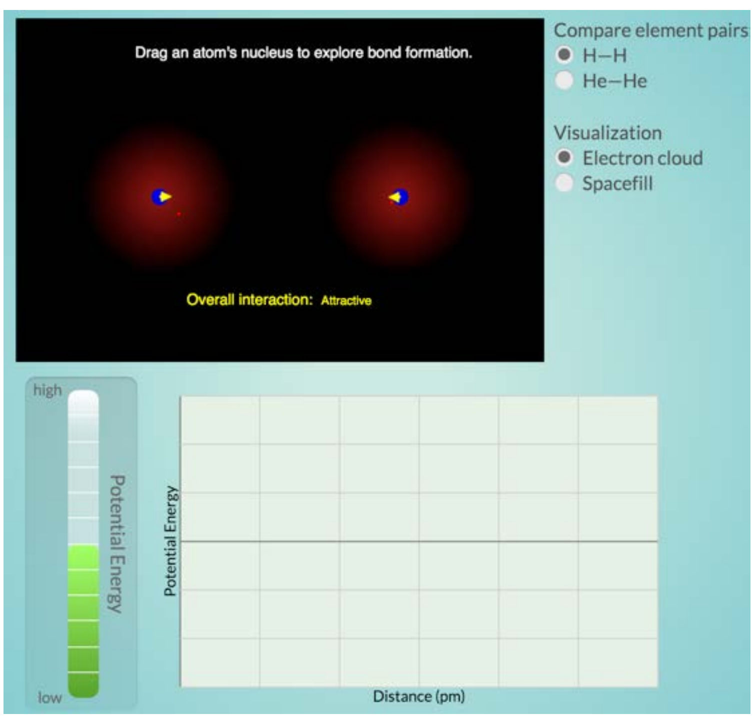
Possible questions:

- *How do the binding energies compare for different combinations of atoms in the simulation?*
- *Which ones have large binding energies?*
- *Which ones have small binding energies?*
- *If a bond has a large binding energy, what does that tell you about the potential energy of the electric field when the atoms have bonded?*
- *How would you describe a bond with a large binding energy?*



Investigate

Use the simulation to investigate the change in potential energy as you change the distance between two atoms. Observe the graph below the atoms to see a trace of the energy as you change the distance.



Simulation link: http://lab.concord.org/interactives.html#interactives/interactions/non-bonding-no-axes.json

7. [snapshot prompt] Observe what happens when two hydrogen atoms (H–H) move close together. Take a snapshot of the atoms when their potential energy is lowest.

Student responses:

- Students' snapshot should show the H–H selection, and the position where the potential energy curve drops to its lowest point. The forces are balanced.

8. In the graphs is the energy at a high point or low point when the atoms form a bond?

Student responses:

- the energy is at the low point when atoms form a bond

9. According to the graphs, do bonds have high energy or low energy?

Student responses:

- bonds have low energy according to the graph

10. [snapshot prompt] Observe what happens when two helium atoms (He–He) move close together. Take a snapshot of the atoms when their potential energy is lowest.

Student responses: Students' snapshot should show the He–He selection, and the position where the potential energy curve drops to its lowest point. The forces are balanced. The snapshot may also show the potential energy curve for hydrogen.

Discussion

Display student examples of energy graphs from the simulation above and discuss how binding energy might be related to bond breaking and formation.

Possible questions:

- *What do you think you would need to do to separate atoms once they have bonded?*
- *What does the graph below tell you about how energy changes when the bond is broken (atoms get further away)?*
- *What does the graph below tell you about how energy changes when the bond forms?*

Point out that one of the most common misconceptions is that bonds store energy. In general, all chemical bonds require energy to break because the bond forms at the position where an energy minimum for a given system exists. This is analogous to the ball falling from the top of the hill to a well. The ball will roll down the hill to the lowest position because that's where energy is minimal. SImilarly, the bond will form at a distance where energy of the system is minimal. Further, It requires energy to get the ball out of the well which is the position of minimal energy. Similarly, it takes energy to ensure that molecules overcome the minimum energy that they exist in when they are bonded together. It is important to stress this idea to the students to avoid this misconception.This idea will be further developed in the next activity and in Investigation 4. For now, address this issue in the context of the simulation that students did and specifically the binding energy graph.

11. [snapshot prompt] Select the hydrogen atoms (H–H) and change the distance between them until you see the complete trace of potential energy vs. distance in the graph below the atoms. Then take a snapshot and indicate on the graph the binding energy of two hydrogen atoms.

Student responses: NOTE: Since students will move the atoms back and forth until the trace is established, the positions occupied by the atoms in the upper part of the display will vary.

12. [snapshot prompt] Select the helium atoms (He–He) and change the distance between them until you see the complete trace of potential energy vs. distance in the graph below the atoms. Then take a snapshot and indicate on the graph the binding energy of two helium atoms.

Student responses: NOTE: Since students will move the atoms back and forth until the trace is established, the positions occupied by the atoms in the upper part of the display will vary.

13. Based on your answers to the two previous questions, compare the binding energy of two hydrogen atoms with the binding energy of two helium atoms.

Student responses:

- The binding energy of two hydrogen atoms is much greater compared with the binding energy of two helium atoms.

14. Why do hydrogen atoms form a molecule but helium atoms do not? In your answer, make sure to include potential energy, and electrons.

Supplemental content: Systems move toward the lowest potential energy. When two hydrogen atoms are at an optimal distance from each other, their potential energy is much lower than when they are separate, and their electrons are shared between the nuclei. This indicates that hydrogen atoms are much more stable if they are at this optimal distance than if they are separate. This is why hydrogen atoms form a bond and stay as a molecule. However, there is not much of a difference between the potential energy of two helium atoms when they are at an optimal distance compared with when they are separate, and their electrons are not shared. This means that the binding energy of two helium atoms is very small, so helium atoms do not form a stable bond.

Clarification- students should notice the difference in potential energy at the balanced position and difference in how electron density is shared in helium and hydrogen molecules.

Student responses:

- When the forces are balanced, the potential energy of H–H is much lower than the potential energy of He–He, so an H–H bond is more stable. The electrons are shared by two hydrogen atoms at the balance point, but they are not shared by two helium atoms at the balance point. So the helium atoms do not bond together in a molecule.

Discussion

Lead a discussion about why hydrogen atoms form a molecule but helium atoms do not. Compare the potential energy and binding energy of each molecule. Point out that when two atoms of helium come close together, the potential energy lowers just a little bit. As a result, helium atoms move apart very easily and do not form a bond.

Possible questions:

- *What is similar about the changes in potential energy that occur when two hydrogen atoms are brought close together and when two helium atoms are brought close together?*
- *What is different about the changes in potential energy that occur when two hydrogen atoms are brought close together and when two helium atoms are brought close together?*
- *What is the most stable position of two atoms?*
- *How does the area where electrons are most likely to be found compare between hydrogen and helium when their potential energy is lowest?*
- *Why do hydrogen atoms form a molecule but helium atoms do not?*

NOTE: Students do not need to know about electron configurations at this point. The focus is only on differences in potential energy and the sharing of electrons.

15. Describe what causes two atoms to bond together to form a molecule. Your description should include force, potential energy, and electrons.

Supplemental content: The formation of a chemical bond between the two atoms is achieved by sharing electrons and driven by the principle of achieving higher stability within the system through minimizing potential energy of the system. For some atoms (for example, noble gases like helium, argon etc.), the potential energy of the system for two separate atoms is almost equal to the potential energy of the system of the atoms when they are at the distance where the attractive and repulsive forces are balanced. At this distance electrons are also not shared by the two atoms, so the bond cannot form. This is due to electronic configuration of helium and other noble gases which we are not discussing here.If, however, at the distance where attractive and repulsive forces are balanced out the atoms share electron density, a chemical bond can form.

Clarification- students don't need to know about electron configuration and how it is involved in atom's ability to form a bond.

Student responses: Explanations should include the following: a) The attractive force between the electrons of one atom and the nucleus of another atom pulls both atoms toward each other until they reach a point where the attractive and repulsive forces are balanced. b) In this balanced position, the potential energy is lowest. This is the most stable position of the two atoms. And c) if electrons are shared between the atoms when they are in this stable position, a molecule is formed.

- The nucleus of one of the atoms attracts the electrons of the other atom, which makes the two atoms move towards each other until they reach the distance at which the repulsive forces between the nuclei equal the attractive forces. At this point, the potential energy is lowest, and so a bond can form.

Discussion and Conclusion

Share students' answers to the previous question and discuss the following:

- There is a distance at which the attractive and repulsive forces of two atoms are balanced. The less potential energy there is, the more stable the bond is between the atoms.
- The potential energy is lowest when the two atoms are in the most stable position. This is the distance at which the forces are balanced, the potential energy is lowest, and the bond is formed. This distance is called *bond length*, and it is the distance between two atoms when they form a bond.

Possible questions:

- *What causes atoms to bond together?*
- *What factors determine the distance at which two atoms form a bond?*
- *How are forces and energy involved in the formation of bonds between atoms?*
- *How are electrons involved in the formation of a bond between atoms?*

Activity 3.4: How are bonds formed and broken?

SUMMARY

In this activity, students will explore simulations and construct scientific explanations and models involving energy transfer and conversion that explain how a molecule is formed or broken. At the end of this activity, students will be able to explain why a spark is needed to start an explosion, but they still won't have enough information to answer the driving question for the unit: *How can a small spark start a huge explosion?* In the next activity, students will study how energy is involved in various chemical reactions in order to explain how a small spark can start a huge explosion.

LEARNING GOALS

- Students will be able to construct an explanation and develop a model to describe the relationship between energy and molecules breaking and forming.
    - When a bond is formed, potential energy decreases so energy is transferred to the surroundings
    - When a bond is broken, energy is absorbed.
    - The amount of energy that is needed to break a bond is exactly equal to the binding energy of the molecule.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Structure and Properties of Matter: A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.(NGSS Lead States, p. 92)	*Energy and Matter:* Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (NGSS Appendix G p.86)	*Constructing explanations:* 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 (NGSS Lead States, p. 61).

- Students will be able to use conservation of energy to explain that energy conversion takes place between potential energy and other forms of energy, and that energy transfer also occurs, when a molecule forms or breaks.

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Structure and Properties of Matter: A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart(NGSS Lead States, p. 92)	*Energy and Matter:* Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (NGSS Appendix G p. 86)	*Constructing explanations:* 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 (NGSS Lead States, p. 61))

POINT FOR CONSIDERATION

Students may have difficulty understanding how energy is converted between potential energy and kinetic energy when a molecule forms. In the simulation of bond formation, when the third atom is added to the simulation, students may need help making a connection to energy transfer (i.e., energy is transferred from the two atoms forming the bond to the third atom). It should become apparent to students that the third atoms has gained kinetic energy when they see that it is moving faster.

PREPARATION

Class Time: 60 min.

Materials (always bullet)

- two billiard balls (or any other balls that make a sound upon collision)

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introduction
2. Billiard balls demonstration
    a. Questions
    b. Discussion
3. Simulation: Molecule formation
    a. Questions
    b. Discussion
4. How is energy involved when a bond forms?
    a. Review Basketball/tennis ball demonstration
    b. Discussion
    c. Simulation
    d. Questions
    e. Discussion
5. How is energy involved when bond breaks?
    a. Simulation
    b. Questions
    c. Discussion
6. Conclusion
    a. Questions
    b. Discussion

Activity 3.4 (Student materials): How are bonds formed and broken?

Introducing the Activity
Review what has been learnt so far in the investigation.
Possible questions:

- *What have we learnt so far?*
- *What questions do we still have?*
- *Do we have any new questions ?*

Show students the following demo with billiard balls moving towards each other and bouncing apart. Introduce the question "What about two atoms moving towards each other"?

Possible questions:

- *Do you think two atoms would bounce apart?*
- *What could keep the two atoms from bouncing apart?*
- *How does energy change when the two balls interact?*

Page title:
Introduction

In a previous activity, you learned that substances are made up of individual atoms or groups of atoms called *molecules*. A molecule forms when the forces of attraction and repulsion between two atoms are balanced, electrons are shared, and the potential energy of the molecule is lower than the potential energy of the separate atoms. In this activity, you will learn more about the relationship between energy and the formation and breaking of bonds, using the ideas of energy transfer and conversion.

Demonstration

Collide billiard balls (or any other balls) and let students observe what happens during collision.

Possible questions:

- *What forms of energy are present in this demonstration?*
- *How does energy change of the system change in this demonstration?*
- *Does anybody have a different idea?*

1. **In the demonstration, is energy converted from one form to another when the billiard balls collide?? What evidence supports your claim?**

Student responses: Answers will vary. This is a formative question, so it is not important that students have a correct answer at this point. Possible responses might include:

- Yes. It is converted from potential energy to sound.

2. Is energy transferred from one ball to another when the billiard balls collide? What evidence supports your claim?

Student responses: Answers will vary. This is a formative question, so it is not important that students have a correct answer at this point. Possible responses might include one of the following:

- Yes. Energy is transferred. We hear the sound of the collision, so energy is transferred from the collision to the air.
- Yes. Energy is transferred. The collision transfers energy to the surroundings.
- No. The balls hit then bounce off and keep moving so it is still kinetic energy.
    - *Do you think they are moving with the exact same speed or could some of the energy have changed to a different form?*

3. Is energy conserved in this demonstration? What evidence supports your claim?

Student responses: Answers will vary. This is a formative question, so it is not important that students have a correct answer at this point. Possible responses might include one of the following:

- No. Even though the collision was not strong, spheres continued to move for a long time .
- Yes. Energy must be conserved because the spheres continue moving after the collision.

Discussion

If students have trouble with the concepts of energy transfer, energy conversion, and conservation of energy, remind them of the experiment they did with the springin Unit 2, Activity 2.1. For that experiment, they used a spring to demonstrate energy transfer and conversion.

Possible questions:

- *What forms of energy were present in the experiment with the spring and toy car?*
- *When you compressed or stretched the spring, what was defined as the system, and what was defined as the surroundings?*
- *What evidence showed that energy had been converted?*
- *What evidence showed that energy had been transferred?*
- *How did the experiment with the spring and toy car show that energy is conserved?*

Page title:
How does a bond form?

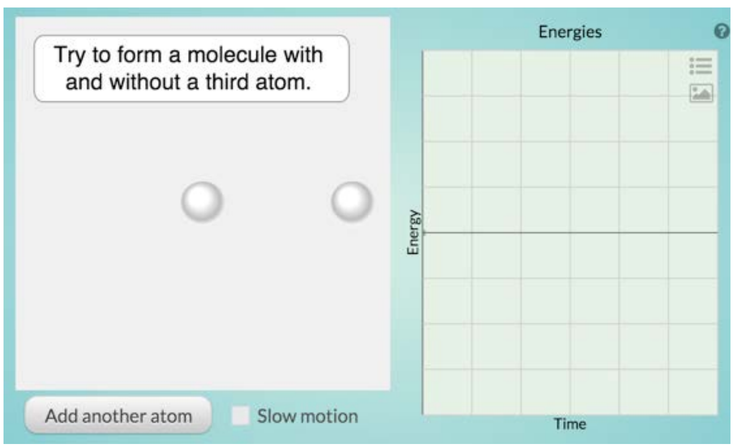
Discussion

Refer to students' energy graphs from the previous activity, which show the potential energy of molecules and separate atoms. Use these graphs to discuss why molecules have lower potential energy than separate atoms.

Possible questions:

- *Which graphs best explain binding energy?*
- *How does the graph help explain this idea?*
- *Where does the energy go when a molecule is formed?*

Use the simulation to explore what happens to energy when individual atoms collide.



http://lab.concord.org/interactives.html#interactives/interactions/forming-molecular-bond-no-axes.json

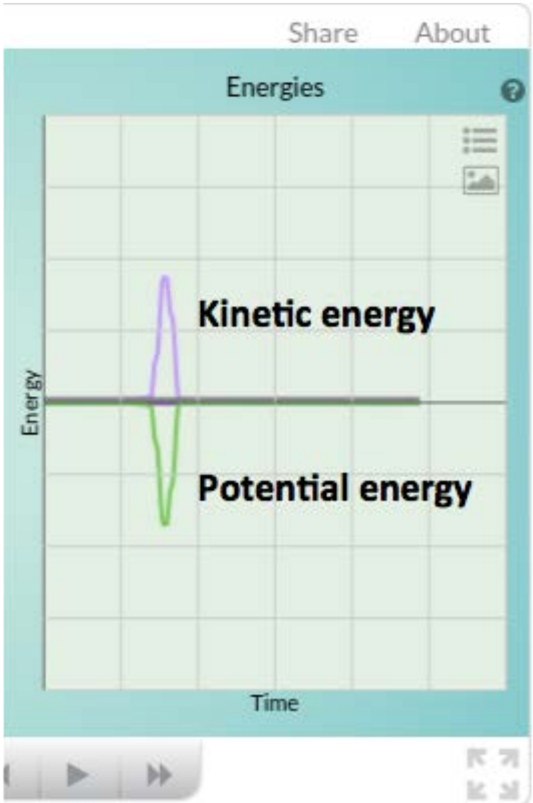
4. Describe what happens in the simulation when there are only two atoms and they collide.

Student responses:

- The atoms keep bouncing off each other and do not bond together.

5. [snapshot prompt] **Take a snapshot of the simulation after the atoms have collided. On the graph, label the potential and kinetic energy traces.**
[text prompt] **When the potential energy is at its lowest point, attractive and repulsive forces are balanced, but the two atoms do not form a molecule. Why doesn't a stable bond form?** ***Hint: Think about what the kinetic energy trace tells you about the speed of the two atoms.***

Student responses:

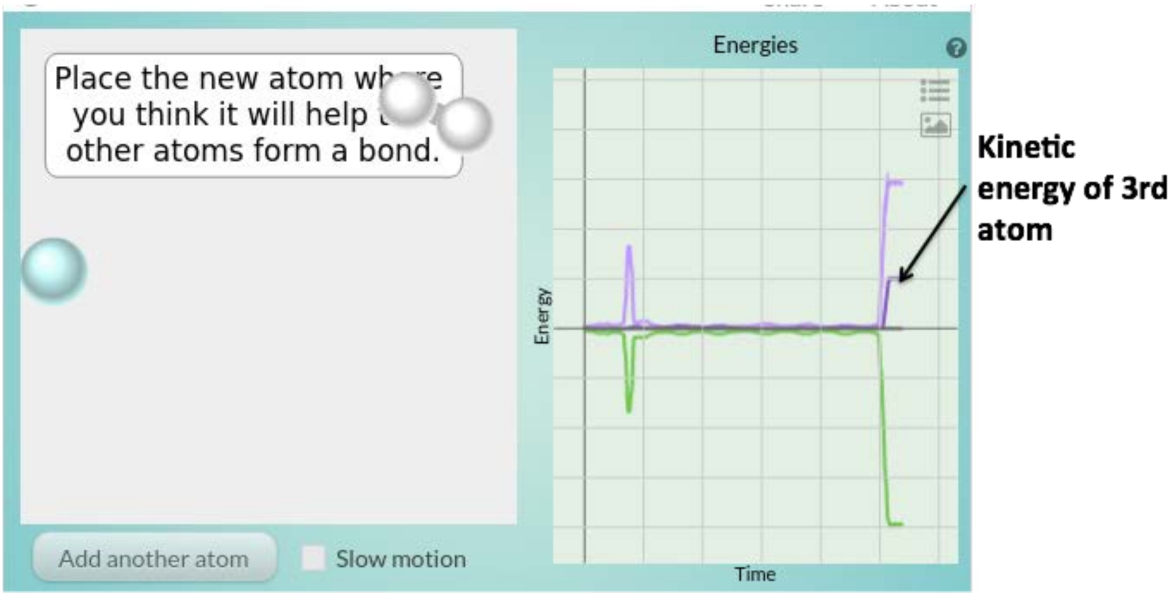


- The increase in kinetic energy shows that the atoms are moving faster and faster as the potential energy is dropping. The atoms have enough kinetic energy that they bounce off each other.

Add a third atom to the simulation. Try a variety of positions for the third atom until you find a way for it to enable the formation of a bond between the first two atoms.

6. [snapshot prompt] **Take a snapshot of the molecule that was formed after adding the third atom, and label the trace of the kinetic energy of the third atom.**
[text prompt] **Where does the kinetic energy of the third atom come from?**

Student responses:



- The third atom moves faster after the collision. Some potential energy was transferred to the third atom during the collision.

Discussion
Display student answers to the questions above. Discuss how energy changes before and after a third atom is introduced. Discuss the role of the third atom in the bond formation.

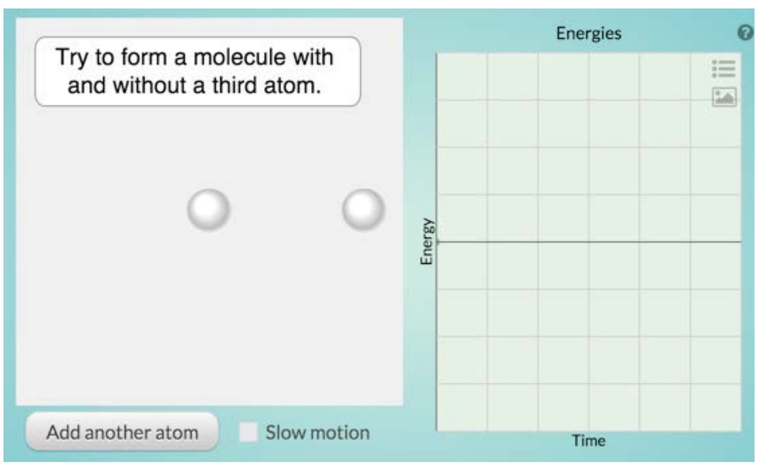
Possible questions:
- *What did you notice about energy change before the third atom was introduced?*
- *What did you notice about energy change after the third atom was introduced?*
- *What is the role of the third atom in bond formation?*

Page title:
How is energy involved when a bond forms?

Recall the demo in which a tennis ball and basketball were dropped together. Think about how it might connect to the role of the third atom in the simulation you just explored. How can the transfer of energy between the basketball and tennis ball help us understand the transfer of energy between atoms when they form a molecule?

Discussion
Revisit the demonstration with a basketball and tennis ball from Unit 2, Activity 1.2. Ask students to recall what they observed in the demonstration and how that might help explain the observations of the simulation.

Possible questions:
- *Remember the demo in which a tennis ball was dropped on top of a basketball? What did we observe?*
- *Why did the tennis ball bounce so much higher when it was on top of the basketball?*
- *Could our observations of the tennis ball and basketball help explain what happens in this simulation?*



http://lab.concord.org/interactives.html#interactives/interactions/forming-molecular-bond-no-axes.json

8. When two atoms form a molecule, the molecule has lower energy than the two separate atoms. However, when only two atoms are present, they bounce off each other and do not form a molecule. Explain what happens to the energy of the atoms when there are only two atoms and they collide.

Supplemental content: If there is no way for the two atoms to transfer the kinetic energy they have to the surroundings, then the kinetic energy they have is enough to break the bond that has just formed. If, however, there is a third atom present (which in reality is almost always the case since there are a lot of atoms bouncing around and many collisions happening at the same time), then they can transfer extra kinetic energy to the third atom through collision. The energy is still conserved, the third atom will move faster. Once the extra energy is transferred from the system, two atoms can form a bond with lower energy than the original two atoms before collision with the third one.

> *Clarification- Students should indicate in their answer that if there are only two atoms present, the kinetic energy they have left when the bond is formed is enough to break the bond, and so it can't form. Students don't need to know that there are multiple collisions happening simultaneously.*

Student responses:

- When two atoms from a bond, potential energy is converted to kinetic energy. In a system that has only two atoms, there is no other object to receive the kinetic energy. As a result, the kinetic energy of the atoms is high enough that they can break free of the newly formed bond.

9. [snapshot prompt] **Take a snapshot and use it to draw a model that shows the role of the third atom when two atoms form a molecule. Make sure to show what happens to the energy of the atoms.**
[text prompt] **Describe the role of the third atom in breaking the bond.**

Student responses: The model should include energy transfer from the molecule to the third atom, indicating that the third atom has higher energy (moves faster) after the molecule forms. Students should include an explanation of how the energy of the system changes when the two hydrogen atoms form a bond.

Discussion
Discuss conservation of energy and energy transfer when two atoms form a molecule.

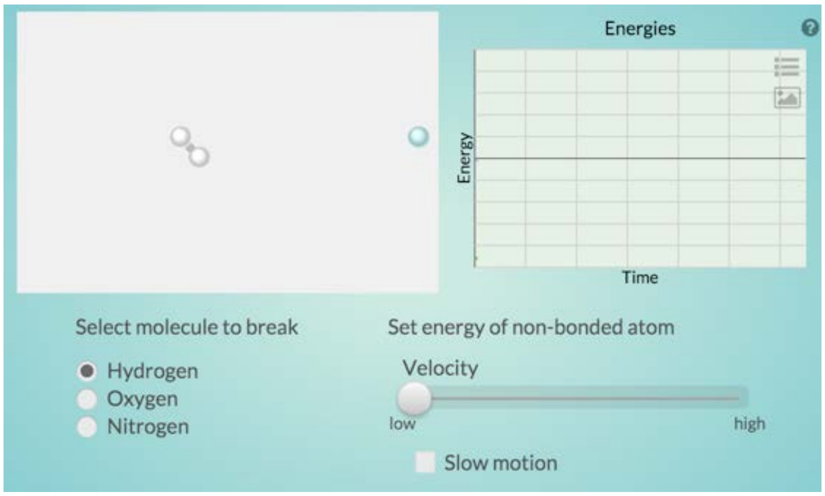
Possible questions:

- *Why is a third atom needed when two atoms form a molecule?*
- *Why does the third atom move faster after two atoms bond together?*
- *How could we explain this phenomenon using conservation of energy?*
- *Is it possible to form a molecule without the third atom?*
- *What is the system and what are the surroundings in this phenomenon?*

Page title:
How is energy involved when a bond breaks?

When atoms bond together to form a molecule, the potential energy decreases and available energy is transferred to the surroundings. How is energy involved when a molecule breaks apart?

Investigation
Use the simulation to explore how energy is involved when a molecule breaks apart into individual atoms.



http://lab.concord.org/interactives.html#interactives/interactions/breaking-molecular-bond-no-axes.json

10. How does the speed of the third atom change after it hits the molecule?

Student responses:
- The third atom slows down.

11. What does the change in speed tell you about the kinetic energy of the third atom at the moment it hits the molecule?

Student responses:
- The third atom has lower kinetic energy.

12. What happens to the energy of the atoms in the molecule at the moment it is hit by the third atom? How can you tell?

Student responses:

- The atoms in the molecule gain energy. I can tell because the atoms in the molecule move faster and break apart.

13. What is the role of the third atom when the bonds of the molecule break? Explain.

Student responses: *The third atom transfers kinetic energy to the molecule, causing the energy of the atoms in the molecule to increase so that their kinetic energy becomes greater than the attractive forces between them, breaking the bond between atoms.*

14. [drawing prompt] Construct a model to show the process of bond breaking. Your model should include energy and forces.

[text prompt] Explain your model.

Student responses:
The model should include a transfer of energy from the third atom to the molecule, and an increase in energy or motion of the atoms in the molecule. The explanation should include that the energy of the atoms in the molecule increases. As a result, the forces between the two atoms become unbalanced, and the atoms break apart from each other.

Discussion:
Discuss the role of energy in breaking bonds.

Possible questions:

- *How do you think the balance of forces necessary for bonding is involved in bond breakage?*
- *How much energy is needed to break a bond? How is this energy related to binding energy?*
- *Will different molecules need the same amount of energy to break their bonds?*
- *How is the simulation above not realistic? (Hint: do you think there are only 3 atoms interacting in reality?)*
- *When a lot of atoms interact and form bonds, what would you observe as evidence for energy transfer (area getting cooler)?*
- *You might have heard in other classes a common idea that breaking bonds releases energy. What really happens to energy when bonds break?*

Page title:
Conclusion

Energy is involved when a bond forms and when it breaks. Based on things you learned in this activity, answer the questions below focusing on how energy changes when bonds form.

17. Is there energy available to transfer to the surroundings when bonds break? Justify your answer.

Student responses:

- No. It takes energy to break bonds. The potential energy of separate atoms is higher than the potential energy of those atoms bonded together

18. Is there energy available to transfer to the surroundings when bonds form? Justify your answer.

Student responses:

- Yes. Energy is released when a bond forms. A bond forms when the potential energy of separate atoms is higher than the potential energy of those atoms bonded together.