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INVESTIGATION 4: Where does all the energy in an explosion come from?

Overview

In the previous investigation, students tracked the energy transfers and conversions involved when a molecule forms or breaks apart to establish that molecules form when the arrangement of the atoms in the molecule is more stable than the separate atoms.

In this investigation, students will characterize a chemical reaction as a process involving the rearrangement of atoms that results in the formation of a new substance or substances. Students will track energy throughout the process of a chemical reaction, including the energy that is needed to start the reaction and the energy transfer that occurs between the system and its surroundings. In addition, by comparing the energy of reactants and products, students will learn to classify reactions as endothermic or exothermic processes. These ideas will enable students to construct an explanation that answers the Unit 2 driving question: *How can a small spark start a huge explosion?*

The Performance Expectations (NGSS)

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, pp. 91 - 93)	**Connections to this investigation**
Elements of Disciplinary Core Idea	
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.	In this investigation, students observe phenomena and develop a model to explain that chemical reactions involve breaking and forming bonds. Initiating a chemical reaction requires energy equal to at least the energy of the reactants, which is the amount of energy required to break the bonds. The relative amount of energy transferred from and to the surroundings determines whether the reaction is endothermic or exothermic.
Crosscutting concept	

Overview

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.	Students track energy transfers and conversions in chemical reactions to explain why some reactions build from a small input to a large output of energy, while others require a continuous input of energy to continue.
Science and engineering practice	
Developing and Using a Model • Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. • Develop a model based on evidence to illustrate the relationships between systems or between components of a system.	Throughout this investigation, students use computer-based simulated experiments and hands on experiments to develop and revise their models of energy transfers in chemical reactions. They consider how kinetic energy is involved in breaking molecular bonds and how the relative amounts of reactants' and products' potential energy determine exothermic and endothermic reactions.

HS-PS1-5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. [*Clarification Statement*: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.]

Elements from NGSS (NGSS Lead States, 2013, pp. 91 - 93)	**Connections to this investigation**
Elements of Disciplinary Core Idea	
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.	In this investigation, students develop understanding of the relationships between temperature, kinetic energy, particle motion, and particle collisions to explain breaking and forming chemical bonds and the amount of energy required to start a reaction. The investigation helps students to start think about the role of energy to explain why temperature affects reaction rate.
Crosscutting concept	

Pattern • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.	Students find patterns from the various (hands-on, computer simulation) activities that they explored to construct scientific explanation of why energy is needed to start chemical reactions.
Science and engineering practice	
Constructing Explanations Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Apply scientific principles and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects	Students conduct an experiment involving hydrogen peroxide at different temperatures to gather evidence to explain the effect of temperature change in chemical reaction. Throughout the investigation, students also use computer-based simulation to develop their explanation.

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

Elements from NGSS (NGSS Lead States, 2013, pp. 97 -99)	**Connections to this investigation**
Elements of Disciplinary Core Idea	

Overview

Definition of Energy • Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. • At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. • These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.	In this investigation, students will construct a model showing the mechanism of a chemical reaction and the flow of energy in a chemical reaction at microscopic level to explain macroscopic phenomena and answer the driving question.
Crosscutting concept	
Energy and Matter • Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems.	Students track energy transfers and conversions in chemical reactions to explain why some reactions build from a small input to a large output of energy, while others require a continuous input of energy to continue.
Science and engineering practice	
Developing and Using a Model • Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. • Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.	Students tracks energy using computer simulation to develop a models to explain the mechanism of a chemical reaction in a sample.

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

Students will construct a model to explain how energy and electrostatic forces are involved in chemical reactions. The model should include the following:

- If the properties of the substances before and after a process differ, then new substances have formed and a chemical reaction has occurred.
- Chemical reactions involve bonds breaking and forming such that the same atoms rearrange to form new molecules.
- Breaking bonds requires an input of energy. When bonds form, the potential energy decreases; the available energy is used to continue the reaction or is transferred to the surroundings, or both.
- When a chemical reaction transfers energy to the surroundings after the product molecules have formed, it is an *exothermic reaction*; if energy must continually be transferred in from the surroundings for the chemical reaction to continue, it is an *endothermic reaction*.

Background Knowledge

A *system* is a part of the universe upon which we wish to focus. In this investigation, the system is the chemical reaction. For example, in the electrolysis of water, the system is the molecules of water that decompose, and the molecules of oxygen and hydrogen that are produced. The surroundings are everything else—the rest of the universe. In the same example, the beaker, electrodes, and batteries are part of the surroundings.

The conservation of energy means that the total amount of energy in a system and its surroundings cannot change. However, energy can transfer between the system and its surroundings, and can change form from kinetic energy to potential energy and vice versa.

Activities

Activity 4.1	*What energy changes occur during an explosion?*	*90 min*
Activity 4.2	*What happens to atoms during a chemical reaction?*	*200 min.*
Activity 4.3	*What changes in energy occur when atoms rearrange during a chemical reaction?*	*120 min.*
Activity 4.4	*How does a spark trigger an explosion?*	*20 min.*

Activity 4.1: What energy changes occur during an explosion?

SUMMARY

In Investigation 3, students developed the relationship between bonding and the changes in energy that occur when two atoms interact. In this activity, students will begin to apply that relationship to larger systems were several atoms are interacting. Students start by observing patterns in a simulation showing the formation of bonds as water molecules form from individual hydrogen and oxygen atoms. Students will compare the relationships shown in this simulation with observations of what happens when hydrogen and oxygen gas are mixed in a balloon. In the simulation, a reaction happens spontaneously and converts potential energy to kinetic energy. The gases in the balloon do not react spontaneously. A flame is needed to initiate the reaction, once the reaction starts there is evidence (heat, light, sound) that energy is being transferred to the surroundings. Students are asked to evaluate the usefulness of the simulation and to identify questions that need to be answered in order to answer the unit driving question: *How can a small spark start a huge explosion?* In the next activity, students will analyze various chemical reactions to describe what happens to atoms during reactions and explosions.

LEARNING GOAL

Students will ask questions about the changes that occur related to energy, atoms and molecules during an explosion.

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:* [Students] can describe changes of energy and matter in a system in terms of energy and matter flows into, out of, and within that system. (NGSS Appendix G p. 86)	*Asking questions and defining problems:* Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships. (NGSS Appendix F p. 51)

POINTS FOR CONSIDERATION

- Even though students have discussed the relationship between energy and bonds in Investigation 3, the idea that bonds store energy is a common idea that will likely come up again in this activity. Push students to track the energy changes in the system in order to connect the release of energy to the transfer of energy to the surroundings when bonds form, ***not*** when bonds break.
- Connecting macroscopic observations with changes at the atomic level. Encourage students to connect their observations with changes that are happening to atoms.

PREPARATION

Class Time: 90 min.

Materials for whole-class demonstration

- balloon filled with air
- balloon - about the size of a large orange - filled with a mixture of hydrogen and oxygen gas
- small candle
- long stick or pole
- hydrogen gas (tank or evolved from a reaction)
- oxygen gas (tank or evolved from a reaction)
- matches
- earplugs or earmuffs

Activity Setup

- Blow up one balloon, tie it off, and label the balloon “air.”
- Fill a second balloon with a mixture of hydrogen gas and oxygen gas. This balloon should be about the size of a large orange or grapefruit; it will create a large explosion so it is important that it is not too large. If you have tanks of hydrogen and oxygen gas, this is the easiest way to fill a balloon. If not, there are several methods for evolving hydrogen and oxygen gas using a reaction. Be sure to use a method and solutions with higher concentrations so the reaction will be vigorous enough to create adequate gas pressure to inflate the balloons. For specific instructions see Preparing a Balloon for the Explosion
- Attach the small candle to the end of a meter stick or pole using string, rubber bands, or duct tape. You will use the candle to ignite the balloons so make sure the pole is at least a meter long so that you can be far enough away from the balloon with hydrogen and oxygen gas when it explodes.
- Note: if you do not feel comfortable with the reactions to fill the balloon or the explosion itself, you can show the class a video of the demonstration.

SAFETY ISSUES

The hydrogen and oxygen filled balloon transferred a lot of energy when it reacts to environment. This reaction produces a loud noise and a lot of heat. Make sure you ignite the balloon in a large enough room so that it can be far enough away from students. Use earplugs or earmuffs to protect your hearing. Instruct the students to cover their ears as well. Igniting the balloon near a smoke detector could set of the fire alarm. If possible this demonstration should be conduct behind a safety shield.

Activity 4.1 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introduction
    a. Discussion
    b. Predictions
2. Simulation
    a. Simulation of forming bonds and energy
    b. Questions
    c. Predictions
3. Demonstration
    a. Balloon demo and discussion
    b. Questions about simulation and balloon
    c. Discussion

Activity 4.1 (Student materials): What energy changes occur during an explosion?

Introducing the Lesson: Review the unit driving question, *how can a small spark start a huge explosion?* what has been answered and what still remains to be answered.

Possible questions:

- *What have we learned about sparks?*
- *What have we learned about energy and atoms?*
- *How could these ideas help us explain how a small spark triggers a huge explosion?*
- *What happens to energy when atoms interact?*
- *What about when lots of atoms interact?*
- *What happens during an explosion?*

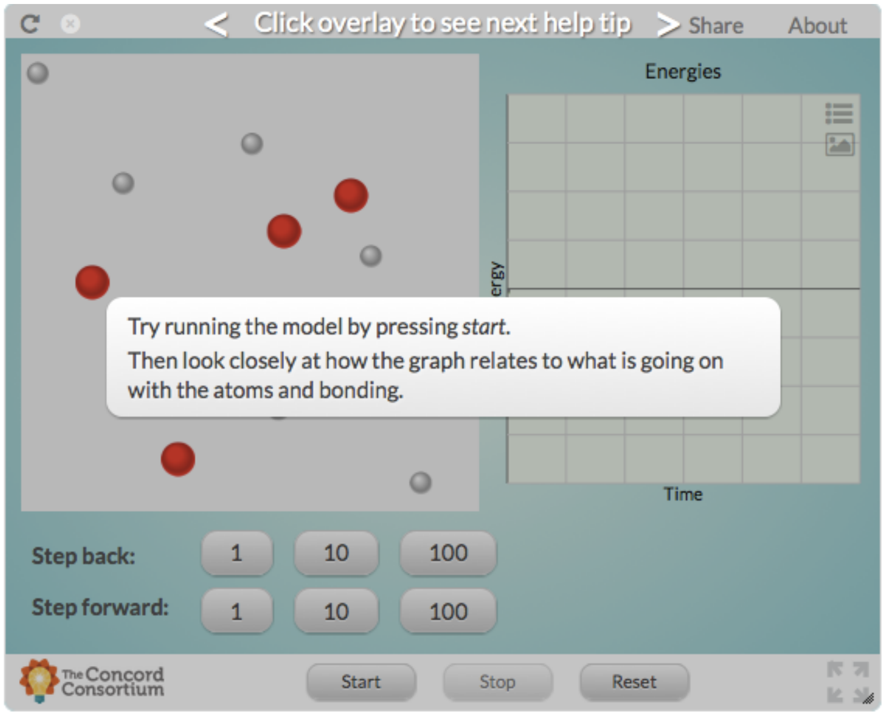
Page title:
Introduction

1. **[Prediction question] What do you think you would observe when molecules break apart or bonds form between atoms to make new molecules?**

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

- An explosion
- Light

Page title:
Simulation



http://lab.concord.org/interactives.html#interactives/interactions/hydrogn-oxygen-atoms-rxn.json

2. As the simulation runs, what do you observe happening to the atoms?

Student responses:
- More and more atoms are bonded into molecules
- The atoms are moving around more

3. As the simulation runs, what do you observe happening to the energy?

Student responses:
- The energy increases
- There is more kinetic energy

4. At the end of the simulation, use the backward and forward buttons to observe the different points during the change. Use what you observe to describe the relationship between the atoms and changes in energy.

Student responses: Students should connect the moments when bonds form (break) to changes in the graph of energy.
- The energy graph always increased when a bond was formed.

5. [Prediction question] If you had a balloon that was filled with a mixture of hydrogen and oxygen, what do you think you would observe?

Student responses:

- It would release a lot of energy when they reacted together.
    - *Push students to identify observations they could make that would indicate or align with this idea.*
- It would turn into water.
- It would float to the ceiling.

Page title:
Demonstration

Demonstration: Discussion and demonstration of igniting a balloon filled with a mixture of hydrogen and oxygen.

Before showing the explosion, inform students that the balloon is filled with a mixture of oxygen and hydrogen, ask them what they observe, and how it relates to what they observed in the simulation with the mixture of hydrogen and oxygen.

Possible questions:

- *In the simulation, what happened to the mixture of hydrogen and oxygen?*
- *If a balloon were filled with a mixture of hydrogen and oxygen gas, what would you predict you would see?*
- *This balloon is filled with a mixture of hydrogen and oxygen. What do you observe? Is anything happening?*

Ignite the balloon filled with hydrogen and oxygen gas using a candle.

Important safety note: This reaction can potentially create a loud and powerful explosion. Only conduct it if you feel comfortable. The demonstration should be conducted behind a safety shield.

- Be sure you have enough space for the energy to dissipate - a large science room, open windows, or perform the demonstration outside
- Be sure you have students cover their ears and that you use earplugs or earmuffs to protect your own ears
- Use a meter stick or long pole so that you can stand far away from the balloon while igniting it
- Clear the area of anything flammable and have a fire blanket handy
- Make sure you were goggles.

Note: If you are not confident that you could do the demo safely, you can use this video of the demonstration instead.

6. Record your observations of the balloon filled with hydrogen and oxygen gas.

Student responses:
- Explosion
- Nothing till the flame started an explosion
- Bright light, loud sound

7. The simulation showed how hydrogen and oxygen atoms interact. How does the simulation connect to your observation of the balloon that is filled with hydrogen and oxygen?

Student responses:
- In the simulation when atoms of hydrogen and oxygen bond, energy is transferred to the environment . Evidence of the transfer of of energy to the environment can be observed as light, sound, and heat in the explosion.

8. In the simulation, the reaction started right away. However, the hydrogen and oxygen in the balloon did not do anything until it was touched with a flame. What is different between the balloon and the simulation that could account for your observations of the explosion?

Student responses: Students' answers will vary. Students may or may not be aware that oxygen and hydrogen are diatomic molecules. The point of this question is to highlight that the simulation (a type of model) needs to be revised in order to explain all the observations.
- The atoms are not moving enough to start a reaction without the flame.
- Oxygen is O_2, not individual atoms like in the simulation.

Discussion: Review the simulation and what is missing in the simulation in order to explain all of the observations of the oxygen and hydrogen balloon. Revisit the unit driving question and identify what questions still need to be answered.

Possible questions:

- *What happened with the regular balloon and fire?*
- *What happened with the balloon filled with hydrogen and oxygen and the fire?*
- *How might the simulation with hydrogen and oxygen connect with the observations of the balloon with hydrogen and oxygen?*
- *How is the simulation different from the observations of the balloon?*
- *In the simulation, the atoms bonded and transferred energy to the environment. In the balloon, the explosion did not just happen. What might be missing from the simulation?*
- *What do we know about energy and atoms at this point?*
- *What is still missing in order to answer our driving question?*
- *What additional questions do we have?*

Activity 4.2: What happens to atoms in chemical reactions?

SUMMARY

In the previous activity, students explored the bonding of several atoms and compared the simulation to their observations of the same atoms reacting at the macroscopic level . Students used their observations to identify additional questions to explore before answering the unit driving question, *How can a small spark start a huge explosion?* In this activity, students will observe a variety of chemical reactions. Explosions are chemical reactions, so students need to describe what happens in chemical reactions in order to explain what happens in an explosion. In the next activities, students will connect their description of chemical reactions to changes in energy in order to answer the unit driving question.

LEARNING GOAL

Students will develop a model to make sense of observations of chemical reactions at the atomic-level. (Clarification: Students' models should show that molecules break apart and the same atoms rearrange and form new bonds in a reaction. Students do not need to include reaction mechanisms.)

Disciplinary core idea	Crosscutting concept	Science and engineering practice
Chemical reactions: The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (NGSS Lead States, p. 92)	*Structure and function:* Students investigate systems by examining the properties of different materials, the structures of different components, and their interconnections to reveal the system's function and/or solve a problem. (NGSS Appendix G p. 87)	*Developing and using models:* Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (NGSS Appendix F p. 53)

POINTS FOR CONSIDERATION

- Students have a hard time connecting observations to atomic-level descriptions of changes. Push students to connect their atomic-level descriptions to what they can observe at the macroscopic scale.
- Students interpret equations of reactions as left-side and right-side rather than a before and after representation. Students need to realize that reactions and equations are describing the same set of atoms arranged in different ways and at different scales before the reaction and after the reaction. Instead of referring to the left-side or right-side of the equation, try to consistently refer to the before-side and after-side of the equation. Also push students to describe all the changes represented in a chemical equation.

PREPARATION

Class Time: 200 min.

Materials for whole-class demonstration

- steel wool
- vinegar
- 50 mL beaker or small bowl
- 250 mL flask (x2)
- rubber stopper or balloon
- scale

Materials (for each group)

- copper (II) chloride ($CuCl_2$)
- beaker
- aluminum (Al)
- water (from tap)
- scoop
- funnel
- filter paper
- Erlenmeyer flask
- evaporation dish (watch glass, plastic weigh boat, or other container with short walls will also work)

Activity Setup

- For demonstration, gather materials. There is no set-up needed before class.
- For lab, put samples of copper (II) chloride in several containers so students can access and use them during the lab. Label the containers "copper (II) chloride, $CuCl_2$" Gather materials for each group.
- Prepare a waste container for students to dump excess solution from lab.

SAFETY ISSUES

Copper (II) chloride is toxic and causes eye irritation. Be sure to wear safety goggles and vinyl or latex gloves at all times. In case of eye contact, flush eyes with water for at least 15 min. Copper (II) chloride is also toxic to fish and algae in water. Do NOT dump down the drain.

WORKSHEET

Worksheet for Activity 4.2 Lab: Copper (II) chloride and aluminum

HOMEWORK

Reading for Activity 4.2: Chemical reactions in your everyday life

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Introduction
    a. Introducing the lesson discussion
2. Examples of chemical reactions
    a. Demonstration and discussion
    b. Record observations of demonstration
3. Copper (II) chloride and aluminum
    a. Lab
    b. Discussion
    c. Model
    d. Discussion
4. Steel wool
    a. Observations of demonstration
    b. Predictions
    c. Demonstration - mass of steel wool
    d. model
    e. Discussion
5. Chemical reactions
    a. Model of electrolysis
    b. Discussion
    c. Questions
    d. Discussion
    e. Prediction

Activity 4.2 (Student materials): What happens to atoms in a chemical reaction?

Introducing the Activity: Review what we have learned about energy and reactions. Introduce the term chemical reactions.

Possible questions:

- *The balloon explosion was an example of a chemical reaction. When you hear the term chemical reaction, what do you think about?*
- *What does that mean to you?*
- *Any other ideas?*

In this activity, students will observe several examples of chemical reactions in order to describe what a chemical reaction is.

Possible questions:

- *What do we know so far about energy and explosions?*
- *What do we still need to answer?*
- *Does our model of bonding explain why explosions don't just happen?*

Inform students that the balloon explosion is an example of a chemical reaction. In this activity, we will develop a description of chemical reactions.

Page title:

Introduction

We know that when atoms form bonds energy is released. When the balloons explode, that is an example of a chemical reaction. Let’s analyze some additional chemical reactions to see if we can figure out why the balloon does not just explode without the spark to start it.

Page title:

Examples of chemical reactions

Demonstration: Demonstrate the reaction between iron and air using steel wool. Set up the reaction and ask for students prediction. You can allow the reaction to continue while students move on to work on the lab.

Add two samples of steel wool (loosely packed about the size of an egg) to a beaker or bowl full of vinegar. Allow them to sit in the vinegar for about 1 min. (The vinegar will dissolve the protective coating of oil - be sure to let students know why you are doing this. Remove the steel wool and squeeze out excess vinegar. Place the samples of steel wool in each of the Erlenmeyer flasks. Cover one of the flasks with the stopper or the balloon (do not inflate, just stretch the rubber over the opening of the flask.)

NOTE: If you use a rubber stopper to cover the flask, the stopper will get pushed down into the neck of the flask as the air pressure inside decreases. Make sure the stopper is large enough that it will not get pulled all the way through or stuck in the neck.

Measure and record the mass of each flask.

Possible questions:

- *What do you predict we might observe happen to the steel?*
- *What do you predict will happen to the mass?*
- *Do you think there will be a difference between the sealed flask and the unsealed flask?*

Your teacher will conduct a demonstration to test what happens to steel wool under two different conditions.

1. **Record the mass of each flask.**

Student responses: Students answers will depend on the amount of iron used and flask.

2. What do predict you will observe in the flasks at the end of the class?

Student responses: Students answers will vary. This is a prediction question, students are not expected to agree at this point.

- Nothing will change because there is no spark or fire to start a reaction.
- The iron will rust.

Page title:

Copper (II) chloride and aluminum

Follow the steps on the lab sheet and record your observations before, during, and after the reaction.

3. Copy your observations of the substances from the lab sheet into the data table. Take a snapshot of your data table.

Substances before reaction	Substances During reaction	After filtering the reaction	After water evaporates

4. Before the reaction, the substances were the blue crystals called copper (II) chloride and the aluminum. Do you think the substances after the reaction were still $CuCl_2$ and Al? Support your answer with your observations.

Student responses:
- No the substances after the reaction are not the same. The substances after are a rust color powder and clear or yellowish crystals.

Discussion: Discuss the reaction and student's observations of the reaction between copper (II) chloride and aluminum. Push the students to think about what happened at the atomic level in the reaction.

Possible questions:
- *Do you think we had the same substances after the reaction?*
- *What might have happened to the atoms in the reaction?*
- *According to the chemical formula, what atoms make up copper (II) chloride?*
- *Where could the atoms of copper and chloride ended up after the reaction?*
- *What do you think happened to the atoms of aluminum?*
- *What substances do you think we might have after the reaction*
    - *Note: Students are not expected to know that aluminum chloride and copper are formed in the reaction, but they should think about their observations and what may have happened to the atoms.*
- *What do you think happened to the copper atoms?*
- *What do you think could be in the filter paper? What does it look like? How could we explain that observation?*

5. [draw prompt] Draw a model to represent how you think the atoms are arranged before and after the reaction.
[text prompt] How does your model relate to your observations of the reaction?

Arrangement of atoms before reaction	Arrangement of atoms after reaction

Supplemental content: Copper (II) chloride and aluminum is an example of a single replacement reaction. One way to think of what happens in this reaction is that the copper atoms and aluminum atoms trade places. The aluminum atoms bond with the chloride ions and the copper atoms group together in small pieces of copper metal (the metal may oxidize quickly to form rust-colored or greenish copper oxide).

> *Clarification - Students are not expected to know the products of the reaction or the details of what happens. The goal is to get students to realize that the atoms rearranged, it is not important how students rearrange the atoms.*

Student responses: Students should indicate that two chlorine and one copper atom are bonded together in the beginning (based on the formula) and the aluminum atoms are not bonded to anything else. In the after image, students should show two new substances (the substance on the filter paper and the new crystals). Students may show the aluminum and chloride bonded and the copper on its own, they may also show both copper and aluminum bonded to chloride atoms, or that the chlorine atoms are separated and the copper and aluminum bonded. It is not important that students create reasonable compounds just that they have two new compounds and that they justify their choices by connecting them to their observations.

Discussion: Display students' models and discuss how the models connect with the observations of the substances before and after the reactions.

Possible questions:

- *According to this model, what happened to the atoms during the reaction?*
- *How does that connect with what we observed during the reaction?*

Page title:

Steel wool

Demonstration: Return to the demonstration with the steel wool in the two flasks.

Ask students to compare their observations to what they observed before it was set up.

Possible questions:

- *What do you notice now?*
- *Do you think the substance in the flasks is still steel wool?*
- *Do the two flasks have the same thing?*

Ask the students to predict how they expect the mass to compare to what the was mass before.

6. [prediction question] Predict how you think the mass of the new substance in the open flask will compare to the mass of the steel wool.

A. Higher
B. Lower
C. The same

7. [prediction question] Justify your prediction.

Student responses: At this point, it is reasonable for students to select any of the three answer choices.

- A. Higher - It looks like rust and I know that rust is a combination of iron with oxygen from the air. The added oxygen will make the mass go up.
- B. Lower - The substance is flaky so it looks lighter than the steel before.
- C. The same - Mass is conserved so it can't change.

Demonstration: Display students' predictions and discuss them.

Possible questions:

- *How do you think the mass will compare to what it was earlier?*
- *Who has a similar or different idea?*

Measure and record the mass of the flask that was not covered and compare the mass to what was measured earlier.

Possible questions:

- *Given that the mass increased, what does that tell us about the number of atoms?*
- *Where could the extra mass have come from?*
- *What could have happened at the atomic level to cause the increase in mass?*

To verify that the extra mass came from adding air, the flask that was sealed with a balloon or rubber stopper can be compared to the open flask. The balloon or stopper should have been pulled into the neck of the flask and the mass of this flask should not have changed.

Possible questions:

- *If the mass increased because atoms from the air bonded with atoms of the steel, what would happen to the amount of air in the sealed flask?*
- *How do our observations align with that conclusion?*
- *Since this flask was sealed so no extra air could get in, should the mass of this flask increase?*
- *What does this tell us about where the extra mass came from?*

8. [draw prompt] The main component of steel is iron. Draw a model that shows what caused the changes you observed when the steel wool reacted. For simplicity, you can treat the steel wool as if it is made of just iron.
[text prompt] How does your model provide a causal account for why the mass changed and your observations of the reaction?

Arrangement of atoms before reaction	Arrangement of atoms after reaction

Supplemental content: Rust is the product of the oxidation of iron, or the combination of iron with oxygen from the air. The mass increases because the oxygen atoms from the air combine with the iron, so the new substance has more atoms.

> *Clarification - Students are not expected to know the products of the reaction or the details of what happens. The goal is to get students to realize that the atoms rearranged, it is not important how students rearrange the atoms or what atoms from the air students incorporate into their model.*

Student responses: Students should indicate that after the reaction additional atoms have bonded with the iron atoms. Students may identify the new atoms as oxygen or other atoms from the air.

Discussion: Display students' models and discuss how the models connect with the observations of the substances before and after the reactions.

Possible questions:

- *According to this model, what happened to the atoms during the reaction?*
- *How does that connect with what we observed during the reaction?*

Page title:

Chemical reactions

Recall when you used a battery, cup of water, and tacks to conduct electrolysis of water in the last investigation. This was another example of a chemical reaction. You tested the gases and compared the properties of those gases to identify that it made oxygen and hydrogen gas.

9. [draw prompt] The reaction for electrolysis is written using the formula

$$H_2O \rightarrow H_2 + O_2$$

Draw a model to represent the atoms in this reaction.
[text prompt] How does your model account for your observations of the electrolysis reaction.

Arrangement of atoms before reaction	Arrangement of atoms after reaction

Student responses: Students should indicate that before the reaction one oxygen and two hydrogens are bonded together. After the reaction two hydrogens should be bonded together and two oxygens are bonded together. Students should describe how the rearrangement of the atoms describes what accounted for their observations and the formation of the two different gases.

Discussion: Display students' models and discuss how the models connect with the observations of the substances before and after the reactions.

Possible questions:
- *According to this model, what happened to the atoms during the reaction?*
- *How does that connect with what we observed during the reaction?*

Review the symbolic representation and what is communicated in the way the formula is written.

Possible questions:
- *How does the formula indicate what happened to the atoms during the reaction?*
- *What does the arrow in the equation represent?*
- *What do the different sides of the equation represent?*
- *During the reaction, hydrogen and oxygen gas was formed. Where did the atoms that make up the hydrogen and oxygen gas come from?*

10. The changes to the steel wool, copper (II) chloride and aluminum, and electrolysis of water are all examples of chemical reactions. Review the observations you made in all these reactions. What patterns do you see among these three examples?

Student responses: Students may focus on the specifics and details of the reactions and think there is not any similarities across the different reactions. Push students to look for patterns and make more generalities.
- A new substance is formed shown by the new properties of the substances.

11. In general, what happens to the atoms in all three of the chemical reactions?

Student responses: Students may focus on the specifics and details of the reactions and think there is not any similarities across the different reactions. Push students to make more generalities.
- The atoms rearranged and formed new bonds.

Discussion: Discuss the different reactions and develop a description of chemical reactions.

Possible questions:

- *In general, what happened to atoms in the three example reactions?*
- *What are some characteristics of a chemical reaction?*
- *If new substances are formed during a reaction, where do the atoms that make those new substances come from?*
- *What has to happen to the original substances in order for those atoms to make new substances?*

By the end of this discussion, students should agree that:

- New substances are formed in a chemical reaction
- Atoms are rearranged and form new bonds
- In order to form new substances, the molecules in the original substance need to break apart
- Once atoms break apart, they reform to form new molecules with the same atoms but different combinations.

12. An explosion of the balloon filled with hydrogen and oxygen gas is also an example of a chemical reaction. Use the description of a chemical reaction that your class has developed to describe what happened to cause what you observed when the balloon exploded.

Student responses: This is a formative assessment question, asking students to apply their new idea to the question about explosions. At this point, students are not expected to agree.

- The atoms rearranged and formed new bonds and energy is released when new bonds form.

Reading for Activity 4.2: Chemical reactions in your everyday life

Activity 4.3: What changes in energy occur when atoms rearrange during a chemical reaction?

SUMMARY

In the previous activity, students developed a description of chemical reactions by modeling changes at the atomic-level and connecting those to their observations. Explosions are chemical reactions, so describing the atomic-level changes is an important part of answering the unit driving question, *How can a small spark start a huge explosion?* In this activity, students will connect the relationship between bonding and energy changes they developed in Investigation 3 and their description of atomic-level changes that occur during chemical reactions. Students will describe that energy must be transferred from the surroundings to break bonds for a reaction to start, then energy is transferred to the surroundings as new bonds from. Students will compare reactions that transfer more energy out to the environment than is transferred in and reactions that transfer less energy out to the environment than is transferred in.

LEARNING GOAL

- Students will develop a model to connect the changes in energy with the change in the arrangement of atoms during chemical reactions. (Clarification: Students' models should indicate that energy from the surroundings always needs to be added to break bonds and that forming bonds always releases energy.)

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:* Students learn that the total amount of energy and matter in closed systems is conserved. They can describe changes of energy and matter in a system in terms of energy and matter flows into, out of, and within that system. (NGSS Appendix G p. 86)	*Developing and using models:* Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. (NGSS Appendix F p. 53)

LEARNING GOAL

- Students will analyze and interpret data in order to compare the changes of energy in various reactions. (Clarification: Students describe the transfer of energy in endothermic and exothermic reactions)

Disciplinary core idea	Crosscutting concept	Science and engineering practice
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. (NGSS Lead States, p. 92)	*Patterns:* Students observe patterns in systems at different scales and cite patterns as empirical evidence for causality in supporting their explanations of phenomena. (NGSS Appendix G p. 82)	*Analyze and interpret 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)

POINTS FOR CONSIDERATION

- Students have a hard time connecting macroscopic observations with atomic-level causes. Push students to connect their observations with changes that occur as atoms are arranged and the transfer of energy that is observed..
- It is a common idea that energy is stored in bonds and breaking bonds releases energy. Help students to carefully analyze the changes of energy and when bonds are forming or breaking.

PREPARATION

Class Time: 120 min.

Materials

- 500 mL beaker
- hot plate

Materials (for each group)

- test tube (x2)
- plastic cup or beaker (x2)
- cool water
- warm water
- hydrogen peroxide (3% H_2O_2)

Activity Setup

- Gather materials for lab.
- Turn a hot plate on low. Fill large beaker with water and set on the hot plate to begin heating some water.

Materials for each student

- goggles
- disposable latex or vinyl gloves

SAFETY ISSUES

Hydrogen peroxide (H_2O_2) is extremely corrosive. Even dilute hydrogen peroxide is hazardous in case of eye contact. Be sure to wear goggles and disposable latex or vinyl gloves at all times. If you spill some on your skin or counter, wash with water and dry. In case of contact with eyes, rinse with water for at least 15 mins.

WORKSHEET

Worksheet for Activity 4.3: Hydrogen peroxide lab

HOMEWORK

Reading 1 for Activity 4.3: Energy and Reactions
Reading 2 for Activity 4.3: Harnessing chemical reactions

Activity 4.3 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Hydrogen peroxide lab
    a. Lab
    b. Discussion
    c. Model & simulation
    d. Discussion
2. Simulation
    a. Questions
    b. Discussion
3. Electrolysis of water versus hydrogen and oxygen balloon explosion
    a. Questions
    b. Simulation
    c. Discussion
    d. Questions
    e. Discussion

Activity 4.3 (Student materials): What changes in energy occur when atoms rearrange during a chemical reaction?

Introducing the Activity: Review reading from Activity 4.2

Possible questions:

- *What are some chemical reactions you may have seen since class yesterday? Any other ideas?*

Review what students have agreed on so far regarding energy, bonding, and what happens to atoms during chemical reactions. Revisit the driving question board and identify what can be added, what has been answered, and what questions still need to be answered.

Possible questions:

- *What happens during a reaction?*
- *How is energy related?*
- *How can this help us answer our driving question: How does a small spark trigger a huge explosion?*
- *Does that mean that all reactions release large amounts of energy?*
- *Do all reactions require a spark to start?*

Page title:

Hydrogen peroxide lab

Follow the steps and answer the questions on the Worksheet for Activity 4.3: Hydrogen peroxide lab

Note: This is not a vigorous reaction. Students should observe small bubbles forming on the side of the test tube but will likely not observe a significant amount of gas forming.

1. Based on the equation for this reaction, describe what happened to the atoms and how those changes relate to what you observed in the lab.

$$H_2O_2 \rightarrow H_2O + O_2$$

Student responses: In general, students have a hard time connecting their observations with changes at the atomic-level. Push students to connect the observation with the changes happening to the atoms.

- According to the equation, the hydrogen peroxide breaks apart and forms water and oxygen. Oxygen is a gas and little gas bubbles were observed in the test tube in the warm water.
- Water and oxygen are formed.
  - *What did you observe that would match with the formation of water or oxygen?*
- In the tube in the warm water, bubbles formed.
  - *What part of the chemical equation could be associated with those bubbles?*

2. How did the temperature of the water affect what you observed?

Supplemental content: Water and oxygen are much more stable (lower potential energy when bonded) than hydrogen peroxide, so this reaction occurs even at room temperature. However, the reaction has a very large activation energy, or requires a large amount of energy to break apart the reactants in order to get the reaction started. Therefore, while the reaction does occur at room temperature, it proceeds very slowly. Placing the test tube of hydrogen peroxide in a warm water bath provides some additional energy. As students noted in Unit 2 Investigation 1, temperature is a measure of the average kinetic energy. By heating up the hydrogen peroxide, the average speed of the molecules increases. When the atoms bump into each other with greater speed and higher kinetic energy, they are more likely to break bonds and start the reaction. Therefore, while it is still slow, more bubbles build up in the test tube in the warm water bath as compared to the test tube in the cool water bath.

Clarification - students are not expected to know about activation energy or to connect their observations with an explanation based on energy at this point. This question only asks students to describe their observations.

Student responses:

- The test tube in the warmer water had more bubbles on the side.
- There was no reaction in the test tube in the colder water and only a little bit of bubbles formed in the test tube in the warm water.

Discussion: Discuss the observations from the hydrogen peroxide lab and connect those observations with the idea of energy students have been developing during this unit.

Possible questions:

- *What did you observe?*
- *How do your observations relate to the equation for this reaction?*
- *How did the temperature of the water affect the reaction?*

Review the lab students did in Unit 2 Investigation 1 Activity 1.3 where they added a drop of food coloring to a petri dish filled with water at different temperatures.

Possible questions:

- *Remember the lab we did with food coloring and water? What did that lab tell us about temperature, atoms, and energy?*
- *How could the results of that lab help explain why we saw different results for the hydrogen peroxide in the warm water bath and the cool water bath?*
- *Does anyone have anything to add or a different idea?*

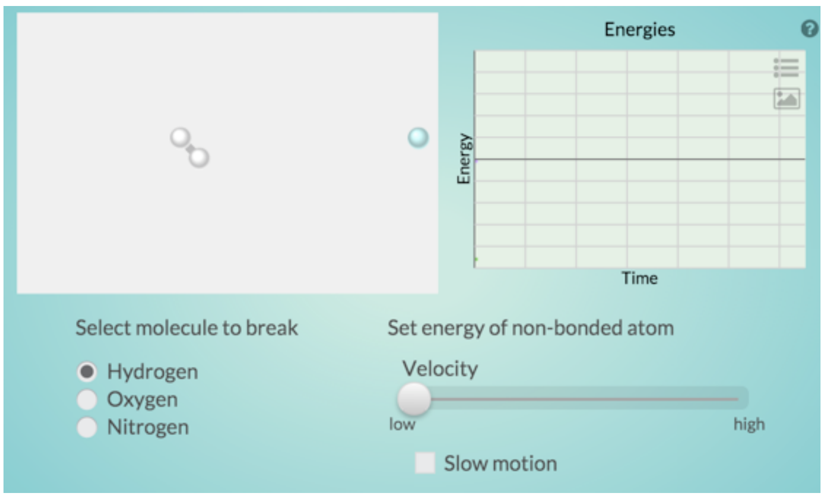
It may be helpful to revisit the simulation students explored in that activity. http://lab.concord.org/interactives.html#interactives/interactions/dropping-dye-with-temp.json

Possible questions:

- *According to the simulation, how does the temperature affect the molecules?*
- *How could this help explain why we saw different results for the hydrogen peroxide in warm and cool water baths?*

3. [draw prompt] Draw a model to show how the arrangement of atoms changed during the reaction of hydrogen peroxide. Be sure to indicate any bonds that are broken or formed. [text prompt] How does your model align with your observations?

Student responses: Students may draw atypical arrangements of atoms within molecules, but they should clearly indicate which atoms are connected. For example, they should show that before the reaction there are molecules made of two hydrogens and two oxygens connected together. Students may show a chain of these atoms, or connect them to each other in a square or other shape. The shape of the molecule is not important, just that it is clear which atoms are connected. After the reaction, the student should indicate molecules of two hydrogens and one oxygen connected and molecules of two oxygen atoms connected to each other. The students should indicate that some or all of the bonds in the hydrogen peroxide molecules had to break apart in order for the oxygen atoms to bond to each other.



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

4. The simulation from Investigation 3 allowed you to try to break apart bonds. Use the ideas from the simulation and your model to explain why the reaction was different in the cool water bath compared to the warm water bath.

Student responses: • Higher temperature means the molecules are moving around faster. If they are moving fast enough when they bump into each other, then the molecules can break apart and then form new molecules.

Discussion: Review the models students drew, ask students to connect the models to their observations and to the relationship between energy and bonding from Investigation 3.

Possible question:

- *How does this model align with our observations of the reaction?*
- *What is happening to the bonds during the reaction?*
- *From the simulation from the last investigation, how is temperature related to breaking a bond in a molecule?*
- *What does increasing the temperature do to the atoms in the hydrogen peroxide?*
- *What do you think we would observe if we placed a test tube into a cup of ice water?*

Reading 1 for Activity 4.3: Energy and Reactions

Page title:

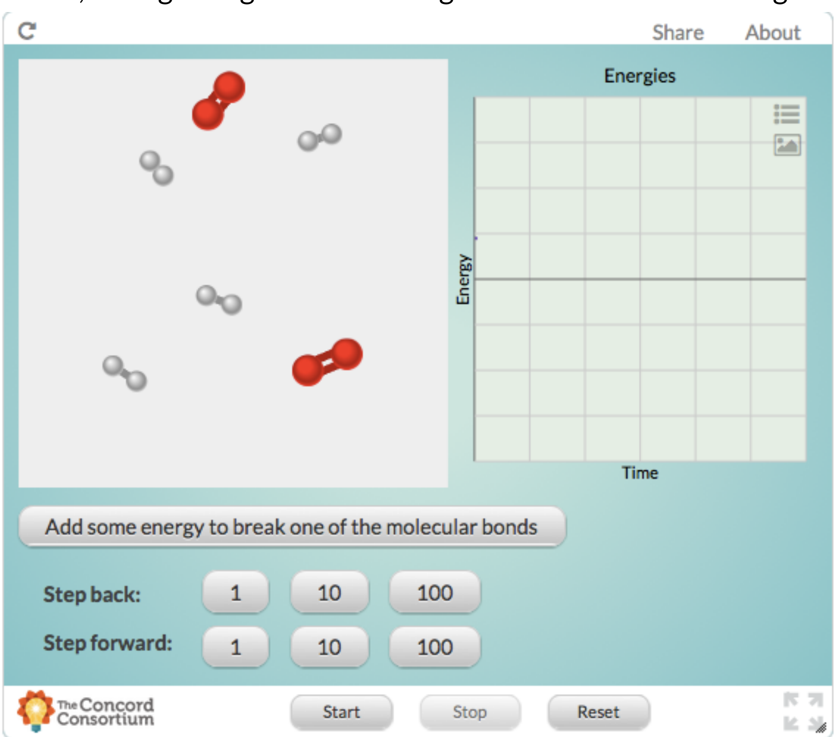
Simulation

Discussion: Review the Reading 1 for Activity 4.3, the relationship between energy changes and bond formation/breakage, and chemical reactions.

Possible question:

- *What happens during a chemical reaction?*
- *Why does energy have to be added to start a reaction?*
- *The reading talked about an important reaction in biology, what is happening in this reaction?*
- *What must happen to energy in order to break apart the ATP molecule?*
- *The reading said this reaction transfers a lot of energy to the surroundings, if energy must be transferred into the system in order to break the bond, what do you think could be the source of the energy that is transferred out to the surroundings?*

Explore the simulation, noting changes to the arrangement of atoms and changes in energy.



http://lab.concord.org/interactives.html#interactives/interactions/hydrogen-oxygen-spark.json

5. Chemical reactions occur when substances change by breaking and/or forming bonds. Describe the changes that occur in this reaction.

Student responses:
- Hydrogen and oxygen molecules broke apart and formed water molecules.
- H_2 and O_2 break apart and form H_2O.

6. In the simulation, initially no reaction occurs. What had to happen to get the reaction started? Justify your answer.

Student responses: Push students to explain what is being represented not just what they did in the simulation.
- Energy had to be added to break the bonds in one of the molecules of H_2 or O_2.
- I had to click on one of the molecules to get it started.
    - *What did this represent in terms of what happens in an actual reaction?*

7. After the reaction in the simulation ends, step forward and backward. Find a point when a lot of energy was converted from potential energy to kinetic energy. What was happening to the atoms at that point?

Student responses:
- The energy changes from potential to kinetic when a new bond is formed.

8. What is happening to the atoms at the points when kinetic energy converted to potential energy?

Student responses:
- The energy changes from kinetic to potential when a bond is broken.

Connection between this simulation and your observations of the exploding balloon.

9. The balloon filled with hydrogen and oxygen exploded, but only after a small flame was used to start the reaction. Use the simulation to explain why a flame was needed to start the reaction.

Student responses:
- Energy had to be added to break bonds holding either the hydrogens or oxygens together or both. If the atoms are not broken apart, they cannot form new bonds.

10. Once the reaction in the balloon started, a bright light, loud sound, and lots of heat were observed. Light and sound are indications of energy transfer. Use the simulation to connect this transfer of energy to what was happening to the atoms when the balloon exploded.

Student responses:

- When the atoms formed bonds, it released kinetic energy making the atoms move faster.

Discussion: Review the simulation and the connection between energy, what happens when bonds between atoms break apart and new bonds between atoms are formed, and the observations of the balloon reaction.

Possible questions:

- *What is the relationship between changes in atomic arrangement and changes in energy?*
- *What happens to the energy when bonds are broken?*
- *What happens to the energy when bonds are formed?*
- *How do these changes in atomic arrangement and energy explain our observations of the balloon?*

Students should agree

- breaking bonds means that energy from the surrounding is transferred into the system.
- forming bonds converts potential energy into kinetic energy.
- in a reaction bonds are broken and formed.

Page title:

Electrolysis of water versus hydrogen and oxygen balloon explosion

The equation for the electrolysis of water reaction you did with a battery in Investigation 3 is

$$H_2O \rightarrow H_2 + O_2$$

The equation for the reaction in the hydrogen and oxygen balloon is

$$H_2 + O_2 \rightarrow H_2O$$

11. Compare these two reactions. What is happening to the atoms in the electrolysis of water reaction and the atoms in the hydrogen and oxygen balloon reaction?

Student responses: Encourage students to compare the two reactions to each other, not just describe each reaction in turn. • The reactions are basically opposites. In the electrolysis, water molecules break apart and make hydrogen and oxygen molecules. In the balloon reaction, hydrogen and oxygen molecules break apart then make water molecules. • In electrolysis water breaks apart and makes hydrogen and oxygen molecules. In the balloon reaction, hydrogen and oxygen make water molecules.   ○ *How are these two reactions related to each other?*

12. In the electrolysis reaction, if you removed the tacks from the battery, the reaction stopped. Use your understanding of what happens to atoms in this reaction and energy to explain why the reaction would stop when removed from the battery.

Student responses: • In the reaction, water molecules are being broken apart. In order to break bonds, energy from the surroundings must be added.

13. Based on your observations, how do the changes of energy in these two reactions compare?

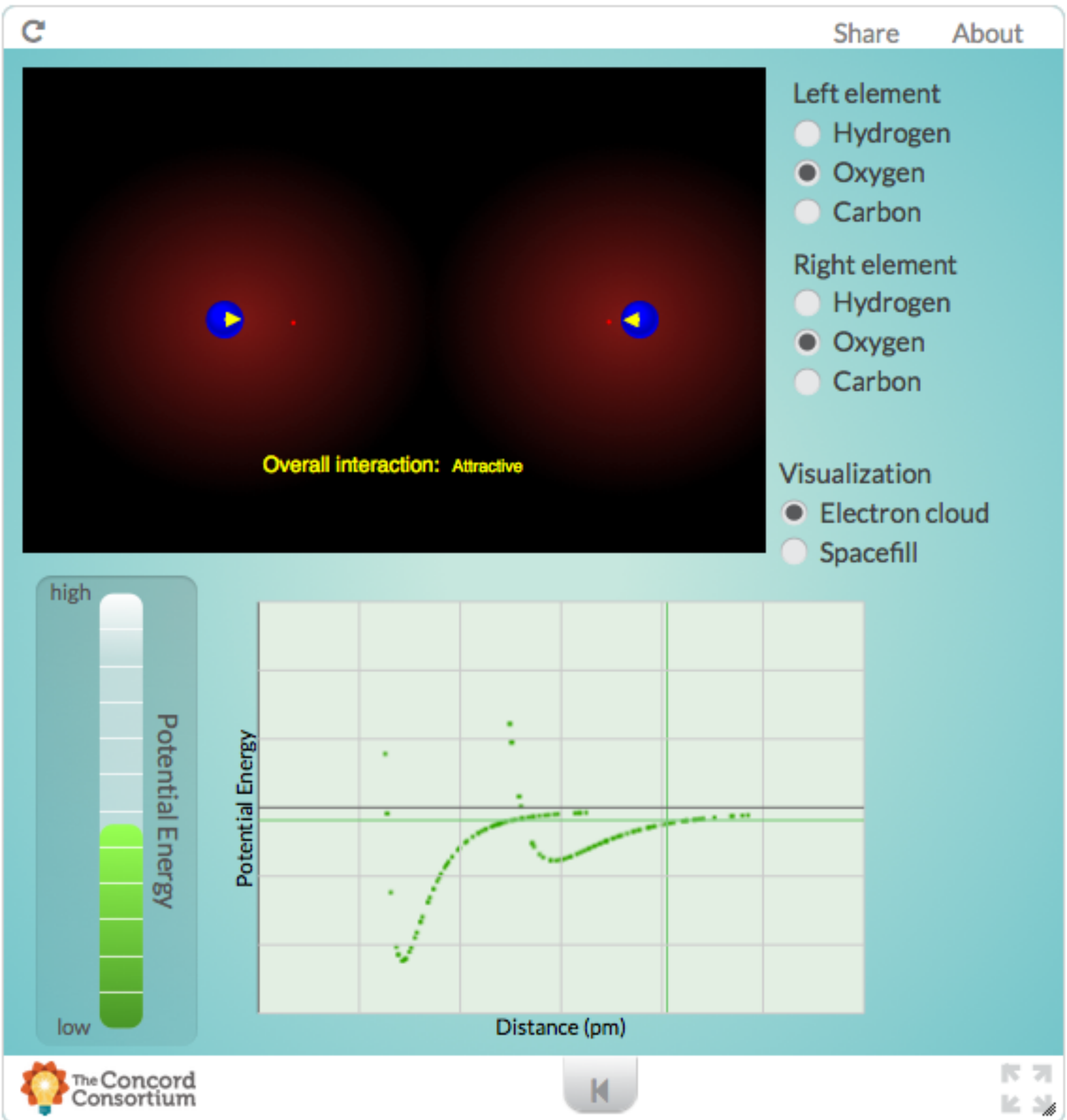
Student responses:

- The balloon explosion transferred a lot of energy to the surroundings. In the electrolysis energy had to be continuously transferred into the system or the reaction stopped.
- One reaction transferred energy out and one transferred energy in.

Page title:

Bonds breaking and forming

Review the relationships in the simulation from Unit 2 Investigation 3. Compare the changes of energy when the different atoms in the reaction form and break bonds.



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

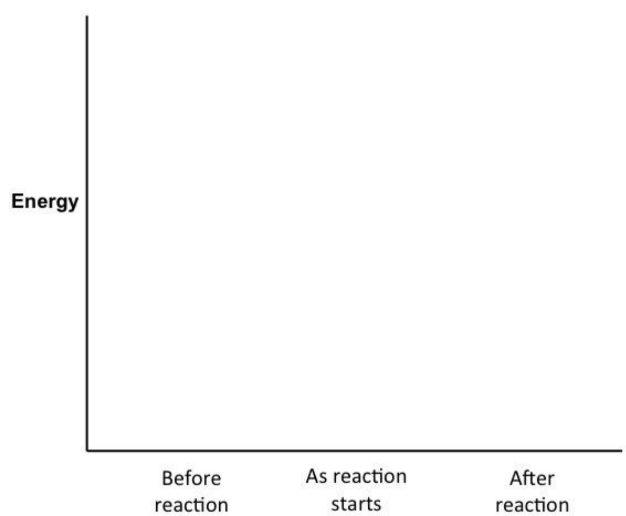
14. Compare the changes of energy in the following bonds: H-H, O-O, and O-H.

Student responses:
- When H-H and O-H bonds form there is a significant change in potential energy in the electric field. However, when O-O bond forms, there is a much smaller change in potential energy.

15. [Draw prompt] Draw a stacked energy bar graph to show any changes of energy during the reaction. For each bar, draw a model of the atoms and molecules each point in the electrolysis reaction.

$$H_2O \rightarrow H_2 + O_2$$

[Text prompt] How does your model account for your observations during the water electrolysis reaction?



Student responses: Students' models should indicate that at least some of the bonds in the water molecules need to break apart to start the reaction.
Note: Students may break all the bonds and indicate individual atoms in the middle of the reaction, or they may break a few select bonds, at this point either is acceptable. In the final image, the atoms should be rearranged to form hydrogen molecules and oxygen molecules. The potential energy should be highest in the middle when bonds are broken. The potential energy should be lowest in the beginning, because the hydrogen-oxygen bonds in water are more stable than those in hydrogen or oxygen molecules so the potential energy is low. The potential energy for the products should be lower than when the bonds were broken because new bonds have formed, but higher than before the reaction because the new bonds are not as stable as the original bonds. Since the potential energy is higher after the reaction as compared to before the reaction, the reaction will not continue without an energy source continually transferring in energy from the surroundings.

Discussion: Explore the simulation as a class and display students' models to compare the changes of energy for different bonds.

Possible questions:

- *How do the changes in energy compare when the different atoms bond?*
- *Which bonds do you think are more stable, harder to break apart? Why?*
- *Which bonds would transfer more energy to the surroundings when the bonds form?*

Students should agree

- bonds that have larger changes in energy are more stable and would require more energy to break
- bonds that have smaller changes in energy are less stable and require less energy to break
- more stable bonds transfer more energy to the surroundings, less stable bonds transfer less energy to the surroundings

Use these reactions to introduce the terms exothermic and endothermic reactions.

Possible questions:

- *Reactions that transfer in more energy and transfer out more energy have special terms. The water electrolysis is an example of an endothermic reaction and the explosion is an exothermic reaction. What do you think those terms mean?*
- *What are some indications that a reaction is endothermic or exothermic?*
- *If an exothermic reaction transfers a lot of energy to the surroundings does that mean no energy is transferred into the system from the surroundings?*

Exothermic reactions are reactions that transfer more energy to the surroundings than is transferred in to start reaction; endothermic reactions are reactions where more energy is transferred in from the surroundings than is available to transfer to surroundings after product bonds form.

16. In the electrolysis reaction, H-O bonds are broken then H-H bonds and O-O bonds are formed. Use the simulation to describe why this reaction would stop when energy from the battery is no longer transferred into the system.

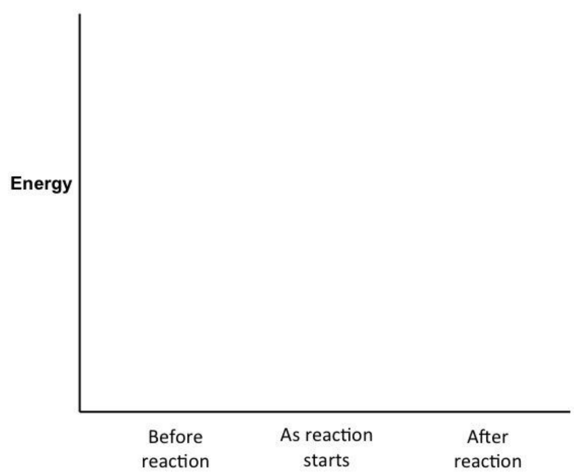
Student responses:

- It takes a lot of energy to break the H-O bonds. Making the H-H bonds releases a lot of energy, but the O-O bonds do not release much energy. More energy has to be added because the bonds that are formed do not release enough energy to keep breaking up more H-O bonds.

17. [Draw prompt] Draw a stacked energy bar graph to show any changes of energy during the reaction. For each bar, draw a model of the atoms and molecules each point in the electrolysis reaction.

$$H_2 + O_2 \rightarrow H_2O.$$

[text prompt] Use your model and energy graphs to account for why a small flame leads to a big explosion for the hydrogen and oxygen-filled balloon.



Supplemental content: Oxygen molecules are not very stable molecules so they are very reactive. A small amount of energy has to be added to break up some of the hydrogen and oxygen molecules, but since oxygen is unstable, it does not take a large amount of energy to break these atoms apart. As the new H-O bonds form, a lot of energy is released. Since the bonds that form release more energy than required to break the O-O bonds the energy that is released when the H-O bonds is enough to break up more hydrogen and oxygen molecules and continue the reaction.

Clarification - Students are not expected to connect the release of energy when the H-O bonds form to continuing the reaction. Students will develop this idea of a chain reaction in the next Activity. At this point, students are just being asked to compare the energy needed to break bonds to the energy that is released when new bonds form.

Student responses: The models should indicate that H_2 and O_2 molecules break apart to start the reaction. When this happens, energy transfers from the surroundings to increase the potential energy. Once the hydrogen and oxygen molecules are broken apart, the atoms can rearrange and form different bonds to form water molecules. The potential energy at this point is lowest and energy is transferred to the surroundings. The molecules that are broken apart are less stable, so a small spark can provide enough energy to break the bonds. The water molecules that are formed have more stable bonds so the potential energy is very low so a lot more energy can be transferred out to the surroundings.

18. How do you think the amount of energy transferred from the balloon to the surroundings during the explosion compares to the amount of energy transferred from the battery in the electrolysis reaction?

Supplemental content: Since the reactions are the opposite of each other (forming water from hydrogen and oxygen gas and breaking water into hydrogen and oxygen gas) if the same number of atoms react in each case, the amount of energy released in the explosion is equal to the amount of energy that is transferred from the battery to the system. The amount of energy would depend on the number of molecules that react, so the energies would only be equal if the same number of atoms react.

Clarification - This question is asking students to theoretically compare the changes of energy in the two reactions. Students are not expected to connect the exact amounts to the number of atoms that react but rather discuss the relationship in general and theoretical terms.

Student responses: Students may not agree on the relationship between the energy in the two reactions. These questions are just aimed at making sure students realize that some reactions release energy while others taken in more energy than they release. It depends on the stability of the reactants and products.

- The changes in bonds are opposite (the balloon explosion breaks H-H and O-O and makes H_2O while electrolysis goes the opposite way breaking H_2O and making H-H and O-O). Since O-O bond is less stable than the other bonds, in the explosion where the oxygen molecules are broken only a little energy needs to be added to break the bonds and lots of energy is released; however in electrolysis a lot of energy needs to be added to break apart the water molecules and less energy is released.

Concluding the Activity: Review students' models and the relationship between energy forming bonds and breaking bonds and the unit driving question: *How can a small spark start a huge explosion?*

Possible questions:

- *Do all reactions release lots of energy?*
- *How does electrolysis compare to the balloon explosion?*
- *What would make some reactions release lots of energy but other reactions take in energy?*
- *What do we know about how a small spark triggers a huge explosion?*
- *Are there ways to start reactions without a spark?*
- *Do all reactions need to be started in some way?*

Homework for Activity 4.3: Reading 2: Harnessing chemical reactions

Activity 4.4: How does a spark trigger an explosion?

SUMMARY
In the previous activities, students explored the relationship between energy changes, bonding, and chemical reactions. In this activity, students put all these ideas together to explain how a small spark can trigger a huge explosion. Students use a simulation to observe the pattern of how atoms change during a reaction and how breaking a few bonds can lead to to a reaction taking place as the energy from bonds forming is used to break additional bonds apart and spread the reaction. Students use the evidence and observations they have gathered throughout Unit 2 to answer the unit driving question, *How can a small spark start a huge explosion?*

LEARNING GOAL
Students will apply their models of bonding and chemical reactions to explain how a spark ignites an explosion. (Clarification: Bonding includes the forces between atoms in a molecule and the energy changes that occur when atoms interact.)

Disciplinary core idea	Crosscutting concept	Science and engineering practice
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. (NGSS Lead States, p. 92)	*Cause and effect:* [Students] suggest cause and effect relationship to explain and predict behaviors in complex natural and designed systems. They also propose causal relationships by examining what is known about smaller scale mechanisms within the system. (NGSS Appendix G p. 83)	*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 Appendix F p. 61)

POINTS FOR CONSIDERATION
- As in the previous activities push students to connect atomic-level changes with macroscopic observations and connect changes in energy to observation of temperature change, light and sound when bonds are broken and formed.

PREPARATION
Class Time: 20 min.

Materials
- No materials needed.

HOMEWORK
Reading for Activity 4.4: [Where there's a spark, there can be a fire]

Activity 4.4 - Teacher Preparation

BASIC OUTLINE OF ACTIVITY

Use this space to make notes to prepare for your lesson

1. Simulation
    a. Discussion
    b. Simulation
    c. Discussion
    d. Explanation
    e. Discussion

Activity 4.4 (Student materials): How does a spark trigger an explosion?

Introducing the Activity: Review the reading from Activity 4.3.

Possible questions:

- *What are the differences between exothermic and endothermic reactions?*
- *How are chemical reactions and energy used in different ways by plants and animals?*

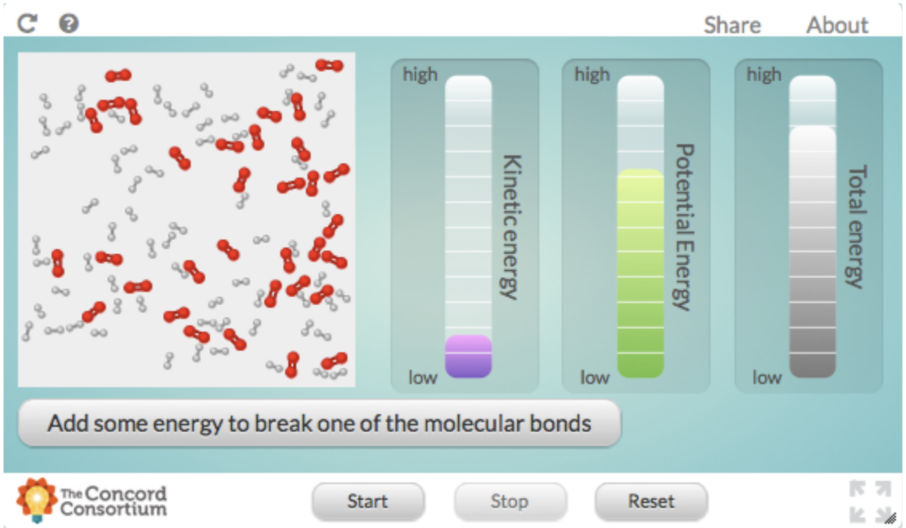
Discuss the unit driving question, *How can a small spark start a huge explosion?* and the relationship between bonding and energy.

Possible questions:

- *What do we know about how a spark triggers an explosion?*
- *Where do you think the energy in the explosion comes from?*
- *What happens to atoms in molecules during an explosion?*
- *How does energy change when bonds are formed and broken?*

Page title:
Simulation

Explore the simulation and observe the changes in energy and the arrangements of atoms during the reaction.



http://lab.concord.org/interactives.html#interactives/interactions/hydrogen-oxygen-chain-reaction.json

1. **What keeps the reaction going once it has been started?**

Student responses:
- As bonds form, the kinetic energy increases and then more bonds break as the faster molecules bounce into each other.

2. In this case, H_2O, which has H-O bonds, is formed. These bonds are very stable with very low potential energy in the electric field. What would happen in a reaction where less stable bonds are formed?

Student responses:
- The reaction might stop because the molecules would not be moving fast enough to break apart other molecules.

Discussion: Review the simulation and the relationship between changes to bonds and energy.

Possible questions:

- *Why doesn't the reaction start on its own?*
- *Once the reaction starts do all the bonds change at once?*
- *How does the reaction continue once it is started?*
- *Where does the energy come from to break bonds?*
- *What do you think happens to the energy once all the bonds change?*
- *What would happen if the new bonds did not convert a lot of potential energy to kinetic energy when the bonds formed?*

3. Write a complete scientific explanation to answer *How can a small spark start a huge explosion?* **Be sure to include evidence from the activities you have done in this unit and reasoning to support your claim.**

Student responses:

- A small spark triggers an explosion by breaking apart some molecules, which allows the atoms to rearrange and form more stable bonds. As the more stable bonds are formed, potential energy is converted to kinetic energy, so the molecules move faster, collide with greater speed with other molecules and can break up other molecules, so the reaction continues and rapidly spreads. As the reaction occurs, a bright light is seen, a loud sound is heard, and heat can be felt. These are all sources of evidence that energy is transferred to the surroundings from the reaction. The simulations showing the relationship between the distance between atoms and the potential energy showed that potential energy is always lowest when atoms have formed a bond. This means that some energy must be added in order to break the bonds that are there before the reaction (i.e., explosion occurs). When the new bonds form, energy is released to the surroundings as heat, light, and sound.

Reading: Where there's a spark, there can be fire

DQ

Concluding the Unit: Review the unit driving question and the relationship between bonding and energy.

Possible questions:

- *How does a spark trigger an explosion?*
- *What happens to atoms during an explosion?*
- *Why do atoms form bonds?*
- *What happens to energy when atoms form bonds?*
- *In Unit 1 we studied how objects become charged when electrons move from one object to another. Do you think energy changes during that process?*