4. What Makes Fires Burn?
The Fire Triangle 2—Oxygen

Lesson Overview: In this activity, students learn more about the Fire Triangle and further test it experimentally. **We describe 2 options for doing the experiment: Option 1 uses vinegar and baking soda; Option 2 uses dry ice.**

Lesson Goal: Increase students' understanding of combustion and the Fire Triangle model.

Objective: Students can use the Fire Triangle to explain why various techniques work to stop fires

Subjects: Science, Health and Safety, Writing, Speaking and listening

Duration: One half-hour session

Group size: Whole class, working in teams of about 4 students each

Setting: Indoors

New FireWorks vocabulary: *molecule. If you use Option 2 with dry ice, additional vocabulary: phase change, sublime/sublimation*

Standards		6th	7th	8th
Common Core ELA	Writing	1,4,7,10	1,4,7,20	1,4,7,10
	Speaking/Listening	1,2,5	1,2,5	1,2,5
	Language Standards	1,2,3,6	1,2,3,6	1,2,3,6
	Reading Standards Science/Tech	9	9	9
	Writing Standards Science/Tech	2	2	2
NGSS	Structures and Property of Matter	PS3.A, PS1.A, PS1.B		
	Chemical Reactions	ETS1.B		
	Energy	ETS1.B		
	Engineering Design	ETS1.A, ETS2.B, ETS1.C		
EEEGL	Strand 1	A, B, C, E, F, G		

Teacher Background -- Initial background is in the previous activity (M03). Here is more: The 2 options for experiments in this activity (Handout M04-1 and M04-02) demonstrate that oxygen is required for fire. Both options use carbon dioxide gas.

- In Option 1, the gas is produced by combining baking soda and vinegar; if you use this option, you can explore the chemical reactions between baking soda and vinegar.

- In Option 2, the gas is produced from dry ice; if you use this option, you can explore the difference between phase change and chemical change.

About carbon dioxide gas: Carbon dioxide is one of the components of air. It is heavier than oxygen, as you can see from this calculation of the molecular weights of the two compounds:

Element	Atomic weight
Carbon (C)	12 g
Oxygen (O)	16 g

A mole of CO_2 weighs 12 g + 2 * 16 g = 44 g

A mole of O_2 weighs 2 * 16 g = 32 g

Thus, if carbon dioxide and oxygen are placed together in a container with no turbulence, the carbon dioxide will sink to the bottom and the oxygen will rise to the top.

Option 1 background: These 2 equations describe the chemical changes that produce carbon dioxide gas from vinegar and baking soda:

[1]	vinegar	+	baking soda	→	carbonic acid	sodium acetate
	(acetic acid)		(sodium bicarbonate)			
	CH_3COOH	+	$NaHCO_3$	→	$H_2CO_3(aq)$	$NaCH_3COO\ (aq)$

Sodium acetate is the goo at the bottom of the container. Carbonic acid looks like water. The carbonic acid immediately breaks down into carbon dioxide gas and water:

[2] $H_2CO_3 \rightarrow CO_2(g) + H_2O$

Option 2 background: When a substance changes from one phase (solid, liquid, gas) to another, it undergoes a phase change. This is different from a chemical change. As described in the previous activity, in a chemical change the molecules in the ingredients are broken into their component atoms, and the atoms are recombined to form new molecules; the change cannot be reversed easily. In a phase change, the atoms in the ingredients are not recombined, and the change can be reversed fairly easily.

When you use dry ice for this experiment, you convert frozen carbon dioxide from the solid phase, at a temperature of −78.5 °C (−109.3 °F) or lower, into its gaseous phase. Note that carbon dioxide does not form a liquid at Earth's atmospheric pressure, so it goes directly from the solid phase to the gas phase – hence the term "dry" ice. We say that the dry ice "sublimes," and the process is called "sublimation."

Option 1: Experiment using vinegar and baking soda

Materials and preparation:
Choose your location. You will be burning individual votive candles. Can you do this safely in your classroom and without setting off a smoke alarm? Can you take your students to a lab where it will be safe? Do not try to burn outdoors because even the slightest wind will blow out the candles.

- The day before doing this activity, remind students to follow the safety guidelines about clothing and hair when they get ready for school tomorrow.
- Get a package of hair bands to keep in your pocket so you can give them out as needed.
- Get 4 boxes of wooden kitchen matches. The boxes need not be full.
- Get 1 box of long fireplace matches.
- Set up the teacher's lab bench with this equipment:
  - Fire extinguisher, fully charged
  - Two spray bottles, filled with water
- Set up a lab bench or other safe space for each student team[1], using the following equipment:
  - 1 metal tray (i.e., cookie sheet)
  - 1 ashtray
  - 1 box of matches
  - 2 votive candles
  - 2 beakers or freezer containers
  - 1 pair safety goggles
  - 1 oven mitt
  - 1 long fireplace matches (Students can re-light these and use them repeatedly rather than using a new match for every iteration of the experiment.)
- If possible, have a *metal* trash can *without a plastic liner* available.
- Print **Handout M04-1** for each student.

Procedure:

1. Explain: In the last activity, we saw that both fuel and heat are essential for fire to occur, but we didn't really look at the role of oxygen. That's that we'll explore in this experiment.

2. Review the "Oxygen" part of the Fire Triangle: It comprises about 21% of the air we breathe, and we use only about 20 % of that oxygen in a single breath. If we used it all in breathing, we couldn't use cardiopulmonary resuscitation (CPR) to help a person who is not breathing.

3. As a review, ask students to describe the nature of a *chemical change* (a rearrangement of atoms that changes substances from one kind to another, producing a different kind of molecule).

[1] The trunk is supplied with 4 sets of equipment.

4. Explain: You will combine vinegar and baking soda in a chemical reaction that produces carbon dioxide. When vinegar and baking soda are combined, they produce carbonic acid and sodium acetate. The carbonic acid breaks down into carbon dioxide and water. You may want to share the chemistry below.

	vinegar (acetic acid)	+	baking soda (sodium bicarbonate)	→	carbonic acid	sodium acetate
[1]	CH_3COOH	+	$NaHCO_3$	→	$H_2CO_3(aq)$	$NaCH_3COO\ (aq)$

Sodium acetate is the goo at the bottom of the container. Carbonic acid looks like water. The carbonic acid immediately breaks down into carbon dioxide gas and water:

[2] $H_2CO_3 \rightarrow CO_2(g) + H_2O$

5. Do a **safety checkup** with students using the *FireWorks Safety* poster.
6. Give each student or team a copy of **Handout M04-1**. Have students go over the instructions. Answer questions. Then give out materials and have them conduct the experiment.
7. After students have finished, discuss their responses to A-D in the table on the handout. Soon after vinegar has been added to the baking soda in the container, they should find it impossible to light the candle. Carbon dioxide has filled the bottom of the container. It is heavier than oxygen, so it doesn't rise and mix with the surrounding air. Instead, it crowds the oxygen out. Without oxygen, the candle won't burn.
8. Now ask students to apply what they have learned: Ask them to name some techniques for putting fires out. List these on the board. Select one of them. In a discussion, get students to use concepts from the Fire Triangle to explain why the technique works. Then erase this technique from list, leaving the rest for the Assessment.

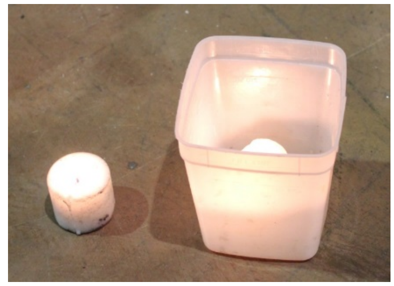
Assessment: Select one of the techniques listed on the board for putting fires out.
   a. Write down the technique you've chosen.
   b. Use one or more components of the Fire Triangle to explain why the technique works. In your explanation, use at least one sentence and terms from the Fire Triangle.

Evaluation:

-Student named the technique chosen. -Explanation was logical. -Used 1 or more term(s) from Fire Triangle.	-Student named the technique chosen. -Explanation was logical. -Did not use term(s) from Fire Triangle.	-Student did not name a technique. -Explanation was illogical. -Did not reference Fire Triangle.

Handout M04-1. Why does the candle go out?

Name: ______________________________



1. Place one votive candle on the metal tray and light it. You will light matches from this candle.
2. Place the other candle in a beaker or other container.
3. Light the long fireplace match from the burning candle on the metal tray. Then use it to light the candle in the container. If either candle is hard to light, you may need to scrape some wax from around the wick. This step proves that the candle in the container can be lighted.
4. Blow out the candle in the container.
5. Spoon 1-2 tablespoons of baking soda around the base of the candle, about enough to coat the bottom of the container. Be careful not to get the baking soda on the candle. Alternative: Add the baking soda to an empty container and then replace the candle.
6. Light the candle to make sure that the baking soda did not alter its ability to burn. Then blow it out.
7. Pour about ¼ c (60 mL) of vinegar into the baking soda <u>around</u> the candle. <u>Do this slowly</u> so the mixture doesn't foam so enthusiastically that it wets the candle wick.
8. Relight the fireplace match from the candle on the metal tray. Then use it to relight the candle in the container.
9. Try different techniques for lighting the candle in the container.
10. Use complete sentences to answer the questions below.

A. Describe what you observed when you mixed vinegar and baking soda.
B. Describe what you observed when you were lighting the candle in the container after vinegar was added.
C. Describe any other techniques you used to light the candle in the container, and explain how well each technique worked.
D. Use the Fire Triangle to explain your observations.

Handout M04-1 Answer Key. Why does the candle go out?

A.	Describe what you observed when you mixed vinegar and baking soda. The mixture foamed. Then a white substance accumulated at the bottom of the container, and it was covered by a clear liquid.
B.	Describe what you observed when you were lighting the candle in the container after vinegar was added. It was impossible to light… unless the air in the room was turbulent or someone blew into the container.
C.	Describe any techniques you used to light the candle in the container, and explain how well each technique worked. This is a fun part of the experiment. Students may try moving more quickly; this won't work. They may try tipping the container sideways; this may work because you are pouring some of the carbon dioxide out. They may also try taking the candle out and pouring the carbon dioxide onto the lighted candle on the tray; that will probably extinguish the flame.
D.	Use the Fire Triangle to explain your observations. Carbon dioxide is heavier than oxygen, so it stays in the container while the oxygen is pushed out. Without oxygen, the candle cannot be lit.

Option 2: Experiment using dry ice

Materials and preparation:

Choose your location. You will be burning individual votive candles. Can you do this safely in your classroom and without setting off a smoke alarm? Can you take your students to a lab where it will be safe? Do not try to burn outdoors because even the slightest wind will blow out the candles.

- The day before doing this activity, remind students to follow the safety guidelines about clothing and hair when they get ready for school tomorrow.
- Get a package of hair bands to keep in your pocket so you can give them out as needed.
- Get 4 boxes of wooden kitchen matches. The boxes need not be full.
- Get 1 box of long fireplace matches.
- Set up the teacher's lab bench with this equipment:
    - Fire extinguisher, fully charged
    - Two spray bottles, filled with water
    - Tongs for handling dry ice
- The morning of the experiment, get 2-3 pounds of dry ice from a local supermarket. Store it in a cooler or freezer until class time. Find a hammer or something else for crushing the dry ice.
- Set up a lab bench or other safe space for each student team[2], using the following equipment:
    - 1 metal tray (i.e., cookie sheet)
    - 1 ashtray
    - 1 box of matches
    - 2 votive candles
    - 2 beakers or freezer containers
    - 1 pair safety goggles
    - 1 oven mitt
    - 1 long fireplace matches (Students can re-light these and use them repeatedly rather than using a new match for every iteration of the experiment.)
- If possible, have a *metal* trash can *without a plastic liner* available.
- Print **Handout M04-2** for each student.

Procedure:

1. Explain: In the last activity, we saw that both fuel and heat are essential for fire to occur, but we didn't really look at the role of oxygen. That's that we'll explore in this experiment.

2. Review the "Oxygen" part of the Fire Triangle: It comprises about 21% of the air we breathe, and we use only about 20 % of that oxygen in a single breath. If we used it all in breathing, we couldn't use cardiopulmonary resuscitation (CPR) to help a person who is not breathing.

[2] The trunk is supplied with 4 sets of equipment.

3. Review: Ask students to describe the nature of a *chemical change* (a rearrangement of atoms that changes substances from one kind to another, which produces a different kind of molecule).

4. Explain: As dry ice changes from the solid phase to the gas phase, the atoms are <u>not</u> rearranged and a different kind of molecule is <u>not</u> produced. The process of *subliming* dry ice is a *phase change* as opposed to a *chemical change.* Other familiar phase changes are the melting of "regular" ice into water and the evaporation of liquid water into water vapor. Phase changes are usually easy to reverse if you add or remove heat. For example, we can thaw ice (change from solid to liquid) and easily refreeze the liquid water back to ice again. In contrast, consider how hard it would be to un-bake a cake!

5. **Do a safety checkup** with students using the *FireWorks Safety* poster.

6. **More about safety - Explain: You'll be using "dry ice."** This is frozen carbon dioxide, and it's very cold (−78.5 °C (−109.3 °F)) – much colder than ice made from water. Because it is so cold, it should never be handled without tongs or gloves or a thick oven mitt. If you leave dry ice in a container for a while, it will disappear because the solid carbon dioxide is *subliming*—going from the solid phase to the gas phase without a liquid phase in between. Gaseous carbon dioxide is invisible and comprises about 1% of air.

7. Give each student or team a copy of **Handout M04-2**. Have students go over the instructions. Explain that you will provide them with dry ice when they have finished the first 4 steps in the experiment. Answer questions. Then give out materials and have them conduct the experiment. When each team is ready for dry ice, use the tongs to place a few pieces in their candle container. (The volume of about 2-3 ice cubes should do.)

8. After students have finished, discuss their responses to A-C in the table on the handout. Soon after the dry ice has been added to the container, they should feel the cold around the container and it should be impossible to light the candle inside. They may also observe fog in the container. This is not gaseous carbon dioxide. (Remember, that is invisible.) Instead, it is water vapor condensing out of the room's air because the gas in the container is so cold. Carbon dioxide has filled the bottom of the container. It is heavier than oxygen (and it is cold so it is much dense than room-temperature), so it doesn't rise and mix with the surrounding air. Instead, it crowds the oxygen out. Without oxygen, the candle won't burn.

9. Now ask students to apply what they have learned: Ask them to name some techniques for putting fires out. List these on the board. Select <u>one</u> of them. In a discussion, get students to use concepts from the Fire Triangle to explain why the technique works. Then erase this technique from list, leaving the rest for the Assessment.

10. Use the Assessment and Evaluation from Option 1 above.

Handout M04-2: Why does the candle go out?

Name: ________________________

1. Place one votive candle on the metal tray and light it. You will light matches from this candle.

2. Place the other candle in a beaker or other container.

3. Light the long fireplace match from the burning candle on the metal tray. Then use it to light the candle in the container. If either candle is hard to light, you may need to scrape some wax from around the wick. This step proves that the candle in the container can be lighted.

4. Blow out the candle in the container.

5. Ask the teacher to place some pieces of dry ice next to the candle in the container. <u>If you need to handle the dry ice, use the oven mitt.</u>

6. Relight the fireplace match from the candle on the metal tray. Then use it to relight the candle in the container.

7. You may repeat the experiment and use different techniques to light the candle in the container.

8. Answer the questions below.

A. Describe what you observed when you were relighting the candle in the container.
B. Describe techniques you used to try to light the candle in the container. Explain how well each technique worked.
C. Use the Fire Triangle to explain your observations.

Handout M04-2 Answer Key. Why does the candle go out?

A. Describe what you observed when you were relighting the candle in the container. The container was cold. It may have had fog inside. It was impossible to light the candle… unless the air in the room was turbulent or someone blew into the container.	
B. Describe techniques you used to try to light the candle in the container. Explain how well each technique worked. This is a fun part of the experiment. Students may try moving more quickly; this won't work. They may try tipping the container sideways; this may work because you are pouring some of the carbon dioxide out. They may also try taking the candle out and pouring the carbon dioxide onto the lighted candle on the tray; that will probably extinguish the flame.	
C. Use the Fire Triangle to explain your observations. Carbon dioxide is heavier than oxygen, so it stays in the container while the oxygen is pushed out. In addition, carbon dioxide gas that has just sublimed from dry ice is very cold, so it is much denser than it would be at room temperature – again, staying put in the container while oxygen is pushed out. Without oxygen, the candle cannot be lit. Students may think that it is too cold inside the container to light the candle, so the "heat" component of the Fire Triangle is missing. That is unlikely, but this experiment doesn't provide a good way to test the hypothesis. Perhaps they can come up with an experiment to do so!	