



### 3. Making Fires Burn or Go Out 2: Demonstrating the Fire Triangle and Heat Plume

**Lesson Overview:** This activity contains three demonstrations in which students observe real fires to see how the conceptual model of the Fire Triangle applies to real combustion.

**Lesson Goal:** Increase students’ understanding of combustion. Increase their awareness that use of fire requires safe practices and responsible adult supervision.

**Objectives:**

- Students can use the Fire Triangle to explain why lighted matches go out.
- Students can use the Fire Triangle to explain why it is difficult to light a candle in the presence of a mixture of baking soda and vinegar (or dry ice).



**Subjects:** Science, Mathematics, Writing, Speaking and Listening, Writing, Health and Safety

**Duration:** One to two half-hour sessions

**Group size:** Whole class

**Setting:** Indoors

**Vocabulary:** *heat plume, carbon dioxide*

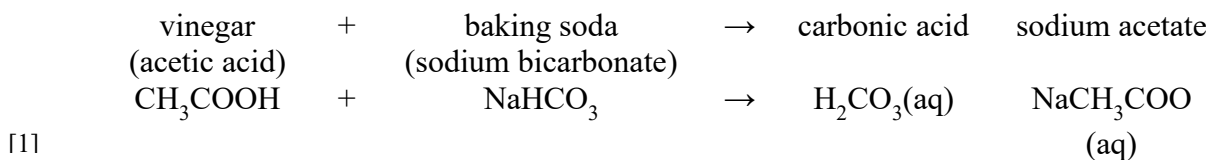
Standards:		1st	2nd	3rd	4th	5th
CCSS	Writing	2, 7, 8	2, 7, 8	2, 7, 10	2,7, 9, 10	2,7, 9, 10
	Speaking/Listening	1, 2, 4, 6	1, 2, 4, 6	1, 2, 4, 6	1, 2, 4, 6	1, 2, 4, 6
	Language	1, 2, 4, 6	1, 2, 4, 6	1, 2, 3, 4, 6	1, 2, 3, 4, 6	1, 2, 3, 4, 6
	Math	MP.5	MP.5	MP.5, 3.MD.4	MP.5, 4.MD.1	MP.5
NGSS	Matter and Its Interactions		PS1.B			PS1.B
	Engineering Design		ETS1.B			ETS1.B
EEEGL	Strand 1	A, B, C, E, F, G				A, B, C, E, F, G

**Teacher Background – initial background is in the previous activity (E02). Further background:** The three demonstrations in this activity show how the Fire Triangle model applies to actual combustion. In **Demonstration 1**, students observe the shape of a fire’s heat plume. In **Demonstration 2**, they see what happens when heat and fuels come together in different spatial arrangements. In the third, they observe what happens when a fire is deprived of oxygen (O<sub>2</sub>). All three demonstrations use fire – burning individual matches or votive candles. Take all safety precautions outlined in the FireWorks Safety poster

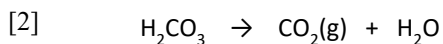
(*FireWorks\_Safety\_poster.pptx*). Explain them to students to increase their awareness of fire safety.

**Demonstration 3** shows that oxygen is required for fire. We describe 2 ways to do this; both of them use carbon dioxide. Option A, which is written into the lesson below, uses carbon dioxide gas produced by mixing baking soda and vinegar; if you use this option, you can explore the chemical reactions between baking soda and vinegar. Option B, which is described after the “Evaluation” section at the end of the lesson, uses carbon dioxide gas produced from dry ice; if you use this option, you can explore the difference between phase change and chemical change.

Additional background for Option A. Here are the 2 equations that describe the chemical changes that produce carbon dioxide gas from vinegar and baking soda:



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



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:

<u>Element</u>	<u>Atomic weight</u>
Carbon (C)	12 g
Oxygen (O)	16 g

A mole of CO<sub>2</sub> weighs 12 g + 2 \* 16 g = 44 g

A mole of O<sub>2</sub> weighs 2 \* 16 g = 32 g

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

Additional background for Option B. When you use dry ice for this demonstration, you convert dry ice (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 to the gas phase – hence the term “dry” ice. We say that the dry ice “sublimes,” and the process is called “sublimation.”

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## Materials and preparation:

We recommend doing this activity as three demonstrations for the whole class. First, choose your location. Demonstrations 1 and 2 can produce flames 10-15 cm long. 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 safer? It would be very difficult to do these demonstrations outdoors, because even the slightest wind will blow out single matches and candles.

Ask individual students to help with various tasks. It is best for a teacher or another adult to light the matches and candles, explaining how to handle matches and fire safely as you do the demonstrations.

- Display the FireWorks Safety poster (*FireWorks\_Safety\_poster.pptx*). Follow safety guidelines about clothing and hair when you prepare for this activity. Have a package of hair bands in your pocket so you can give them out if needed.
- Get a box of wooden kitchen matches. The box need not be full.
- Display the Fire Triangle poster (*Fire Triangle poster.pptx* from **Activity E02**) or simply draw it on the board.
- Set up your work station with this equipment:
  - Box of wooden matches
  - Fire extinguisher, fully charged
  - Spray bottle, filled with water
  - 1 ruler
  - 1 metal tray (i.e., cookie sheet)
  - 1 ashtray
  - 2 votive candles
  - 2 beakers or other containers
  - 1 pair safety goggles
  - 1 oven mitt
  - 1 support stand
  - 1 metal rod with alligator clips at the ends
  - About ½ cup of baking soda
  - About ½ cup of white vinegar
  - a long fireplace match
  - 1 clamp
- Have a METAL trash can WITHOUT A PLASTIC LINER available.

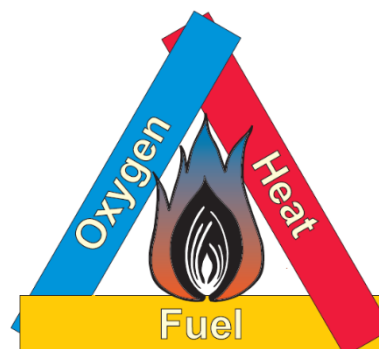
### FireWorks Safety



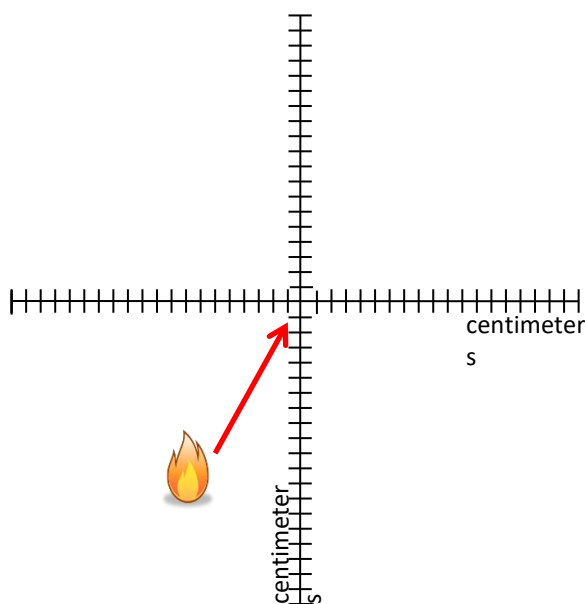
**When you do experiments with fire...**

1. Wear cotton clothing. No synthetic pants, soccer shorts, etc.
2. Wear closed-toed shoes. No sandals or flipflops.
3. Tie back loose sleeves.
4. Tie back loose hair.
5. Make sure a fire extinguisher is close. Make sure it is charged. Know how to use it.
6. Make sure spray bottles are close and filled with water.
7. Wear safety goggles when burning.
8. *Never* lean over a fire.
9. Extinguish burned materials with water before putting them in the trash. *Fire is not out if there is any smoke or heat coming from the fuels.*
10. If a fire starts on you, stop, drop, and roll.

Use fire ONLY if a responsible adult is working with you.



Set up your demonstration table for **Demonstration 1** (see photo at right): Place the support stand in the center of the metal tray. Attach the clamp to the stand. Attach the metal rod with alligator clips so it forms a “+” with the stand. Place a wooden match in one alligator clip, with its tip pointing down.



Draw the illustration at left on the board or print/display it from the file ***GraphForDescribingHeatPlume.pdf***.

### **Procedure, Demonstration 1, “Where does the heat Go?”**

1. Explain: According to the Fire Triangle, a fire cannot burn if it does not have all three of these things: heat, fuel, and oxygen. Now we will watch fire burning individual matches to see if the model seems to be valid – if it “works” to explain what we observe. In this activity, the teacher will perform the demonstrations with student assistance.
2. Do a **Safety Briefing** using the FireWorks Safety poster (***FireWorks\_Safety\_poster.pptx***).
3. Organize your team:
  - An **Observer** who is dressed safely
  - A **Measurer**, also dressed safely
  - A data **Recorder**
4. Explain:
  - **Observer:** Your job is to find out how tall and wide the heat plume is from a burning match. You’ll start by holding one hand about 40 centimeters to one side of the match. When the match is completely on fire, you’ll bring your hand in closer until you can sense a change in temperature. The goal is to sense even a LITTLE warmth – NOT to see

how close you can get without getting burned! We'll use as many matches as needed to get observations from two sides of the flame, above it, and below it. When you make the "below" observation, don't put your hand directly under the burning match, in case the tip breaks off and falls. Instead, hold your hand just a little to one side.

- **Measurer:** After each match is out, you'll measure the distance from its tip to the observer's hand (in centimeters).
- **Recorder:** You'll mark an axis of the graph to show each measurement.

5. Light the first match. As soon as it is completely on fire, obtain a "side" measurement. After it goes out, USE THE OVEN MITT to remove it from the clip, put a fresh one in, and get a measurement from the other "side" ... then a "below" measurement... then an "above" measurement. Use as many matches as you need. Dispose of burned matches in the ashtray or on the metal tray.
6. Connect the marks on the four axes, making a roughly oval shape.
7. Discuss: Where did the heat go? (Most of it went upward, but a little went sideways and downward. Some also went into the metal clip and metal rod, which is why you needed the oven mitt.) Have students touch their hands high above their head. This is roughly the shape of the heat plume, so each of them is creating a model of the heat plume.

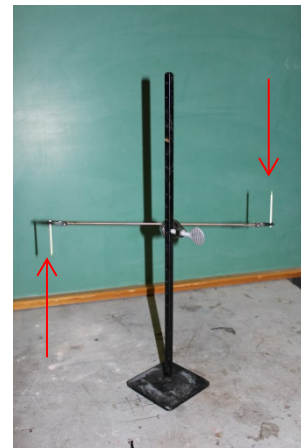
**Procedure, Demonstration 2, "Why Does the Match Go Out?"**

8. Organize your team:
  - One student (the **Timer**) should measure the duration of burning (in seconds).
  - One student (the **Measurer**, who is dressed safely) should measure the length of flames.
  - One student (the **Recorder**) should record data.
9. Copy this table onto the board:

Match is pointing...	Down	Up
How long did the flame get (centimeters)?		
How long did the match burn (seconds)?		
Why did the fire go out?		

10. Place a downward-pointing match in one clip and an upward-pointing match in the other. Light a separate match and use it to ignite the **downward-pointing** one. Measure flame lengths and burning times and record measurements on the board. Repeat, if necessary. If you use additional matches, use the oven mitt to handle the alligator clips.

11. Ask: Why did the fire go out? Ask students to use the Fire Triangle to explain. **The downward-pointing match probably burned almost completely. (Combustion is complete if you can pulverize any remaining pieces into powdery ash.) The fire went out mainly because it ran out of fuel. If a tiny stub of unburned wood remained in the alligator clip, it didn't burn because the clip absorbed much of the heat and limited the oxygen getting to the fuel.**



12. Light a match and use it to ignite the **upward-pointing** match. Take measurements and record them on the board. Repeat, if necessary. Ask: Why did the fire go out? Use the Fire Triangle to explain. **The match went out before it burned completely, so it was NOT limited by fuel. It was not limited by oxygen either – since everyone in the classroom was still breathing comfortably. However, most of the heat was moving up, away from the fuel. If any heat was going down, it was not sufficient to keep the wood burning.**

**Assessment #1-2:** Ask students to use the three components of the Fire Triangle to explain in writing why the upward-pointing match went out.

**Procedure, Demonstration 3, “Why Does the Candle Go Out?” Option A – using vinegar and baking soda**

13. Do safety reminders.

14. Explain: You are using 2 candles – one “in the open” on the metal tray, and the other inside a beaker. The one on the tray is just your source for easily igniting matches. The one inside the beaker is the focus of the experiment. You will change 1 thing at a time in the experiment, so you know what changes are important.

15. Place one votive candle on the metal tray and light it. Place the other candle in a beaker or other beaker.

16. Ignite a long fireplace match from the lighted candle, then use it to light the candle in the beaker. This step simply demonstrates that the candle is indeed able to be lit inside the beaker. Blow out the candle in the beaker.



17. Spoon 1-2 tablespoons of baking soda around the base of the candle in the beaker, about enough to coat the bottom. Don't get baking soda on the

candle itself. Alternatively, you can add the baking soda to an empty beaker and then place the candle on top of it.

18. Relight the fireplace match from the burning candle on the metal tray. Then use it to light the candle in the beaker to demonstrate that the baking soda did not alter its ability to burn. Then blow it out.
19. Pour about  $\frac{1}{4}$  c (60 mL) of vinegar into the baking soda around the candle. Do this slowly so the mixture doesn't foam so enthusiastically that it wets the candle wick.
20. Relight the fireplace match from the candle on the metal tray. Then use it to relight the candle in the beaker. (You probably can't.)
21. You may repeat the experiment and use different techniques to light the candle in the beaker.
22. Ask: Why was it so hard to light the candle after the vinegar was combined with baking soda? **When baking soda and vinegar are combined, they form CO<sub>2</sub>, an invisible gas that is heavier than oxygen. The resulting CO<sub>2</sub> gas crowded the O<sub>2</sub> out of the beaker. Thus there was not enough O<sub>2</sub> available for burning.**
23. **Clean up:** Make sure all burned materials and matches are out before you dispose of them – that is, there is no smoke and no heat being released. Use a metal trash can without a plastic liner. If in doubt, dump them in a bucket of water before putting in trash.

**Assessment #3, Option A:** In writing, have students use the Fire Triangle to explain why it was hard to light the candle after vinegar was combined with baking soda.

**Procedure, Demonstration 3, “Why Does the Candle Go Out?” Option B – using dry ice**

- Set up your work station with this equipment:
  - Box of wooden matches
  - Fire extinguisher, fully charged
  - Spray bottle, filled with water
  - 1 metal tray (i.e., cookie sheet)
  - 1 ashtray
  - 2 votive candles
  - 2 beakers
  - 1 pair safety goggles
  - 1 oven mitt
  - a long fireplace match
  - tongs for handling dry ice

## Procedure:

1. Do a safety briefing. In it, explain that you'll be using "dry ice". This is frozen carbon dioxide (one of the components of air), and it's very cold ( $-78^{\circ}\text{C}$  ( $-109^{\circ}\text{F}$ ))—much colder than ice made from water. Because it is so cold, it should never be handled without tongs or thick gloves. You perform this experiment while the class makes observations.
2. Explain: You are using 2 candles – one "in the open" on the metal tray, and the other inside a beaker. The one on the tray is just your source for easily igniting matches. The one inside the beaker is the focus of the experiment. You will change 1 thing at a time in the experiment, so you know what changes are important.
3. Place one votive candle on the metal tray and light it. Place the other candle in a beaker or other beaker.
4. Ignite a long fireplace match from the lighted candle, then use it to light the candle in the beaker. This step simply demonstrates that the candle is indeed able to be lit inside the beaker. Blow out the candle in the beaker.
5. Place 3-4 small pieces of dry ice next to the candle in the beaker. Use tongs or a mitt to handle the dry ice.
6. Relight the fireplace match from the candle on the metal tray. Then use it to relight the candle in the beaker. (You probably can't because carbon dioxide has sublimed from the dry ice, crowding out the oxygen.)
7. You may repeat the experiment and use different techniques to try to light the candle in the beaker. You may also pour the invisible carbon dioxide onto the lighted candle, which will extinguish it.
8. Ask: Why was it so hard to light the candle with dry ice present? **Dry ice was turning from a solid to a gas as it warmed up – a process called sublimation. We say the dry ice is "subliming." The resulting  $\text{CO}_2$  gas was crowding the  $\text{O}_2$  out of the beaker for two reasons: because  $\text{CO}_2$  is heavier than  $\text{O}_2$  – based on its molecular weight – and because the  $\text{CO}_2$  gas subliming from dry ice is very cold, which means the gas is more dense than it would be at room temperature. Thus there was no  $\text{O}_2$  available for burning.**
9. **Clean up:** Make sure all burned materials and matches are out before you dispose of them – that is, there is no smoke and no heat being released. Use a metal trash can without a plastic liner. If in doubt, dump them in a bucket of water before putting in trash.

**Assessment #3, Option B:** In writing, have students use the Fire Triangle to explain why it was hard to light the candle after dry ice was placed inside the beaker.



**Evaluation:**

	Excellent	Good	Fair	Poor
Assessment #1-2	-Heat moved up, so it was not reaching the fuel. -Fuel and oxygen were still present.	-Heat moved up, so it did not reach the fuel.	-Heat was removed.	Unclear if student understood.
Assessment #3 Option A	-When baking soda and vinegar combined, they produced carbon dioxide, which is heavier than oxygen. The carbon dioxide sank to the bottom and crowded the oxygen out of the beaker. -No oxygen was available for burning.	-Carbon dioxide sank to bottom and crowded oxygen to top. -No oxygen was available for burning.	-No oxygen was available for burning.	-Student did not indicate that they understood the experiment.
Assessment #3 Option B	-Dry ice (frozen carbon dioxide) is changing from the solid phase to the gas phase. The carbon dioxide is heavier than oxygen and also very cold (that is, dense), so it stays at the bottom of the beaker and displaces the oxygen upward and out. -Thus no oxygen is available for burning.	-Dry ice changed to gaseous carbon dioxide and crowded oxygen to the top. -No oxygen was available for burning.	-No oxygen was available for burning.	-Student did not indicate that they understood the experiment.