3. What Makes Fires Burn?
The Fire Triangle 1—Heat and Fuel

Lesson Overview: In this activity and the next one, students learn about the concept of the Fire Triangle, then test it experimentally. This activity focuses on fire's requirement for fuel and a heat source.

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

Duration: One to two half-hour sessions

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

Setting: Indoors

Vocabulary: *atom, carbon, carbon dioxide, chemical change, Fire Triangle, fuel, heat, hydrogen, model, oxygen*

Lesson Goal: Increase students' understanding of fire as a process of chemical change.

Objectives:

- Students can describe the chemical change that occurs in combustion.
- Students can explain why combustion is a chemical change.

Standards		6th	7th	8th
CCSS	Writing	2, 4, 7, 10	2, 4, 7, 10	2, 4, 7, 10
	Speaking/Listening	1, 2, 4, 6	1, 2, 4, 6	1, 2, 4, 6
	Language	1, 2, 3, 4, 6	1, 2, 3, 4, 6	1, 2, 3, 4, 6
	Writing Standards Science/Tech	1, 2, 4, 7, 10	1, 2, 4, 7, 10	1, 2, 4, 7, 10
	Math	MP.4	MP.4	MP.4
NGSS	Matter and Its Interactions	PS1.A, PS1B, PS3.A, ETS1.B		
EEEGL	Strand 1	A, C, E, F, G		

Teacher Background: This activity and the next one explore the chemistry of combustion as described by a conceptual model called the Fire Triangle. A fire cannot start without three things: fuel, oxygen, and a heat source. If a fire runs out of any of these things, it will stop. The three requirements for fire are conceptualized in the Fire Triangle. This is an appealing model because the geometric properties of the triangle are a good analog to the requirements for combustion: A triangle is very stable as long as all three legs are present (so stable, in fact, that it is used in the construction of buildings, furniture, and many other structures), and it collapses if one leg is removed. The triangle model is also appealing because it provides an easy way to introduce students to understanding a chemical change - the process of combustion. The three legs of the Fire Triangle actually represent the three inputs to the chemical equation for combustion, where H represents Hydrogen atoms, O represents Oxygen atoms, and C represents Carbon atoms:

Fuel + Oxygen + Heat ⟶ Carbon dioxide + Water + Heat&Light

C&H atoms + O_2 + a little heat ⟶ CO_2 + H_2O + Heat&Light

The equation above does not give a specific formula for fuels, because they could be any mixture of millions of compounds. The point is that all fuels contain a lot of carbon and hydrogen. They may contain oxygen and many other kinds of atoms as well. For example, the equation for combustion of glucose, with numbers of molecules balanced to show conservation of matter, is this:

$C_6H_{12}O_6$ + $6O_2$ + a little heat ⟶ $6CO_2$ + $6H_2O$ + Heat/Light

The same equation represents cellular respiration, the process by which cells convert sugar into the energy that keeps living things – including us – alive. How can cells do this without burning up? They have enzymes! These are catalysts that make sure the energy in carbohydrates is released in multiple tiny steps. At each step, a little energy from the bonds in the carbohydrate molecule is captured in special energy-storage molecules, such as adenosine triphosphate (ATP).

Because the equation for combustion and cellular respiration is the *reverse* of the chemical formula for photosynthesis…

$6CO_2$ + $6H_2O$ + Heat/Light ⟶ $C_6H_{12}O_6$ + $6O_2$

…the Fire Triangle can be used to introduce not only basic chemistry but also the basic principles of the biochemistry of life.

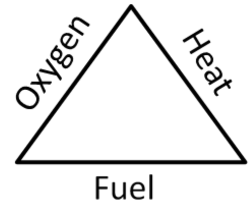
For additional information, see William Cottrell's *The Book of Fire* (2004, available from http://mountain-press.com/). This is a well-illustrated, easy-to-read description of the physical science of combustion and wildland fire.

Handout **M03-1: Why Does the Match Go Out?** describes an experiment to demonstrate that both heat and fuel are essential for fire, and the heat must be able to reach the fuel for combustion to occur. In the next activity, students use an experiment to investigate the importance of oxygen in combustion, and they may also learn the difference between chemical change and phase change.

Materials and preparation:

Choose your location. If you burn in the classroom, be aware that this demonstration can produce flames 10-20 centimeters 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 safe? Do not try to burn outdoors because even the slightest wind will blow out single matches and 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 four boxes of kitchen matches. The boxes need not be full.
- Draw the Fire Triangle on the board, labeling the sides. Make it big enough that you can add information next to and below it during class discussion:



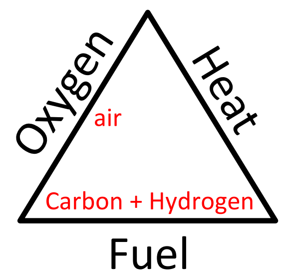
- Set up the teacher's lab bench with this equipment (mostly available in trunk):
  - Two spray bottles, filled with water
  - Fire extinguisher, fully charged
  - A votive candle
  - A box of matches
- Set up a lab bench or other safe space for each student team with the following equipment:
  - 1 ruler
  - 1 metal tray (i.e., cookie sheet)
  - 1 ashtray
  - 1 box of matches
  - 1 pair safety goggles
  - 1 oven mitt
  - 1 support stand with cross-piece attached by clamp (see photo, at right)

- Have a METAL trash can or bucket WITHOUT A PLASTIC LINER available.
- Make 1 copy/student of **Handout M03-1**: **Why Does the Match Go Out?**

Procedure:

1. Explain: The Fire Triangle is one way to understand what makes fires burn and what makes them go out. It is a model – something that helps us understand a process and make predictions about it. In the last activity we made a <u>physical</u> model to demonstrate heat transfer (conduction, convection, and radiation). The Fire Triangle is a <u>conceptual</u> model. Let's briefly review and discuss the Fire Triangle model. Then we'll test it experimentally.

2. Ask students to name some fuels. List them on the board below the "Fuels" label on the Fire Triangle. Don't limit the list to wildland fuels; for example, gasoline, birthday candles, and coal can be included. When the list is fairly long, ask <u>which fuels occur in wildland fires</u> and underline them. Explain that all fuels are made up of many kinds of atoms all stuck together – especially carbon and hydrogen atoms. Inside the Fire Triangle and parallel to the "Fuels" label, write these element names. (You can add that fuels can contain dozens of other kinds of atoms, but carbon and hydrogen are the ones that are essential for combustion.)



3. Point out that, according to the list of fuels, burnable things surround us every day. Why aren't they on fire? (There is not enough heat available to ignite them.) Ask students to name some heat sources for fire, and list them on the board next to the "Heat" label. Again, don't limit the list to ignition sources for wildland fire; for example, spark plugs and static electricity can be included. Underline the <u>heat sources that can start wildland fires without human help</u> (lightning and volcanic activity).

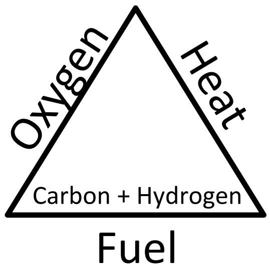
4. Ask where the oxygen for fires comes from. It is, of course, from air; oxygen comprises about 21% of the air we breathe. Write "air" next to the "Oxygen" label on the Triangle. By the way, we use only about 20 % of air's oxygen in a single breath. If we used all of it, the use of "rescue breaths" in cardiopulmonary respiration (CPR) wouldn't work!

5. **Do a safety briefing** in preparation for handling matches in these experiments. Demonstrate a safe way to light a match—that is, hold it level or pointing slightly down, strike away from you, and work over a noncombustible surface so you can drop it quickly but safely even if it is still burning. Review the location of spray bottles and fire extinguisher.

6. Give each student or team a copy of **Handout M03-1**, and tell them to follow the instructions on the handout. If they record multiple observations for (A) and (B), you may ask them to calculate means and medians. As a class, discuss their answers. In regard to (C):

   - The downward-pointing match probably burned almost completely. 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 also limited the oxygen that could get to the fuel.
   - The upward-pointing match probably went out before it burned completely, so it could not have been limited by fuel. Students may guess that it was limited by oxygen. You can respond to this by asking if they have any indication that the air around them is short of oxygen – were they having trouble breathing? The explanation lies in the relationship between heat and fuel: Most of the heat was moving up, away from the fuel, as they learned in **Activity M02**. If any heat was going down, it was not sufficient to keep the wood burning.

7. Below the Fire Triangle on the board, add the following line, which summarizes the chemical changes that occur during combustion. "C," "H," and "O" are abbreviations for the three kinds of atoms in this process.



C&H atoms + O_2 + a little heat ⟶ carbon dioxide (CO_2) + water (H_2O) + lots of heat & light

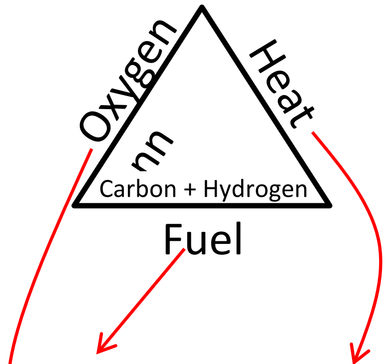
Show and explain:

- The carbon and hydrogen atoms (C&H) in fuels provide the first ingredient for combustion, oxygen (O_2) is the second ingredient, and heat is the third "ingredient."
- Exactly the same kinds of atoms are present in the products of combustion (carbon dioxide and water), but they have been recombined. It is that rearrangement of atoms that produces so much heat and light.
- Combustion is a chemical change, a rearrangement of atoms that changes substances from one kind to another.
- Most chemical changes are hard to reverse. For example, baking a cake causes chemical changes – and it is very hard to turn a cake back into its original ingredients! In combustion, fuels and pure oxygen are changed into carbon dioxide and water, and the change produces heat and light.
- Plants are the only thing on earth that can easily reverse the combustion reaction. Photosynthesis combines carbon dioxide with water to form carbohydrates (comprised, as the name implies, mainly of carbon and hydrogen).

Assessment: Ask students to copy the Fire Triangle diagram and the chemical equation for combustion onto a piece of paper. On the paper, have them:

1. Draw an arrow from each leg of the Fire Triangle to each ingredient in the chemical formula for combustion.

2. Explain in writing why combustion is a chemical change.



C&H atoms + O_2 + a little heat ⟶ carbon dioxide (CO_2) + water (H_2O) + lots of heat & light

Evaluation:	Correct	Incorrect
1. Connect the Fire Triangle with the combustion equation	Student drew three lines from the three legs of the Fire Triangle to the appropriate parts of the combustion equation.	Student did not draw three lines correctly from Fire Triangle to the appropriate parts of the combustion equation.
2. Combustion as chemical change	Combustion is a chemical change because the atoms in the fuels and oxygen are broken apart and then recombined to form new substances – carbon dioxide and water.	Student did not communicate in writing an understanding of combustion as a chemical change.

Handout M03-1: Why Does the Match Go Out?

Name: ___________________________

Organize your team. Change jobs if you repeat the experiment. On a team of 4:

- The **Observer** should light the matches.
- The **Timer** should measure the duration of burning (in seconds).
- The **Measurer** should measure the length of flames.
- The **Recorder** should record data.

Steps:

1. Place the metal tray on a heat-resistant surface. Set the support stand in the center of the metal tray. Attach the clamp to the stand. Attach the cross-piece with alligator clips to the clamp, so it forms a "+" with the stand.
2. Clip a wooden match to each alligator clip. Attach one match so the ignitable tip points straight up. Attach the other so the ignitable tip points down.
3. Light a third match and use it to ignite the downward-pointing match. Record your observations (A and B in first column below). Always dispose of burned matches in the ashtray or on the metal tray.
4. Use another match to ignite the upward-pointing match. Record your observations (A and B in second column below).
5. You may repeat the experiment to get more observations. If you do, use the oven mitt to handle the alligator clips. If you forget, you will quickly learn about conduction.
6. Answer question C for the downward-pointing match, then for the upward-pointing match.
7. **Clean up:** Make sure all burned materials and matches are our 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 them in the trash.

Match is pointing…	Down	Up
A. With the ruler near the flame but not in it, measure the flame length (centimeters). Record up to 3 observations. Try to get a MAXIMUM flame length.		
B. How long did the match burn (seconds)? Record up to 3 observations.		
C. Use the Fire Triangle to explain why the match went out.		