Fire, for elementary sites

BEAM Fall 2011
Contact: Robert Chen
Last modified: 10/17/11

Lesson Overview:

This lesson is composed of short, 10-minute long modules to show several important properties of fire. These modules are flexible and can be removed from a lesson if necessary. They should also be rotated (each group does a different one, then switches) to minimize the amount of supplies you need to bring to each site. Unless you can find the bottles for eggs in the given time, do modules 1, 2, 4, and 5, skipping the egg in a bottle module.

Introduction (in General Overview) - 10min
Modules - 10min each

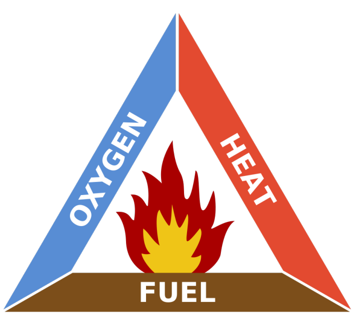
1. CO_2 and O_2 effects on fire
2. Rising water
3. Egg in bottle
4. Tall vs short candle
5. Fireproof Balloon

Conclusion (in General Overview) - 10min

Materials Overview

General Overview

Teaching goals:
- Students will understand the fire triangle (below) and ways to extinguish fires.
- They should know how where each of the sides of the triangle (oxygen, heat, fuel) comes from and how to remove them.
- Students should understand fire safety and the rationale behind certain practices such as smothering flames, stop-drop-and-roll, staying as close to the ground as possible, and dousing fire with water.



Background for Mentors

Fire is rapid oxidation of material via combustion. What we see as a flame is actually hot gases that glow due to Blackbody radiation and photon emission by excited electrons falling back to their ground states. For example, what happens in a burning candle is that the heat of an existing fire causes the paraffin to vaporize into gaseous particles. These gaseous particles react with O_2 more readily, and do so in the area we see as the flame. These reactions generate heat, which vaporize more paraffin, allowing the reaction to continue. Once certain energy thresholds are reached, the electrons in some of the combustion intermediates are excited and release visible light as those electrons release their excess energy. Combustion can be generalized by this equation: $C_xH_y + (x+y/13)O_2 \rightarrow xCO_2 + (y/2)H_2O$

Fire requires *heat* to provide energy in order to activate the oxidation reaction. By removing heat via water or by scraping embers away, a fire can be killed.

Fire requires fuel to provide the oxidation reaction something to oxidize. Removing the fire's fuel can halt or slow down a fire.

Fire requires oxygen as the most common oxidizer for the reaction. Oxygen can be removed by suffocating the fire.

Introduction

- What is fire?
- What causes fire?
- What makes fire dangerous? (heat, uncontrollable)
- What do you do in the event of a fire?
- How do you put out a fire?
- Explain the 3 sides of the fire triangle
- How can you eliminate or reduce
- Safety for this lesson

Safety

- Although the lesson use "just" matches/lighters and candles, take precaution to watch the students and make sure they don't get hurt from the flame or from the hot wax.
- These modules can all be done indoors unless the minimal smoke produced by matches or candles will set off fire alarms.

Conclusion

- What did you learn about the fire triangle today?
- What are ways to put out fires?
- What are ways to protect yourself from fires?

Module 1: CO2 and O2 effects on fire

Background for Mentors

Fire requires oxygen to (see fire triangle) live. Students will see the effects of oxygen deprivation (by CO_2 smothering) and oxygen addition affect a fire.

CO_2 is provided by the reaction of vinegar and baking soda, a acid-base reaction: $CH_3COOH + NaHCO_3 \rightarrow CH_3COONa + H_2O + CO_2$, which is the reason why the reaction foams. Stoichiometrically, you'll need much more vinegar than baking soda because household vinegar is ~5% acetic acid while baking soda is ~99% sodium bicarbonate.

O_2 is provided by the catalytic decomposition of hydrogen peroxide by yeast. Because hydrogen peroxide is a harmful oxidizing byproduct in many cellular chemical reactions, living organisms utilize catalase to decompose hydrogen peroxide according to this reaction: $2H_2O_2 \rightarrow 2H_2O + O_2$. While this decomposition occurs normally because of the relative instability of hydrogen peroxide, we want it to occur fast enough for the local oxygen concentration to increase before diffusing away, so we use a simple organism, yeast. Stoiochiometrically, you need much more hydrogen peroxide than yeast because household hydrogen peroxide is ~3% while catalase is one of the most efficient enzymes known.

Lesson for Mentees

What you should be teaching the students is that one of the most foolproof ways to extinguish a fire is just to smother it by covering it in order to force the fire to exhaust its oxygen supply. For example, kill a grease or barbecue fire by covering it with the lid or kill a lab fire by smothering it with a lab blanket.

Talk about how CO_2 fire extinguishers work similar to the baking soda and vine-agar experiment in that both put out fire by eliminating the fire's access to oxygen. However, this is not how most modern fire extinguishers work; they use a mixture of various chemical powders to coat the fire's fuel.

Make sure they understand that this is the reasoning behind Stop, Drop, and Roll, versus patting a fire out. Swatting at a fire will provide it with extra circulation and thus more oxygen whereas rolling will gently smother a fire and deprive it of its oxygen (rolling will introduce oxygen, but less so than swatting).

Materials (per group of 3-5 students)

- Tea candle
- Matches or lighter
- 3 plastic cups, one clear
- Small ½ cup of plain vinegar
- Small spoonful of baking soda
- Small ½ cup of hydrogen peroxide
- Small spoonful of dry activated yeast

Procedure

CO_2 smothering

1. Place the candle in the bottom of the clear plastic cup and light it. The cup serves as a trap for gas.
2. Combine the baking soda and vinegar in one plastic cup.
4. When the reaction stops bubbling, pour the CO_2 over the candle without pouring any of the liquid out. The CO_2 pools at the bottom of the container because it is heavier than air.
5. You should notice the flame get snuffed out.

O_2 lighting

5. Combine the hydrogen peroxide and dry yeast in a plastic cup .
6. Light the candle in the bottom of the plastic cup and gently blow it out so that the wick is still glowing but there is no flame.
7. When the reaction begins to stop bubbling, pour the O_2 over the candle without pouring any of the liquid out.
8. You should notice the flame come back to life.

9. If the flame does not “come back to life,” just pour the oxygen over a lit flame. It should flare up.
Self-suffocating
10. With the candle in the cup alight, place another cup any other type of cover on top to seal the container closed.
11. Within a few seconds, the candle should run out of oxygen and burn out.
12. Wash the two yeast or vinegar plastic with water and reuse.
13. Keep repeating all the demos if you have extra time.

References
http://www.stevespanglerscience.com/experiment/invisible-fire-extinguisher
http://www.metacafe.com/watch/1000896/experimenting_yeast_and_hydrogen_peroxide_reaction/

Module 2: Rising Water

Background for Mentors:

This demonstration is very similar to module one, with the added component of vacuum. There are three effects at work here: one chemical and two physical. Candle wax combusts according to this equation: $C_{25}H_{52} + 38O_2 \rightarrow 25CO_2 + 26H_2O$. Comparing just the O_2 and CO_2, there is a loss of gas volume as the parrafin is consumed. H_2O is hard to account for because some of it condenses. In addition, there is the effect of the temperature on gas expansion, which can be modeled by the Ideal Gas Law: $PV = nRT$. Because the temperature of the gas given off by the candle is hot, it takes up more volume. However, once the candle begins to die, the gas begins to cool, and thus contracts.

What happens as the demonstration is occurring is that although there is a net loss of gas via the chemical equation, the expansion of the gas due to the temperature of the combustion increases its volume. This effectively delays the contraction and subsequent vacuum creation until the gas cools when the flame dies. When the vacuum is created, it draws up water because of the pressure gradient created.

Of course, all this is theoretical. In reality, there are other factors to consider such as incomplete combustion that increases as the O_2 gets progressively depleted, that the ideal gas law does not always hold true, convection within the cup allowing all the oxygen to be used, the temperature-dependent solubility of water in air, and the complex equilibrium of liquid and vapor water.

Lesson for Mentees

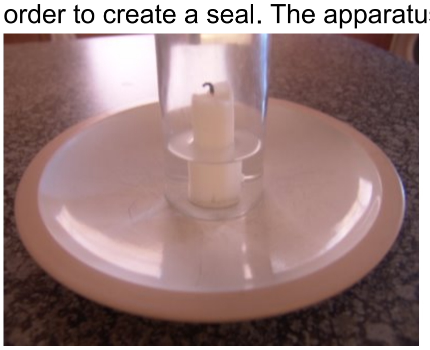
The main concept you should be teaching is that fire requires oxygen and will die without it. LIke with module 1, explain that one of the easiest way to kill a fire is to smother it. Show that the amount of water that replaced the gas is equal to how much oxygen the fire required (not exactly, but close enough). Have them understand that even a small candle requires a decent amount of oxygen, which is an indicator of how easy it is to suffocate a fire.

Materials (per group of 3-5 students)

- Clear plastic cup
- Plate larger than the plastic cup filled with water
- 3 of the same type of coin as spacers
- Tea candle
- Matches or lighter

Procedure

1. Place the three coins in a triangle on the bottom of the plate so that they can prop up the plastic cup up.
2. Check that the water level is higher than the lip of the plastic cup when it is placed on the coins, in order to create a seal. The apparatus should be similar to the image below:



3. Place the candle in the center of the coins and light it.
4. At first the water level should be the same, but as the oxygen runs out in the container, the candle should begin to die and the water level should rise.
5. Repeat with both tall and short candles if desired.

References

http://www.math.harvard.edu/~knill/pedagogy/waterexperiment/index.html

Module 3: Egg in a Bottle

Background for Mentors:

This demonstration is very similar to modules one and two, with the added component of sucking a egg using the vacuum for dramatic effect. Like above, when the gas cools, it creates a vacuum, only this time it is used to pull an egg into the container.

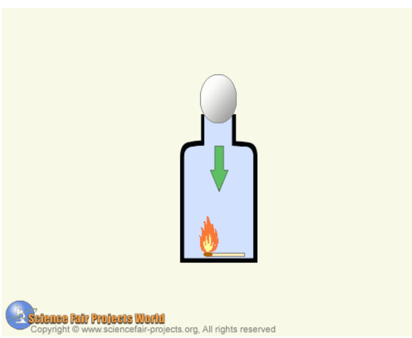
Lesson for Mentees: The concepts should be the same as with module 2 above.

Materials (per group of 3-5 students)

- Peeled hard boiled egg
- Matches or candle or newspaper
- Lighter (if no candles)
- Jar or bottle with opening that is barely smaller than the diameter of the egg

Procedure

1. Light 2-3 matches or light a piece of newspaper and drop into the container
2. Quickly place egg on top of opening
3. Egg should be sucked into the bottle.
4. If the egg does not get sucked in, try redoing with more matches or paper and after dampening the egg (to make it easier to squeeze in).



References

http://www.stevespanglerscience.com/experiment/00000022

Module 4: Tall vs. Short Candle

Background for Mentors

This module is very similar to the basic idea here is that candles require oxygen, but is slightly modified.. here are two forces at work here: the intrinsic density of the CO_2 given off by combustion, and the effect that heat has on fluid density. The intrinsic density of gaseous CO_2 is ~1.842 g/L versus ~1.275 g/L of air, which vary depending on the temperature and altitude. According to these data, CO_2 should sink because it is denser than air.

However, heating a gas increases its density, causing it rise relative to the surrounding air. This can be shown with the Ideal Gas Law: PV = nRT. Because volume and temperature are directly related, as the temperature of the air increases, the volume taken up by "n" moles of particles increases. Because density is mass/volume, it is proportional to n/V in the context of the Ideal Gas Law. As V increases while n stays the same, the density drops. Thus, the CO_2 and other gases given off by the candles rises to the top of the container, smothering from the top and extinguishing the taller candle first then the shorter one second.

Lesson for Mentees

The main idea to teach is that heat, or more specifically, hot air, rises. What you should be teaching your students is that if you're trapped in a building fire, you want to stay as close to the ground as possible because the harmful fumes given off by the fire collect from the top down. Also, this is why you have to be most wary of things catching fire above a campfire or candle because of how heat rises and will carry sparks upwards rather than laterally. Also make sure they know that certain appliances that give off heat, such as toasters, ovens, waffle irons, etc. have a upright position and should stay in that position because they were designed to have a certain top of the machine for the heat to vent.

Materials (per group of 3-5 students)

- Tall (3-5") and short (tea) candle
- Matches or lighter
- Container (preferably glass jar) that can cover both together

Procedure

1. Place both candles upright on a flat surface.
2. Light both candles.
3. Cover the candles with the container.
4. The taller one should extinguish first in a few seconds, followed by the shorter one.

References

http://www.pages.drexel.edu/~wb34/C3.which%20candle%20goes%20out%20%20first.htm
http://www.uq.edu.au/_School_Science_Lessons/topic08.html

Module 5: Fireproof Balloon

Background for Mentors

The idea behind this experiment is the abnormally conductivity and specific heat of water. The high conductivity allows the water to draw away heat from the skin of the balloon, keeping it from burning. The high specific heat allows the water to absorb this heat without raising its own temperature much.

Lesson for Mentees

You should teach students part of why we use water to combat fires: because it can absorb lots of heat quickly in order to reduce the heat of the fire. Reducing the heat of the fire is one way to kill a fire because it will reduce the temperature so that the thermal activation of the combustion reaction will not occur.

If you can get to the part with heating the metal utensil, you can explain to them that metal heats up a lot faster than water. This is why, in the case of a fire, you test to see if the doorknob is hot. Because metal is such a good heat conductor, it will accurately reflect the temperature of the room, unlike wood or the air. This is why you don't get burnt from hot oven air but do get burnt from touching a pot pan.

Materials (per group of 3-5 students)

- 2 balloons, one filled with ~1 cup of water and one filled with air
- Candle
- Matches or lighter
- Metal utensil, like a spoon

Procedure

1. Have students feel both balloons for temperature.
2. First hold the air-filled balloon over the candle until it pops. Explain that the air could not conduct the heat away from the rubber skin, which got burnt and burst.
3. Hold the water-filled balloon over the candle.
4. When the water becomes warm, allow the students to feel that the water absorbed much of the energy from the fire.
5. Show that the black soot from incomplete combustion on the balloon can be rubbed off and that the balloon itself was not damaged.
6. If you have enough time, hold the metal utensil over the flame. Allow the students to feel how much faster the metal heats up than the water did.

References

http://www.youtube.com/watch?v=qeDZQ9-gsjY
http://www.scifun.org/homeexpts/FIREBALLOON.html

Materials Needed Per Kit (assuming 4 groups/site)
- 4 tea candles
- 1 tall candle
- 4 small matchboxes or lighters
- 4 clear plastic cups
- 1 large jar or tall plastic cup
- 1 plate
- 1 box baking powder
- 1 bottle vinegar
- 1 jar of activated dry yeast
- 1 bottle hydrogen peroxide
- 8 balloons (fill 4 with water on site)

Mentors need to bring
- 1 metal spoon/utensil