UNIT: H02-2 TITLE: The Fire Triangle Part 2- Oxygen

TYPE: Lesson Plan

This activity is based on the US Forest Service's "FireWorks Northern Rocky Mountains & Northern Cascades" Curriculum

Overview

In this activity, students continue to learn about the fire triangle conceptual model. This activity focuses on the fact that there must be oxygen (O_2) available in order for fire to begin and to continue. Since this investigation uses a chemical reaction that produces carbon dioxide (CO_2) to displace O_2, students will review or be introduced to the importance of atomic/molecular masses. An extension is included that can review/introduce how to determine/calculate atomic/molecular masses.

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

Duration: 45 minutes

Group Size: Groups of 2-4

Setting: Classroom for introduction, laboratory for activity

Vocabulary: molecule, atomic mass, molecular mass

Lesson Goals:

- Increase students' understanding of combustion and the fire triangle conceptual model.
- Can determine the atomic/molecular masses of the most abundant gasses in Earth's atmosphere (if the extension is included).
- Appreciate the effect atomic/molecular mass can have on the behavior of atoms/molecules when combined with atoms/molecules that have different masses.

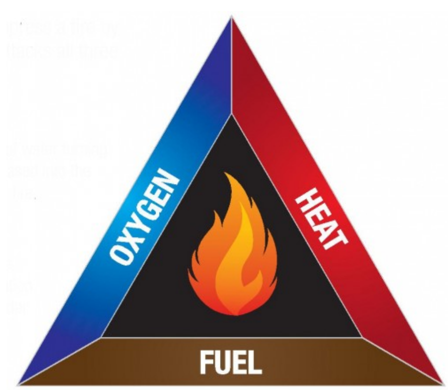
Objectives:

- Students can use the fire triangle to explain how various techniques extinguish fires.
- Students can explain how the atomic/molecular mass of a gas present in Earth's atmosphere can influence the gas' behavior when it is combined with other gases.

Academic Standards:

Standards		High School (9-12)
NGSS – Disciplinary Core Ideas	**HS-PS1 Matter and Its Interactions**	• PS1.A, PS1.B
	HS-PS3 Energy	• PS3.A, PS3.D
	HS-LS1 From Molecules to Organisms	• LS1.C
	HS-ETS1 Engineering Design	• ETS1.B, ETS1.C
NGSS – Performance Expectations	**HS-PS1 Matter and Its Interactions**	• HS-PS1-7
	HS-LS1 From Molecules to Organisms	• HS-LS1-7
	HS-ETS1 Engineering Design	• HS-ETS1-2

Teacher Background:



In the teacher background for “The Fire Triangle (Part 1) - Heat and Fuel - Lesson Plan,” a thorough explanation was given of **conceptual models**, the **fire triangle**, **chemical change**, and **physical change**. The key terms from the previous lesson are also important for this one and are included in “Table 5.”

This lesson continues to investigate the fire triangle by exploring the importance of **oxygen** (O_2) in the chemical reaction known as combustion. For a chemical change to occur, reactants must be converted into different products as a result of a chemical reaction. The reactants and products will usually be **molecules**. Composed of two or more bonded atoms, a molecule is the smallest identifiable group that a pure substance can be divided into and still maintain that substances' chemical properties. In order to use a combustion reaction that is familiar, the "simple" glucose ($C_6H_{12}O_6$) molecule has been used as the "**fuel**" in the chemical equation below:

$$C_6H_{12}O_6 + 6O_2 + \text{Heat} \rightarrow 6CO_2 + 6H_2O + \text{Heat \& Light}$$

A source of **heat** has been included on the reactant side to initiate the combustion of $C_6H_{12}O_6$ with O_2. All three components of the fire triangle are present which allows combustion to begin and to continue. If $C_6H_{12}O_6$ or O_2 is depleted, then combustion will cease. Likewise, if a fire is cooled sufficiently, it will go out.

In the activity for this lesson, students will develop a situation where O_2 is not present in adequate quantities for ignition by using CO_2 to displace O_2. Students will also use CO_2 to extinguish a candle that is burning. The CO_2 will be produced by combining vinegar (acetic acid/CH_3COOH) and baking soda (sodium bicarbonate/$NaHCO_3$). There are two chemical reactions that result in the production of CO_2 gas when vinegar (CH_3COOH) and baking soda ($NaHCO_3$) are combined. Here is the equation for the first reaction [1] which produces carbonic acid (H_2CO_3) and sodium acetate ($NaCH_3COO$):

$$[1]\ CH_3COOH + NaHCO_3 \rightarrow H_2CO_3 + NaCH_3COO$$

Sodium acetate ($NaCH_3COO$) is the "goo" at the bottom of the plastic container. The carbonic acid (H_2CO_3) immediately breaks down into CO_2 and H_2O according to this equation for the second reaction [2]:

$$[2]\ H_2CO_3 \rightarrow CO_2 + H_2O$$

Note about CO_2 gas: CO_2 is one of the components of air. CO_2 has more mass than O_2, as you can see from these calculations of the **molecular masses** of the two compounds:

8
O
Oxygen
15.999

Molecule	Element	# of Atoms (atoms)		Atomic Mass (amu/atom)		Product (amu)
O_2	Oxygen	2	x	15.999	=	31.998
						31.998

6
C
Carbon
12.011

Molecule	Element	# of Atoms (atoms)		Atomic Mass (amu/atom)		Product (amu)
CO_2	Carbon	1	x	12.011	=	12.011
	Oxygen	2	x	15.999	=	31.998
						44.009

To calculate a molecule's molecular/molar mass, the **atomic mass** of each atom in the molecule must be known. The atomic mass of an element is important not only to figure out what the mass of an atom of a particular element is but also as a necessary step when calculating molecular mass. The values in red above are the molecular/molar masses for O_2 and CO_2. The units used for the results above were "amu" or "atomic mass units." "Grams per mole" could also have been used. Thus, CO_2 (44.009 amu) has more mass than O_2 (31.998 amu). If CO_2 and O_2 are placed together in a container with no turbulence, the CO_2 will sink to the bottom and the O_2 will rise to the top. Of the major gases in Earth's atmosphere, CO_2 is one of the heaviest. This is important because if a reaction takes place in a container that releases CO_2, it will accumulate in the bottom of the container and displace the "lighter" air upwards. Students will discover this to be the reason they are unable to relight the candle in the plastic cup; the air containing O_2 has been displaced away from the candle by CO_2 being produced by the combination of vinegar and baking soda.

Optional "Approaches" for the Laboratory Activity: There are laboratory situations that present a better learning opportunity if students begin without some "prior knowledge." This lesson provides such an opportunity. It is suggested that the "white powder" and "clear liquid" remain a mystery and remain unlabeled.

Because of the bubbles produced, students quickly recognize that a chemical reaction takes place when the "white powder" and "clear liquid" are mixed. Since many students have already performed some sort of experiment that combined vinegar and baking soda previously in their academic careers, many students will know the gas produced is CO_2. Leaving the "white powder" and "clear liquid" unlabeled may reduce the number of students that remember this particular chemical reaction. If students are not familiar with the reaction, they are often confused and frustrated with their inability to relight the candle in the plastic cup. It's amazing to see the connections students make when they realize O_2 has been displaced by the CO_2 from the reaction of vinegar and baking soda!

There are instructions in the slide show's script that describe the appropriate slide progression to use depending on the chosen approach: 1) students don't know "the reactions" before the activity; or 2) students have been shown the reactions producing CO_2 before the activity. The slides describing the two reactions that produce CO_2 from mixing vinegar and baking soda can always be used while responses on the student worksheets are evaluated in class.

Table 5: Key Terms

Molecule	Composed of two or more bonded atoms, a molecule is the smallest identifiable group into which a pure substance can be divided and still maintain that substances' chemical properties.
Atomic Mass	The mass of an atom of a chemical element. The mass can be expressed in atomic mass units (amu) or in grams per mole. An element's atomic mass is approximately equal to the number of nucleons (protons and neutrons) in a typical/average atom of that

	element.
Molecular/Molar Mass	The mass of a molecule expressed in atomic mass units (amu) or in grams per mole.
Conceptual Model	In science, a simplified representation of a concept or of concepts related to a phenomenon. Often depicted as diagrams, conceptual models show processes or describe the relationships between concepts or factors essential to a phenomenon.
Fire Triangle	Conceptual model that depicts the relationship between fuel, oxygen, and heat that is necessary for fire to occur.
Heat	In the fire triangle, "heat" is a source of energy that raises the temperature of fuels to the point that they spontaneously react with oxygen through combustion. Typical heat sources that can produce fire include lightning, sparks, and flames.
Fuel	Any material that will react with oxygen through combustion when its temperature reaches the ignition point for that material. Easily recognized fuels include fossil fuels and vegetative biomass (wood, grasses, etc.).
Oxygen	To be involved in combustion, as depicted in the fire triangle, oxygen must be in its gaseous, diatomic form, O_2. About 21% of the gas in Earth's atmosphere is O_2.
Chemical Change	A process whereby the unique chemical identity of a material/substance is converted into a different chemical identity. Such a process is often referred to as a chemical reaction.
Physical Change	A transformation in which a specific molecule/substance/material undergoes a change or changes form without the molecule/substance/material having its unique chemical identity altered. Phase changes are excellent examples of physical changes.

Materials and Preparation:

When selecting the location for this activity, remember that votive candles and matches will be burned. Can this be done 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 conduct this activity outdoors because even the slightest wind will blow out the candles.

- Purchase enough fireplace matches well in advance since locating a store that sells them could be challenging.

- Purchase vinegar (acetic acid/CH_3COOH) and baking soda (sodium bicarbonate/$NaHCO_3$) sufficient for all groups/classes. Inexpensive vinegar and baking soda from a grocery store is adequate for this activity.
- The day before the activity, review the “FireWorks Safety” poster and remind students to follow safety guidelines about clothing and hair when they get ready for school the day of the activity. Be sure the “FireWorks Safety” poster is hanging in the lab area.
- If you plan on using the molecular/molar mass extension, be sure that a periodic table is available for each student (handout, hanging in class, internet, etc.).
- Print a student worksheet for each student.
- Prepare a “common” station that has enough vinegar and baking soda for all groups. These materials may be labelled or unlabeled depending on the approach being used (options discussed in **Teacher Background**).

- Set up a lab station for each student group that includes the following:
    - Safety glasses/goggles for each student
    - Spray bottle full of water
    - Leather gloves (one pair should be sufficient)
    - Metal Tray
    - 2 votive candles
    - Plastic cup
    - Stove lighter
    - Fireplace matches (long)
    - Spoon
    - Small beaker (50 mL)
    - Needle-nose pliers
- If possible, have a metal bucket or metal trash can without a plastic liner available.

Procedure:

1. Give each student a copy of the student worksheet.
2. Go over this activity’s slideshow.
    a. A script is provided in the speaker notes for the slide show.
    b. A document of the slide show’s speaker notes can be found in this activity’s folder.
3. Students groups complete the laboratory portion of the activity according to the procedure on their worksheets.
4. After experiments have been concluded, be sure students appropriately dispose of burnt matches and clean/organize the laboratory area.
5. Groups should use their observations/results to address the prompts on the student worksheet.
6. The molecular/molar mass **Extension** could be used. This includes practice molecular mass calculations.
7. The sample questions in **Assessment** could be used as a quiz. There are two molecular mass calculations included as sample questions.

Assessment:

Student Worksheet

Sample quiz/review questions for the "Fire Triangle (Part 2) - Oxygen"

1) Which of the following elements is a noble gas?
 a) Argon
 b) Carbon
 c) Nitrogen
 d) Oxygen

 Answer: a

2) Oxygen makes up what percent of Earth's atmosphere? (Select the closest percentage.)
 a) 0.04%
 b) 1%
 c) 20%
 d) 78%

 Answer: c

3) The thermolysis of H_2O can be described by the following: $2H_2O \rightarrow 2H_2 + O_2$. The thermolysis of water is which type of change?
 a) elemental change
 b) chemical change
 c) intrinsic change
 d) physical change

 Answer: b

4) Which of the following is an example of a physical change?
 a) Water evaporating
 b) Metal rusting
 c) Photosynthesis
 d) Trees burning
 e) Cellular respiration

 Answer: a

5) Which of the following is not necessary for combustion/fire to begin?
 a) Heat
 b) Oxygen gas (O_2)

c) Fuel - organic molecules containing carbon (C) and hydrogen (H)
d) Nitrogen gas (N_2)

Answer: d

6) **To be used if molecular/molar mass was introduced/reviewed.** Which value is closest to the molecular mass of hydrogen gas (H_2)?
a) 0 (H_2 has no mass because it is lighter than air)
b) 1 amu (or g/mol)
c) 2 amu (or g/mol)
d) 28 amu (or g/mol)

Answer: c

7) **To be used if molecular/molar mass was introduced/reviewed.** Which value is closest to the molecular mass of methane (CH_4)?
a) 4 amu (or g/mol)
b) 5 amu (or g/mol)
c) 10 amu (or g/mol)
d) 16 amu (or g/mol)

Answer: d

Evaluation:

Student Worksheet

A key for the student worksheet can be found as a separate document entitled "Key for Student Worksheet."

Sample quiz/review questions for the "Fire Triangle (Part 2) - Oxygen"

Answers provided with the questions in the **Assessment** section.

Extensions:

This lesson could be used as an opportunity to review or introduce how to determine the atomic mass for a particular element or how to calculate the molecular mass of the most prevalent polyatomic gases in Earth's atmosphere. Additional molecular mass "***EXTENSION SLIDES**" have been included with this lesson's slide show. Students can use the **Notes** section of their worksheet to complete calculations. If atomic mass values are rounded, the mathematics should be simple enough that a calculator will not be necessary. However, if students wish to use atomic masses as presented on a periodic table, the use of a calculator will simplify work. Students will need to have access to a periodic table (handout, hanging in class, internet, etc.) to practice the calculations. A periodic table is not included with this activity. There are many interactive periodic tables online.

References/Resources:

Slide Show

Images and diagrams by Bryan Yockers unless listed below.

Abstract and Table 1 from “The Legend of Carbon Dioxide Heaviness”

https://caves.org/pub/journal/PDF/v71/cave-71-01-100.pdf