Name

What is Complete & Incomplete Combustion? – Vocabulary

Use web resources to define the following terms:

Combustion:

Capillary Attraction (Capillary Action):

Exothermic:

Tetrahedron:

Oxidation:

Hydrocarbon:

Thermal Equilibrium:

Hemoglobin:

Teacher Comments:

Name

Lab 1: The Life of a Candle – OPTION 1

Guiding Question: How does a candle combust and what products are produced in the process?

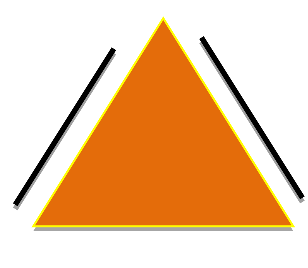
In this lab, you will use a candle to demonstrate the properties of complete and incomplete combustion. Follow the directions below to complete the experiment.

Student Directions:

1. Light the candle and allow it burn until there is consistent flame. Draw a diagram in the space provided below of the candle and flame. Label your diagram with as many details as possible.

2. Place a white background behind the candle (e.g., a white piece of cardstock or paper but be careful not to ignite the paper). Turn the lights off and shine a flashlight towards the candle. Observe the shadow cast on the white background. Note: You may have to move the flashlight back and forth to get a clearly focused shadow of the candle flame. Summarize your observations.

3. Blow out the candle and let the smoke dissipate. Consider some of the other experiences you have had with fire. What does a fire/candle need to burn? With the supplies provided by your teacher, conduct experiments that provide evidence that supports your answer. Fill in the *"fire triangle"* below and explain your findings.



4. What do you think is produced when a candle is burned (i.e., what are the products)?

5. If the candle is not already lit, relight it now. Hold a small glass jar (e.g., 4" x 2") or beaker above the candle so that half of the flame is inside the container for approximately 10 seconds. Record your observations below. Hint: you should identify one of the products produced from a burning candle.

6. Repeat step 5 with a clean glass jar. This time, however, quickly put a lid on the jar after it has been above the candle for 10 seconds. Being careful not to lose the contents of the jar, quickly remove the lid and add 20 to 30 mL of limewater to the jar. Replace the lid as quickly as possible. Shake the contents of the jar vigorously for approximately 10 seconds. Record your observations below.

7. What compound is present in your exhaled breath?

8. Pour 20 to 30 mL of limewater solution into a clean glass jar. Insert a flexible straw into the jar and blow air into the solution for approximately 30 to 60 seconds. Record your observations below.

9. Based on your findings from questions 6, 7, and 8, what additional product can be inferred to be produced from a burning candle? Or, cloudy limewater indicates the presence of what type of gas?

10. Using the answers from questions 3 through 9, use words, not chemical formulas, to write the products and reactants of a burning candle. Identify which products/reactants are gases, liquids, or solids.

__________ + __________ → __________ + __________

11. Light a splint with the candle flame. Blow out the candle. Being careful not touch the wick (~1/2 to 1 cm), quickly place the lit splint in the smoke stream. Record your observations. What does this experiment tell you about the smoke? Hint: Refer back to question 3.

12. Using your answer to question 11, explain why the wax from a candle eventually "disappears" when burned?

13. Pour just enough water in a glass jar to coat the bottom of the container. Add 3-4 drops of food coloring and swirl the jar to make sure the solution is homogenous. Roll up a piece of tissue and place one end vertically into the beaker. Describe your observations.

14. Referring to your vocabulary sheet, what is the name for the process you observed in question 13?

15. Based on the results from questions 11 through 14, how does the fuel from the candle burn? Describe the process below.

16. Refer back to your answer in question 10 and then write the ***skeleton chemical equation*** for a burning candle. Include the state of each reactant/product ((i.e., liquid (l), solid (s), or gas (g)). The general formula for the candle's fuel (i.e., a hydrocarbon) is $C_{25}H_{52}$.

    ________ + ________ → ________ + ________

    Your equation above should now show the general equation for complete combustion.

17. Chemical analysis can be used to determine that 340.5 g of oxygen, O_2, is required to completely burn 100.0 g of wax, $C_{25}H_{52}$. Determine the total mass of product, $CO_2 + H_2O$, if 100.0 g of wax is burned in 340.5 g of oxygen. Explain.

18. The experiment outlined in question 17 is carried out under carefully controlled conditions. The CO_2 and H_20 are collected and their masses are totaled. It is found that their total mass is less than 440.5g. Provide two possible explanations for the apparent discrepancy between the expected product mass and the actual product mass.

19. If the candle is not lit, relight it now. Using tongs, hold a microscope slide for a few seconds above the flame so it just barely touches the tip of the flame. Record your observations. IMPORTANT: USE TONGS TO HOLD THE SLIDE to avoid burned fingers!

20. Next, refer back to your diagram of the candle flame in question 1 and identify the middle, darker area of the flame. Using tongs, quickly place (~1 second) a clean microscope slide in this region of the candle flame. Describe your observations.

21. How do your results in questions 16, 19, and 20 compare? How can you explain this? Hint: Think about the three things a candle needs to burn?

22. From questions 18-20, you should be able to identify an additional product of a burning candle. What is this product? Why was this product produced?

23. Revisit your response to question 18. Again, provide a possible explanation for the observation that the mass of CO_2 and H_2O formed is less than 440.5 g.

24. Another experiment is performed where 100.0 g of wax is burned in 340.5 g of oxygen. All of the resulting CO_2, H_2O, and C (soot) are carefully collected. Again, the total mass of the product is less than the expected 440.5 g. Provide a possible explanation for the apparent discrepancy between the total mass of the reactants and the total mass of the products.

25. The other product of **incomplete combustion** discovered in question 24 is an odorless, colorless, and dangerous gas called carbon monoxide, CO. Write the skeleton chemical equations for both the complete and incomplete combustion of candle wax, $C_{25}H_{52}$, in oxygen, O_2.

    Complete combustion:

    Incomplete combustion:

26. If 100.0 g of $C_{25}H_{52}$ burns in 340.5 g of O_2 and all of the resulting CO_2, H_2O, C, and CO is collected. What will be the total mass of the products? Explain.

Teacher Comments:

Name

Lab 1: The Life of a Candle – OPTION 2

Guiding Question: How does a candle combust and what products are produced in the process?

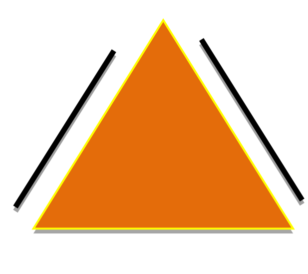
In this lab, you will use a candle to demonstrate the properties of complete and incomplete combustion. Follow the directions below to complete the experiment.

Student Directions:

1. Light the candle and allow it burn until there is consistent flame. Draw a diagram in the space provided below of the candle and flame. Label your diagram with as many details as possible.

2. Place a white background behind the candle (e.g., a white piece of cardstock or paper but be careful not to ignite the paper). Turn the lights off and shine a flashlight towards the candle. Observe the shadow cast on the white background. Note: You may have to move the flashlight back and forth to get a clearly focused shadow of the candle flame. Summarize your observations.

3. Blow out the candle and let the smoke dissipate. Consider some of the other experiences you have had with fire. What does a fire/candle need to burn? With the supplies provided by your teacher, conduct experiments that provide evidence that supports your answer. Fill in the *"fire triangle"* below and explain your findings.



4. What do you think is produced when a candle is burned (i.e., what are the products)?

5. If the candle is not already lit, relight it now. Hold a small glass jar (e.g., 4” x 2”) or beaker above the candle so that half of the flame is inside the container for approximately 10 seconds. Record your observations below. Hint: you should identify one of the products produced from a burning candle.

6. Repeat step 5 with a clean glass jar. This time, however, quickly put a lid on the jar after it has been above the candle for 10 seconds. Being careful not to lose the contents of the jar, quickly remove the lid and add 20 to 30 mL of limewater to the jar. Replace the lid as quickly as possible. Shake the contents of the jar vigorously for approximately 10-15 seconds. Record your observations below.

7. What compound is present in your exhaled breath?

8. Pour 20 to 30 mL of limewater solution into a clean glass jar. Insert a flexible straw into the jar and blow air into the solution for approximately 30 to 60 seconds. Record your observations below.

9. Based on your findings from questions 6, 7, and 8, what additional product can be inferred to be produced from a burning candle? Or, cloudy limewater indicates the presence of what type of gas?

10. Using the answers from questions 3 through 9, write the products and reactants of a burning candle below using words. Identify which products/reactants are gases, liquids, or solids.

__________ + __________ → __________ + __________

11. Light a splint with the candle flame. Blow out the candle. Being careful not touch the wick (~1/2 to 1 cm), quickly place the lit splint in the smoke stream. Record your observations. What does this experiment tell you about the smoke? Hint: Refer back to question 3.

12. Using your answer to question 11, explain why the wax from a candle eventually "disappears" when burned?

13. Pour just enough water in a glass jar to coat the bottom of the container. Add 3-4 drops of food coloring and swirl the jar to make sure the solution is homogenous. Roll up a piece of tissue and place one end vertically into the beaker. Describe your observations.

14. Referring to your vocabulary sheet, what is the name for the process you observed in question 13?

15. Based on the results from questions 11 and 12, how does the fuel from the candle burn? Describe the process below.

16. Refer back to your answer in question 10 and then write and balance the *chemical equation* for a burning candle. Include the state of each reactant/product ((i.e., liquid (l), solid (s), or gas (g)). Hint: Begin with your products to determine the reactant that is the fuel source of the candle. The general formula for the candle's fuel (i.e., a hydrocarbon) is $C_n + H_{2n+2}$. For this exercise, use a n = 25.

__________ + __________ → __________ + __________

Your equation above should now show the general equation for complete combustion.

17. If the candle is not lit, relight it now. Using tongs, hold a microscope slide for a few seconds above the flame so it just barely touches the tip of the flame. Record your observations. IMPORTANT: USE TONGS TO HOLD THE SLIDE to avoid burned fingers!

18. Next, refer back to your diagram of the candle flame in question 1 and identify the middle, darker area of the flame. Using tongs, quickly place (~1 second) a clean microscope slide in this region of the candle flame. Describe your observations.

19. How do your results in questions 17 and 18 compare? How can you explain this? Hint: Think about the three things a candle needs to burn?

20. From questions 17-18, you should be able to identify an additional product of a burning candle. What is this product? Why was this product produced?

21. Now that you know the reactants involved in a burning candle, complete the chemical equation with the product you identified in question 20. Use $C_{25}H_{52}$ as the fuel and include the state of each reactant/product.

$$\_\_\_\_\_\_ + \_\_\_\_\_\_ \rightarrow \_\_\_\_\_\_ + \_\_\_\_\_\_$$

Your equation above should now show the one of the general equations for incomplete combustion.

22. Another example of incomplete combustion involves a harmful gas. Identify this gas by balancing the equation below.

$$C_{25}H_{52} + 25.5\ O_2 \rightarrow \_\_\_\_\_\_ + 26\ H_2O$$

23. Write the equation for complete combustion (question 16) and the two equations for incomplete combustion (questions 21 and 22) below. Compare the products and reactants of each equation. How does complete combustion differ from incomplete combustion?

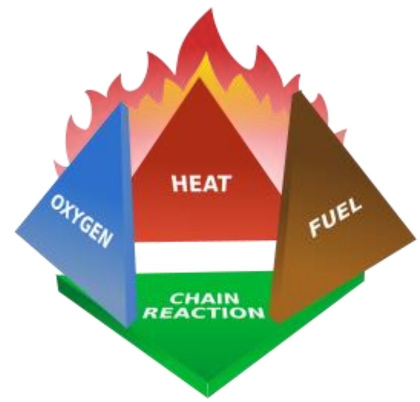
Teacher Comments:

COMPREHENSION 1

What is Complete & Incomplete Combustion?

WHAT IS THE FIRE (COMBUSTION) TRIANGLE?

The fire triangle (or combustion triangle) is a simple model that explains the dependent nature of the three primary components required for combustion: oxygen, heat and fuel. A common misconception about the fire triangle is that an ignition source (e.g., a flame), rather than heat is required to complete the reaction. For example, think about how you can create fire by focusing the sun's rays on a piece of paper using a magnifying glass. In addition, an exothermic chain reaction is required to maintain the fire once it has started. Therefore, the fire triangle is sometimes depicted as a tetrahedron or pyramid. Removal of any one "leg" of the fire triangle will alter the chemical process of combustion. For example, applying water to a fuel source may sufficiently lower the temperature below the required temperature (heat) necessary for fire to occur.



WHAT IS THE CHEMICAL PROCESS OF COMBUSTION?

Combustion is the process by which a fuel (usually a hydrocarbon such as natural gas, CH_4, or propane, C_3H_8) is rapidly oxidized, producing oxygen-containing compounds (e.g., CO_2, H_2O, and CO) and soot (i.e., C). This occurs when oxygen in the air combines with elements in the fuel, releasing heat and light energy—usually in the form of fire. In order for combustion to occur, the temperature of the fuel must be increased to a sufficient level, known as the ignition temperature. Once the ignition temperature has been reached, combustion begins. The process of combustion maintains the fuel at temperatures at or above the ignition temperature, allowing it to continue. Combustion, like most chemical reactions, terminates when a thermal equilibrium has been reached and the total heat energies of the reactants and of the products have equalized.

WHAT IS THE DIFFERENCE BETWEEN COMPLETE AND INCOMPLETE COMBUSTION?

When complete combustion occurs, the maximum amount of energy contained by the fuel will be used—leaving only carbon dioxide and water as the end products. For example, an equation for the complete combustion of methane would be as follows:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O.$$

However, in order for complete combustion to occur there needs to be an unlimited and constant supply of oxygen, as well as maintenance of an optimal temperature throughout the period of combustion. Generally, either a lack of continuous or sufficient oxygen results in "incomplete" combustion. In the case of incomplete combustion, a portion of the carbon atoms from the fuel will combine with only one atom of oxygen, forming carbon monoxide. This is shown in the following equation for the incomplete combustion of methane:

$$2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$$

Subsequently, a portion of the unburned fuel (the remaining hydrocarbons) may be released into the atmosphere as carbon particles—causing environmental pollution.

“ . . I have to ask...where, after all, the whole candle goes to; because . . . a candle being . . .burned, disappears, if burned properly . . . and this is a very curious circumstance.”

- *Michael Faraday*

WHAT ARE THE BYPRODUCTS OF COMPLETE AND INCOMPLETE COMBUSTION?

If ideal conditions are maintained for the complete combustion of a hydrocarbon, then carbon dioxide and water will be the resulting end products. This is because they are the compounds with the lowest energy (i.e. most stable) that can be formed from the chemical process of combustion. However, with insufficient oxygen, a state of incomplete combustion occurs resulting in the production of other byproducts, namely carbon monoxide and carbon particles.

SAFETY ISSUES INVOLVED IN COMBUSTION: CARBON MONOXIDE

Many households rely on the process of combustion for heat and/or cooking through gas appliances and fireplaces. However, when gas appliances or fireplaces are not properly designed, adjusted and/or maintained they become inefficient, releasing carbon monoxide as a byproduct of incomplete combustion. Carbon monoxide is also a product of incomplete combustion that occurs in internal combustion engines that power machines such as automobiles and lawn mowers. Carbon monoxide is a colorless, odorless and tasteless gas that is extremely toxic due to its ability to preferentially bind to hemoglobin—the oxygen-carrying protein in the blood. When this happens, the blood is no longer able to carry sufficient amounts of oxygen to the tissues and cells of the body. Symptoms of carbon monoxide poisoning include dizziness, nausea, shortness of breath, confusion and may ultimately lead to death.

“There is not a law [of nature] under which any part of this universe is governed which does not come into play and is touched upon in these phenomena [of the burning of a candle].”

- *Michael Faraday*

A CANDLE: AN EXAMPLE OF INCOMPLETE & COMPLETE COMBUSTION

As Michael Faraday presented in his lecture series “*The Chemical History of a Candle,”* a candle provides an excellent means for studying combustion. A candle is comprised of a wick and a hydrocarbon (paraffin wax) that has a general formula of $C_n + H_{2n+2}$. When heat and oxygen are available, the wick of the candle can be lit. The heat from the wick then melts the solid wax into a liquid state. Through the process of capillary attraction, the wax then moves up the wick where the heat from the flame turns the liquid wax into a gas that can be burned. In other words, the wax of a candle goes through two state changes, ultimately providing a gas as a fuel for the candle to burn. Under ideal conditions (i.e., an adequate balance of oxygen, fuel, and heat), a candle will completely combust and produce carbon dioxide and water. When oxygen is limited, incomplete combustion will occur resulting in carbon (seen as black soot) and carbon monoxide. Burned carbon particles are also what produce the bright color of the flame.

Name

Combustion Comprehension 1 - Guiding Questions

1. What are the components of the fire (combustion) triangle? What additional component makes it a fire tetrahedron?

2. Using the fire triangle to explain your answer, why is water so effective at putting out most fires?

3. Similar to question 2, provide another example of removing a leg from the combustion/fire triangle that would result in an extinguished fire.

4. Explain the differences between the processes of complete and incomplete combustion.

5. What happens when oxygen is present during the process of combustion, but limited?

6. Why is the production of carbon monoxide a public health concern?

Teacher Comments:

Name

Combustion Evaluation Questions

Place the letter of the best answer in the space before the question.

_____1. The wick on a candle serves as the primary fuel when the candle burns.
A. true B. false

_____2. A chemical process or reaction that involves the release of heat energy is referred to as _____.
A. homeothermic B. isothermic C. endothermic D. exothermic

_____3. Oxidation occurs when _____from a molecule, atom, or ion are lost during a chemical reaction.
A. electrons B. protons C. neutrons D. alpha particles

_____4. Which of the following **is** a product of complete combustion?
A. oxygen B. water C. carbon monoxide D. carbon

_____5. Carbon monoxide exposure poses a health hazard because hemoglobin in the blood is more likely to bind to the carbon monoxide than it is to oxygen.
A. true B. false

Answer the following questions completely and concisely.

6. How is the fire tetrahedron different from the traditional fire triangle?

7. Explain why water is used to suppress most types of fire.

8. Water is not an effective fire retardant for grease fires because grease is less dense than water so the flaming grease will simply float on the water. If a fire extinguisher is not available, describe another method you could use to extinguish a grease fire in a burning pan.

9. As you recall from “The Life of a Candle” lab, the candle wax serves as the fuel to support the combustion of a candle. Is the burning wax in the form of a solid, liquid, or gas? Use data from the lab to support your hypothesis.

10. How does complete combustion differ from incomplete combustion?

11. Why is the production of carbon monoxide dangerous to air breathing organisms?

Teacher Comments:

Updated 7/26/16 ND

Carbon Monoxide Detector Data Sheet

Student Name: ____

Start Date / Time: ____________________ / ____________________

End Date / Time: _____________________ / ____________________

Total Sample Time: __________________ (min)

Description of Sampling Location:

Minimum CO concentration: ___________(ppm)

Average CO concentration: ____________(ppm)

Maximum CO concentration: ___________(ppm)

Notes about sampling run (any information that may have influenced the results of your sample):

Were there any errors reported in the data (check one)? ☐ YES or ☐ NO If yes, please explain:

Did the Carbon Monoxide levels ever exceed the warning level (check one)? ☐ YES or ☐ NO