CARBON MONOXIDE: LESSON ONE

What is Complete & Incomplete Combustion?

LENSON SUMMARY
This lesson introduces students to the concepts of complete and incomplete combustion, and ultimately the production of carbon monoxide during incomplete combustion. In Lab 1 “The Life of a Candle,” students examine the process of combustion by subjecting a burning candle to differing conditions. Additionally, students will determine the reactants and products involved in complete and incomplete combustion, and the role each of these plays in combustion. Finally, students will conclude that incomplete combustion can result in the production of carbon monoxide. “What is Complete and Incomplete Combustion” also serves as an introduction to Lesson Two: What are the Health Effects of Carbon Monoxide?

CORE UNDERSTANDING/OBJECTIVES
By the end of this lesson, students will have a basic understanding of the Combustion Triangle, complete and incomplete combustion, and the reactants/products of combustion. Students will be introduced to the importance of carbon monoxide as a dangerous environmental pollutant that is often a by-product of combustion. For specific learning objectives and standards addressed, see pages 32 and 33.

MATERIALS/INCORPORATION OF TECHNOLOGY
The Life of a Candle?
- Taper candle & holder
- Matches or lighter
- White paper or cardstock
- Flashlight
- 3 clear glass jars with lids (~200 mL)
- Limewater solution
- Flexible straws
- Wooden splint
- Food coloring
- Tissue
- Tongs
- Microscope slides
- Lab goggles

Detecting Carbon Monoxide
- Lascar CO Detector Protocol

SUGGESTED READINGS
- The origin, fate, and health effects of combustion by-products: a research framework. http://1.usa.gov/1cQyfRK

INDIAN EDUCATION FOR ALL
Fire was a critical resource for the early American Indians and had functions beyond just warmth and cooking. According to Henry T. Lewis, early Indians used fire to aid in hunting, crop management, to improve
vegetation, and for safety reasons including fireproofing areas of settlement. There were many other uses for fire as well, ranging from insect collection to warfare signaling.

ENGAGE

Begin the lesson by lighting a candle in front of the class. Let it burn for a few minutes until there is consistent flame. Instruct the students to take out a piece of paper and record as many observations as they can about the burning candle. This may be a good place to discuss the differences between observation and inferences. Initiate a class discussion concerning student observations. Then, have the students number 1 through 5 below their burning candle observations. Ask the following questions allowing students time to record their answers: 1) How does a candle burn? and 2) How does a candle continuously produce a flame? After students have recorded their answers, have them review their answers to the questions in small groups. Have each group write their answers on the board and review the answers as a class. Have students return to their individual desks.

Next, light a Coleman lantern or a Bunsen burner near the candle. Ask the students to record their answers to the following questions: 3) How does a Coleman lantern/Bunsen burner burn?, 4) If the lantern/Bunsen has no fuel, will it still burn? Please explain. After students answer these questions, ask them to revisit their answers about the candle. For question #5, ask students to answer question #1 again and revise their original answer if needed, “How does a candle burn?” Collect the students' answers and let them know you will revisit them at the end of the lesson.

VOCABULARY

Copies of blank student vocabulary banks (see page 4) can be distributed for completion as either a classroom or homework assignment.

EXPLORE

Distribute Lab 1: “The Life of a Candle.” Students will complete this activity in small groups of 3-4. This activity is based on Michael Faraday’s work: “The Chemical History of a Candle” and introduces students to the processes of complete and incomplete combustion using a candle. There are two versions of this activity. Option One (p. 6-10) guides students through the combustion process and the resulting products of incomplete combustion in relation to the Law of the Conservation of Mass. Students are provided with masses of the reactants of the combustion reaction and compare those masses to the masses of the resulting products. They discover that the masses are not equal if they only consider the predicted products of complete combustion. Option Two (p. 16-19) compares complete and incomplete combustion through a series of chemical equations that students have to balance. Successful completion of Option Two requires a solid foundation in general chemistry including the
ability to balance intricate chemical equations. The “Life of a Candle” experiments can be found on page 5 of this lesson. **Note:** The teacher may want to check in with students at various points in Lab 1: “The Life of a Candle” to make sure students are on track (e.g., Questions 3, 5, 9, and 10). Limewater can be prepared by adding five scoops of calcium hydroxide, Ca(OH)$_2$, to approximately two liters of distilled water; a two liter soda bottle makes a good mixing vessel. Shake vigorously then allow the contents to settle overnight. Filter the mixture into a clean bottle. You may have to filter several times to get the desired clarity of the limewater.

**EXPLAIN**

Refer back to the anticipatory set and return students’ answers to the questions you asked at the beginning of the lesson. Lead a class discussion comparing a kerosene lamp/Bunsen burner and a candle (e.g., the wick (or solid/melted wax) is not the fuel of the candle or the kerosene lamp. Rather the wax vapor or gas produced is the fuel, just as the liquid kerosene is turned to a gas and supplies the fuel for the lamp or the gas provides fuel for the Bunsen burner.)

**ELABORATE**

Once students complete “The Life of a Candle” lab, distribute Comprehension 1: “What is Complete and Incomplete Combustion?” (p. 24-26) for students to complete individually during class or as a homework assignment. At the beginning of the next class (or as class time allows), lead a class discussion to review the Life of a Candle lab and Comprehension 1, and check for understanding. Some possible discussion questions include:

- Discuss ways in which firefighters can take advantage of the fire triangle to fight fires. How can the same principles be used at home to improve safety?
- Discuss every day activities that might involve incomplete combustion and explain why it is important to understand the dangers?

**EVALUATE**

The vocabulary sheets, lab worksheets, Comprehension Guiding Questions, and Evaluation Questions (p. 28 and 29) all offer opportunities for formal assessment. There are numerous opportunities for informal assessment including during the discussions generated from the ‘Engage’, ‘Explain’ and ‘Elaborate’ activities. Equally, teachers should circulate around the lab tables as students work through the lab in order to monitor and evaluate student comprehension.

**Notes:**
What is Complete & Incomplete Combustion? – Vocabulary

Combustion: ________________________________

Capillary Attraction (Capillary Action): ________________________________

Exothermic: ________________________________

Tetrahedron: ________________________________

Oxidation: ________________________________

Hydrocarbon: ________________________________

Thermal Equilibrium: ________________________________

Hemoglobin: ________________________________
What is Complete & Incomplete Combustion? – Vocabulary

**Combustion:** The process of rapid oxidation that results in burning and a corresponding chemical change, producing heat and light.

**Capillary Attraction (Capillary Action):** The movement of a liquid along the surface of a solid caused by the attraction of molecules of the liquid to the molecules of the solid.

**Exothermic:** A process or reaction that involves the release of heat.

**Tetrahedron:** The shape that is formed from four triangular faces of a polyhedron, which meet at each corner or vertex.

**Oxidation:** When the electrons from a molecule, atom or ion are lost in a chemical reaction.

**Hydrocarbon:** A compound composed of hydrogen and carbon (and often oxygen), including many fuels such as petroleum and natural gas.

**Thermal Equilibrium:** The condition under which two substances in physical contact with each other exchange no heat energy.

**Hemoglobin:** An iron containing protein in red blood cells that transports oxygen.
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. Explain your findings below.
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}.

\[ C_{25}H_{52}(l) + O_2(g) \rightarrow CO_2(g) + H_2O(g) \]

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 CO₂ and H₂O 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 CO₂ and H₂O 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 CO₂, H₂O, 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, C₂₅H₅₂, in oxygen, O₂.

Complete combustion:

Incomplete combustion:

26. If 100.0 g of C₂₅H₅₂ burns in 340.5 g of O₂ and all of the resulting CO₂, H₂O, C, and CO is collected. What will be the total mass of the products? Explain.
Lab 1: The Life of a Candle – OPTION 1  Teacher Key

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.

   ![Diagram of a candle showing wick, melted wax, and bright yellow flame]

   Bright Yellow Flame

   Darker Area of Flame

   Wick

   Melted Wax

   Solid Wax

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.

   Students should conclude that gas is visible in the shadow casted by the candle flame. This activity also allows students to see that solids or particulates make up part of the flame. The students could additionally infer that the gas that is visible is the solid wax melting and turning to gas, which is the fuel that allows the candle to burn.

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. Explain your findings below.

   ![Diagram of a triangle showing heat, fuel, and oxygen]

   Note to Teacher: Provide students a tea light candle, matches, a glass jar, a wick/piece of twine, and water.

   1. Fuel – Students may use a combination of the wick/piece of twine and candle to determine that fuel (i.e., wax) is required for combustion to occur.

   2. Oxygen – Students can use a glass jar to cover the candle and thus eliminate oxygen to show that further combustion will not be supported.

   3. Heat – Using the matches, some students may determine that an ignition source rather than heat is required. This will be clarified later in the lab. Water can also be used to lower the temperature of the fire.
4. What do you think is produced when a candle is burned (i.e., what are the products)?

   Answers will vary – e.g., smoke, soot, heat, etc.

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.

   The students should observe condensation inside the glass container. This example identifies water as one of the products produced during combustion. It is possible that students may also see soot collect in the container.

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.

   The solution should turn to a milky color. The white precipitate produced is calcium carbonate, CaCO₃, according to the reaction – CO₂ + Ca(OH)₂ → CaCO₃ + H₂O.

7. What compound is present in your exhaled breath?

   Carbon Dioxide

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.

   The solution should again turn to a milky color.

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?

   Students should realize exhaled carbon dioxide and carbon dioxide produced by the candle caused the limewater to change to a milky color. CO₂ therefore is a product of combustion.

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.

   **Fuel** (s, l, g) + **Oxygen** (g) → **Heat** → **Carbon Dioxide** (g) + **Water** (g)

   **Note:** Some students may identify the fuel as a solid, liquid, and/or gas. Gas is the correct answer and will be clarified later in the lab. Students may also notice soot and include it as a product here.
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.

This activity shows that the fuel is in the smoke (i.e. a gas), rather than a solid or liquid. Students may also determine that heat (rather than an ignition source) is required for combustion.

12. Using your answer to question 11, explain why the wax from a candle eventually “disappears” when burned? Refer back to question 1.

A candle is an example of a chemical change. The wax starts as a solid, is melted to a liquid, and ultimately heated to a gas that is used for fuel.

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.

The liquid should move from the bottom of the jar and up through the tissue.

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

Capillary Attraction

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

When the wick of the candle is lit, it produces heat that melts the solid wax of the candle. The liquid wax then moves up the wick through the process of capillary attraction. The liquid wax is then heated to a gas, thus providing fuel for the candle to burn.

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_{n}H_{2n+2}.

\[ \text{C}_{25}\text{H}_{52} \text{(g)} + \text{O}_{2} \text{(g)} \xrightarrow{\text{HEAT}} \text{CO}_{2} \text{(g)} + \text{H}_{2}\text{O} \text{(g)} \]

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_{2}O, if 100.0 g of wax is burned in 340.5 g of oxygen. Explain.

The Law of Conservation of Mass states that the total mass of reactants must be equal to the total mass of the products. 100.0 g C_{25}H_{52} + 340.5 g O_{2} = 440.5 g of products.
CO Lesson 1

18. The experiment outlined in question 17 is carried out under carefully controlled conditions. The CO₂ and H₂O are collected and their masses are totaled. It is found that their total mass is less than 440.5 g. Provide two possible explanations for the apparent discrepancy between the expected product mass and the actual product mass.

Students will probably explain that not all of the carbon dioxide or water was collected. To get them to think beyond this result, you may want to state that the two products were carefully collected. This may lead students to postulate that products other than carbon dioxide and water were produced. This provides a nice segue to the next experiment.

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!

The students should observe black soot on the microscope slide.

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.

A ring of black soot should appear on the microscope slide.

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?

When the microscope slide is placed on top of the flame, oxygen is limited where the flame and the slide meet, producing black soot or carbon. When the microscope slide is moved to the middle portion of the flame, no oxygen is available in the center of the flame so combustion does not occur. In addition, the oxygen available to the outer part of the flame is limited where the flame meets the slide, thus producing a ring of black soot or carbon. Additionally, there is less heat on the top and outside of the flame.

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?

Carbon is an additional product produced. This occurs when available oxygen is limited.

23. Revisit your response to question 18. Again, provide a possible explanation for the observation that the mass of CO₂ and H₂O formed is less than 440.5 g.

The results from 19 and 20 above indicate that there is another product, carbon or soot formed.
24. Another experiment is performed where 100.0 g of wax is burned in 340.5 g of oxygen. All of the resulting CO₂, H₂O, 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.

Students should now realize that there are products other than the expected carbon dioxide and water that result from the combustion of wax.

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, C₂₅H₅₂, in oxygen, O₂.

**Complete combustion:**

\[
\text{C}_{25}\text{H}_{52}(g) + \text{O}_2(g) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(l)
\]

**Incomplete combustion:**

\[
\text{C}_{25}\text{H}_{52}(g) + \text{O}_2(g) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(l) + \text{C}(s) + \text{CO}(g)
\]

26. If 100.0 g of C₂₅H₅₂ burns in 340.5 g of O₂ and all of the resulting CO₂, H₂O, C, and CO is collected. What will be the total mass of the products? Explain.

The **Law of Conservation of Mass** states that the total mass of reactants must be equal to the total mass of the products. 100.0 g C₂₅H₅₂ + 340.5 g O₂ = 440.5 g of products. The combustion of the candle wax involves incomplete combustion so when all of the products, CO₂, H₂O, C, and CO, are collected and massed, their total mass should be approximately equal to the total mass of the reactants.
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. Explain your findings below.
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 $n = 25$.

$$C_{25}H_{52}(g) + 38O_2(g) \rightarrow 25CO_2(g) + 26H_2O(g)$$

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.

\[
C_{25}H_{52} + 25.5 \text{O}_2 \rightarrow \text{____} + \text{____} + 26 \text{H}_2\text{O}
\]

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.

\[
C_{25}H_{52} + 25.5 \text{O}_2 \rightarrow \text{____} + 26 \text{H}_2\text{O}
\]

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?
Lab 1: The Life of a Candle – OPTION 2 Teacher Key

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.

   Students should conclude that gas is visible in the shadow casted by the candle flame. This activity also allows students to see that solids or particulates make up part of the flame. The students could additionally infer that the gas that is visible is the solid wax melting and turning to gas, which is the fuel that allows the candle to burn.

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. Explain your findings below.

   Note to Teacher: Provide students a tea light candle, matches, a glass jar, a wick/piece of twine, and water.

   1. Fuel – Students may use a combination of the wick/piece of twine and candle to determine that fuel (i.e., wax) is required for combustion to occur.

   2. Oxygen – Students can use a glass jar to cover the candle and thus eliminate oxygen to show that further combustion will not be supported.

   3. Heat – Using the matches, some students may determine that an ignition source rather than heat is required. This will be clarified later in the lab. Water can also be used to lower the temperature of the fire.
4. What do you think is produced when a candle is burned (i.e., what are the products)?

   Answers will vary – e.g., smoke, soot, heat, etc.

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.

   The students should observe condensation inside the glass container. This example identifies water as one of the products produced during combustion. It is possible that students may also see soot collect in the container.

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.

   The solution should turn to a milky color. The white precipitate produced is calcium carbonate, CaCO$_3$, according to the reaction – CO$_2$ + Ca(OH)$_2$ → CaCO$_3$ + H$_2$O.

7. What compound is present in your exhaled breath?

   Carbon Dioxide

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.

   The solution should again turn to a milky color.

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?

   Students should realize exhaled carbon dioxide and carbon dioxide produced by the candle caused the limewater to change to a milky color. CO$_2$ therefore is a product of combustion.

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.

   HEAT

   Fuel (s, l, g) + Oxygen (g) → Carbon Dioxide (g) + Water (g)

   Note: Some students may identify the fuel as a solid, liquid, and/or gas. Gas is the correct answer and will be clarified later in the lab.
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.

This activity shows that the fuel is in the smoke (i.e. a gas), rather than a solid or liquid. Students may also determine that heat (rather than an ignition source) is required for combustion.

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

A candle is an example of a chemical change. The wax starts as a solid, is melted to a liquid, and ultimately heated to a gas that is used for fuel.

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.

The liquid should move from the bottom of the jar and up through the tissue.

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

Capillary Attraction

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

When the wick of the candle is lit, it produces heat that melts the solid wax of the candle. The liquid wax then moves up the wick through the process of capillary attraction. The liquid wax is then heated to a gas, thus providing fuel for the candle to burn.

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.

\[
\begin{align*}
C_{25}H_{52} (g) + 38 O_2 (g) & \rightarrow 25 CO_2 (g) + 26 H_2O (g) \\
\text{HEAT} & \end{align*}
\]

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!

The students should observe black soot on the microscope slide.
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.

A ring of black soot should appear on the microscope slide.

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?

When the microscope slide is placed on top of the flame, oxygen is limited where the flame and the slide meet, producing black soot or carbon. When the microscope slide is moved to the middle portion of the flame, no oxygen is available in the center of the flame so combustion does not occur. In addition, the oxygen available to the outer part of the flame is limited where the flame meets the slide, thus producing a ring of black soot or carbon.

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?

Carbon is an additional product produced. This occurs when available oxygen is limited.

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.

Note the teacher may provide $H_{2}O$ below if needed.

$$C_{25}H_{52} (g) + 13 O_{2} (g) \rightarrow 25 C (s) + 26 H_{2}O (g)$$

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.

$$C_{25}H_{52} + 25.5 O_{2} \rightarrow 25 CO (g) + 26 H_{2}O$$

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? Less oxygen is present in the incomplete combustion equations. The teacher may ask students “What could you do to your candle to produce CO?” and “What type of combustion is going on when a candle is burning?” BOTH!

$$C_{25}H_{52} + 38 O_{2} \rightarrow 25 CO_{2} + 26 H_{2}O$$
$$C_{25}H_{52} + 13 O_{2} \rightarrow 25 C + 26 H_{2}O$$
$$C_{25}H_{52} + 25.5 O_{2} \rightarrow 25 CO + 26 H_{2}O$$
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, CH₄, or propane, C₃H₈) is rapidly oxidized, producing oxygen-containing compounds (e.g., CO₂, H₂O, 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:

\[ \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}. \]

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
burning of a candle]."

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

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

**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.

**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 CₙH₂ₙ₊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.
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?
Combustion Comprehension 1 - Guiding Questions
Teacher Key

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

   The three items necessary for combustion to occur are a fuel source, heat, and oxygen. The fourth component of the fire tetrahedron is a chemical chain reaction. All four of these are required for combustion to continuously occur.

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

   The fire triangle consists of three dependent components: heat, fuel, and oxygen. When any one of those components is missing or present in insufficient amounts, combustion (fire) cannot occur or the continuous chemical chain reaction cannot continue. When water is added to a fire, the water is first turned to steam and then the temperature of the steam increases. Both of these processes require energy from the fire. This lowers the temperature of the fire, or the heat leg of the fire triangle, stopping the chemical chain reaction.

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

   In most cases, it is difficult to remove fuel from a fire unless it is a simple matter of turning off the gas to a stove, heater, etc. Students will probably describe a situation where oxygen is removed from a fire such as placing a cover over a pan that has a grease fire.

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

   The reactants of complete combustion and incomplete combustion are the same, oxygen and a hydrocarbon. The products of complete combustion are carbon dioxide and water. Incomplete combustion occurs when insufficient oxygen is present. The products of incomplete combustion are carbon monoxide and/or carbon particles, and water.

   During incomplete combustion, oxygen is present in insufficient amounts to fully oxidize the fuel, therefore carbon atoms will react with only one molecule of oxygen instead of two molecules, forming carbon monoxide rather than carbon dioxide. In addition, because combustion is incomplete, some of the hydrocarbon fuel remains un-oxidized and is released into the air.

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

   If oxygen is abundantly present during the process of combustion, then the fuel is completely combusted and produces carbon dioxide and water. However, if oxygen is present but limited then incomplete combustion occurs resulting in the formation of carbon monoxide and/or carbon particles, which can be released into the environment in the form of pollution.

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

   Carbon monoxide is an extremely dangerous gas at very low concentrations and can result in serious illness or even death. In addition, due to the odorless, colorless, and tasteless nature of carbon monoxide, it is very difficult to detect making exposure assessment problematic.
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?
Combustion Evaluation Questions - Teacher Key

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.

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

   The fire triangle is used to demonstrate the three requirements for fire: heat, fuel and oxygen. The
   fire tetrahedron incorporates these three requirements and includes the addition of an exothermic
   chain reaction.

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

   When water is put on a fire, heat energy from the fire is used to change the water from liquid to
   steam and then used to increase the temperature of the steam. This removes heat, one of the legs of
   the fire triangle, from the fire.

14. 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.

   If the fire is small, has limited grease fuel, and not a threat to spread, you could simply let the fire
   burn itself out by combusting all of the fuel. If this is not the case, the best method would be to
   remove the oxygen leg of the fire triangle by using a lid to cover the burning pan.
15. 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.

The wax that combusts in a burning candle is a gas. This observation is supported by the experiment where a burning splint was held in the smoke above an extinguished candle and the candle re-lit.

16. How does complete combustion differ from incomplete combustion?

Complete combustion occurs when there is adequate oxygen present to completely oxidize or burn the hydrocarbon fuel. The products of complete combustion are carbon dioxide and water. Incomplete combustion occurs when there is not adequate oxygen to completely burn the hydrocarbon fuel so carbon (soot) and carbon monoxide are also formed as products.

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

Carbon monoxide production is a dangerous byproduct of incomplete combustion. It is undetectable because it is odorless and colorless and it is extremely hazardous because the oxygen carrying hemoglobin in the blood has a higher chemical affinity form carbon monoxide than it does for oxygen. Inhalation of carbon monoxide causes tissue suffocation, which can result in death.
Carbon Monoxide Lesson 1: 
Specific Learning Objectives and Standards

Specific Learning Objectives
Upon completion of this lesson, students will be able to:

- define combustion.
- identify the three components required for combustion.
- observe and identify capillary action.
- solve problems demonstrating conservation of mass.
- compare and contrast complete and incomplete combustion.
- infer the reactants and products of the two types of combustion through lab experimentation.
- identify sources of carbon monoxide in the home and describe the dangers of breathing in CO gas.
- summarize why carbon monoxide is hard to detect and how that increases its danger to humans.

NEXT GENERATION SCIENCE STANDARDS
Students who demonstrate understanding can:

**HS-PS1-2** Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

**HS-PS1-6** Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

**HS-PS1-7** Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.

MONTANA STATE SCIENCE STANDARDS
A proficient student will (upon graduation):

Science Content Standard 1: Students, through the inquiry process, demonstrate the ability to design, conduct, evaluate, and communicate the results and form reasonable conclusions of scientific investigations.

1.2 select and use appropriate tools including technology to make measurements (in metric units), gather, process and analyze data from scientific investigations using appropriate mathematical analysis, error analysis and graphical representation.

1.4 analyze observations and explain with scientific understanding to develop a plausible model (e.g., atom, expanding universe).

Science Content Standard 2: Students, through the inquiry process, demonstrate knowledge of properties, forms, changes and interactions of physical and chemical systems.
2.3 describe the major features associated with chemical reactions, including (a) giving examples of reactions important to industry and living organisms, (b) energy changes associated with chemical changes, (c) classes of chemical reactions, (d) rates of reactions and (e) the role of catalysts.

2.4 identify, measure, calculate, and analyze relationships associated with matter and energy transfer or transformations, and the associated conservation of mass.

**ALASKA STATE SCIENCE STANDARDS**

SA1 Students develop an understanding of the processes of science used to investigate problems, design and conduct repeatable scientific investigations, and defend scientific arguments.

**[10] SA1.1** The student demonstrates an understanding of the processes of science by asking questions, predicting, observing, describing, measuring, classifying, making generalizations, analyzing data, developing models, inferring, and communicating.

**[10] SB2.1** The student demonstrates an understanding of how energy can be transformed, transferred, and conserved by examining energy (i.e., nuclear, electromagnetic, chemical, mechanical, thermal) transfers, transformations, and efficiencies by comparing useful energy to total energy.

**IDAHO STATE STANDARDS**

**Chemistry:**

**Goal 1.3:** Understand Constancy, Change, and Measurement

11-12.C.1.3.1 Identify, compare and contrast physical and chemical properties and changes and appropriate computations.

11-12.C.1.3.5 Analyze and solve reaction stoichiometry problems.

**Goal 1.6:** Understand Scientific Inquiry and Develop Critical Thinking Skills

11-12.C.1.6.2 Select and use appropriate scientific equipment, materials and techniques.

**Goal 1.8:** Understand Technical Communication

11-12.C.1.8.1 Correctly write symbols, formulas and names for common elements, ions and compounds.

**Goal 2.3:** Understand the Total Energy in the Universe is Constant

11-12.C.2.3.2 Demonstrate the conservation of matter by balancing chemical equations.

**Goal 2.5:** Understand Chemical Reactions

11-12.C.2.5.2 Classify, write and balance chemical equations for common types of chemical reactions and predict the products.

**Goal 5.1:** Understand Common Environmental Quality Issues, Both Natural and Human Induced

11-12.C.5.1.1 Demonstrate the ability to work safely and effectively in a chemistry laboratory.

**Goal 5.3:** Understand the Importance of Natural Resources and the Need to Manage and Conserve Them

11-12.C.5.3.1 Evaluate the role of chemistry in energy and environmental issues.
LASCAR Electronics El-USB-CO
Carbon Monoxide (CO) Gas Detector Protocol

Note: You will need to install the EL-USB-CO software prior to setting up the sampler. **NOTE: This software is not compatible with Macintosh computers.**

Each of the following steps (listed below) should be followed when collecting a CO sample. During sampling, the CO detector will continuously collect data over a period of time. Following the sampling event, the EL-USB-CO software will be utilized to retrieve the data. Final results will be presented in parts per million (ppm) of CO in the air.

**Battery Installation**

1. Remove the EL-USB-CO Carbon Monoxide Gas Detector from the box.
2. Before using the CO detector, you will need to insert the 3.6V 1/2AA battery. Handle the lithium batteries carefully, and observe warnings on the battery casing.
   a. Remove the cap from the USB end of the CO Detector.
   b. Place the tip of a small, flat screw driver onto the metal latch nearest the LED lights and press down gently.
   c. You will be releasing the dark grey end from the lighter grey side. Pull the pieces apart and place the battery inside, following the illustration printed there.
   d. Push both pieces back together gently until it clicks and is secure.
3. When the battery is first installed, the red and then green LED will flash for approximately 2 minutes, while the detector stabilizes. Do not connect the CO detector to a computer until this has finished.

**USB Driver Installation**

1. Insert the USB end of the CO Detector into a USB port on the computer.
2. Insert the software CD into the computer, or access the software at [http://www.lascarelectronics.com/data-logger/easylogger-software.php](http://www.lascarelectronics.com/data-logger/easylogger-software.php)
3. Your computer should ask you if you want to search for software, answer “No, not this time”.
4. On the next screen, you can choose to install via the CD in the drive.
5. The next screen will ask if you want to install the software on your computer, select “Next”.
6. On the next screen, accept the terms of the license agreement.
7. On the next screen, click “Next”.
8. Your download should begin. After completing the setup, click “Finish”.
9. There will be a new icon on your desktop.

**Starting the Logger for Sampling**

1. Attach the CO detector to the software to set up your sampling event.
2. Double click the desktop icon for EasyLog USB and choose what action you would like to perform (starting the logger, stopping the logger, or viewing data).
3. If you choose to start the logger, you will then need to agree to the safety disclaimer.
4. On the next screen you can name the CO Detector if necessary to keep track of it from other detectors. (This does not name a data file, but instead gives an ID for the actual detector.)
5. Choose the frequency of data logging you prefer (ex. 10 seconds). This means a sample will be collected every 10 seconds for the duration of the sampling event (or until the data storage runs out).
6. On the next screen you can choose the alarm LED (red) to light up when you reach a warning level you choose. The Detector can also sound an alarm, (requiring the plastic cap be fitted when it's running). If you don't want the sound, you can choose to disable it.
7. The next page allows you to select a time and date for your sample to begin. Or, if you prefer, you can press Finish without changing anything and it will start immediately.

As long as the battery is installed (and holds a charge), the CO Detector is running. The LED lights will indicate what the instrument is doing. Here are the LED light options you will encounter (note that when the battery is first installed the red and then green LED will flash for approximately 2 minutes, while the detector stabilizes):

- **Green single flash (every 10 seconds):** The CO Detector is currently logging. No alarm.
- **Green single flash (every 20 seconds):** The CO Detector is currently logging. No alarm. However, the battery is low and should be replaced before logging important data.
- **Green single flash (every 30 seconds):** The CO Detector is not currently logging, but is primed to start at a later date and time (via computer program as discussed above).
- **Green double flash (every 20 seconds):** The CO Detector is full and has stopped logging. No alarm.
- **Red single flash (every 10 seconds):** The CO Detector is currently logging. Alarm.
- **Red/Green single flash (every 20 seconds):** The CO Detector is full and has stopped logging. Alarm.
- **No LED flash:** The CO Detector has stopped, the battery is empty, or there is no battery inserted.

**Stopping the Logger**

To stop the CO sampler, you need to link it with the software.

1. Choose the stopping option by clicking it.
2. The screen will now show you what the name (ID) of the detector is and how many readings it stored.
3. You can now click “OK” to download the data, or “Cancel” to return to the main menu. You can now exit from the program.

**Viewing Data**

1. If you are downloading data after stopping the CO Monitor, a screen will pop up that allows you to name your file and save it to whatever folder you like. Choose something unique for a name, including the date of the sampling event (i.e. Weiler080613).
2. After you save it, you will be shown a screen that graphs your data.
3. You can access saved files by using the software’s main menu too, by selecting “View Previously Saved Data”.
4. After selecting this, you will be presented with a graph like before. To look at the data in table form, click “EXPORT.”
5. A new Excel workbook will open. On one sheet will be a more detailed graph, and on the second sheet will be the tabulated data.

**After Sampling**

1. If sampling will not be performed again for a while, remove the battery by using the small, flat screwdriver again. Store the battery with the CO Detector.
2. Place the plastic cap gently over the USB end of the CO Detector and put back into box.
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 (circle one)?  YES  or  NO
If yes, please explain: __________________________________________________________

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

Carbon Monoxide LESSON 1: What is Complete and Incomplete Combustion?


A Candle in the Wind. 2008. Journal of Science Education. (JCE Classroom Activity: #95). 85(4)528A-528B. Available on-line at:

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