# The Chemistry and Impacts of Incomplete "Dirty" Combustion

## Introduction

When a fuel source burns, we call that chemical reaction combustion. **Combustion** is typically an **exothermic** (energy-releasing) chemical reaction, usually involving oxygen, that results in light and heat. In this lesson, you will learn about an unusual way some scientists today have studied combustion reactions that have occurred long ago. Spoiler alert: it has something to do with dead birds. We know, weird, right? Read on!

## What To Do

**Step 1.** Examine your teacher's demonstration of a burning candle.

a. What does the flame look like? Describe it below.

**Step 2.** Now your teacher will place a spoon or slide in the flame. Make careful observations of this entire process.

a. What does the spoon or glass look like before it is placed in the flame?

**Step 3.** Examine how the flame changes when the spoon or glass is in the flame.

a. How does the shape and behavior of the candle flame change?

b. Can you see any change in the emissions? If yes, describe what you see.

c. What does the part of the spoon or glass that has been exposed to the flame look like after it has been removed from the flame?

**Step 4.** Read the information below about incomplete and complete combustion and answer the analysis questions, reading the Bite when instructed.

**Incomplete vs. Complete Combustion**

All combustion reactions—whether the fuel is gasoline in your car, wood in a fireplace, wax from a candle, or a pie forgotten in the oven—emit both gasses and aerosols. **Aerosols** are tiny amounts of liquids or solids that are suspended in the air. Aerosols include smoke, fog, dust, and pollen.

Picture the tailpipe of a new car or truck. Most of the time you cannot see anything coming out, but this doesn't mean there are no emissions, it's just that the emissions produced are in the form of transparent gasses. The combustion of gasoline in a car engine that is working properly is an example of complete combustion. In **complete combustion**, all of the fuel is turned into carbon dioxide, heat, and light. Please note, in the real-world, true complete combustion is nearly impossible and there are always some emissions of other gasses and aerosols besides carbon dioxide. However, it is often more useful—and simpler—to make some idealized assumptions, as we do here.

A vehicle engine that is not working as it should emits large amounts of gasses besides carbon dioxide as well as a large variety of aerosols. While the gasses are invisible, we see these aerosols as gray or black smoke. The black smoke results from very inefficient combustion and we call this stuff **black carbon** or **soot**. This is an example of **incomplete combustion**.

The chemical reactions below summarize the chemistry of **complete combustion** and of **incomplete combustion** of fuel sources that contain carbon.

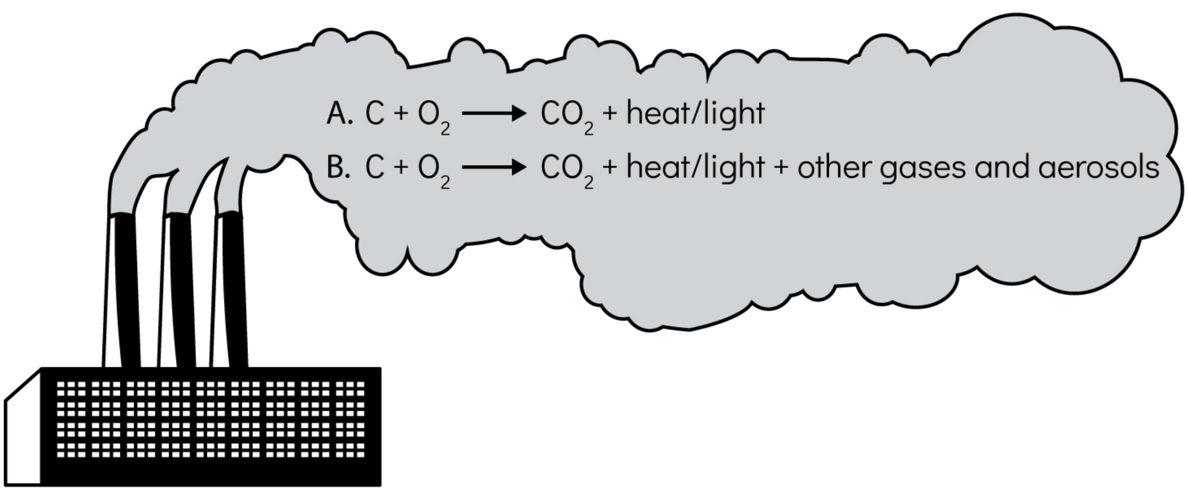


**Figure 1. Complete and Incomplete Combustion. A.** Complete combustion; In the real world, combustion reactions are never absolutely complete, there is always some production of gasses besides $CO_2$. **B.** Incomplete combustion

Sometimes, incomplete combustion emits molecular rings of carbon that stick together and form clumps. We call this emitted compound black carbon, or soot, and the compound they form we call **tar balls**, which are thick, sticky spheres. As shown in **Figure 2,** The growth of these tar balls is a complex process.

What happens to this smoke, soot, and tar balls once they are emitted into the air? They can block sunlight and stick to buildings, animals, and the inside of our lungs. Scientists have been studying combustion emissions for decades, and while they have learned a lot, there's still new things to learn. In this lesson, you'll learn about a group of researchers who measured soot deposits on the feathers of birds collected over the past 100 years to learn more about historical soot emissions in order to understand how combustion emissions have changed over time.

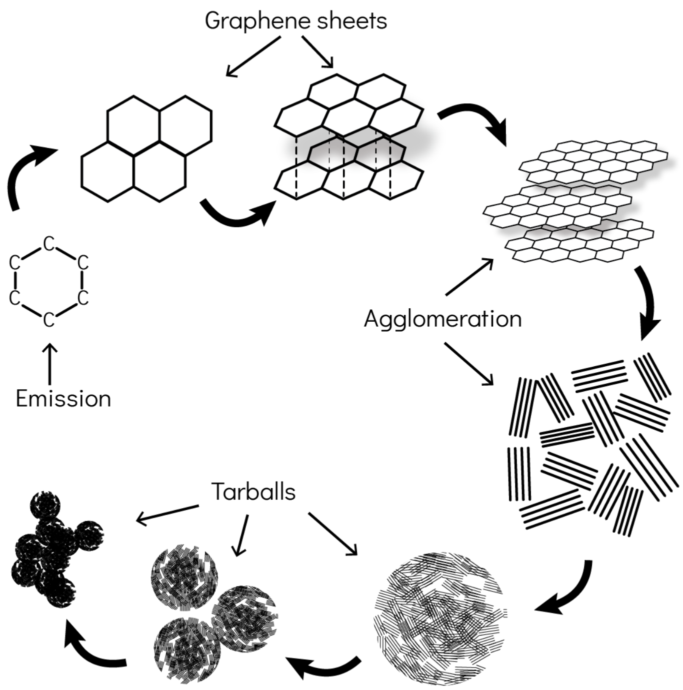


**Figure 2. The Formation of Tar Balls.** Incomplete combustion leads to production of large carbon-based compounds. These then form into graphene sheets which agglomerate, eventually forming tar balls.

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## Analysis Questions

**1.** Consider the candle demonstration you saw earlier.

**a.** Based on what you have read, what are some possible gasses being produced by this combustion reaction? Where are those gas emissions going?

**b.** Based on your observations and what you have read, what chemical compound do you think formed on the spoon or glass?

**c.** As you will soon read about, that compound was once produced in large quantities by humans through a variety of combustion reactions. Based on your observations of the compound, why do you think it would be harmful to humans and wildlife?

**2.** An unbalanced chemical reaction showing the combustion of methane ($CH_4$) is shown below. Use it to answer the following questions.

$$\mathbf{CH_4 + O_2 \rightarrow CO_2 + H_2O}$$

**a.** Draw a Lewis structure for a molecule of methane and a molecule of carbon dioxide. *Remember: Carbon atoms form four bonds. Oxygen atoms form two bonds. Hydrogen atoms form one bond.*

**b.** How many of each type of atom (C, H, and O) are on the reactants side of the above equation? How many are on the products side?

Reactants: ___ C ___ H ___ O    Products: ___ C ___ H ___ O

**c.** Balance the chemical equation representing the combustion of methane. Write your balanced equation below.

**3.** Examine the unbalanced chemical reaction showing combustion of a component in candle wax ($C_{31}H_{64}$) below. Use it to answer the following questions.

$$\mathbf{C_{31}H_{64} + O_2 \rightarrow CO_2 + H_2O}$$

**a.** What are similarities and differences in the chemical structure of methane ($CH_4$) and the chemical structure of candle wax ($C_{31}H_{64}$)?

**b.** Balance the chemical equation for the combustion of candle wax ($C_{31}H_{64}$).

**4.** Two students take the mass of a birthday candle and then let it burn. When the candle stops burning, the students take the mass again. The mass of the candle is now ½ of its original value.

**a.** Student 1 states, "I watched the candle get smaller and smaller while it was burning. The candle's mass disappears into the air, therefore mass is not conserved in this reaction." Do you agree or disagree with the student? Explain your answer.

**b.** Student 2 states, "The candle is just melting, not burning. The decrease in mass was just due to errors in our measurements. Mass is conserved in this reaction." Do you agree or disagree with the student? Explain your answer.

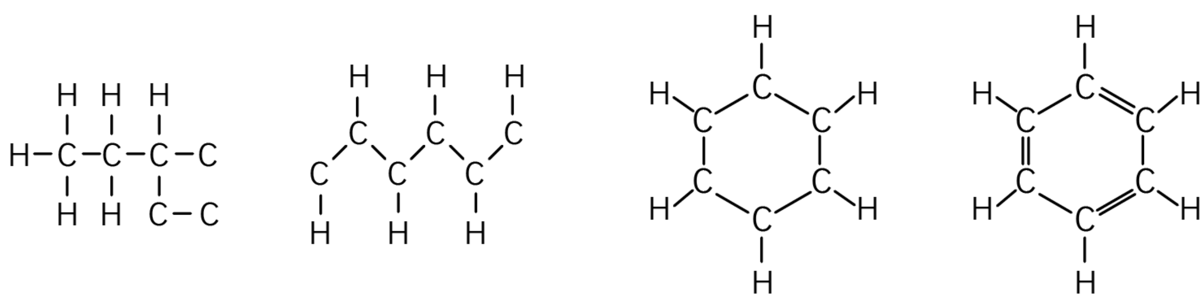
**5.** Are the combustion reactions of methane and candle wax shown in Questions 2 and 3 examples of complete or incomplete combustion? Make a claim and support your claim with evidence and reasoning.

**6.** The reaction below is an example of incomplete combustion of a component of candle wax ($C_{31}H_{64}$). Use it to answer the questions that follow.

$$\mathbf{12C_{31}H_{64} + 99O_2 \rightarrow 62C_6H_6 + 198H_2O}$$

**a.** How can we tell that this reaction is an example of incomplete combustion?

**b.** Four students drew the structure of the product $C_6H_6$. The structures they drew are shown below.



(A) (B) (C) (D)

**i.** Which student drew a chemically correct structure for $C_6H_6$? Explain your answer.

**ii.** Choose one of the incorrect structures and describe one reason why the structure is incorrect.

**7.** Examine the molecular formula of a molecule found in coal.

$$C_{137}H_{97}O_9NS$$

If this molecule undergoes complete combustion, $SO_2$, $H_2O$, and $NO_2$ will likely be some of the products. If the molecule undergoes incomplete combustion, $N_2O$ and HCN will likely be some of the products.

**a.** Draw Lewis structures for $SO_2$, $H_2O$, and $NO_2$.

**b.** Draw Lewis structures for $N_2O$ and HCN.

**c.** Based on what you have read, name at least one other potential product of the incomplete combustion of $C_{137}H_{97}O_9NS$.

STOP & read Science Bite:

Dirty Birds and Tar Balls

**8.** What was the fuel source that was responsible for most pre-1950s black carbon emissions?

**9.** Examine the bird from 1906 and the bird from 1996 in **Figure 2** of the Bite.

**a.** What difference do you notice about their feathers? What is the difference caused by?

**b.** Based on that information, consider what you can infer about the combustion of fossil fuels in 1906 compared to 1996—at what time point did the burning of fossil fuels involve more incomplete combustion? Explain how the information from part a supports your answer.

**10.** Why do you think humans decided to change the way coal was combusted between the 1900s and today?

**11.** **Connect to the Big Question**. Often scientists are able to learn new things from old data. This might be due to advances in technology or new ideas about how to use old data sets. How did the researchers in this study take a fresh look at old data? How does that impact your understanding of what it means to observe?