

**Teacher’s Guide**

**Shining a Light on Candles**

***February 2022***

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Activate students’ prior knowledge and engage them before they read the article.

[Reading Comprehension Questions](#_Student_Reading_Comprehension) 3

These questions are designed to help students read the article (and graphics) carefully. They can help the teacher assess how well students understand the content and help direct the need for follow-up discussions and/or activities. You’ll find the questions ordered in increasing difficulty.

[Graphic Organizer 6](#_Graphic_Organizer)

Thishelps students locate and analyze information from the article. Students should use their own words and not copy entire sentences from the article. Encourage the use of bullet points.

[Answers 7](#_Answers_to_Reading)

Access the answers to reading comprehension questions and a rubric to assess the graphic organizer.

[Additional Resources 12](#_Additional_Resources_1)

Here you will find additional labs, simulations, lessons, and project ideas that you can use with your students alongside this article.

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# Anticipation Guide

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Directions: *Before reading the article*,** in the first column, write “A” or “D,” indicating your **A**greement or **D**isagreement with each statement. Complete the activity in the box.

As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

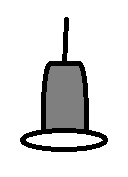
|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. Candles were developed in the early 1700s. |
|  |  | 1. Waxes are hydrocarbons that may come from plant or animal sources. |
|  |  | 1. All waxes are solids at room temperature. |
|  |  | 1. Combustion (burning) was not understood until the late 1700s. |
|  |  | 1. Once a candle starts burning, it remains lit because the wax burns. |
|  |  | 1. Paraffin is a petroleum byproduct. |
|  |  | 1. Wicks are soaked in a fire-retardant chemical to keep them from burning too fast. |
|  |  | 1. Complete combustion occurs in the yellow part of the candle flame. |
|  |  | 1. A candle on the International Space Station has more complete combustion than one on Earth. |
|  |  | 1. Scientists continue to research candle flames. |

# Student Reading Comprehension Questions

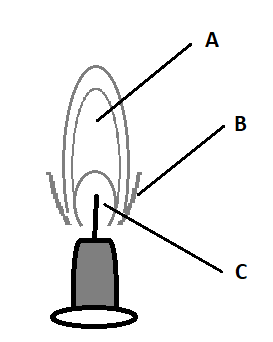
Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Directions**: Use the article to answer the questions below.

1. Lavoisier’s experiments from 1772 showed that the substance that makes something burn is not a part of the thing but rather is in the air around it. What experimental finding led to this conclusion? Explain.
2. Organic molecules are molecules that have a framework composed of carbon atoms bonded in a chain-like sequence with the remaining bonding sites occupied mostly by hydrogen atoms. Draw a line of four carbons with a single bond between each pair of carbons. If all other bonding sites are occupied by hydrogens, how many hydrogens will be on this molecule? Draw the bonded hydrogens to complete the Lewis structure for the molecule.
3. A combustion reaction involving organic molecules will always produce both carbon dioxide and water as the organic molecule splits apart and its parts recombine with oxygen. Write a balanced chemical equation for the combustion of docosane, which is one of the waxes shown in the article.
4. Consider the bonding changes for the reaction.
   1. Docosane has a similar structure to the structure you drew in question 2, though it has a longer chain. If docosane were to completely break apart into its individual atoms, what are the types of bonds that would have to break? (A bond is identified by saying the two atoms that are bonded and then saying whether the bond is single, double, or triple.)
   2. Draw a Lewis structure for water and a Lewis structure for carbon dioxide.
      1. If water and carbon dioxide form from their individual elements, then what are the types of bonds that would form?
   3. Circle the correct words to complete the description: Energy is *given off / taken in* when bonds are broken, and energy is *given off / taken in* when bonds are formed.
   4. The light and heat from a flame are evidence that energy is given off during a combustion. This means there is more energy released than there is energy consumed during the reaction.
      1. With this conclusion, which must have stronger bonds—the reactants or the products? Explain.
      2. Using your answers from 4a-c, propose a reason for this difference in overall bond strength.
5. On the candle image below, label the portions of the candle where the wax is solid, liquid, and gas while the candle is lit.



1. Explain the role of convection in providing the flame a constant supply of fresh oxygen to continue burning the wax molecules.
2. Use the image below to answer the questions.



* 1. Portion A of the flame is mostly yellow. Is this portion comprised of matter, energy, both, or neither? Explain.
  2. Portion B of the flame is blue. This along with a mostly invisible area surrounding the outside of the flame is where combustion of the fuel is most complete. Why are these areas able to burn so efficiently?
  3. Portion C of the flame is called the dark zone. This is the area of the least complete combustion. Incomplete combustion occurs when the fuel molecule only partially breaks up. Only some of the molecule is converted into carbon dioxide and water, and new organic molecules are created by the un-burned fragments that remain. These new molecules escape as soot. Why is a candle that burns in space so much cleaner (less soot) than one that burns on Earth?

1. When lighting a candle, you must hold the flame to the wick for a few moments and then you can take your flame away. Explain the mechanism of the burning candle that allows it to continue burning on its own when you take away the flame.

**Questions for Further Learning**

***Write your answers on another piece of paper if needed.***

1. Soy candles are made by hydrogenating natural soybean oil to turn the unsaturated fats into saturated fats. Why are saturated fats better for burning in candles than unsaturated fats?
2. Explain why a candle can burn for hours without any concern of the candle itself catching fire.

# Graphic Organizer

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Directions**: As you read, complete the graphic organizer below to describe each term relating to candles in your own words, with examples from the reading.

|  |  |
| --- | --- |
| **Term** | **Relation to candles burning** |
| **Wax** |  |
| **Oxidation** |  |
| **Capillary action** |  |
| **Saturated hydrocarbons** |  |
| **Unsaturated hydrocarbons** |  |
| **Wick design** |  |
| **Convection** |  |

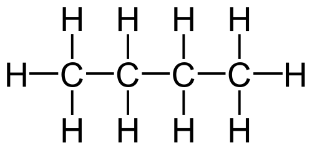
**Summary:** On the back of this sheet, write a short email to a friend about what can be learned about chemistry by studying candles.

# Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. **Lavoisier’s experiments from 1772 showed that the substance that makes something burn is not a part of the thing, but rather is in the air around it. What experimental finding led to this conclusion? Explain.**

*The burned substances gained weight. This means that, in burning, the substances must have combined with something to account for the extra weight.*

1. **Organic molecules are molecules that have a framework composed of carbon atoms bonded in a chain-like sequence with the remaining bonding sites occupied mostly by hydrogen atoms. Draw a line of 4 carbons with a single bond between pair of carbons. If all other bonding sites are occupied by hydrogens, how many hydrogens will be on this molecule? Draw the bonded hydrogens to complete the Lewis structure for the molecule.**

*Ten hydrogens.*

1. **A combustion reaction involving organic molecules will always produce both carbon dioxide and water as the organic molecule splits apart and its parts recombine with oxygen. Write a balanced chemical equation for the combustion of docosane, which is one of the waxes shown in the article.**

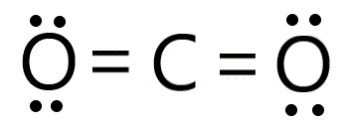
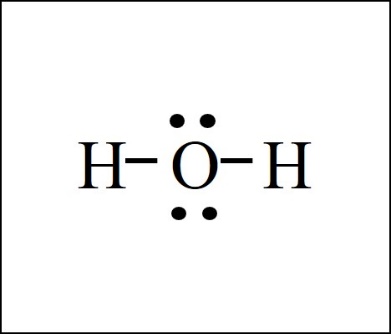
*2C22H46 + 67 O2 🡪 44 CO2 + 46 H2O*

1. **Consider the bonding changes for the reaction.**
   1. **Docosane has a similar structure to the structure you drew in question 2, though it has a longer chain. If docosane were to completely break apart into its individual atoms, what are the types of bonds that would have to break? (A bond is identified by saying the two atoms that are bonded and then saying whether the bond is single, double, or triple.)**

*Carbon-hydrogen single bonds, C – H*

*Carbon-carbon single bonds, C – C*

* 1. **Draw a Lewis structure for water and a Lewis structure for carbon dioxide.**



* + 1. **If water and carbon dioxide form from their individual elements, what are the types of bonds that would form?**

*Oxygen-hydrogen single bonds, O – H*

*Carbon-oxygen double bonds, C = O*

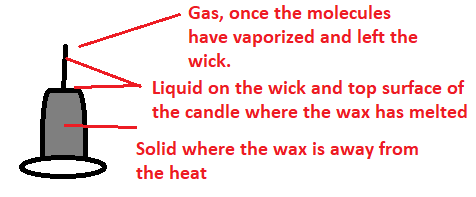
* 1. **Circle the correct words to complete the description: Energy is *given off / taken in* when bonds are broken and energy is *given off / taken in* when bonds are formed.**
  2. **The light and heat from a flame are evidence that energy is given off during a combustion. This means there is more energy released than there is energy consumed during the reaction.** 
     1. **With this conclusion, which must have stronger bonds, the reactants or the products? Explain.**

*The products must have stronger bonds. Since there is a net result of energy being given off, the energy released when new bonds formed (to make products) must be more than the amount of energy required to break bonds (of the reactants).*

* + 1. **Using your answers from 4a-c, propose a reason for this difference in overall bond strength.**

*The products have some double bonds, while the reactants have mostly single bonds. Double bonds are generally stronger than single bonds. The single bonds in the products will be shorter, and thus stronger, than the single bonds in the reactants because the H is bonding to O, which is smaller in size than C. Using Coulomb’s Law, the shorter distance between the bonded nuclei leads to a stronger bond.*

1. **On the candle image below, label the portions of the candle where the wax is solid, liquid, and gas while the candle is lit.**



1. **Explain the role of convection in providing the flame a constant supply of fresh oxygen to continue burning the wax molecules.**

*Convection occurs when heated air rises as its density decreases due to expanding. When the hot air rises, surrounding air (with the normal amount of oxygen because it hasn’t yet been used in the combustion) flows in to fill the space previously occupied by the newly expanded air. As the air and gases near the wick will continually get hot due to the heat generated by the combustion, there will be a continual supply of “fresh” oxygen-containing air flowing in.*

1. **Use the image below to answer the questions.**

Diagram

Description automatically generated

* 1. **Portion A of the flame is mostly yellow. Is this portion comprised of matter, energy, both, or neither? Explain.**

*Both. The soot particles, which result from the wax molecules that did not completely combust into CO2 and H2O, rise up in the flame and get heated by the energy generated by the combustion. Like red-hot coals or the glow from heating elements of an electric stove, materials can emit light when they reach a certain temperature. The yellow glow is the energy being emitted from the hot soot particles. The yellow we see is light (energy) radiating from matter.*

* 1. **Portion B of the flame is blue. This, along with a mostly invisible area surrounding the outside of the flame, is where combustion of the fuel is most complete. Why are these areas able to burn so efficiently?**

*The outside portions of the flame are in direct contact with the surrounding atmosphere, so they are the most oxygen-rich. When there is not enough oxygen, combustion will be incomplete.*

* 1. **Portion C of the flame is called the dark zone. This is the area of the least complete combustion. Incomplete combustion occurs when the fuel molecule only partially breaks up. Only some of the molecule is converted into carbon dioxide and water, and new organic molecules are created by the un-burned fragments that remain. These new molecules escape as soot. Why is a candle that burns in space so much cleaner (less soot) than one that burns on Earth?**

*In space, where there is no gravity, hot air would simply expand, rather than rise. Since this would occur in a symmetrical way, the flame spreads out in a more spherical way. This keeps a more consistent “shell” of oxygen-rich air surrounding the entire sphere, which leads to more even and thorough combustion.*

1. **When lighting a candle, you must hold the flame to the wick for a few moments and then you can take your flame away. Explain the mechanism of the burning candle that allows it to continue burning on its own when you take away the flame.**

*The flame used to light the candle must be held to the wick long enough for some of the wax to melt and then vaporize. Only once it vaporizes can it combust in the presence of heat. Once some of the wax combusts, energy is released. This energy is released in all directions, so the wax nearest to the combusting fuel (in the wick) takes in that energy and vaporizes while there is still enough heat to cause more combustions of wax molecules. Each molecule that combusts provides the heat for the “next” molecules to vaporize and combust, thus creating a self-sustaining cycle.*

**Questions for Further Learning**

***Write your answers on another piece of paper if needed.***

1. **Soy candles are made by hydrogenating natural soybean oil to turn the unsaturated fats into saturated fats. Why are saturated fats better for burning in candles than unsaturated fats?**

*Unsaturated means there are double and/or triple bonds between some of the carbons in the chain. These bonds are much stronger than a single bond between carbons. Weaker bonds in a fuel require less heat to initiate combustion once vaporized, so they are more able to sustain the cycle of burning.*

1. **Explain why a candle can burn for hours without any concern of the candle itself catching fire.**

*The candle is made of wax in its solid form. The flame stays concentrated at the wick because that is the area where the wax molecules are vaporizing. The wax cannot combust until it is in its gas form because the intermolecular forces in the liquid or solid forms attract it into the condensed states which prevents it from reaching the activated state where it can react with the oxygen.*

**Graphic Organizer Rubric**

If you use the Graphic Organizer to evaluate student performance, you may want to develop a grading rubric such as the one below.

|  |  |  |
| --- | --- | --- |
| **Score** | **Description** | **Evidence** |
| 4 | Excellent | Complete; details provided; demonstrates deep understanding. |
| 3 | Good | Complete; few details provided; demonstrates some understanding. |
| 2 | Fair | Incomplete; few details provided; some misconceptions evident. |
| 1 | Poor | Very incomplete; no details provided; many misconceptions evident. |
| 0 | Not acceptable | So incomplete that no judgment can be made about student understanding |

# Additional Resources

**Labs and demos**

* Some related classic demos are:
  + Fire Extinguisher: <https://teachchemistry.org/classroom-resources/fire-extinguisher>
  + Fish Tank Carbon Dioxide: <https://teachchemistry.org/classroom-resources/fish-tank-carbon-dioxide>
  + Make the Water Rise: <https://teachchemistry.org/classroom-resources/make-the-water-rise>
  + The Jumping Flame: <https://teachchemistry.org/classroom-resources/the-jumping-flame>

**Simulations**

* Short video with a simulation that nicely shows the involved molecules: <https://www.acs.org/content/acs/en/education/whatischemistry/adventures-in-chemistry/experiments/flame-out.html>

**Lessons and lesson plans**

* Combustion and Burning: <https://highschoolenergy.acs.org/content/hsef/en/how-do-we-use-energy/combustion-and-burning.html>
* Observing a Candle (A middle school lesson, easy to scale up if desired): <https://teachchemistry.org/classroom-resources/observing-a-candle>

**Projects and extension activities**

* Several videos and other sources at this page: <https://www.chemistryviews.org/view/0/searchResults.html?term=candle>
* More candle science with project ideas: <https://candles.org/candle-science/>

# Chemistry Concepts, Standards, and Teaching Strategies

**Connections to Chemistry Concepts**

The following chemistry concepts are highlighted in this article:

* Chemical change
* Observations
* Combustion
* Density
* Saturated vs. unsaturated

**Correlations to Next Generation Science Standards**

This article relates to the following performance expectations and dimensions of the NGSS:

|  |
| --- |
| **HS-PS1-3.** Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. |

**Disciplinary Core Ideas:**

* PS1.A: Structure and Properties of Matter
* ETS1.C: Optimizing the Design Solution

**Crosscutting Concepts:**

* Cause and effect
* Structure and function
* Stability and change

**Science and Engineering Practices:**

* Constructing explanations and designing solutions

**Nature of Science:**

* Scientific knowledge is open to revision in light of new evidence
* Science is a way of knowing.

See how *ChemMatters* correlates to the[**Common Core State Standards** online](https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/teachers-guide.html).

**Teaching Strategies**

Consider the following tips and strategies for incorporating this article into your classroom:

* **Alternative to Anticipation Guide:** Before reading, ask students what they know about the chemistry of candles. Their initial ideas can be collected electronically via Jamboard, Padlet, or similar technology.
  + As they read, students can find information to confirm or refute their original ideas.
  + After they read, ask students what they learned about candles.