

ChemMatters®

Demystifying Everyday Chemistry

Teacher's Guide

February 2022

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ChemMatters™

Demystifying Everyday Chemistry

Teacher's Guide

The Photoelectric Effect

February 2022

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Name: _____

Anticipation Guide

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. Einstein discovered the photoelectric effect.
		2. Electromagnetic radiation includes visible light as well as X-rays and radio waves.
		3. The color of light determines whether electrons will be knocked loose from a metal.
		4. Red light has more energy than blue light.
		5. If the minimum threshold frequency is reached, increasing the brightness of light will cause the dislodged electrons to move faster.
		6. The photoelectric effect led Einstein to develop the concept of photons.
		7. Photoelectric sensors must be in put in vacuum-sealed containers.
		8. Infrared radiation has lower energy than visible light.
		9. Night-vision goggles can work in complete darkness.
		10. The intensity of the light has no effect on the number of electrons emitted in the photoelectric effect.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. Explain how the photoelectric effect works.
2. What are photoelectrons?
3. What type of charge do electrons have?
4. Define frequency in terms of light.
5. Once the minimum threshold frequency is reached, if the frequency of light is increased, what happens to the number of electrons emitted?
6. What type of light is typically used in photoelectric sensors in automatic grocery store doors?
7. What must occur to remove an electron from an atom?
8. Explain how photoelectrons differ from other electrons.
9. Once the minimum threshold frequency is reached, if the frequency of light is increased, what happens to the movement of electrons?

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

1. Explain how the structures in night vision goggles contribute to their function of helping someone see in low light.
2. When examining the electromagnetic spectrum, what is the relationship between energy and wavelength?
3. The article mentions that the photoelectrons come from the surface of a metal. Perform research to identify at least two metals that can be used to achieve the photoelectric effect.
4. Select a photoelectric technology that is not already explained in the article. Create a diagram to demonstrate your understanding of how the process works within that product.
5. Use your understanding of the photoelectric effect to propose a new use for the technology. Explain how an existing device or a new invention would incorporate the photoelectric effect.

Name: _____

Graphic Organizer

Directions: As you read, complete the graphic organizer below to describe important terms related to the photoelectric effect.

Term	Definition in your own words	Relationship to photoelectric effect
Frequency		
Electromagnetic Radiation		
Photons		
Night-vision goggles		

Summary: On the back of this sheet, write a one-sentence summary (18 words or less) of the article.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. Explain how the photoelectric effect works.

The photoelectric effect is when electrons are released from the surface of a metal that is bombarded by light.

2. What are photoelectrons?

Photoelectrons are electrons that are released from a metal when its surface is bombarded by light.

3. What type of charge do electrons have?

Electrons have a negative charge.

4. Define frequency in terms of light.

Frequency is how frequently a wave is vibrating.

5. Once the minimum threshold frequency is reached, if the frequency of light is increased, what happens to the number of electrons emitted?

The number of electrons emitted stays the same.

6. What type of light is typically used in photoelectric sensors in automatic grocery store doors?

Invisible infrared radiation is typically used in photoelectric sensors in grocery store doors.

7. What must occur to remove an electron from an atom?

Energy must be applied to overcome the attraction between the protons and the electrons in the atom.

8. Explain how photoelectrons differ from other electrons.

Photoelectrons are different because they are released from the surface of a metal because of light, otherwise, they are identical to other electrons.

9. Once the minimum threshold frequency is reached, if the frequency of light is increased, what happens to the movement of electrons?

The electrons move faster because the energy of the light is changed to kinetic energy.

Questions for Further Learning

Write your answers on another piece of paper if needed.

- 1. Explain how the structures in night vision goggles contribute to their function of helping someone see in low light.**
Light hits a photocathode, which causes electrons to be released from the metal. Those electrons enter a photomultiplier which causes more electrons to be released. All of these photons then come into contact with a phosphor screen which excites them and causes them to emit visible light.
- 2. When examining the electromagnetic spectrum, what is the relationship between energy and wavelength?**
Waves with shorter wavelengths have more energy.
- 3. The article mentions that the photoelectrons come from the surface of a metal. Perform research to identify at least two metals that can be used to achieve the photoelectric effect.**
Student responses will vary but should list two metals that are used to elicit the photoelectric effect.
- 4. Select a photoelectric technology that is not already explained in the article. Create a diagram to demonstrate your understanding of how the process works within that product.**
Student responses will vary but should exhibit an understanding of the photoelectric effect.
- 5. Use your understanding of the photoelectric effect to propose a new use for the technology. Explain how an existing device or a new invention would incorporate the photoelectric effect.**
Student responses will vary but should exhibit an understanding of the photoelectric effect.

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

[Demonstrate the Photoelectric Effect](#): This video demonstrates the use of an electroscope in explaining the photoelectric effect.

Simulations

[Photoelectric Effect PhET](#): In this PhET simulation students are able to modify light intensity and various metals to study the photoelectric effect.

[Photoelectric Effect Gizmos](#): Students can use this online simulation to explore the photoelectric effect by adjusting both the type of metal and wavelength of light.

Lessons and lesson plans

[Introduction to PES](#): This lesson can be used to help students learn how to interpret photoelectron spectroscopy spectra through using their knowledge of electron configurations, periodic trends, and Coulomb's law.

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Electrons
- Electricity
- Electromagnetic spectrum

Correlations to Next Generation Science Standards

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

HS-PS4-3. Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.

Disciplinary Core Ideas:

- PS.4.A: Wave Properties
- PS4.B: Electromagnetic Radiation

Crosscutting Concepts:

- Cause and effect
- Energy and matter
- Systems and System Models

Science and Engineering Practices:

- Constructing explanations and designing solutions

Nature of Science:

- Science models, laws, mechanisms, and theories explain natural phenomena.

See how *ChemMatters* correlates to the [Common Core State Standards online](#).

Teaching Strategies

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

- **Alternative to Anticipation Guide:** Before reading, ask students how they think automatic sensors that open doors or turn on water faucets work. 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 the photoelectric effect.
- After students have read and discussed the article, ask students how they will use the information from the article in the future.
 - What other practical uses can they think of for the photoelectric effect besides those that were mentioned in the article?

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Teacher's Guide

Could Future Vaccines Be Pain-Free? *February 2022*

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Anticipation Guide

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
		11. Hypodermic needles and syringes were first used to deliver medicine in the early 20 th century.
		12. Vaccines introduce material that trains a body’s immune system to produce antibodies to destroy the target virus or bacteria.
		13. Antigens interact with antibodies through noncovalent forces such as hydrogen bonding.
		14. Vaccines injected into your arm also protect your nose.
		15. Vaccines developed for arm injections would also work in intranasal vaccines.
		16. There are more immune cells in your muscle than in your skin.
		17. One type of microneedle technology uses warm water to dissolve the separator layer above the microneedles.
		18. Dissolvable microneedles using sugar and polymer molecules are now undergoing clinical trials in West Africa.
		19. Vaccines in microneedle patches can be stored at room temperature.
		20. People have been inoculated through the nose and skin for centuries.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. State some other options for delivering vaccines to the body
2. What are vaccines composed of that help our bodies fight infections?
3. Briefly explain how antibodies stop viruses.
4. State the 2 types of immunity cells found in our skin.
5. What are some reasons that allow us to believe that skin patches are better than traditional needles for delivering vaccines?
6. State some benefits from microneedles versus regular needles.
7. Explain why arm injections are not very effective for respiratory viruses? What would be more effective?
8. Explain the difference between a covalent force and a non-covalent force.
9. Give at least one example of a chemical that exhibits the following non-covalent forces: Electrostatic force (Hint: ionic), hydrogen bonding, London dispersion force.
10. What is the reason for cells or other substances to exhibit hydrophobic properties?
11. What should medical researchers consider when making and using patches and microneedles in medicine, with regards to health and safety?
12. Why was Pascal's discovery of liquid pressure useful for the application of syringes and vaccines?

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

1. What are some other uses for patches and microneedles that could help people?

Name: _____

Graphic Organizer

Directions: As you read, complete the graphic organizer below to compare different types of vaccine delivery methods. Try to find at least two advantages and two disadvantages for each.

Vaccine Delivery Method	Advantages	Disadvantages
Needle and Syringe		
Intranasal		
Microneedles		

Summary: On the back of this sheet, write three new things you learned about vaccines.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. Besides using needles, vaccines can be introduced into the body using intranasal sprays and skin patches.
2. To fight infections, vaccines contain weakened or inactive parts of the disease, or genetic instructions to make parts of the disease.
3. Antibodies stop viruses from locking onto the viruses and destroy them. They hook on using *noncovalent* forces.
4. The two types of immunity cells in our skin are called dendritic cells and Langerhans cells.
5. Some reasons that we believe skin patches are better are that skin cells contain a lot more immune cells, and that the patches are less painful than needles.
6. Microneedles are better than regular needles because they can keep the vaccine more stable, thus lasting longer. Also, the microneedles are more efficient in delivery, so much less vaccine is needed.
7. Arm injections are not good for respiratory viruses because many times, the virus will replicate in the nose, before it reaches the specific antibodies. Introducing antibodies through the nose will activate the antibodies there, which will attack the virus much quicker.
8. Covalent means sharing of electrons. This is when 2 atoms share electrons between each other (when the electron orbitals of each atom overlap) and create a covalent (chemical) bond. A non-covalent force is an attraction between 2 substances that do not involve sharing of electrons. Typically the attractions tend to occur between opposite charges on the substances.
9. Electrostatic force: Sodium Chloride (NaCl)
Hydrogen bonding: water
London dispersion forces: carbon dioxide
(answers will vary)
10. Cells need to have hydrophobic properties in order to contain the proteins and other components inside without dissolving in water.
11. (Answers may vary). Many people may have specific skin allergies that could create an adverse reaction to the skin patches and microneedles. Everybody's skin is different, so the effects may be different for different people. Scientists also need to make sure the dissolving needles do not contain substances that could harm people.
12. Pascal discovered that when pressure was applied on one section of a liquid, the pressure is distributed throughout the liquid. This is because liquid is incompressible. This property of liquids allows vaccine to be "pushed" through a needle to get into the body quickly.

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.
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Additional Resources

Labs and demos

Under pressure: Hands on activity

https://www.teachengineering.org/activities/view/cub_dams_lesson03_activity1

Simulations and Videos

Syringe simulation

<https://demonstrations.wolfram.com/PascalsSyringe/>

Intermolecular Forces

<https://teachchemistry.org/classroom-resources/intermolecular-forces-2020>

Pascal's Pressure with syringes

<https://youtu.be/cAz-YEN2S9Q>

Projects and extension activities

Make a Cartesian Diver

<https://sciencebob.com/make-a-cartesian-diver/>

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Physical properties
- Intermolecular forces

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.

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Disciplinary Core Ideas:

- PS1.A: Structure and properties of matter
- PS2.B: Types of interactions
- ETS1.C: Optimizing the design solution

Crosscutting Concepts:

- Stability and change
- Cause and effect
- Systems and system models

Science and Engineering Practices:

- Planning and carrying out investigations
- Constructing explanations and designing solutions

Nature of Science:

- Scientific knowledge is based on empirical evidence.

See how *ChemMatters* correlates to the [Common Core State Standards online](#).

Teaching Strategies

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

- **Alternative to Anticipation Guide:** Before reading, ask students why they think vaccines are usually administered through intramuscular injection. 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 vaccine delivery systems.

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What's in Marshmallows? *February 2022*

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Name: _____

Anticipation Guide

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
		21. Gelatin is an important ingredient in marshmallows.
		22. Gelatin comes from animal tissues.
		23. Gelatin’s form (liquid or gel) depends on the temperature.
		24. Gelatin melts at about 50 °C (120 °F).
		25. Marshmallows and gummy bears have the same ingredients.
		26. The sweeteners sugar and corn syrup are the same.
		27. The ratio of sugar to corn syrup determines the texture of the marshmallow.
		28. Microwaved Peeps inflate as they are heated because the air bubbles expand.
		29. Microwaving Peeps makes them softer.
		30. Peeps can be used to demonstrate the ideal gas law.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

Reading Comprehension

1. What are the common ingredients in marshmallows?
2. Define the term collagen and describe the structure and composition of a collagen.
3. Explain how gelatin is made from collagen.
4. Discuss how temperature and the amount of gelatin impacts the texture of foods containing gelatin.
5. Explain how the texture of a marshmallow containing treat can be altered and adjusted.

Connecting Concepts

6. Use your knowledge of chemistry to explain what happens to marshmallows when placed inside a microwave oven.
7. Explain why marshmallows that were placed inside a microwave or subjected to heat often have a crunchy texture.
8. According to Charles' Law, the volume of a gas sample is directly proportional to the temperature of a gas sample (when pressure is constant). If the internal temperature of a marshmallow increased from 25 °C to 100 °C would you expect the air inside the marshmallow to also expand by a factor of 4? Explain your answer.
9. If the internal temperature inside a marshmallow increased from 25 °C to 100 °C, by what factor would the volume of the air inside the marshmallow increase? (Hint on number 8, the volume does not increase by a factor of 4)
10. The phrase "Ideal Gas Law" is mentioned in the article. What assumptions are made about gases in order for them to behave "Ideally".
11. Why do marshmallows get more sticky as they are heated? Use chemistry to explain your answer.

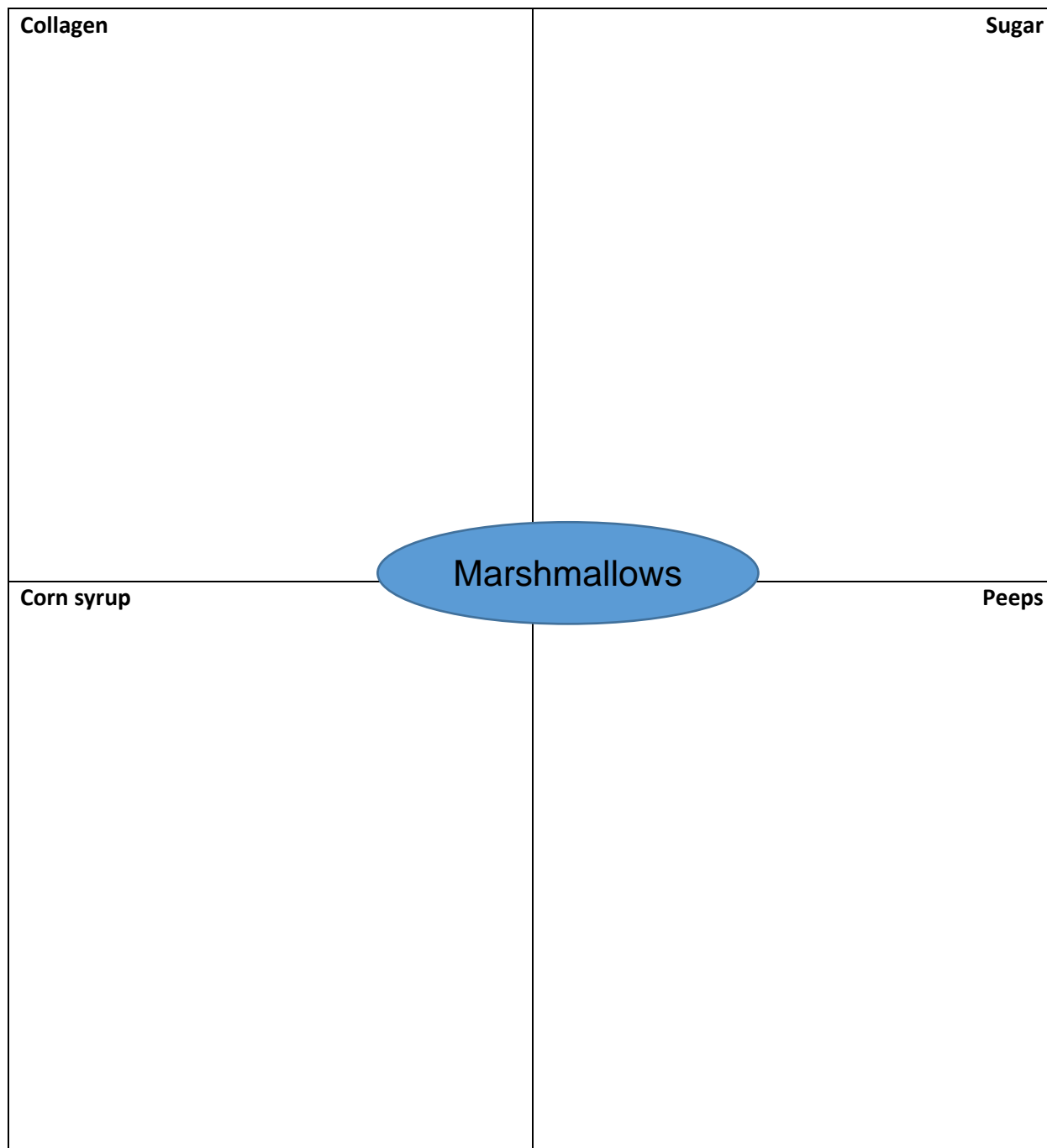
Questions for Further Understanding and Exploration

12. Create a “Chemistry of Marshmallows” infographic highlighting the main points of the article and demonstrating your new understanding of the popular sugary treat!

Name: _____

Graphic Organizer

Directions: As you read, complete the graphic organizer below to describe each term related to marshmallows. Include formulas where appropriate.



Summary: On the back of this sheet, write three interesting facts about marshmallows you would like to share with a friend.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

Reading Comprehension

1. What are the common ingredients in marshmallows?

The common ingredients in marshmallows are sugar, corn syrup, gelatin, and air.

2. Define the term collagen and describe the structure and composition of a collagen.

A collagen is a protein made up of 3 polypeptide chains (in a triple helix structure) composed of amino acids.

3. Explain how gelatin is made from collagen.

Collagen is treated with acids or bases which partially break down the triple helical structure into individual strands.

4. Discuss how temperature and the amount of gelatin impacts the texture of foods containing gelatin.

Higher temperatures break down the bonds holding the helices polypeptide chains which can reset and recoil when cooled. This gives marshmallows the ability to melt and mold into different shapes. Warm temperatures inside a person's mouth allow marshmallows to "melt in your mouth" for easy consumption. The amount of gelatin can also influence the firmness of a marshmallow containing treat.

5. Explain how the texture of a marshmallow containing treat can be altered and adjusted.

Manufacturers can alter the type of corn syrup and the ratio of sugar to corn syrup.

High levels of sugar will cause a more firm product such as circus peanuts and less sugar will create a softer, fluffier product such as an original marshmallow.

Connecting Concepts

6. Use your knowledge of chemistry to explain what happens to marshmallows when placed inside a microwave oven.

The high energy waves cause water molecules inside the marshmallow to vibrate which heat and soften the sugar matrix inside the marshmallow. The weakened sugar matrix allows air bubbles within the marshmallow to expand rapidly and the marshmallow puffs up.

7. Explain why marshmallows that were placed inside a microwave or subjected to heat often have a crunchy texture.

As the marshmallow cools the air bubbles shrink and the sugar matrix hardens. Combine that with the decreased amount of water lost during the heating results in a hard, crunch texture.

8. According to Charles' Law, the volume of a gas sample is directly proportional to the temperature of a gas sample (when pressure is constant). If the internal temperature of a marshmallow increased from 25 °C to 100 °C would you expect the air inside the marshmallow to also expand by a factor of 4? Explain your answer.

No, gas law relationships are dependent on the absolute temperature. Therefore, the temperature must be in Kelvin when comparing values. Since the 4 fold increase in temperature was in the celsius scale, which would not be the case on the Kelvin scale, a 4 fold increase would not occur.

9. If the internal temperature inside a marshmallow increased from 25 °C to 100 °C, by what factor would the volume of the air inside the marshmallow increase? (Hint on number 8, the volume does not increase by a factor of 4)

$$25\text{ }^{\circ}\text{C} = 298\text{ K}$$

$$100\text{ }^{\circ}\text{C} = 373\text{ K}$$

$$373\text{ K} / 298\text{ K} = 1.25$$

Since there was 1.25 fold increase in temperature, the volume of air would increase by a factor of 1.25 as well because temperature and volume are directly proportional (when pressure is constant)

10. The phrase "Ideal Gas Law" is mentioned in the article. What assumptions are made about gases in order for them to behave "Ideally".

Ideal gases are assumed to be in constant random motion. Collisions between gas molecules are considered to be completely elastic, meaning energy is conserved. The gas are assumed to not have any attractive or repulsive forces between gas molecules and the volume of the gas molecules themselves is considered negligible.

11. Why do marshmallows get more sticky as they are heated? Use chemistry to explain your answer.

The air bubbles and sugar matrix help contain the gelatin inside the marshmallow. When heat or moisture is added to the marshmallow the air bubbles collapse allowing the gelatin to move freely. Gelatin is a large polymer with strong London dispersion forces which attract to your hand or anything else a marshmallow comes in contact with.

Questions for Further Understanding and Exploration

12. Create a “Chemistry of Marshmallows” infographic highlighting the main points of the article and demonstrating your new understanding of the popular sugary treat!

Students' responses will vary.

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.
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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

Marshmallow Lab connected to Gas Chemistry

<https://teachchemistry.org/classroom-resources/three-station-gas-lab>

Kinetic Molecular Theory Activity

<https://teachchemistry.org/classroom-resources/mega-marshmallows>

Stoichiometry Practice with Marshmallows

<https://teachchemistry.org/classroom-resources/smores-stoichiometry>

Related Article on Collagens

https://teachchemistry.org/pdf/2020/08/27/15/17/10/b59a8c65-d078-4ff8-988f-8b324b07013f/2011_Dec.pdf

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Physical properties
- Gas laws
- Mixtures

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
- ETS1C: Optimizing the design solution

Crosscutting Concepts:

- Stability and change
- Structure and function

Science and Engineering Practices:

- Constructing explanations and designing solutions

Nature of Science:

- Scientific knowledge assumes an order and consistency in natural systems.

See how *ChemMatters* correlates to the [Common Core State Standards online](#).

Teaching Strategies

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

- **Alternative to Anticipation Guide:** Before reading, engage students by asking them if they enjoy eating marshmallows. Also ask if they know the ingredients, and how each is important to the final product. Ask if they have ever microwaved a Peep, and what happened. 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 marshmallows.
- You may want to show one of these short Peep Jousting videos:
<https://youtu.be/qWQeOWLsDUw> (Arizona Science Center) and
<https://youtu.be/RdMvJqlykhA> (Smithsonian)

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Shining a Light on Candles *February 2022*

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

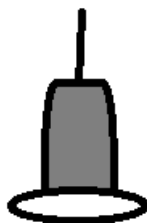
Student Reading Comprehension Questions

Name: _____

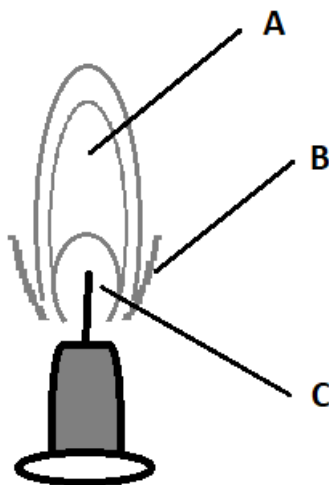
Directions: Use the article to answer the questions below.

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.
 - a. 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.)
 - b. Draw a Lewis structure for water and a Lewis structure for carbon dioxide.
 - i. If water and carbon dioxide form from their individual elements, then what are the types of bonds that would form?
 - c. 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.
 - d. 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.

- i. With this conclusion, which must have stronger bonds—the reactants or the products? Explain.
 - ii. 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.



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



- a. Portion A of the flame is mostly yellow. Is this portion comprised of matter, energy, both, or neither? Explain.
- b. 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?
- c. 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?

8. 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.

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

9. 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?
10. Explain why a candle can burn for hours without any concern of the candle itself catching fire.

Name: _____

Graphic Organizer

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.

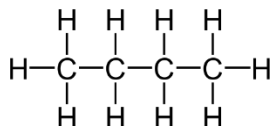
Answers to Reading Comprehension Questions & Graphic Organizer Rubric

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.

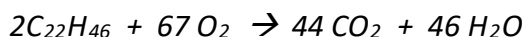
The burned substances gained weight. This means that, in burning, the substances must have combined with something to account for the extra weight.

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 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.



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.
- a. 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

- b. Draw a Lewis structure for water and a Lewis structure for carbon dioxide.

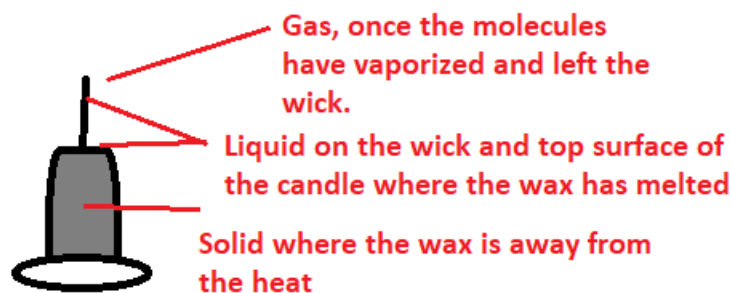


- i. If water and carbon dioxide form from their individual elements, what are the types of bonds that would form?

Oxygen-hydrogen single bonds, O – H

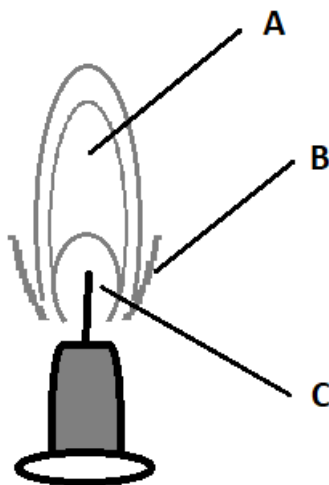
Carbon-oxygen double bonds, C = O

- c. 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.
- d. 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.
- 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).
 - 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.
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.



6. 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.

7. Use the image below to answer the questions.



- a. **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 CO_2 and H_2O , 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.

- b. **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.

- c. **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.

8. **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.

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

- 9. 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.

- 10. 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](#).

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.

About the Teacher's Guide

Teacher's Guide team editors Dusty Carroll, Scott Hawkins, Matt Perekupka, and Jennifer Smith created the Teacher's Guide article material. Susan Cooper prepared the anticipation, reading guides, and connections to standards.

Christine Suh (Managing Editor) coordinated the production and development of the Teacher's Guides.
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