ChemMatters®

Demystifying Everyday Chemistry

Teacher's Guide

December 2021

www.asc.org/chemmatters

ACS Chemistry for Life®

ChemMatters™
Demystifying Everyday Chemistry

Teacher's Guide

Bath Bombs: The Chemistry Behind the Fizz
December 2021

Table of Contents

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. Water is needed as a solvent for bath bombs to work.
		2. Bath bombs and Alka-Seltzer are based on a simple acid-base reaction.
		3. Baking soda is a weak acid.
		4. Citric acid is a strong acid.
		5. Water is a polar molecule because hydrogen is more electronegative than oxygen.
		6. Cool bath water causes the bath bomb fizz faster than warm water.
		7. Epsom salts soothe rashes.
		8. Epsom salts contain magnesium.
		9. Both artificial and naturally derived fragrances can cause contact dermatitis.
		10. Linalool, found in lavender and citrus, is a compound composed of only carbon, hydrogen, and oxygen.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. Explain how a water molecule "pulls apart" the sodium bicarbonate molecule into its separate ions.

2. What are some uses for citric acid (and other similar weak acids)?

3. State some health benefits from Epsom salts. What are some "claimed" (but not yet confirmed benefits?

4. Why is the element magnesium so important to the human body?

5. What are some ways a bath bomb could affect a person's skin?

6. Think of how molecules move, and the effect of temperature on their movements. Explain how a bath bomb would react more quickly in warm water versus cold water, in terms of molecular motions.

7. What are some reasons that you would not get a chemical or acid burn from the citric acid in the bath bombs?

8. Look at a model of the water molecule. Explain why its angular/bent shape allows the water molecule to be polar. If the molecule was linear, how would that affect the polarity of water?

9. Explain why citric acid is a weak acid and hydrochloric acid is a strong acid (you may need to research on the differences between strong and weak acids).

10. Look up the definition of "spectator ion." What is a spectator ion? Look at the reaction in the section called "The Fizz Effect." What ion (or ions) could be considered a spectator ion, and why?

Student Reading Comprehension Questions, cont.

11. Research the concept of Bronsted acids and bases. Define what a Bronsted acid is, and what a Bronsted base is. Explain why the reaction in the section "The Fizz Effect" is an example of a Bronsted acid/base reaction. Label the compounds as either Bronsted acids or bases.

Questions for Further Learning

Write your answers on another piece of paper if needed.

1. Do internet research on aromatic hydrocarbons. What is the common structure of an aromatic hydrocarbon molecule? Find some examples of these compounds, and the odor they create.

2. One of the uses for citric acid is to prevent the browning of some fruits, especially apples. Research and explain why browning occurs and how citric acid prevents it.

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe the chemicals often found in bath bombs.

Ingredient	Chemical Formula	Purpose
Baking soda		
Citric acid		
Epsom salts		
Fragrance(s)		

Summary: On the back of this sheet, write a tweet (280 characters or less) about what to look for when choosing bath bombs.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. **Explain how a water molecule "pulls apart" the sodium bicarbonate molecule into its separate ions.**
The oxygen atom, which has a partial negative charge, will attract the positive sodium ions, and the more positive hydrogen end of the water molecule would attract the negative bicarbonate ion (HCO_3^{-1}).

2. **What are some uses for citric acid (and other similar weak acids)?**
Citric acid is the natural acid found in citrus fruits. It is also used as an additive to preserve other foods (i.e. adding lemon juice to apples to keep them from browning).

3. **State some health benefits from Epsom salts. What are some "claimed" (but not yet confirmed benefits?**
Epsom salts (MgSO4) helps to soothe skin rashes. Other claims, such as relieving stress or improving sleep, have not been officially confirmed.

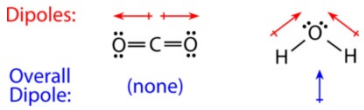
4. **Why is the element magnesium so important to the human body?**
Magnesium is such an important mineral for the human body. It is needed in many enzymatic reactions, for nerves, muscles, and heart.

5. **What are some ways a bath bomb could affect a person's skin?**
The essential oils in the bath bombs could affect people with sensitive skin, causing irritations and rashes.

6. **Think of how molecules move, and the effect of temperature on their movements. Explain how a bath bomb would react more quickly in warm water versus cold water, in terms of molecular motions.**
When temperature increases, molecules speed up. In a reaction, the faster molecules collide with more frequency, which causes the reaction to happen at a quicker rate. When you put a bath bomb in warm water, this is causing the sodium bicarbonate and citric acid molecules to warm up and move faster. They will thus react at a faster pace.

7. **What are some reasons that you would not get a chemical or acid burn from the citric acid in the bath bombs?**
The citric acid will not burn the skin for a variety of reasons. First, the small amount of citric acid dissolved in a large amount of water dilutes the acid. Second, the sodium bicarbonate reacts with the acid to neutralize it.

8. **Look at a model of the water molecule. Explain why its angular/bent shape allows the water molecule to be polar. If the molecule was linear, how would that affect the polarity of water?**
Because of the angular shape of the water molecule, the negative oxygen is on one end of the molecule, and the two hydrogens are at the other end. This gives the water molecule definitive positive and negative ends, thus making it polar.
If the molecule was linear, then the two hydrogen atoms would be 180^0 apart from each other, on either side of the oxygen atom. This would not create definite positive and negative ends. Carbon dioxide is an example of a molecule that is not polar because of its linear shape.



9. **Explain why citric acid is a weak acid and hydrochloric acid is a strong acid (you may need to research on the differences between strong and weak acids).**

A strong acid is an acid that dissociates 100%. This means that 100% of the acid molecules produce a hydrogen ion (H+) which gives the molecule its acid properties. For example, hydrochloric acid (HCl) splits 100% into H^+ and Cl^- ions in water. No HCl molecules are present. In a weak acid, like citric acid, only a small percentage of acid molecules produce a hydrogen ion. For citric acid ($C_6H_8O_7$), some molecules would split into H^+ and $C_6H_5O_7^-$. Others would not dissociate at all, and remain $C_6H_8O_7$. Therefore, the less hydrogen ions produced, the weaker the acid.

10. **Look up the definition of "spectator ion." What is a spectator ion? Look at the reaction in the section called "The Fizz Effect." What ion (or ions) could be considered a spectator ion, and why?**
A spectator ion is an ion in a reaction that remains unchanged in any way. The spectator ion will keep its ionic charge, and remain unbonded to other ions. Consider the reaction on page 6:

$$3NaHCO_3 + C_6H_8O_7 \rightarrow Na_3C_6H_5O_7 + H_2CO_3$$

The ionic equation is as follows:

$$3Na^+ + 2HCO_3^- + C_6H_8O_7 \rightarrow 3Na^+ + C_6H_5O_7^{-3} + H_2CO_3$$

Sodium remains the same on both sides of the reaction. Therefore it is a spectator ion.

11. **Research the concept of Bronsted acids and bases. Define what a Bronsted acid is, and what a Bronsted base is. Explain why the reaction in the section "The Fizz Effect" is an example of a Bronsted acid/base reaction. Label the compounds as either Bronsted acids or bases.**
A Bronsted acid is a molecule that donates a hydrogen ion (H+) to another molecule. The molecule that accepts the hydrogen ion is a Bronsted base. Using the ionic equation from above:

$$3Na^+ + 2HCO_3^- + C_6H_8O_7 \rightarrow 3Na^+ + C_6H_5O_7^{-3} + H_2CO_3$$

The citric acid molecule, $C_6H_8O_7$, loses 3 hydrogen ions to become $C_6H_5O_7^{-3}$. The bicarbonate ion, HCO_3^-, gains the hydrogens to become H_2CO_3.

Questions for Further Learning

1**. Do internet research on aromatic hydrocarbons. What is the common structure of an aromatic hydrocarbon molecule? Find some examples of these compounds, and the odor they create.**
Aromatic hydrocarbons (or aromatic compounds) are organic compounds that create an odor. There are many artificial smells that are made by these aromatic compounds. All aromatic compounds contain a benzene ring in them. An online search can yield many examples.

2. One of the uses for citric acid is to prevent the browning of some fruits, especially apples. Research and explain why browning occurs and how citric acid prevents it.
The process is called enzymatic browning. Specific enzymes react and cause the fruit or vegetable to turn brown. The students can find the chemical reaction for enzymatic browning and find ways to slow or prevent it in foods.

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

Simulations

Acid/Base Solutions PhET Simulation: Students can learn about acid and base strengths and learn how different tools such as a pH meter and pH paper can help identify whether a solution is an acid or base. Students cand determine whether a solution is a strong or weak acid or base and whether a solution is concentrated or diluted.
https://phet.colorado.edu/en/simulations/acid-base-solutions

Lessons and lesson plans

Esterfication Lab: Students will make at least six esters from different combinations of available organic acids and alcohols. In addition, they will attempt to identify the scent of each ester that is created.
https://teachchemistry.org/classroom-resources/esterfication
Calculating Acid in Lemon-Lime Soda Lab: students will investigate the molarity of citric acid in a clear, lemon-lime flavored soft drink through titrations with 0.10M NaOH and an indicator
https://teachchemistry.org/classroom-resources/calculating-acid-in-lemon-lime-soda
Science of Bath Bombs Video: Learn about the acid-base chemistry in bath bombs.
https://youtu.be/UT1qWPeY5mA

Other Resources

Enzymatic Browning: A resource explaining the process of enzymatic browning in food.
https://nieonline.com/downloads/fighting_with_food/keeping_it_fresh.pdf
Why do apple slices turn brown after being cut?:
https://www.scientificamerican.com/article/experts-why-cut-apples-turn-brown/
A Guide to Acids, Acid Strength, and Concentration Compound Interest Infographic:
https://www.compoundchem.com/2016/09/28/acids/
Table of esters and their smells:
https://jameskennedymonash.files.wordpress.com/2013/12/table-of-esters-and-their-smells.jpg

Projects and extension activities

How to make bath bombs at home:
https://www.popsci.com/how-to-make-your-own-bath-bombs/

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Acid-base reactions
- Strong vs. weak acids/bases
- Solute/solvent
- Electronegativity

Correlations to Next Generation Science Standards

This article can be used to achieve the following performance expectations of NGSS:

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.

Disciplinary Core Ideas:

- PS.1.B: Chemical Reactions

Crosscutting Concepts:

- Patterns
- Structure and function
- Cause and effect

Science and Engineering Practices:

- Constructing explanations and designing solutions

Nature of Science:

- Science addresses questions about the natural and material world

Correlations to Common Core State Standards

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 if they have ever used bath bombs, and why they think they are useful. 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 ingredients in bath bombs.
- After students have read and discussed the article, ask students how they will use the information from the article in the future.
  - Will they use bath bombs? If so, how will they decide which ones to buy?
  - What other consumer products (besides bath bombs and Alka-Seltzer) can they think of for the reaction between a weak acid and a weak base?

ChemMatters™
Demystifying Everyday Chemistry

Teacher's Guide

Radiation. The Good. The Bad. And Its Place in Our Modern World.

December 2021

Table of Contents

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. In the 1910s and early 1920s, glow-in-the-dark watches were painted with a green paint containing radium.
		2. The element radium glows by itself.
		3. Radioactivity can safely be used to treat certain medical conditions.
		4. Marie Curie coined the term "radioactivity."
		5. Radium undergoes alpha decay to produce radon and an alpha particle.
		6. Alpha particles go through skin.
		7. Radium and calcium are both alkaline earth metals, so they react similarly.
		8. Many early inventors and scientists who worked with radiation developed cancer.
		9. All radiation is radioactive.
		10. Today's glow-in-the-dark watches use radioactive isotopes that emit beta particles which are blocked by the watch case.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. Identify the two primary ingredients in Undark.

2. Who is credited for discovering that uranium emits radiation?

3. Who coined the term radioactivity and in what context?

4. What are alpha particles made of?

5. Explain the function of the Us Occupational Safety and Health Administration.

6. How many protons and neutrons does the nucleus of an atom of radium-226 contain?

7. Explain how radium causes zinc sulfide to glow.

8. Why did Marie Curie, Pierre Curie and Henri Becquerel win the Nobel Prize in Physics in 1903?

9. What are the two scientific definitions of the term *radiation*?

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

1. Analyze two benefits and two drawbacks of radioactivity.

2. Explain aplastic anemia and how it can be caused by radiation.

3. Explain how smoke detectors utilize radiation.

4. The article mentions that gamma rays can be used to sterilize food. Conduct research to learn more about this process and explain why foods are sterilized in this way, how the process works, and the labeling requirements.

5. In the article you learned about some of the symptoms that resulted from radiation exposure. Perform research to learn about some of the treatments for radiation exposure that are available today. Select one treatment and write a paragraph about how it works.

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe radioactivity and its uses. Make a bulleted list in each column.

History of radioactivity	**Important scientists and their discoveries:**
Dangers of radioactivity	**Different types of ionizing radiation and how they affect the body:**
Modern uses of radioactivity	**Medical and other uses and how to protect people from harmful effects:**

Summary: On the back of this sheet, write a short email to a friend explaining why many of the Radium Girls developed cancer.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

Directions: Use the article to answer the questions below.

1. **Identify the two primary ingredients in Undark.**
   Undark's two main ingredients are zinc sulfide and an isotope of radium.

2. **Who is credited for discovering that uranium emits radiation?**
   Henri Becquerel discovered that uranium spontaneously emits radiation.

3. **Who coined the term radioactivity and in what context?**
   Marie Curie coined the term radioactivity in her thesis.

4. **What are alpha particles made of?**
   Alpha particles are made of two protons and two neutrons that are released from a nucleus.

5. **Explain the function of the Us Occupational Safety and Health Administration.**
   OSHA is the US Occupational Safety and Health Administration tasked with defining and enforcing safe working conditions.

6. **How many protons and neutrons does the nucleus of an atom of radium-226 contain?**
   The nucleus contains 88 protons and 138 neutrons.

7. **Explain how radium causes zinc sulfide to glow.**
   When a particle of radiation collides with an atom or molecule, it excites an electron to a higher energy level. When the electron returns to its ground state, it emits energy in the form of light.

8. **Why did Marie Curie, Pierre Curie and Henri Becquerel win the Nobel Prize in Physics in 1903?**
   Henri Becquerel, Marie Curie and Pierre Curie won the Nobel Prize in 1903 for their exploration of radioactivity and discovering that it was a nuclear rather than chemical characteristic.

9. **What are the two scientific definitions of the term *radiation*?**
   Radiation can be used to refer to the energy that is part of the electromagnetic spectrum or it can be used to refer to the process of radioactive decay.

Questions for Further Learning

Write your answers on another piece of paper if needed.

1. **Analyze two benefits and two drawbacks of radioactivity.**
   Two benefits are that radioactivity can be used to slow or destroy cancer and can sterilize foods. Two drawbacks are that it can cause sickness and death and, in the case of nuclear accidents, be costly to contain and clean up.

2. **Explain aplastic anemia and how it can be caused by radiation.**
   Aplastic anemia is when the body stops producing enough new blood cells. This can be caused by radiation destroying the stem cells in bone marrow which are responsible for producing new blood cells.

3. **Explain how smoke detectors utilize radiation.**
   Smoke detectors have small amounts of 241Am that sends out a steady stream of alpha particles. When the stream is disrupted by smoke, the alarm is triggered.

4. **The article mentions that gamma rays can be used to sterilize food. Conduct research to learn more about this process and explain why foods are sterilized in this way, how the process works, and the labeling requirements.**
   As a starting point for their research, students can use this webpage hosted by the Food and Drug Administration.

5. **In the article you learned about some of the symptoms that resulted from radiation exposure. Perform research to learn about some of the treatments for radiation exposure that are available today. Select one treatment and write a paragraph about how it works.**
   As a starting point for their research, students can use this CDC website.

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

Simulations

Radioactivity Simulation: Students can use this simulation to explore four different radioactive sources and materials that can be used to block radiation.
https://www.farlabs.edu.au/radioactivitysimulation/

Lessons and lesson plans

Detecting Radiation in our Radioactive World: This resource developed by the American Nuclear Society includes a variety of lesson plans and activities on topics related to radiation including half-life, irradiation, fission, decay chains, radiation types, and waste.
https://assets-global.website-files.com/5ed97259050e9609486076e1/5ed977227025a348a1925667_ANS-Teacher_Resource_Guide_web.pdf

Radiological Applications of Isotopes: Using this activity will provide students with the opportunity to apply their understanding of nuclear notation to learn more about the applications of radioisotopes in the field of medicine.
https://teachchemistry.org/classroom-resources/radiological-applications-of-isotopes

Projects and extension activities

Marie Curie Video Questions: Students can learn more about Marie Curie and her work by viewing this video resource and accompanying questions on the American Association of Chemistry Teachers website.
https://teachchemistry.org/classroom-resources/marie-curie-video-questions

Backgrounder on Smoke Detectors: This resource explains how smoke detectors utilize radiation to detect smoke. Diagrams of the process are included.
https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/smoke-detectors.html

Use of Radiation in Medicine: Students can use this EPA resource to learn more about the types of radiation that are used in the medical field.
https://www.epa.gov/radtown/use-radiation-medicine

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Nuclear chemistry
- Alpha/beta/gamma decay
- Radioactive isotopes
- Radiation

Correlations to Next Generation Science Standards

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

HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy levels of atoms.
HS-PS1-7. Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.
See how *ChemMatters* correlates to the **Common Core State Standards** online.

Disciplinary Core Ideas:

- PS1.A: Structure and Properties of Matter
- PS1.C: Nuclear Processes

Science and Engineering Practices:

- Engaging in argument from evidence
- Constructing explanations and designing solutions

Crosscutting Concepts:

- Cause and effect
- Energy and matter
- Stability and change

Nature of Science:

- Scientific knowledge is based on empirical evidence.

Correlations to Common Core State Standards

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 radioactive elements were used in the past, and how they are used today. 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 radioactivity and its effects on the body.
- After students have read and discussed the article, consider showing the ACS Reactions Video "Can Radiation Give You Superpowers?" (4:35) at https://youtu.be/GbmSmgTIQ8s to continue the discussion of radiation.

ChemMatters™
Demystifying Everyday Chemistry

Teacher's Guide

Tales of Concrete Forensics

December 2021

Table of Contents

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. We use more concrete than any other construction material except water.
		2. Figuring out why concrete becomes damaged is often complex.
		3. Damage to concrete always creates a safety issue.
		4. Concrete detectives have backgrounds in geology, engineering, chemistry, and materials science.
		5. Concrete is a mixture of cement powder, sand, and gravel.
		6. The hardening of concrete is an endothermic reaction.
		7. As concrete sets, it expands.
		8. The manufacture of Portland cement releases CO_2.
		9. Bacteria in sewage can cause damage to concrete if the sulfate in sewage is converted to sulfuric acid.
		10. Dissolved salt seeping into the pores of concrete strengthens concrete.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. Write out the chemical equation for the hydration of tricalcium silicate, as shown in the article, but on a single line.

2. The compound that is written after the arrow is one compound that contains three parts. The dots between each part signify that the three parts are bonded to each other in some way, acting as a single compound.
   a. According to its chemical formula, what is the mole ratio of calcium oxide to silicon dioxide to water in this new compound?

   b. How many moles of water are incorporated into each mole of the new compound?

   c. According to the chemical equation, how many moles of water are required to react with one mole of tricalcium silicate?

   d. Some of the water from the reactants is not accounted for in the hydrated (3-part) compound. Where did the rest of the water go?

   e. Math Challenge! A typical bag of cement weighs 42.6 kg. Tricalcium silicate composes 50% of the cement weight in a typical mix. Hydration of this compound is the primary process responsible for the first 7 days of curing. How much heat is absorbed or released in that first seven days, per bag of cement?

3. Explain why the extra water in the concrete mixture caused the Ohio warehouse floor to fail after only a few months of use.

4. Microbes in the Indiana wastewater treatment plant were noted as being the reason for the failure of an underground concrete holding tank.
   a. What role did the microbes play in this deterioration?

   b. Most people are familiar with the idea that acid can “eat away” materials and corrode them. This term is describing the fact that chemical reactions change the material in some way.
      i. Write a balanced chemical equation for the reaction of sulfuric acid with calcium hydroxide.

Student Reading Comprehension Questions, cont.

ii. Write a balanced chemical equation for the reaction of sulfuric acid with the calcium oxide portion of calcium silicate hydrate.

iii. Explain how the two reactions described above can weaken the structure of the concrete.

5. "Pesky powders" can sometimes be harmless and can sometimes be a sign of damage.
   a. What is efflorescence?

   b. From where do the water-soluble salts originate when efflorescence occurs?

   c. In efflorescence, how are the salts transferred to the surface of the concrete?

   d. Draw a particle-level model to represent sodium chloride dissolved in water. Show both the salt ions and the water molecules.

   e. Draw a particle-level model to represent sodium chloride after water has evaporated.

   f. When road salt splashes onto concrete it can leave a powdery residue similar to efflorescence, but it is not efflorescence. This, road salt can lead to cracking in the concrete. Referring to the particle models you drew in the previous two questions, explain why road salt causes cracking in concrete.

Questions for Further Learning

Write your answers on another piece of paper if needed.

1. One concrete problem not discussed in the article is that it is a major contributor to global carbon dioxide emissions. Research the reaction(s) involved in this type of emission, record a chemical equation that describes the reaction, and identify three different ways that scientists and engineers are attempting to reduce these emissions.

2. People often confuse terms and use "cement", "concrete", and "mortar" interchangeably. Research these words and create a graphic organizer to compare and contrast the three materials.

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe the problems with concrete in the following locations.

Location	Cause of the Problem	Solution
Tiffin, Ohio warehouse		
Springfield, Indiana wastewater treatment plant		
Saint Charles, Virginia office building		
Lima, Ohio parking structure		

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

Answers to Reading Comprehension Questions & Graphic Organizer Rubric, & EdPuzzle

1. **Write out the chemical equation for the hydration of tricalcium silicate, as shown in the article, but on a single line.**

   $2\ Ca_3SiO_5\ +\ 7\ H_2O\ \rightarrow\ 3CaO{\cdot}2SiO_2{\cdot}4H_2O\ +\ 3\ Ca(OH)_2\ +\ 173.6\ kJ/mol$

2. **The compound that is written after the arrow is one compound that contains three parts. The dots between each part signify that the three parts are bonded to each other in some way, acting as a single compound.**
   a. **According to its chemical formula, what is the mole ratio of calcium oxide to silicon dioxide to water in this new compound?**
      3$CaO{\cdot}$***2***$SiO_2{\cdot}$***4***H_2O *mole ratio is 3:2:4*
   b. **How many moles of water are incorporated into each mole of the new compound?**
      $3CaO{\cdot}2SiO_2{\cdot}$***4*** H_2O *4 moles of H_2O (one mole of the compound contains 3 moles of CaO, 2 moles of SiO_2 and 4 moles of H_2O)*
   c. **According to the chemical equation, how many moles of water are required to react with one mole of tricalcium silicate?**
      2 Ca_3SiO_5 + ***7*** H_2O *→ $3CaO{\cdot}2SiO_2{\cdot}4H_2O$ + 3 $Ca(OH)_2$ + 173.6 kJ/mol*
      3.5 moles of H_2O react with every mole of Ca_3SiO_5.
   d. **Some of the water from the reactants is not accounted for in the hydrated (3-part) compound. Where did the rest of the water go?**
      4 of the 7 moles of H_2O are incorporated into the hydrate. The others are incorporated into the other product, to make the hydroxides of $Ca(OH)_3$.
   e. **Math Challenge! A typical bag of cement weighs 42.6 kg. Tricalcium silicate composes 50% of the cement weight in a typical mix. Hydration of this compound is the primary process responsible for the first 7 days of curing. How much heat is absorbed or released in that first seven days, per bag of cement?**
      2 Ca_3SiO_5 *+ 7* H_2O *→ $3CaO{\cdot}2SiO_2{\cdot}4H_2O$ + 3 $Ca(OH)_2$* ***+ 173.6 kJ/mol***
      50% of 42.6 kg = 21.3 kg → 21300 g
      Molar mass of Ca_3SiO_5 is 228.32 g/mol, so this is 93.3 moles of tricalcium silicate.
      173.6 kJ of heat are released for every 2 moles of tricalcium silicate.
      *93.3/2*173.6=* ***8.10 x 10^3 kJ b released***

3. **Explain why the extra water in the concrete mixture caused the Ohio warehouse floor to fail after only a few months of use.**
   The extra water made the cement paste too runny, so it wasn't dense enough to keep the aggregates suspended. The aggregates, which are the components that makes the concrete durable, all sunk to the bottom, leaving the top few inches free of aggregates. This made the top portion of the floor much less durable, leading to cracking and flaking.
4. **Microbes in the Indiana wastewater treatment plant were noted as being the reason for the failure of an underground concrete holding tank.**
   a. **What role did the microbes play in this deterioration?**
      The microbes (bacteria) converted the sulfates from the concrete into hydrogen sulfide, which turns to sulfuric acid when exposed to moist air. The sulfuric acid reacts with the components of concrete, thus deteriorating it.

b. Most people are familiar with the idea that acid can "eat away" materials and corrode them. This term is describing the fact that chemical reactions change the material in some way.

i. Write a balanced chemical equation for the reaction of sulfuric acid with calcium hydroxide.

$H_2SO_4 + Ca(OH)_2 \rightarrow 2H_2O + CaSO_4$

ii. Write a balanced chemical equation for the reaction of sulfuric acid with the calcium oxide portion of calcium silicate hydrate.

$H_2SO_4 + CaO \rightarrow H_2O + CaSO_4$

iii. Explain how the two reactions described above can weaken the structure of the concrete.

Both reactions change a component of concrete that is part of its rigid structure. By changing these components, the internal structure is broken down, thus weakening the concrete.

5. "Pesky powders" can sometimes be harmless and can sometimes be a sign of damage.

a. What is efflorescence?

Efflorescence is a deposit of salts that is left on a surface after the water that carried it has evaporated.

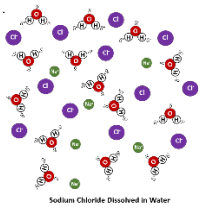
b. From where do the water-soluble salts originate when efflorescence occurs?

The salts in this case originate inside the concrete. They are already dissolved in water inside the concrete.

c. In efflorescence, how are the salts transferred to the surface of the concrete?

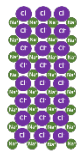
As the concrete continually cures over time, water that was previously bonded in the structure gets released and makes its way to the surface of the concrete, eventually evaporating. Salts that are not chemically bound within the structure can be dissolved along the way, thus left on the surface when the water evaporates.

d. Draw a particle-level model to represent sodium chloride dissolved in water. Show both the salt ions and the water molecules.



(*from https://wou.edu/chemistry/courses/online-chemistry-textbooks/3890-2/ch104-chapter-7-solutions/)*

e. **Draw a particle-level model to represent sodium chloride after water has evaporated**.



(*from https://wou.edu/chemistry/courses/online-chemistry-textbooks/3890-2/ch104-chapter-7-solutions/)*

f. When road salt splashes onto concrete it can leave a powdery residue similar to efflorescence, but it is not efflorescence. This, road salt can lead to cracking in the concrete. Referring to the particle models you drew in the previous two questions, explain why road salt causes cracking in concrete.

Since the salt from the road was not originally a part of the concrete, any salt water that makes its way into the structure can cause cracking as the water evaporates, leaving the crystallized salt in the pores, putting pressure on the pores making them turn into cracks.

Questions for Further Learning

1. **One concrete problem not discussed in the article is that it is a major contributor to global carbon dioxide emissions. Research the reaction(s) involved in this type of emission, record a chemical equation that describes the reaction, and identify three different ways that scientists and engineers are attempting to reduce these emissions.**

$$CaCO_3 \rightarrow CaO + CO_2$$

Answers may vary

2. **People often confuse terms and use "cement", "concrete", and "mortar" interchangeably. Research these words and create a graphic organizer to compare and contrast the three materials.**

Cement is made of limestone, clay, shells, and silica sand. It sets and hardens when combined with water.
Concrete is made of cement, sand, and gravel.
Mortar is made of cement and sand. It is used as glue to hold bricks and blocks together.
Graphic organizers may 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.
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

EdPuzzle Answers

1. Explain what is meant by the term "hydration."

Answers may vary but may include something along the lines of this: This is a chemical reaction when a substance mixes with water. Concrete consisting of aggregates hardens when water is added through hydration.

2. Why does it take a while for the concrete to gain strength?

It needs time for the water to make bonds

3. What is the significance of the little concrete character drinking a glass of water?

Answers may vary but may resemble something like this: It represents concrete's natural self-healing mechanism.

4. Water hydrates the calcium oxide into calcium hydroxide. Write a chemical equation for the process described when calcium hydroxide reacts with carbon dioxide.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

5. Why don't the microbes die inside the concrete?

Some types of microbes can form a protective spore and become inactive until there are nutrients available for them.

Additional Resources

Lessons and lesson plans

So, You Think Concrete Dries Out? Lesson: Students will learn about the hydration process by creating samples of concrete and weighing them before and after the hydration process.
https://www.cement.org/learn/education/concrete-in-the-classroom-(grades-7-12)/lesson-5-so-you-think-concrete-dries-out-

Chemistry of Cement: In this Activity, students use a commercially prepared cement mix to investigate the factors involved in the hardening of cement into concrete. Students manipulate variables such as concentration, curing temperature, and additions to the mixture, as well as testing the products for strength or hardness.
https://pubs.acs.org/doi/abs/10.1021/ed083p1472A

Making Concrete: Students will test to see how varying proportions of cement, water, and different aggregates affect the properties of their concrete mixtures. Using the scientific method, they can theorize which mixture will increase the stability and strength of their concrete mixture.
https://edu.rsc.org/resources/making-concrete/2022.article

What if cracks in concrete could fix themselves? Edpuzzle: Students can watch a video and answer questions on how concrete is prone to catastrophic cracking that has immense financial and environmental impacts and how scientists are trying to overcome these issues.
https://edpuzzle.com/media/6192e4011ae0394171078b0a

Other Resources/Possible Extension Activities

Ask Nature Search: Have students explore several interesting innovations of concrete inspired by nature
https://asknature.org/?s=concrete&page=0&is_v=1

Have students research different ways that scientists and engineers are making concrete "greener." Some examples are:

Alternative materials could shrink concrete's giant carbon footprint:
https://cen.acs.org/materials/inorganic-chemistry/Alternative-materials-shrink-concretes-giant/98/i45

Building's hard problem- making concrete green: https://www.bbc.com/news/business-56716859

Eco-Friendly Alternatives to Traditional Concrete: https://www.specifyconcrete.org/blog/eco-friendly-alternatives-to-traditional-concrete

Is Greener Concrete the Key to Sustainable Construction?:
https://www.constructconnect.com/blog/greener-concrete-key-sustainable-construction

The material could change the world… for a third time: https://youtu.be/hRI0ymx_6aw

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Chemical change
- Physical properties
- Mixtures

Correlations to Next Generation Science Standards

This article can be used to achieve the following performance expectations of NGSS:

> **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:

- ETS1.B: Developing possible solutions

Crosscutting Concepts:

- Cause and effect
- Systems and system models

Science and Engineering Practices:

- Analyzing and interpreting data
- Constructing explanations and designing solutions

Nature of Science:

- Scientific knowledge is based on empirical evidence.

Correlations to Common Core State Standards

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 concrete, how it is made, and problems with concrete structures. 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 carbon dioxide.
- After students have read and discussed the article, consider showing the ACS Reactions Video "Science of Concrete and the Surfside Condo Collapse" at https://youtu.be/4Nr3w1BQE18 to learn more about the science of concrete and what may have happened at the Surfside Condo.

ChemMatters™
Demystifying Everyday Chemistry

Teacher's Guide

The Mesmerizing Pull of Ferrofluids

December 2021

Table of Contents

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. Ferrofluids come in many colors.
		2. Magnetite is a naturally occurring mineral containing iron.
		3. Iron's electron configuration is the key to its magnetic properties.
		4. Iron (II) and iron (III) have the same number of electrons in the d-subshell.
		5. Iron (II) has a larger magnetic field than iron (III).
		6. The spins of neighboring iron atoms in magnetite are oriented randomly.
		7. Ferrofluids are colloidal suspensions containing magnetite and oil.
		8. Ferrofluids have been around for hundreds of years.
		9. Dollar bills have ferrofluids as an anti-counterfeiting feature.
		10. Researchers are developing ways to use ferrofluids to target the delivery of medicine to specific sites in the body.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. What is the chemical composition of ferrofluids?

2. Write the electron configuration for a neutral (ground state) iron atom.

3. Write the electron configuration for the Fe^{+2} and Fe^{+3} ions.

4. Compare and contrast paramagnetism and ferrimagnetism.

5. Define a colloid and give an everyday example (other than ferrofluids) of a common colloid.

6. List some common uses of ferrofluids

7. Write the orbital diagrams for the Fe^{+2} and Fe^{+3} ions and use the diagrams to explain why Fe^{+3} is more magnetic than Fe^{+2}.

8. The article focuses on the magnetic properties of ferrofluids, list some common other magnetic metals. What is the strongest magnetic in the world composed of?

Student Reading Comprehension Questions, cont.

9. Ferrofluids were originally developed as a possible additive to rocket fuel. What is the composition of rocket fuel and how does it compare to the gasoline used in cars?

10. Research and explain how ferrofluids made rocket fuel less efficient and thus rejected as a possible additive to rocket fuel.

Questions for Further Learning

Write your answers on another piece of paper if needed.

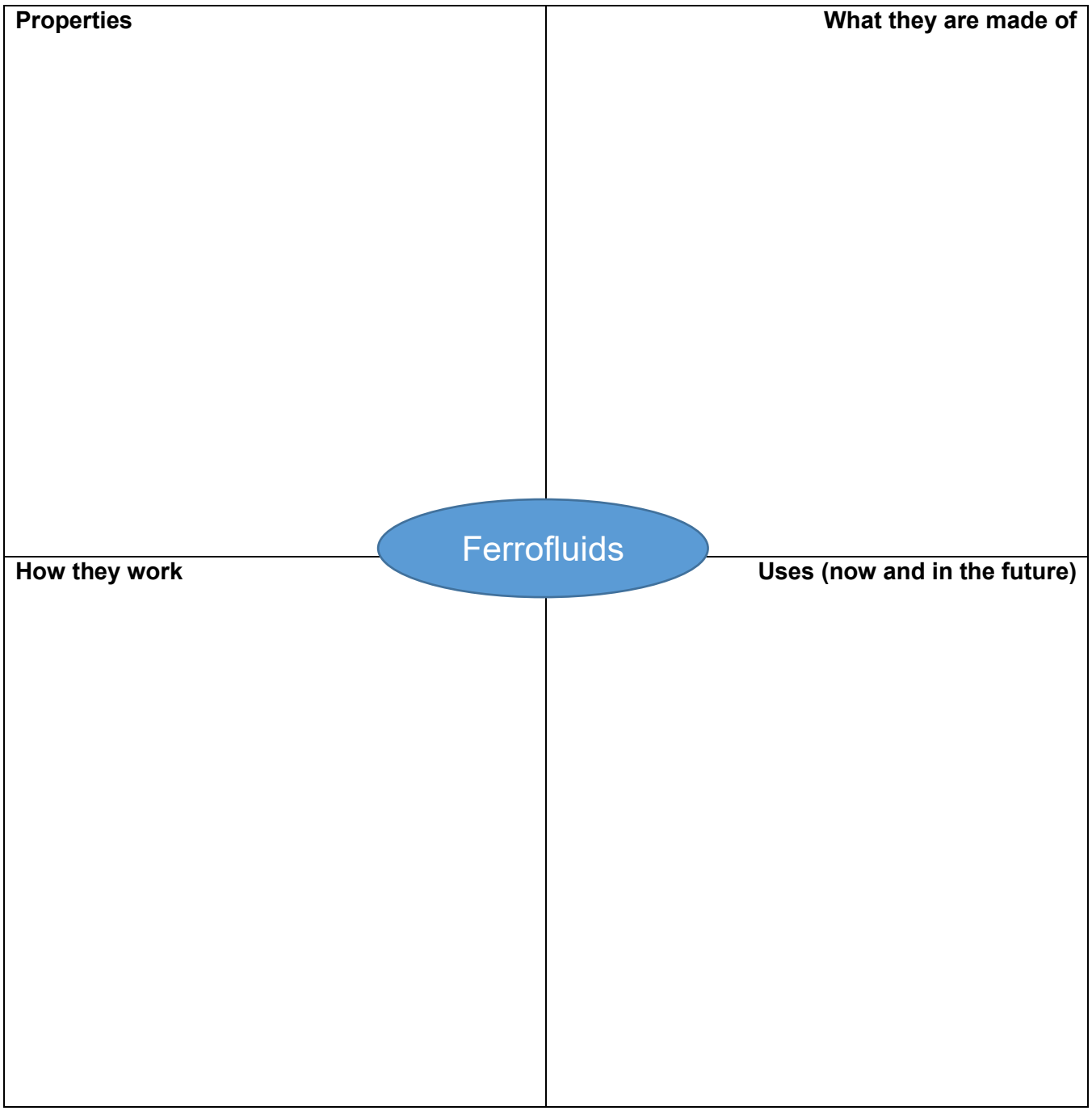
1. Prolonged, commercial, space travel seems to be a primary goal of companies such as SpaceX and Blue Origin. Humans need three basic components of life to survive a long trip into space: Air (gas), water (liquid), and food (solid). What state of matter, based on its properties, is best suited for prolonged space travel? Explain your reasoning.

2. Create an infographic (Digital or hand drawn) about the chemistry of ferrofluids. The infographic must include information on the uses of ferrofluids, composition, colloids, magnetism, and have visuals.

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe adhesives



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

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. **What is the chemical composition of ferrofluids?**
   Ferrofluids contain iron in the form of Fe_3O_4, commonly known as magnetite, oil, and a surfactant (oleic acid or soy lecithin).

2. **Write the electron configuration for a neutral (ground state) iron atom.**
   $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^6$

3. **Write the electron configuration for the Fe^{+2} and Fe^{+3} ions.**
   Fe^{+2} $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6$
   Fe^{+3} $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5$

4. **Compare and contrast paramagnetism and ferrimagnetism.**
   In paramagnetism the electron spins are randomly oriented and causes a weak attraction to a magnetic field. In ferromagnetism the electron spins are parallel which causes a strong attraction to a magnetic field.

5. **Define a colloid and give an everyday example (other than ferrofluids) of a common colloid.**
   A colloid, in simple terms, is a mixture of one substance spread out evenly inside another substance. Examples: Mayonnaise, whipped cream, butter.

6. **List some common uses of ferrofluids**
   Ferrofluids are used in speakers, currency as an anti-counterfeiting measure, and computer chips. Researchers are developing possible uses for ferrofluids in the medical field and to clean up oil spills.

7. **Write the orbital diagrams for the Fe^{+2} and Fe^{+3} ions and use the diagrams to explain why Fe^{+3} is more magnetic than Fe^{+2}.**
   The orbital diagram for Fe^{+2} should end in $3d^6$ and the orbital diagram for Fe^{+3} should end in $3d^5$. Fe^{+3} contains 5 unpaired electrons, while Fe^{+2} has 4 unpaired electrons which makes it more magnetic.

8. **The article focuses on the magnetic properties of ferrofluids, list some common other magnetic metals. What is the strongest magnetic in the world composed of?**
   The strongest magnets in the world are composed of neodymium (Nd). Nickel and cobalt are other examples of magnetic metals.

9. **Ferrofluids were originally developed as a possible additive to rocket fuel. What is the composition of rocket fuel and how does it compare to the gasoline used in cars?**
   The solid component of rocket fuel is composed of aluminum and ammonium perchlorate. The liquid component is composed of liquid hydrogen and liquid oxygen. Both are used to produce a power reaction that propels a rocket into space. Regular gasoline is a mixture of many hydrocarbons derived from oil such as isoalkanes and butane.

10. **Research and explain how ferrofluids made rocket fuel less efficient and thus rejected as a possible additive to rocket fuel.**
    NASA scientists realized that in the low gravity of space the the use for ferrofluids was not needed therefore the extra weight of ferrofluids to the fuel mixture was deemed inefficient and thus canceled due to the creation of simpler, lighter alternatives.

Questions for Further Learning

1. **Prolonged, commercial, space travel seems to be a primary goal of companies such as SpaceX and Blue Origin. Humans need three basic components of life to survive a long trip into space: Air (gas), water (liquid), and food (solid). What state of matter, based on its properties, is best suited for prolonged space travel? Explain your reasoning.**
   Gases, due to the fact that they can be compressed, are best suited for prolonged space travel. Travelers can compress a large amount of oxygen into tanks. Water and food cannot be compressed and will add a great deal of weight and take up significant space inside a prolonged space flight.

2. **Create an infographic (Digital or hand drawn) about the chemistry of ferrofluids. The infographic must include information on the uses of ferrofluids, composition, colloids, magnetism, and have visuals.**
   Answers 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.
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

Lessons and lesson plans

Electron Configuration Activity: In this activity students will learn how to apply the Aufbau principle, Pauli exclusion principle, and Hund's rule to model electron configurations and orbital diagrams.
https://teachchemistry.org/classroom-resources/electron-configuration-and-orbital-diagrams

Metallic Bonding & Magnetics Demonstration: Students will observe how electrons flow through a metal in an example of metallic bonding.
https://teachchemistry.org/classroom-resources/metallic-bonding-magnetics

Rocket Challenge: Students will have the opportunity to construct a rocket, with the challenges of both designing it and preparing a chemical reaction for its "fuel" in order to propel the rocket the highest possible distance.
https://teachchemistry.org/classroom-resources/rocket-challenge

Other Resources

Making Chemistry Visible with Magnets Webinar: See how Doug Ragan uses his colored magnetic circles and molecule magnets to enhance his students' understanding of the particulate level of chemistry. Doug has used them to describe everything from simple solid, liquid, gas representations to balancing equations, formula writing, molecule building, and even to help his students write redox half reactions correctly.
https://teachchemistry.org/professional-development/webinars/making-chemistry-visible-with-magnets

Chemistry Concepts, Standards, and Teaching Strategies

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Electron configuration
- Orbitals
- Periodic table
- Physical properties

Correlations to Next Generation Science Standards

This article can be used to achieve the following performance expectations and dimensions of NGSS:

HS-PS1-1. Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.
HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Disciplinary Core Ideas:

- PS1.A: Structure and properties of matter
- ETS1C: Optimizing the design solution

Crosscutting Concepts:

- Patterns
- Structure and function

Science and Engineering Practices:

- Developing and using models
- Constructing explanations and designing solutions

Nature of Science:

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

Correlations to Common Core State Standards

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 magnets, and if they have ever seen liquid magnets. 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 ferrofluids.

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.
E-mail: chemmatters@acs.org

Subscribe to *ChemMatters* magazine or purchase back-issues of the magazine at www.acs.org/chemmatters.