ChemMatters®

Demystifying Everyday Chemistry

Teacher's Guide

October 2024

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ACS Chemistry for Life®

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October Teacher's Guide Introduction

Lesson Ideas

For all of the articles, encourage students to think about how science is done, how we know what we know, and how chemistry connects to their lives.

This year's National Chemistry Week theme is "Picture Perfect Chemistry." All of the articles in this issue of *ChemMatters* relate to the theme. Prior to sharing the articles with students, you might ask students how images relate to their lives, and what questions they have about how images are formed. Students may be surprised to find that there is more to imaging than photographs.

For most of the articles, a basic understanding of the physics of light waves is helpful. Prior knowledge includes photons, the electromagnetic spectrum, and wavelength.

Teaching Ideas for this issue:

1. "Chemistry in Pictures" on page 2 shows a cyanotype. Before reading, ask students if they have ever made a sun print, which looks similar to a cyanotype. However, the chemistry is different.
2. "Open for Discussion" on page 4 challenges students to think about which is more environmentally friendly, film or digital photography. Ask students if they have used film photography, and what they know about taking photographs with film. Consider asking students to list the pros and cons of each type of photography. Additionally, the examples of emulsions will be helpful for students who are unfamiliar with the term
3. "Quick Read: Digital Cameras—How do they work?" on page 14 describes the chemistry of digital cameras, including those in smart phones. The following vocabulary words are reinforced in this article:
    - Pixels
    - Photons
    - Electrons
    - Energy levels
    - Diodes
    - Red, green, and blue (RGB) filters
4. The "Chemistry in Person" column on page 19 describes how someone with a BFA in photography became interested in preserving photographs, and what chemistry she needed to learn. Ask students to consider how they might use chemistry in their future careers, even if they are not scientists.
5. Assign a team of students to read each feature article, then present what they learned in a podcast, PowerPoint or similar presentation, poster or brochure, or some other engaging format.
    - Prior to reading the article, give students the Anticipation Guide for the article along with the graphic organizer and links to other information provided.
    - Be sure to ask students to include information providing evidence for the claims made in the article.
6. Alternatively, students can create concept maps about the important chemistry concepts in the article they choose.

5E Lesson Ideas for individual articles:

Engage	Provide the Anticipation Guide or ask a thoughtful question (see the individual Teacher's Guide for each article) to engage students in the reading. Students should record their initial ideas individually, in pen, so they can't be erased. Students can then discuss their initial ideas in small groups or as a whole class.
Explore	Students read the article to discover more about the concepts in the article. During this phase, students will revisit their beginning ideas and record how the information in the article supports or refutes their initial ideas, providing evidence from the article.
Explain	Students answer questions and/or complete the graphic organizer provided for each article, then discuss their learning with their classmates. Students should recognize the evidence for the claims made in the articles, and how the evidence supports the claims.
Elaborate	Students can pose questions for further study. For some articles, there are related ACS Reactions videos students can watch to learn more about the concepts presented. See the individual Teacher's Guide for each article to learn more.
Evaluate	Students write a short summary of what they learned that describes how it connects to their lives. Students may also present their learning to their classmates or others.

ChemMatters®
Demystifying Everyday Chemistry

Teacher's Guide

Light It Up

October 2024

Table of Contents

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. High-energy photons used in some imaging tests such as X-rays or CT scans can damage healthy cells.
		2. Fluorescent molecules emit light.
		3. Fluorescent dyes enable us to look at changes in cells over time.
		4. Fluorescence is rare in nature.
		5. Fluorescent molecules emit light when they absorb energy.
		6. Hydrophobic materials easily dissolve in water.
		7. Infrared light contains more energy than visible or ultraviolet light.
		8. The electrons in lanthanide elements can be excited in a step-by-step manner.
		9. In upconversion, the energy released is higher than the energy absorbed by the electrons.
		10. The nanoparticles needed for fluorescent therapy and diagnostics have been developed by engineers.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. State some common ways health professionals can "see" inside a body. What is the main concern for each of these procedures?

2. Define fluorescence.

3. How does the length of a wave relate to the amount of energy the wave will produce?

4. Where are the lanthanides found on the periodic table? State 2-3 lanthanide elements and their symbols.

5. Define upconversion. What types of waves are used and produced through upconversion?

6. What is the major benefit in using fluorescent dyes in the body instead of MRIs, CTs, or cat scans?

7. Explain how the structure of a molecule will determine whether it will release heat or light.

8. Using the electromagnetic spectrum, explain why infrared light is less harmful than ultraviolet light, which can cause damage to people.

9. Consider the law of conservation of energy. How would the amount of energy in 2 infrared waves absorbed by a molecule compare with the energy of the one light wave released by the molecule?

10. Explain how making a solution more concentrated will cause molecules to produce light energy and not heat energy.

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

11. Research other uses for fluorescence and describe the chemistry behind them.

12. Do short research on one of the following medical procedures: X-rays, MRIs, or CTs. Explain how they create images of the body.

Graphic Organizer

Name: _____

Directions: As you read, use information from the article to complete the graphic organizer below to describe how and why scientists are developing fluorescent materials for medical imaging.

3 **Advantages of using fluorescent materials in medical imaging**	
2 **Challenges in using fluorescent materials for medical imaging**	
1 **Possible solution for using fluorescent materials**	
Contact! **How does the information in the article relate to you???**	

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. State some common ways health professionals can "see" inside a body. What is the main concern for each of these procedures?
   X-rays, ultrasounds, CTs and MRIs are used to see inside a body. However, these use high energy particles which could cause damage to cells.

2. Define fluorescence.
   Molecules and materials that emit different colors of light.

3. How does the length of a wave relate to the amount of energy the wave will produce?
   The longer the wave (greater wavelength), the less energy the wave has. All the high energy electromagnetic waves have very short wavelengths.

4. Where are the lanthanides found on the periodic table? State 2-3 lanthanide elements and their symbols.
   They are the second to last row on the periodic table, below the main section. Some common lanthanides are neodymium (Nd), erbium (Er), cerium (Ce), and 12 others.

5. Define upconversion. What types of waves are used and produced through upconversion?
   Upconversion is when 2 longer wavelengths (with less energy), is converted to 1 shorter wavelength (with more energy). Typically 2 lower energy infrared waves are converted to 1 visible wave.

6. What is the major benefit in using fluorescent dyes in the body instead of MRIs, CTs, or cat scans?
   Fluorescent dyes, as opposed to the other procedures, can track cells and fluids as they move throughout the body, as opposed to a static picture.

7. Explain how the structure of a molecule will determine whether it will release heat or light.
   If the molecule has a more flexible structure, it has the ability to vibrate more, which will produce heat energy. If the molecule is more rigid, it cannot vibrate as much, so it will produce energy in the form of light.

8. Using the electromagnetic spectrum, explain why infrared light is less harmful than ultraviolet light, which can cause damage to people.
   Infrared light is less harmful because it has a much longer wavelength, which means it does not produce as much energy. An ultraviolet light has a much shorter wavelength, which will provide much more energy.

9. Consider the law of conservation of energy. How would the amount of energy in 2 infrared waves absorbed by a molecule compare with the energy of the one light wave released by the molecule?
   The combined energy of 2 infrared waves will have about the same energy as one visible wave. The law

of conservation of energy states that energy is neither created nor destroyed, so the 2 energies should be the same amount.

10. Explain how making a solution more concentrated will cause molecules to produce light energy and not heat energy.
    A higher concentration of molecules will have less space for a molecule to move or vibrate. Because vibrations produce heat energy, and the molecules cannot vibrate, they will produce the energy in the form of light instead.

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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 and Teaching Strategies

Additional Resources

❖ Labs and demonstrations

- ➢ Glowing tonic water
  https://www.sciencebuddies.org/stem-activities/tonic-water-glows
- ➢ Flame Test Demos
  https://teachchemistry.org/classroom-resources/flame-test-rainbow-demo
- ➢ Emissions of Light
  https://teachchemistry.org/classroom-resources/emissions-of-light

❖ Lessons and lesson plans

- ➢ DayGlo Fluorescent Pigments
  https://teachchemistry.org/classroom-resources/dayglo-fluorescent-pigments

❖ Projects and extension activities

- ➢ Electromagnetic spectrum book
  https://teachchemistry.org/classroom-resources/electromagnetic-spectrum-book

Teaching Strategies

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

- **Alternative to Anticipation Guide:** Before reading, ask students what medical imaging tests they have had. Ask them if they know how the machines work, and what the risks involved might be. Their initial ideas can be collected electronically via digital whiteboards or similar technology.
  - As they read, students can find information to confirm or refute their original ideas.
- After they read, ask students how knowledge of chemistry (and physics!) can help engineers develop new materials for bioimaging to help physicians diagnose medical problems.

Chemistry Concepts and Standards

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Atomic structure
- Emission spectrum
- Electrons

Correlations to Next Generation Science Standards

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

HS-PS4-5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

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:

- PS.4.B: Electromagnetic radiation
- ETS1.C: Optimizing the design solution

Crosscutting Concepts:

- Cause and effect
- Energy and matter
- Structure and function

Science and Engineering Practices:

- Constructing explanations (for science) and developing solutions (for engineering)

Nature of Science:

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

See how *ChemMatters* correlates to the **Common Core State Standards** online.

ChemMatters®
Demystifying Everyday Chemistry

Teacher's Guide

A Look Inside

October 2024

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. MRI machines use powerful magnets and radio waves.
		2. MRI instruments focus on the behavior of water molecules in the body.
		3. Protons cannot generate their own magnetic fields.
		4. Neurons carry electrical signals within the brain and spinal cord.
		5. Multiple sclerosis (MS) damages cells by stripping away myelin that protects neurons in the brain.
		6. Sometimes a radio-frequency coil is placed around a person's head during an MRI.
		7. With the most common form of MS, the symptoms do not reoccur after treatment.
		8. MRI scans can reveal new damage to the brain.
		9. Paramagnetic metal ions have unpaired electrons.
		10. MRI scans usually take only a few minutes.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. An MRI instrument is designed to focus on changes in water molecules, H_2O. Why are water molecules a convenient target for MRI when analyzing a human being?

2. There are three isotopes of hydrogen, ^{1}H, ^{2}H, and ^{3}H.

    a. Which of these is most prevalent in the water molecules inside a human body?

    b. Which of these has a nucleus containing only a single proton and no other particles?

3. In science, a **field** is a region over which a particular force can act at a distance on a certain type of object. Magnets, such as those found on a refrigerator, are common examples of a **magnetic field** in action. Briefly describe how you could determine the distance away from your favorite refrigerator magnet over which its field extends, using only the magnet and the front of the refrigerator.

4. Electricity and magnetism are paired processes. When any electrically charged particle is moving, it generates a magnetic field; and when a magnetic field is moving relative to an electrically charged particle, it changes the electric field, affecting the motion of the charged particle. The images at the bottom of pages 10-11 show a simple model of certain aspects of a proton.

    a. Why does the proton generate a magnetic field when it spins?

    b. Why do the protons align in a certain way in the presence of a magnetic field?

5. Electromagnetic radiation is a form of energy transfer that is generated in certain conditions when a charged particle oscillates (wiggles) and loses energy. This moving electric charge creates a self-sustaining oscillating electric and magnetic field that propagates across space until it runs into some form of matter. Visible light and radio waves are two forms of electromagnetic radiation.

    a. A typical MRI uses RF at frequencies of 64 MHz and 128 MHz. What are the energy and wavelength values for these two frequencies?

    b. Are the radiofrequency (RF) pulses in an MRI of higher or lower energy than the visible light spectrum?

6. Since an RF pulse has both a magnetic and an electric component, the RF energy can knock the proton out of alignment with the magnetic field. This misalignment causes the proton to be in a high-energy state. Since it is still affected by the external magnetic field, it will release its extra energy to reorient with the magnetic field. The released energy is then detected by the MRI instrument.

    a. When the RF wave encountered the proton, what happened to the energy?

    b. Energy is often defined as “the ability to do work.” What “work” does the RF energy do on the proton?

    c. Once the proton is misaligned, what is the reason that it can realign itself?

7. Gadolinium has been experimentally determined to have an electron configuration of $[Xe]6s^2\ 5d^1\ 4f^7$.

    a. Why is gadolinium used in MRI scans of the brain?

    b. Write the electron orbital diagram (using arrows for electrons) for a gadolinium atom.

    c. Which is more paramagnetic, a gadolinium ion, Gd^{3+}, or a gadolinium atom, Gd? Explain using electron configurations.

    d. Propose a reason that gadolinium ions are used, rather than gadolinium atoms, to inject into the body for the MRI scans.

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

8. An MRI for a human is very similar to an NMR (a popular analytical technique) for a substance. How are these processes the same and different?

9. There is a limit to the number of x-rays your doctor may allow you to have each year. Such a guideline does not exist for an MRI scan. Is getting an MRI safer than getting an x-ray? Compare and contrast these two techniques in terms of safety.

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to explain some of the terms used in the article.

	What is it?	How is it used in diagnosing problems in the body?
Magnetic Field		
Radio Waves		
Protons		
Gadolinium		
Multiple Sclerosis (MS)	*Explain what MS is, how it is diagnosed, and how the person in the article copes with having MS.*	

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. An MRI instrument is designed to focus on changes in water molecules, H_2O. Why are water molecules a convenient target for MRI when analyzing a human being?
   Water makes up more than half of a human body's mass and is in every part of a body. This means that an MRI could theoretically be used to scan any part of the body.

2. There are three isotopes of hydrogen, ^1H, ^2H, and ^3H.

   a. Which of these is most prevalent in the water molecules inside a human body?
      ^1H is most prevalent. Since the average atomic mass of hydrogen is 1.008 amu, it is clear that most hydrogen atoms are hydrogen-1.

   b. Which of these has a nucleus containing only a single proton and no other particles?
      ^1H contains only a single proton and no neutrons.

3. In science, a **field** is a region over which a particular force can act at a distance on a certain type of object. Magnets, such as those found on a refrigerator, are common examples of a **magnetic field** in action. Briefly describe how you could determine the distance away from your favorite refrigerator magnet over which its field extends, using only the magnet and the front of the refrigerator.
   Hold the magnet at increasing distances away from the door and let go. When it drops, instead of sticking to the door, you have reached the outer limit of its field.

4. Electricity and magnetism are paired processes. When any electrically charged particle is moving, it generates a magnetic field; and when a magnetic field is moving relative to an electrically charged particle, it changes the electric field, affecting the motion of the charged particle. The images at the bottom of pages 10-11 show a simple model of certain aspects of a proton.

   a. Why does the proton generate a magnetic field when it spins?
      Because a proton is a charged particle, and charged particles in motion generate a magnetic field.

   b. Why do the protons align in a certain way in the presence of a magnetic field?
      The external magnetic field exerts a directional magnetic force over a distance. The strong external magnetic field influences the weaker magnetic field produced by the proton, lining it up in the same direction.

5. Electromagnetic radiation is a form of energy transfer that is generated in certain conditions when a charged particle oscillates (wiggles) and loses energy. This moving electric charge creates a self-sustaining oscillating electric and magnetic field that propagates across space until it runs into some form of matter. Visible light and radio waves are two forms of electromagnetic radiation.

   a. A typical MRI uses RF at frequencies of 64 MHz and 128 MHz. What are the energy and wavelength values for these two frequencies?

$$E = (6.626 \times 10^{-36} J \cdot s)(64 Ms^{-1} \times \frac{10^6 s^{-1}}{1 Ms^{-1}} = 4.2 \times 10^{-28} J;\ \lambda = \frac{(2.998 \times 10^8 ms^{-1})}{(64 Ms^{-1} \times \frac{10^6 s^{-1}}{1 Ms^{-1}})} = 4.7m$$

$$E = (6.626 \times 10^{-36} J \cdot s)(128 Ms^{-1} \times \frac{10^6 s^{-1}}{1 Ms^{-1}} = 8.5 \times 10^{-28} J;\ \lambda = \frac{(2.998 \times 10^8 ms^{-1})}{(128 Ms^{-1} \times \frac{10^6 s^{-1}}{1 Ms^{-1}})}$$

$$= 2.3m$$

b. Are the radiofrequency (RF) pulses in an MRI of higher or lower energy than the visible light spectrum?
Lower energy. Visible light is in the range of approximately $4x10^{-7}$- $7x10^{-7}$meters; $5x10^{-21}$ - $3x10^{-21}$ Joules.

6. Since an RF pulse has both a magnetic and an electric component, the RF energy can knock the proton out of alignment with the magnetic field. This misalignment causes the proton to be in a high-energy state. Since it is still affected by the external magnetic field, it will release its extra energy to reorient with the magnetic field. The released energy is then detected by the MRI instrument.

a. When the RF wave encountered the proton, what happened to the energy?
The energy was used to knock the proton out of alignment.

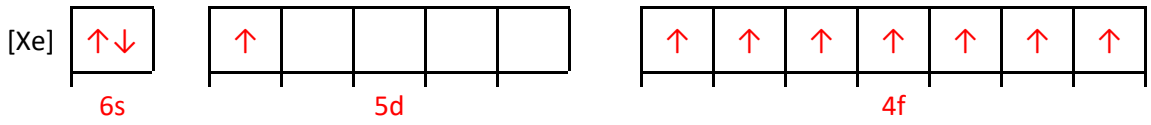
b. Energy is often defined as "the ability to do work." What "work" does the RF energy do on the proton?
Work is defined in physics as energy transferred to or from an object. Therefore the RF energy is transferred to the proton when it is knocked out of alignment.

c. Once the proton is misaligned, what is the reason that it can realign itself?
The magnetic field continues to exert a force on the proton and it pushes the field of the proton back into alignment.

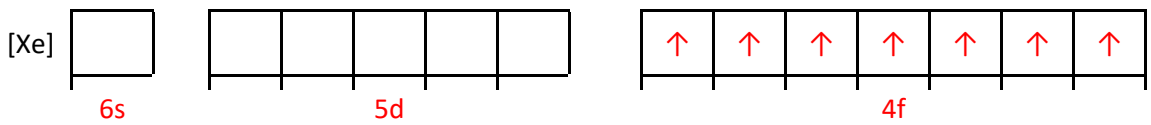
7. Gadolinium has been experimentally determined to have an electron configuration of $[Xe]6s^2\ 5d^1\ 4f^7$.

a. Why is gadolinium used in MRI scans of the brain?
Because it can be affected by a magnet and it can travel all over the body, except in the brain. It can only enter the brain when the brain's barrier is broken down. It is also able to change the energy of the water molecules it comes into contact with enhancing, brightening, their appearance on an MRI image.

b. Write the electron orbital diagram (using arrows for electrons) for a gadolinium atom.



c. Which is more paramagnetic, a gadolinium ion, Gd^{3+}, or a gadolinium atom, Gd? Explain using electron configurations.
Gadolinium atom, because it has 8 unpaired electrons, and the ion only has 7 unpaired electrons.



d. Propose a reason that gadolinium ions are used, rather than gadolinium atoms, to inject into the body for the MRI scans.
Ions dissolve in water due to ion-dipole intermolecular forces between themselves and the water, while metal atoms do not.

8. An MRI for a human is very similar to an NMR (a popular analytical technique) for a substance. How are these processes the same and different?
Both processes use a strong magnetic field to look inside. An MRI looks inside a human body and an NMR (on which the MRI is based) is used to look at the different environments of each atom in a molecule. NMR stands for Nuclear Magnetic Resonance Imaging, the nuclear was dropped in MRI because scientists and doctors thought it would scare patients who might equate it with nuclear energy rather than the nuclei of atoms.

9. There is a limit to the number of x-rays your doctor may allow you to have each year. Such a guideline does not exist for an MRI scan. Is getting an MRI safer than getting an x-ray? Compare and contrast these two techniques in terms of safety.
X-rays are very high energy waves and can cause damage if used repeatedly. Therefore doctors try to limit the amount of exposure a patient has to these potentially damaging energy waves. MRIs, however, use magnetism to move the magnetic field of an atom, but do not change the atom. Additionally, the energy associated with magnetism and radio frequencies used in MRI are well below the energy required to damage cells in the body.

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 and Teaching Strategies

Additional Resources

❖ Labs and demonstrations

- ➢ Explore effects of different frequencies of electromagnetic radiation
  https://teachchemistry.org/classroom-resources/screen-your-sunscreen
  https://teachchemistry.org/classroom-resources/the-most-effective-sunscreen

❖ Lessons and lesson plans

- ➢ Practice w/ electron configurations
  https://teachchemistry.org/classroom-resources/electron-configuration-and-orbital-diagrams

❖ Simulations

- ➢ Simulation Activity: Exciting Electrons
  https://teachchemistry.org/classroom-resources/simulation-activity-exciting-electrons
- ➢ Animation Activity: Electromagnetic Spectrum https://teachchemistry.org/classroom-resources/animation-activity-electromagnetic-spectrum

❖ Projects and extension activities

- ➢ Research the role of magnets in imaging techniques like MRI, and of the substances used to cool the magnets for effective use.
- ➢ Explore effects of absorption of electromagnetic radiation
  https://teachchemistry.org/classroom-resources/let-it-glow

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 had an MRI. If students are willing, they might share their experiences. Ask students if they know how MRI machines work, and why they make all that noise. Their initial ideas can be collected electronically via digital whiteboards or similar technology.
  - As they read, students can find information to confirm or refute their original ideas.
- To help students understand how the magnetic fields of protons are manipulated in MRI machines, encourage them to watch the 1-minute video that can be accessed by the QR code at the bottom of page 10.
- After they read, ask students what they learned about MRIs, and how this knowledge might inform their future decisions about health care.

Chemistry Concepts and Standards

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Atomic structure
- Protons
- Paramagnetism
- Periodic table (lanthanides)

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-ETS1-2. 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:

- PS.1.A: Structure and Properties of Matter
- ETS.1.C: Optimizing the Design Solution

Crosscutting Concepts:

- Cause and effect
- Systems and system models
- Structure and function

Science and Engineering Practices:

- Constructing explanations (for science) and developing solutions (for engineering)

Nature of Science:

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

See how *ChemMatters* correlates to the **Common Core State Standards** online.

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Teacher's Guide

Cyanotypes: Chemistry in Blue

October 2024

Table of Contents

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. The first cyanotypes were made in the 1920s.
		2. Today we use the same method to produce cyanotypes as the inventor used.
		3. Cyanotypes are more expensive than photographs based on silver chemistry.
		4. Only two reagents are needed to produce a cyanotype.
		5. The reaction to produce cyanotypes is a redox (reduction-oxidation) reaction.
		6. UV light is needed to expose cyanotypes.
		7. Prussian blue has iron in only the Fe^{3+} oxidation state.
		8. Prussian blue has a lattice structure.
		9. Prussian blue is a synthetic pigment.
		10. Cyanotype photographs are made without a camera.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. Describe the basic chemical process behind the creation of a cyanotype.
2. What are the two main chemical reagents used in cyanotype photography, and what role does each play?
3. Why is Prussian blue, the compound formed in cyanotypes, blue in color? How does its structure different from the starting compounds, potassium ferricyanide and ammonium ferric citrate?
4. What is special about the structure of ammonium ferric citrate?
5. How does UV light contribute to the cyanotype process?
6. What happens when Prussian blue is exposed to a base, and how can this property be used creatively?
7. Discuss the importance of redox reactions in the cyanotype process, and give an example of how these reactions are involved.
8. Why is Prussian blue considered insoluble, and what effect does this property have on the cyanotype image?
9. What is the significance of electron transfer in the cyanotype process, and how does it relate to the formation of the blue pigment?
10. Explain how tannins can alter the color of cyanotype prints and what chemical interaction is involved.
11. What is oxidation, and what is reduction in the context of redox reactions?
12. Write the half-reactions for the redox process involved in the formation of Prussian blue from iron(III) (Fe^{3+}) and iron(II) (Fe^{2+}).
13. Identify some of the chemical reactions that take place in the cyanotype process and describe the half-reactions involved in the formation of Prussian blue.
14. If a material absorbs light at 680 nm, what color is it likely to appear, and why?

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

15. Research another photochemical reaction besides the cyanotype process. How does this reaction utilize light to drive a chemical change?

16. How do sunscreens prevent UV light from reacting with the skin? Research the chemical properties of sunscreens that make them opaque to UV radiation.

17. What happens chemically when colored materials lose their color after prolonged exposure to sunlight (sun bleaching)? How is this related to photochemistry?

18. What role does experimentation and failure play in both the scientific and artistic processes, according to the article?

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe cyanotype chemistry.

	What is it?	How is it used for cyanotypes?
Potassium ferricyanide		
Ferric ammonium citrate		
Prussian blue		
UV light		
Chemicals used to alter the color of cyanotypes		
Similarities of art and chemistry		

Summary: On the back of this sheet, write a short summary (20 words or less) of the article.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. Describe the basic chemical process behind the creation of a cyanotype.
   The basic chemical process behind a cyanotype involves coating paper with a solution of potassium ferricyanide and ammonium ferric citrate. When exposed to UV light, a redox reaction occurs, forming the deep-blue compound Prussian blue.

2. What are the two main chemical reagents used in cyanotype photography, and what role does each play?
   The two main chemical reagents used in cyanotype photography are potassium ferricyanide, which contributes to the formation of Prussian blue, and ammonium ferric citrate, which enhances the light sensitivity of the process.

3. Why is Prussian blue, the compound formed in cyanotypes, blue in color? How does its structure different from the starting compounds, potassium ferricyanide and ammonium ferric citrate?
   Prussian blue is blue in color due to the electron transfer between iron atoms in different oxidation states within its lattice structure. This electron transfer absorbs orange-red light, causing the material to appear blue. Prussian blue is a repeating lattice, which means it repeats in all directions and is therefore very large, this makes it much less soluble than the starting materials. Both ammonium ferric citrate and potassium ferricyanide are discrete molecules which means they are smaller and move around in solution like balls, whereas Prussian blue is more like a series of linked cages and therefore insoluble.

4. What is special about the structure of ammonium ferric citrate?
   An ammonium ferric citrate is a chelating molecule, that is the metal bonded to several atoms of the same compound. Chelating molecules are generally very stable.

5. How does UV light contribute to the cyanotype process?
   UV light catalyzes the redox reactions that cause potassium ferricyanide and ammonium ferric citrate to react and form Prussian blue, the blue pigment seen in cyanotypes.

6. What happens when Prussian blue is exposed to a base, and how can this property be used creatively?
   When Prussian blue is exposed to a base, it breaks down and forms iron(III) hydroxide, which is brown in color. Photographers can use this property to alter the color of cyanotypes by soaking them in a basic solution.

7. Discuss the importance of redox reactions in the cyanotype process, and give an example of how these reactions are involved.
   Redox reactions are essential to the cyanotype process because they drive the transformation of the light-sensitive chemicals into Prussian blue. For example, when UV light hits the paper coated with potassium ferricyanide and ammonium ferric citrate, iron(III) (Fe^{3+}) is reduced to iron(II) (Fe^{2+}), and the resulting reaction forms the deep-blue compound.

8. Why is Prussian blue considered insoluble, and what effect does this property have on the cyanotype image?
   Prussian blue is considered insoluble due to its extended lattice structure, which makes it difficult for water to break apart the iron-cyanide bonds. This property ensures that the blue pigment remains fixed on the paper, making the cyanotype image permanent and durable.

9. What is the significance of electron transfer in the cyanotype process, and how does it relate to the formation of the blue pigment?
   Electron transfer is central to the cyanotype process because it enables the redox reactions that form Prussian blue. In this process, electrons are transferred between iron atoms in different oxidation states (Fe^{2+} and Fe^{3+}), which stabilizes the formation of the blue pigment.

10. Explain how tannins can alter the color of cyanotype prints and what chemical interaction is involved.
    Tannins, found in substances like tea and coffee, can react with iron(III) hydroxide, which is formed when Prussian blue is broken down by a base. This interaction results in the formation of new iron-tannin complexes, which can give the cyanotype print various tones, such as purplish-brown or blue-black, depending on the specific tannin used.

11. What is oxidation, and what is reduction in the context of redox reactions?
    Oxidation is the process where a substance loses electrons, while reduction is when a substance gains electrons. In redox reactions, one species is oxidized and its electrons are transferred to the other species which is reduced.

12. Write the half-reactions for the redox process involved in the formation of Prussian blue from iron(III) (Fe^{3+}) and iron(II) (Fe^{2+}).
    The half-reactions involved in the formation of Prussian blue are as follows:
    a. Oxidation half-reaction (iron(II) to iron(III)): $Fe^{2+} \rightarrow Fe^{3+} + e^-$
    b. Reduction half-reaction (iron(III) to iron(II)): $Fe^{3+} + e^- \rightarrow Fe^{2+}$

13. Identify some of the chemical reactions that take place in the cyanotype process and describe the half-reactions involved in the formation of Prussian blue.
    In the cyanotype process, potassium ferricyanide and ammonium ferric citrate react under UV light to form Prussian blue. The iron(III) in ammonium ferric citrate is reduced to iron(II), while some iron(II) in the system is oxidized to iron(III). The half-reactions involve the transfer of electrons between these iron species, resulting in the formation of Prussian blue ($Fe_4[Fe(CN)_6]_3$), which contains iron in both +2 and +3 oxidation states.

14. If a material absorbs light at 680 nm, what color is it likely to appear, and why?
    If a material absorbs light at 680 nm, which is in the orange-red part of the spectrum, it is likely to appear blue. This is because the material reflects the complementary color, which in this case is blue.

15. Research another photochemical reaction besides the cyanotype process. How does this reaction utilize light to drive a chemical change?
    One example of a photochemical reaction is the light-induced decomposition of silver halides in traditional photography. When exposed to light, silver bromide (AgBr) decomposes into metallic silver (Ag) and bromine (Br_2), creating a photographic image. This reaction relies on light to break the chemical bonds in the silver halide, driving the change from ionic (Ag1+) to metallic silver (Ag).

16. How do sunscreens prevent UV light from reacting with the skin? Research the chemical properties of sunscreens that make them opaque to UV radiation.
    Sunscreens contain compounds like zinc oxide and titanium dioxide, which reflect or absorb UV light, preventing it from reaching the skin. These compounds are opaque to UV radiation because they either scatter the UV light or absorb it, converting it into harmless heat instead of allowing it to cause damage to the skin cells.

17. What happens chemically when colored materials lose their color after prolonged exposure to sunlight (sun bleaching)? How is this related to photochemistry?
    Sun bleaching occurs when colored materials lose their color after prolonged exposure to sunlight. This happens because UV light causes the chemical bonds in the pigments to break down, leading to a loss of color. Photochemical reactions induced by UV light degrade the molecular structure of the pigments, resulting in fading or discoloration.

18. What role does experimentation and failure play in both the scientific and artistic processes, according to the article?
    Experimentation and failure are critical in both scientific and artistic processes. The article notes that both Anna Atkins and Sir John Herschel faced failures before perfecting their cyanotype work, underscoring the importance of persistence and experimentation in achieving success.

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 and Teaching Strategies

Additional Resources

❖ Labs and demonstrations

- ➢ Lab: Students use sun sensitive paper to test the level of protection of various sunscreens. https://teachchemistry.org/classroom-resources/screen-your-sunscreen

❖ Projects and extension activities

- ➢ Read about the artist Oriana Poindexter and explore her collection of cyanotypes of marine life online at the Getty Museum. https://www.getty.edu/news/capturing-the-feeling-of-the-ocean-on-paper
- ➢ Watch the recorded webinar of Michael Nocella that highlights the use of cyanotype photography in a chemistry classroom. https://teachchemistry.org/professional-development/webinars/self-e-chemistry-photography

Teaching Strategies

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

- **Alternative to Anticipation Guide:** Before reading, show students examples of cyanotypes from the article, or from other sources. Ask students if they have made sun prints of objects. These look similar to cyanotypes, but the chemistry is different. However, the way the prints are produced is similar (laying the object on the paper and exposing it to sunlight). Ask students what questions they have about creating cyanotypes. Encourage students to think about the relationship of art and chemistry as they read the article.
  - As they read, students can find information to confirm or refute their original ideas.
- **After they read**: Ask students what they learned about making cyanotypes.
  - If students are interested in making their own cyanotypes, encourage them to watch the video (see QR code in the article) after they read.

Chemistry Concepts and Standards

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Electrochemistry
- Redox reaction
- Oxidation
- Reduction
- Chemical change
- Solubility
- Energy, light, and color

Correlations to Next Generation Science Standards

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

HS-PS1-6. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

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:

- PS.1.B: Chemical Reactions
- ETS1.C: Optimizing the Design Solution

Crosscutting Concepts:

- Structure and Function
- Stability and Change

Science and Engineering Practices:

- Constructing explanations (for science) and designing solutions (for engineering)

Nature of Science:

- Science is a human endeavor.

See how *ChemMatters* correlates to the **Common Core State Standards** online.

ChemMatters®
Demystifying Everyday Chemistry

Teacher's Guide

Changing the World Through Photography

October 2024

Table of Contents

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. The wilderness areas in the Great Smoky Mountains were protected before those in Montana and Wyoming.
		2. Black and white photography today is basically the same as it was in the early 1900s.
		3. George Masa, the photographer featured in the article, developed his own photographs.
		4. Halides are compounds containing elements from Group 17 on the periodic table.
		5. Silver halides have a crystalline structure similar to NaCl.
		6. Silver halides are very soluble in water.
		7. Cations are negatively charged.
		8. When a photon of light hits black and white film, an electron is knocked off the halide ion, causing a silver ion (Ag^+) to become silver (Ag).
		9. On a black and white negative, light areas are dark in color because of silver atoms.
		10. George Masa's photographs were important in establishing the Great Smoky Mountain National Park as well as the Appalachian Trail.

Student Reading Comprehension Questions

Name: _____

Directions: Use the article to answer the questions below.

1. Explain how George Masa's work was instrumental in creating Great Smoky Mountains National Park.
2. Briefly trace Masa's journey to the Smoky Mountains region of the United States.
3. What are the three stages of film photography?
4. What crystalline compound is contained in the gelatin layer of photographic film?
5. What happens when silver halide salts are exposed to light? How does this help to create a photo? Explain in words and write the chemical equation.
6. Draw or build a model of a silver bromide crystal.
7. How is acid-base chemistry part of the film developing process?
8. What role does solubility play in the film developing process?

Student Reading Comprehension Questions, cont.

Questions for Further Learning

Write your answers on another piece of paper if needed.

9. How does color film development differ from black and white photography discussed in this article?

10. Research the environmental impacts of film development.

Graphic Organizer

Name: _____

Directions: As you read, complete the graphic organizer below to describe the chemistry of black and white photography.

Ingredient	What it is (chemically)	Purpose in photography
Silver Halide		
Emulsion Layer		
Developer		
Stop Bath		
Fixer		
Negative		

Summary: On the back of this sheet, write three interesting facts about black and white photography you learned from the article to share with a friend.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. Explain how George Masa's work was instrumental in creating Great Smoky Mountains National Park.
   In the 1920s, the Smoky Mountains were largely ignored, even by citizens of nearby towns. George Masa's photographs convinced philanthropists, local leaders, and government officials that these mountains in the southeast held great value in natural beauty. His work led to the creation of this national park, which is the most-visited park in the United States.

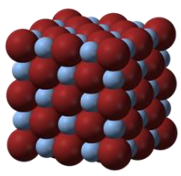
2. Briefly trace Masa's journey to the Smoky Mountains region of the United States.
   Masa was born in Japan, near Mt. Fuji. Although he was initially turned away, he eventually immigrated to the United States, and then settled in Asheville, N.C. Although not much is known about the details of his life, researchers have found him pictured with prominent guests including President Calvin Coolidge, at an inn where it seems that he may have accompanied visitors on hikes into the mountains.

3. What are the three stages of film photography?
   The three stages are (1) image capture, (2) development and (3) printing. When someone takes a photo, a latent image is captured when light reduces the Ag^{1+} ions in the silver bromide that coats the film. Then, during the development stage, chemicals are used to reduce more Ag^{1+} to darken the image and then fix the image so that it doesn't continue to react with light. Finally, another chemical is used to make the unreacted AgX soluble so it can be washed away. This leaves behind a reversed image, the negative. The negative is then used to print the photograph.

4. What crystalline compound is contained in the gelatin layer of photographic film?
   The crystals are compounds called silver halides. Most often this is silver bromide (AgBr) but it can also be AgCl or AgI. Halides is the name for the elements in group 17.

5. What happens when silver halide salts are exposed to light? How does this help to create a photo? Explain in words and write the chemical equation.
   When a photon (particle of light) hits silver halide, the halide ion loses its extra electron. That electron reduces silver ions to silver atoms. Clumps of silver atoms form dark spots when the film is developed, creating the image.
   $2AgX_{(s)} + light \rightarrow 2Ag_{(s)} + X_{2\,(g)}$

6. Draw or build a model of a silver bromide crystal.
   The model should show Ag^{+1} ions and Br^{-1} ions arranged in a 3-D crystal lattice with alternating silver and bromide ions.



https://commons.wikimedia.org/wiki/File:Silver-bromide-3D-ionic.png

7. How is acid-base chemistry part of the film developing process?
   The film needs to be fixed such that no further reaction can continue to take place. Therefore after the film is placed in a solution of the developer to darken the image, it needs to be placed in an acidic "stop bath". Acetic acid (the "stop bath") is used to neutralize the basic hydroquinone developer to pH 7.

8. What role does solubility play in the film developing process?
   Silver halides are quite insoluble in water, so another chemical reaction must occur to convert the silver halides into a soluble compound at the end of the development process. Sodium thiosulfate ($Na_2S_2O_3$) reacts with silver halides to produce a soluble complex anion, bis(thiosulfato)argentate ($[Ag(S_2O_3)_2]^{3-}$).

9. How does color film development differ from black and white photography discussed in this article?
   Color film has different dyes added to emulsions that are sensitive to light of certain wavelengths: red, green, and blue. Each layer absorbs light of a specific wavelength when the film is exposed. Color film also contains compounds that turn yellow, magenta, or cyan during the development phase.

10. Research the environmental impacts of film development.
    Answers will vary depending on student research. Examples include heavy metal waste from the silver compounds and groundwater contamination from the fixers and developers used in the process.

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 and Teaching Strategies

Additional Resources

❖ Labs and demos

- ➢ Students will explore how to create anthotype prints with turmeric. https://www.acs.org/education/outreach/celebrating-chemistry-editions/2024-ncw/sun-prints.html
- ➢ In this inquiry-based lab, students investigate polaroid photography. https://teach-chemistry.s3.amazonaws.com/2024/05/14/12/12/16/e685fc2d-9e7d-4064-b92d-055f1226205d/lesson-landmarkpolaroidphotography-polaroidfilminquiry.pdf

❖ Lessons and lesson plans

- ➢ Students learn about crystal structures by constructing 3-D models of various crystal shapes. https://uwmemc.org/wp-content/uploads/2019/04/Crystal-Lesson.pdf

❖ Articles

- ➢ Students learn about the history of photography when reading: "George Eastman, Kodak, and the Birth of Consumer Photography" https://www.acs.org/education/whatischemistry/landmarks/eastman-kodak.html
- ➢ For a more in-depth look at the chemistry of film, students can read: "Chemistry and the Black and White Photographic Process: The Making of a Negative" https://www.chem.uwec.edu/Chem115_F00/johnstim/Chemandphoto.htm

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 visited Great Smoky Mountains National Park. Ask them how a knowledge of chemistry might have supported the establishment of the region as a national park. Their initial ideas can be collected electronically via digital whiteboards or similar technology.
  - As they read, students can find information to confirm or refute their original ideas.
- After students have read and discussed the article, ask students what they learned about black and white photography.
- How important was George Masa's understanding of light to his success as a photographer?
- Ask students if they can think of other areas where history, art and chemistry overlap.

Chemistry Concepts and Standards

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Chemical change
- Ions
- Redox reactions
- Photochemistry
- Light, energy, and color

Correlations to Next Generation Science Standards

This article relates to the following performance expectations and dimensions of the 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.A: Structure and Properties of Matter
- PS.1.B: Chemical Reactions

Crosscutting Concepts:

- Structure and function
- Stability and change

Science and Engineering Practices:

- Obtaining, evaluating, and communicating information

Nature of Science:

- Science is a human endeavor.

See how *ChemMatters* correlates to the **Common Core State Standards** online.