ChemMatters®

Demystifying Everyday Chemistry

Teacher's Guide

December 2024

ACS Chemistry for Life®

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December Teacher's Guide Introduction

Lesson Ideas

Most of the articles in this issue relate chemistry to careers, especially those with engineering challenges. Encourage students to think about how they might use chemistry in their future, even if they are not scientists.

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.

Teaching Ideas for this issue:

1. "Chemistry in Pictures" on page 2 shows fenugreek seeds. Challenge students to determine which article in this issue relates to the photograph, and what is special about fenugreek.
2. "Open for Discussion" on page 4 describes the value of scientific journalists and science literacy. Ask students to give some examples from the article of the importance of scientific reporting. Ask students if they can think of other instances where science reporting plays an important role. Students who enjoy writing might consider science journalism as a career.
3. "Quick Read: Using Computational Chemistry to Build Proteins" on page 14 describes the work of the 2024 Nobel Prize recipients who used computer modeling and AI to determine the 3-D structure of proteins. Students should contemplate how AI helped solve the problem of determining protein structure. Ask them how this discovery might affect their lives in the future.
4. The "Chemistry in Person" column on page 19 describes the interesting path to becoming an astrophysicist taken by one person. Ask students how she followed her interests as she changed her focus over the years.
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

Microchips: It's a Small, Small World

December 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. Transistors were invented in the 1920s.
		2. Modern computers contain billions of transistors.
		3. Semiconductors can conduct electricity when heated.
		4. Semiconductors have always been made of silicon.
		5. The conduction band and valence band overlap in insulators.
		6. The conductivity of semiconductors may be decreased by doping with elements other than silicon.
		7. Silicon dioxide in microchips are made from highly purified sand.
		8. Microchips are made only of transistors.
		9. One microchip might have 160 billion transistors.
		10. Today's microchips are wired together with copper wire that is one nanometer thick.

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Student Reading Comprehension Questions

Name: ______________________________

Directions: Use the article to answer the questions below.

1. What did the microchip replace in computers and electronics? Why was the microchip an improvement?
2. In Band theory, what makes metals good conductors? What makes nonmetals good insulators?
3. What makes semiconductors similar to both conductors and insulators?
4. Describe the process of photolithography in the making of microchips.
5. Write your name in binary code.
6. Give some reasons why carbon nanotubes are more desirable in microchips as opposed to copper wire.
7. Explain the differences between n and p type doping. Which type is good for donating electrons, and which type is good for accepting electrons?
8. Briefly explain how the distance between the conduction band and valence band affects the transfer of electrons.
9. Using your knowledge of atomic structure and the periodic table, determine what element would be a good substitute for boron to make a p-type semiconductor for silicon, and a substitute for phosphorus in an n-type semiconductor for silicon.
10. How do you think even the smallest impurities can affect a microchip? Give a few examples.
11. There is talk about people embedding microchips in their bodies. These microchips would contain personal information about the person. List some pros and cons for a person having a microchip embedded in their skin.

Graphic Organizer

Name: ______________________________

Directions: As you read, use information from the article to complete the graphic organizer below to describe how microchips are created.

Component	How they are made/What they are	What they do
Transistors		
Semiconductors		
Microchips		
Future challenges		

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. What did the microchip replace in computers and electronics? Why was the microchip an improvement?
   The microchip replaced vacuum tubes. These vacuum tubes were much larger and bulkier, as well as a lot slower.

2. In Band theory, what makes metals good conductors? What makes nonmetals good insulators?
   Metals are good conductors because the conductor band and valence band overlap, allowing the electrons to move freely. In nonmetals, the conduction band and the valence band are far apart, so the energy needed to move between the bands is too large for electrons to move from one band to the other.

3. What makes semiconductors similar to both conductors and insulators?
   In a semiconductor, the conduction band and valence band are very close, but they do not overlap like an insulator. Electrons, however, can cross from one band to another in a semiconductor, but it is not as easy as when they overlap, like in a metal. So, in a semiconductor there is less movement of electrons between the two bands than in a conductor, but there is some movement.

4. Describe the process of photolithography in the making of microchips
   A pattern is etched into the microchip to expose the silicon so it can be either p-doped or n-doped depending on what is needed for the microchip.

5. Write your name in binary code.
   Answers will vary. The class can share and note similarities and differences.

6. Give some reasons why carbon nanotubes are more desirable in microchips as opposed to copper wire.
   Carbon nanotubes are much lighter and create less resistance in electron flow.

7. Explain the differences between n and p type doping. Which type is good for donating electrons, and which type is good for accepting electrons?
   N-type doping adds an atom with one less electron in the valence shell (i.e. boron). There is a hole that is available into which an electron can move. P type doping adds an atom with an extra valence electron (i.e. phosphorus). This provides an extra electron to move in the conduction band.

8. Briefly explain how the distance between the conduction band and valence band affects the transfer of electrons.
   The distance between the valence band and the conduction band is called the band gap. Materials with a big band gap, large distance between the valence and conduction band, are insulators, they do not conduct electricity. If the distance is small to negligible, no band gap essentially, the material is a

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conductor. If the distance is somewhere between large and overlapping, the material is a semiconductor.

9. Using your knowledge of atomic structure and the periodic table, determine what element would be a good substitute for boron to make a p-type semiconductor for silicon, and a substitute for phosphorus in an n-type semiconductor for silicon.

   Boron has 3 valence electrons, one less than silicon which has 4, thus providing the "hole" needed to accept an outside electron. Any element in group 13 has the same valence structure. So, aluminum and gallium would be good substitutes.

   Phosphorus has 5 valence electrons, one more than silicon, thus providing the extra electron needed to transfer. The elements in group 15 have the same valence structure. So, arsenic would be a good substitute.

10. How do you think even the smallest impurities can affect a microchip? Give a few examples.

    Any impurities can disrupt the transfer of electrons, thus making the chip ineffective and cause the electronics to not function properly. Also, impurities may cause overheating because of too much resistance.

11. There is talk about people embedding microchips in their bodies. These microchips would contain personal information about the person. List some pros and cons for a person having a microchip embedded in their skin.

    Answers may vary. Some pros could include easy identification, medical records could be easily retrieved and help in finding missing children. Some cons could include easy stealing the information on the chip, or lack of privacy since the person can be tracked.

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**
  - Chemistry of Art through Alloys and Metal Plating
    https://teachchemistry.org/classroom-resources/chemistry-of-art-through-alloys-and-metal-plating
  - Molding Metal
    https://teachchemistry.org/classroom-resources/molding-metal
- **Lessons and lesson plans**
  - Observing Properties of Those Marvelous Metals
    https://teachchemistry.org/classroom-resources/observing-properties-of-those-marvelous-metals
  - Synthetic Materials Through History
    https://teachchemistry.org/classroom-resources/synthetic-materials-through-history
  - Elements 014: Silicon: Electronic devices, glass, and lubricants
    https://www.compoundchem.com/2019/03/22/iypt014-silicon/
- **Projects and extension activities**
  - How Are Microchips Made?
    https://youtu.be/g8Qav3vIv9s?si=M8a15-C8mkPpXNYJ

Teaching Strategies

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

- Alternative to Anticipation Guide: Before reading, ask students where microchips can be found in their everyday lives. Ask them what they know about microchips. 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 a knowledge of chemistry helped engineers develop the tiny microchips we use today.

Chemistry Concepts and Standards

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Atomic structure
- Electrons
- Valence electrons

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 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:

- PS.1.A: Structure and properties of matter
- ETS1.C: Optimizing the design solution

Crosscutting Concepts:

- Scale, proportion, and quantity
- Structure and function

Science and Engineering Practices:

- Constructing explanations (for science) and designing 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.

Teacher’s Guide

From Blue to Bright: The Path to White LEDs

December 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. The first LED produced red light.
		2. Carborundum contains silicon.
		3. LEDs contain semiconductors that allow electrons to flow in only one direction.
		4. Semiconductors in LEDs are doped with different elements to produce different colors.
		5. LED light is monochromatic.
		6. Energy from a battery is converted into light (photons) in LEDs.
		7. Red and green LEDs were developed before blue LEDs.
		8. The people who developed red LEDs were awarded the Nobel Prize in Chemistry.
		9. Mixing red, green, and blue light produces white light.
		10. LED lights use more energy than incandescent lights.

Student Reading Comprehension Questions

Name: ______________________________

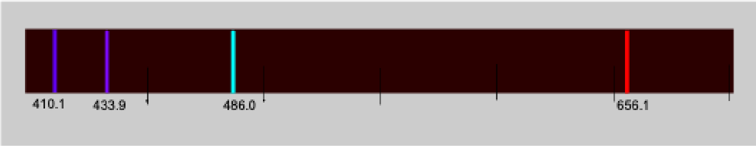
Directions: Use the article to answer the questions below.

Force and Potential Energy Primer

The attractive force between a positively charged species and a negatively charged species acts to decrease the potential energy that results from the interaction. The potential energy is lowest when the two particles are as close to each other as possible within the system. For this reason, when an electron is close to a fixed positive charge, but not close enough, the attractive force will cause the electron to move closer, thus releasing potential energy as kinetic energy in the process. Since an electron is a charged particle, its motion creates the dual electric and magnetic field oscillation known as electromagnetic radiation (light).

A Familiar Example

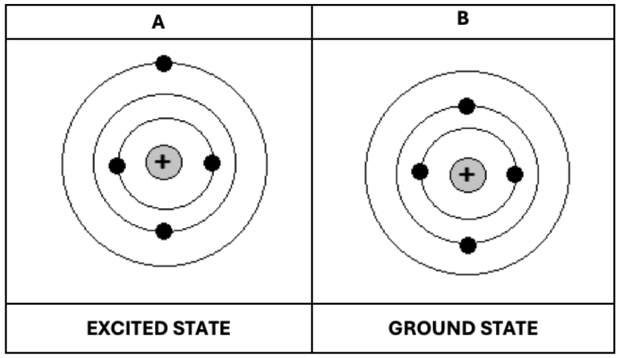
The emission spectrum for an atom is created when energy is continually supplied to a pure sample of gaseous atoms. When absorbing energy, there are several different energy levels where an excited electron may end up. When the electron drops back to where it started, it gives off energy in the form of electromagnetic radiation (light). While energy is supplied, electrons will alternately absorb energy to become excited, then release energy to return to their starting point, resulting in a continual emission of photons (light) that contain the amount of energy a given electron releases when returning to the starting point. Since there are a limited number of energy levels in an atom, there are only a select number of values that represent the different quantities of energy (quanta) released by de-exciting electrons. The visible portion of the hydrogen emission spectrum is shown in the image below. Each of the four colors represent a specific quantity of energy that an electron could release to de-excite to get closer to the nucleus.



1. An LED is a Light-Emitting Diode.
    a. What is meant by "Light-Emitting"?
    b. A "diode" is an electronic device with two sides that are arranged so that electricity can only flow in one direction and will be stopped if set up backwards. Which subatomic particle in an atom is most involved in the flow of electricity?

2. Diodes are made from "semiconductors". If metals are generally considered to be conductors, then what type of element would be a semiconductor? Where are these elements located on the periodic table?

3. The following two Models represent the same atom. Model B shows the electrons in their ground state (lowest energy), and Model A shows them in an excited state (higher energy).



   a. In what # energy level (n) is the excited electron in Model A?
   b. Describe how the position of the electron in the excited state in Model A would need to change to enter the ground state as pictured in Model B.
   c. Using the information in the Primer, explain how the electron changed from Model A to Model B, using concepts of potential energy and attractive force.
   d. In what form is the energy released from the electron returning to the ground state released?

4. In a semiconductor made from pure silicon, the distance between the valence band (where all the electrons are in the lowest energy level) and the conduction band is large enough to require a lot of energy for electrons to move. Very pure silicon is a weak semiconductor. To improve its conductivity, it is doped with other elements.
   a. What is meant by “doping”?
   b. Draw a Lewis Dot Diagram for each of the following atoms: silicon, phosphorus, and gallium.
   c. Explain why replacing some of the silicon atoms in a network with phosphorus allows for greater conductivity than pure silicon.
   d. Explain why replacing some of the silicon atoms in a network with gallium allows for greater conductivity than pure silicon.
   e. Explain the difference between n-type semiconductors and p-type semiconductors.
   f. Examine the diode model on page 10. A diode is created by connecting an n-type semiconductor to a p-type semiconductor. When electricity is run through the diode, it causes electrons from one side to combine with the positive holes on the other side. Using concepts of potential energy and attractive force, explain why this combination process causes light to be released from the diode.

5. If you want to make white light by mixing the light from a combination of three different LEDs that each produce a single color, what three colors could you use?

6. Examine the color wheel of light on page 11. Where the red and blue overlap, there is a pinkish color called magenta. What one other light color could be mixed with magenta light to create white light?

Name: ______________________________

Graphic Organizer

Directions: As you read, complete the graphic organizer below to explain LED light.

	What is it?	How is it produced?
Electroluminescence		
Diode		
Red LED		
Green LED		
Blue LED		
White LED		
Advantages of LEDs		

Summary: On the back of this sheet, write three interesting facts you learned from the article.

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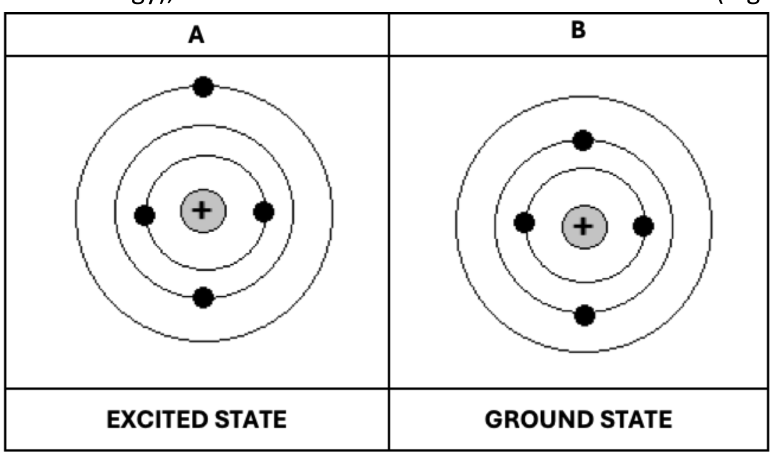
Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. An LED is a Light-Emitting Diode.
   a. What is meant by "Light-Emitting"?
   That something gives off light. When light in the visible range is given off, a glow can be seen.
   b. A "diode" is an electronic device with two sides that are arranged so that electricity can only flow in one direction and will be stopped if set up backwards. Which subatomic particle in an atom is most involved in the flow of electricity?
   An atom is made of protons, neutrons, and electrons. The electrons, which are on the outside of an atom, are what is "flowing" through a material when electricity is generated.

2. Diodes are made from "semiconductors". If metals are generally considered to be conductors, then what type of element would be a semiconductor? Where are these elements located on the periodic table?
   Metalloids. Generally, metals are conductors, nonmetals are insulators, and metalloids can be somewhere in between the two. Metalloids are located between the metals and the nonmetals on the periodic table. They are arranged in a diagonal line toward the right of the table from boron to astatine. [Tennessine might also fall into this pattern, but, as it is a more recently created element, its properties are not yet fully known.]

3. The following two Models represent the same atom. Model B shows the electrons in their ground state (lowest energy), and Model A shows them in an excited state (higher energy).



   a. In what # energy level (n) is the excited electron in Model A? n= 3
   b. Describe how the position of the electron in the excited state in Model A would need to change to enter the ground state as pictured in Model B.
   The excited electron in n=3 moves closer to the nucleus into n=2. It can't go any closer because the first level already has as many electrons as are able to be in that space.
   c. Using the information in the Primer, explain how the electron changed from Model A to Model B, using concepts of potential energy and attractive force.
   In Model A, the electron was already excited (had gained energy). Since it is still near the nucleus,

which has a positive charge, it is attracted toward it. The attractive force pulls the electron closer, reducing its potential energy, and creating electromagnetic radiation to release the extra energy.

d. In what form is the energy released from the electron returning to the ground state released?
Energy in the form of electromagnetic radiation. Depending on the quantity of energy released it might be in the visible region of the electromagnetic spectrum.

4. In a semiconductor made from pure silicon, the distance between the valence band (where all the electrons are in the lowest energy level) and the conduction band is large enough to require a lot of energy for electrons to move. Very pure silicon is a weak semiconductor. To improve its conductivity, it is doped with other elements.

a. What is meant by “doping”?
Adding different metalloid atoms that have a different number of valence electrons to pure silicon.

b. Draw a Lewis Dot Diagram for each of the following atoms: silicon, phosphorus, and gallium.

c. Explain why replacing some of the silicon atoms in a network with phosphorus allows for greater conductivity than pure silicon.
A network of silicon atoms has a set number of electrons arranged throughout the structure. If a phosphorus atom replaces a silicon, there will be one more electron than could normally exist. This makes that electron “mobile” or easily moved, because there is not a set placement for it. It makes the valence band a little bigger and starts to close down the gap between the valence and conduction band.

d. Explain why replacing some of the silicon atoms in a network with gallium allows for greater conductivity than pure silicon.
A network of silicon atoms has a set number of electrons arranged throughout the structure. If a gallium atom replaces a silicon, there will be one less electron than could normally exist. This makes an area of positive charge. This area is called a “hole”, because an electron is “missing” from that spot. This allows for greater conductivity because the hole can move when other electrons in the structure move over to fill it, leaving a different hole in their place. This doesn’t impact the valence and conduction bands but does allow electrons to move within the valence band.

e. Explain the difference between n-type semiconductors and p-type semiconductors.
The n-type semiconductors are those where the atom being doped into the structure has more valence electrons than the original atoms, meaning the mobile charge is negative (n). The p-type semiconductors are those where the atom being doped into the structure has less valence electrons than the original atoms, meaning the mobile charge is the positive hole (p).

f. Examine the diode model on page 10. A diode is created by connecting an n-type semiconductor to a p-type semiconductor. When electricity is run through the diode, it causes electrons from one side to combine with the positive holes on the other side. Using concepts of potential energy and attractive force, explain why this combination process causes light to be released from the diode.
When two unlike charges are near each other, they will be attracted. The attraction causes them to move toward each other until they are as close as possible to each other, reducing the potential

energy. Since they are moving charges, this potential energy is released as electromagnetic radiation (light).

5. If you want to make white light by mixing the light from a combination of three different LEDs that each produce a single color, what three colors could you use?
   Red, green, and blue are the primary colors of light. Mixing these three gives white light. You could also mix the secondary colors of yellow, magenta, and cyan.

6. Examine the color wheel of light on page 11. Where the red and blue overlap, there is a pinkish color called magenta. What one other light color could be mixed with magenta light to create white light?
   Green. Complementary colors (those directly across from each other on the color wheel) mix to create white light.

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**
  - This article would work well after a lab on atomic emission, either using spectrum tubes or flame tests with salts.

- **Lessons and lesson plans**
  - MRSEC lesson modules *Light-Emitting Diodes (LEDs)* https://chemistry.beloit.edu/edetc/modules/HighSchool/LEDs/index.html or https://education.mrsec.wisc.edu/led-high-school-teaching-module/

- **Simulations**
  - AACT (Members only) *The Electromagnetic Spectrum Animation* https://teachchemistry.org/classroom-resources/the-electromagnetic-spectrum-animation; and the associated lesson https://teachchemistry.org/classroom-resources/animation-activity-electromagnetic-spectrum
  - PhET simulation w/ associated lessons *Semiconductors* https://phet.colorado.edu/en/simulations/semiconductor
  - Phet simulation w/ associated lessons *Color Vision* https://phet.colorado.edu/en/simulations/color-vision

- **Projects and extension activities**
  - AACT (Members only) *Understanding Light & Color* https://teachchemistry.org/classroom-resources/understanding-light-and-color

Teaching Strategies

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

A great way to start off a unit involving light is to hand out spectroscopes or diffraction gratings and let students walk around observing different kinds of light sources through the spectroscope. Class discussion can lead to:

- Identifying similarities and differences in observations from different light sources
- Prompting students to ask questions about what they are seeing
- Asking students about other things that glow and why they glow
- **Possible misconception:** Students probably have had much more experience combining pigments (paint) rather than light (energy), so they may not realize that red, green, and blue light combine to make white light. Prior to reading, you may want to discuss what they have learned about combining colors of light. Here is a helpful website: https://www.amnh.org/explore/ology/physics/play-with-color-and-light
- **Alternative to Anticipation Guide:** Before reading, ask students where they have seen LEDs, and what colors they are. 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 what they learned about LEDs, and how the information in the article has changed their ideas about LEDs.

Chemistry Concepts and Standards

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Atomic structure
- Electrons
- Periodic table
- Electromagnetic 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 level of atoms.

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.1.A: Structure and properties of matter
- PS3.D: Energy in Chemical Processes
- ETS1.C: Optimizing the design solution

Crosscutting Concepts:

- Energy and matter
- Structure and function

Science and Engineering Practices:

- Constructing explanations (for science) and designing 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

Recycling: Plastic or Metal?

December 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. We can reach a "zero-waste" society through science alone.
		2. HDPE and LDPE have different chemical formulas.
		3. Monomers for making plastic come from oil.
		4. About 25% of plastic today is recycled.
		5. Product diversity complicates recycling for plastics but not metals.
		6. The United States recycles more PET plastic than European countries.
		7. Steel is an alloy of iron and carbon and other elements.
		8. Steel is the most recycled material.
		9. Plastics are recycled more than metals.
		10. "Cradle-to-cradle" design considers how products will be disassembled after use.

Student Reading Comprehension Questions

Name: ______________________________

Directions: Use the article to answer the questions below.

1. What is a “zero-waste” society and why is it so difficult to attain?
2. Briefly describe the chemical makeup of plastic.
3. List three ways scientists produce different plastic (polymer) materials.
4. Explain how the difference in polymerization between high-density polyethylene and low-density polyethylene changes the properties and therefore, the products made from each.
5. Explain the process of mechanical recycling plastics and its main limitations.
6. Why do Europe and Asia have better recycling rates? Could this be employed in the U.S.?
7. Explain the diversity of metallic materials and how this impacts recycling.
8. What is the “most recycled material on the planet” and why is this label somewhat misleading?

Questions for Further Learning

Write your answers on another piece of paper if needed.

9. Research the compounds in oil and how they are separated into the starting materials for the plastics industry.
10. Investigate household products that are composed of metal alloys. Create a poster that shows the products, the metals used, and the properties of the resulting alloy.

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Graphic Organizer

Name: ______________________________

Directions: As you read, complete the graphic organizer below to describe the issues involved with recycling plastics and metals.

	Plastic	**Metal**
What is it made of? **Provide examples.**		
Diverse components		
Ease of recycling different types		
Challenges to recycling		
Some proposed solutions to our recycling problem		

Summary: On the back of this sheet, write a short email (3 sentences) to a friend describing what you learned about how to recycle more sustainably.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. What is a "zero-waste" society and why is it so difficult to attain?
   A "zero-waste" society is one where nothing is thrown away and recycling is maximized. This is very hard to attain because both metal and plastic recycling is very complex. In addition, current design methods would need to change to envision what will happen to products at the end of their use.

2. Briefly describe the chemical makeup of plastic.
   The raw materials for plastic come from oil. Monomers—molecules primarily composed of carbon and hydrogen atoms—are connected by covalent bonds to form polymers. Some polymers consist of thousands of monomer units. Scientists can modify the characteristics of the polymer chains to produce a wide variety of plastic with different properties.

3. List three ways scientists produce different plastic (polymer) materials.
   The three ways a polymer chemist can produce different plastics are:
   - Changing the starting monomer. Polymers get their physical and chemical properties from the monomers.
   - Cross-linking polymers. Making connections between two polymer chains changes the physical properties of the polymers. A simple example of this is the polymers in glue when borax solution is added to it, and you make slime or glue. The free-flowing polymers of the glue are cross-linked to make a more rigid fluid.
   - Mix the different kinds of monomers that are used. Using two different monomers can make a plastic with physical and chemical properties that are a mixture of the monomers' properties, a kind of hybrid plastic.

4. Explain how the difference in polymerization between high-density polyethylene and low-density polyethylene changes the properties and therefore, the products made from each.
   Although both high-density and low-density polyethylene have the same chemical formula, the way they are polymerized is different. High-density polyethylene is a linear polymer in which the layers pack together. This high density of layered polymer chains results in a plastic used for bottles, pipes, and buckets: hard strong plastics. Low-density polyethylene is a branched polymer in which the layers don't pack as tightly and there are a lot of open spaces within the layers. This plastic is best for garbage bags and squeeze bottles: softer, more flexible plastics.

5. Explain the process of mechanical recycling plastics and its main limitations.
   Mechanical recycling is a process of melting and reshaping materials into new products. Some plastics like polyurethane, break apart when heated instead of melting. In addition, many plastics can only undergo melting and reshaping a few times before the chain links break down, resulting in materials that are not useful.

6. Why do Europe and Asia have better recycling rates? Could this be employed in the U.S.?
   Other countries use a deposit system in which consumers pay a small fee that is refunded when they

recycle the product. One study found that if this system was adopted by the U.S., PET plastic collection would increase from one in four to more than four in five bottles. As of 2024, only four U.S. states have adopted deposits on bottles and cans to encourage recycling.

7. Explain the diversity of metallic materials and how this impacts recycling.
   Some metals are used in their elemental form, so they can be remelted over and over. However, many products are made from alloys, mixtures of metals. The addition of other elements changes the properties of the substance. While it is not difficult to separate a paper label from an aluminum can (the paper burns off) it is very difficult to separate two different metal atoms. If steel from two different sources is mixed, then the composition of the alloy (steel) that results will be unknown and may be of poorer quality.

8. What is the "most recycled material on the planet" and why is this label somewhat misleading?
   Steel, an alloy of iron and mainly carbon, is recycled much more than plastics. However, most steel remains intact in buildings and structures that are not recycled.

9. Research the compounds in oil and how they are separated into the starting materials for the plastics industry.
   Answers will focus on hydrocarbon molecules, compounds made up of mainly carbon and hydrogen atoms. The wide variety of hydrocarbons within the oil mixture are separated through cracking and fractional distillation.

10. Investigate household products that are composed of metal alloys. Create a poster that shows the products, the metals used, and the properties of the resulting alloy.
    Answers could include carbon-steel alloy used in blenders and juicers, stainless steel appliances, doorknobs made from brass, a copper-zinc alloy, and cast-iron frying pans which are made from an iron-steel alloy.

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

- ➢ Students investigate various types of plastics and their properties in the lab. The goal is to choose the best plastic material to construct a compost bin. https://teachchemistry.org/classroom-resources/the-big-six-plastics

- ➢ In this lesson, students will consider how to reclaim metals from both an environmental and economic perspective. In the lab, students will evaluate a copper recycling process. https://teachchemistry.org/classroom-resources/recycling-copper-from-e-waste

- ➢ Students create a device to sort metal paper clips from paper. Build a Recycling Sorting Machine: https://www.sciencebuddies.org/teacher-resources/lesson-plans/recycling-sorting-machine

❖ Lessons and lesson plans

- ➢ Students learn how companies are trying to increase the sustainability of plastics: "Why It's So Hard to Recycle Plastic" https://www.scientificamerican.com/article/why-its-so-hard-to-recycle-plastic/

❖ Projects and extension activities

- ➢ Students problem solve a way to separate plastics using provided density data. https://teachchemistry.org/classroom-resources/identifying-plastics-with-density-data

Teaching Strategies

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

- **Alternative to Anticipation Guide:** Before reading, ask students how recycling is done in their community. Ask them to compare recycling plastic to recycling metals.
  - As they read, students can find information to confirm or refute their original ideas.
- After they read, ask students what they learned about recycling challenges and possible solutions.

Chemistry Concepts and Standards

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Separating mixtures
- Physical properties
- Chemical properties
- Polymers
- Monomer

Correlations to Next Generation Science Standards

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

HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

Disciplinary Core Ideas:

- PS1.A: Structure and properties of matter
- ESS3.C: Human impacts on Earth systems
- ETS1.A: Defining and delimiting engineering problems

Crosscutting Concepts:

- Structure and Function
- Systems and system models

Science and Engineering Practices:

- Asking questions (for science) and defining problems (for engineering)

Nature of Science:

- Science addresses questions about the natural and material world.

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

ChemMatters
Demystifying Everyday Chemistry

Teacher's Guide

Skin Emissions

December 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. Volatile substances vaporize easily.
		2. Some VOCs (volatile organic compounds) are odorless.
		3. Currently, analytical chemists know what VOCs are in the skin emissions of most people.
		4. Gases in a mixture can be separated by gas chromatography.
		5. A mass spectrometer separates compounds according to their charge.
		6. Compounds emitted from the forehead are similar to those emitted from the armpit.
		7. Compounds in fenugreek were detected immediately after volunteers drank a beverage containing fenugreek.
		8. Healthy skin has a pH of 7.
		9. The VOC emissions from older and younger people are the same.
		10. In the future, skin VOC diagnostics may be able to detect diseases inside the body.

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Student Reading Comprehension Questions

Name: ______________________________

Directions: Use the article to answer the questions below.

1. What are volatile organic compounds (VOCs), and why do they have a high vapor pressure?
2. How do London dispersion forces affect the volatility of VOCs?
3. What types of information might skin-emitted VOCs provide about a person's health?
4. What challenges do analytical chemists face when designing sensors for skin VOCs?
5. What is the significance of using mass spectrometry in analyzing VOCs emitted from the skin?
6. Describe how gas chromatography is used to separate VOCs before mass spectrometry.
7. What role do nitrogen and helium play in gas chromatography when analyzing VOCs?
8. How did researchers use a "Mass Specthoscope" to analyze skin emissions, and what was one advantage of this method?
9. What is oxidative stress, and how does it relate to VOCs detected from aging skin?
10. What differences in VOC emissions did researchers observe between younger and older individuals?
11. Why might scientists be interested in the VOC 2-ethyl-1-hexanol, which was found on nearly all test participants?
12. What did researchers discover about the relationship between skin pH and VOC emissions?
13. Explain the significance of aldehydes like nonanal and decanal in skin emissions.
14. How did researchers design a colorimetric pH sensor using bromocresol green, and what does it indicate?
15. Why is understanding the baseline VOC profile important before using VOCs as biomarkers for health diagnostics?

Graphic Organizer

Name: ______________________________

Directions: As you read, use information from the article to complete the graphic organizer below to describe terms used in the article.

	Meaning or Description	**Relationship to skin emissions**
VOCs		
Chromatography		
Mass spectrometry		
"Mass specthoscope"		
pH		
Oxidative stress		

Summary: How does the information in the article relate to you, now or in the future? Answer in 1 or 2 sentences.

Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. What are volatile organic compounds (VOCs), and why do they have a high vapor pressure?
   VOCs are carbon-based molecules that easily vaporize due to their high vapor pressure. This high vapor pressure results from their weak intermolecular attractions, which are primarily London dispersion forces.

2. How do London dispersion forces affect the volatility of VOCs?
   London dispersion forces are weak interactions between molecules, these interactions can be easily disrupted, sometimes just by gentle shaking. This property makes VOCs highly volatile, enabling them to transition into gas form readily.

3. What types of information might skin-emitted VOCs provide about a person's health?
   Skin-emitted VOCs can potentially indicate health conditions, track metabolic processes, and signal changes or anomalies in the body that might serve as biomarkers for diseases.

4. What challenges do analytical chemists face when designing sensors for skin VOCs?
   Analytical chemists face challenges such as establishing a baseline of common VOCs across different individuals and detecting VOCs at low concentrations while ensuring the sensors are compatible with wearable technology.

5. What is the significance of using mass spectrometry in analyzing VOCs emitted from the skin?
   Mass spectrometry helps identify the individual VOCs by ionizing and analyzing them based on their mass-to-charge ratio. This technique enables chemists to detect and profile a wide range of skin-emitted VOCs.

6. Describe how gas chromatography is used to separate VOCs before mass spectrometry.
   In gas chromatography, VOCs are separated based on their interactions with the stationary phase (high-molecular-weight wax) and the mobile phase (inert gas). This process allows chemists to isolate different VOCs before analyzing them with mass spectrometry.

7. What role do nitrogen and helium play in gas chromatography when analyzing VOCs?
   Nitrogen or helium is used as the mobile phase in gas chromatography to move VOCs through the column for separation based on their molecular interactions and weight.

8. How did researchers use a "Mass Specthoscope" to analyze skin emissions, and what was one advantage of this method?
   Researchers used the Mass Specthoscope, a handheld probe, to blow nitrogen over the skin and capture VOCs for immediate analysis by a mass spectrometer. The advantage of this method is real-time analysis without a lengthy preconcentration step—collecting a lot of samples and then reducing its volume.

9. What is oxidative stress, and how does it relate to VOCs detected from aging skin?
   Oxidative stress is caused by the presence of reactive species with unpaired electrons that damage cells and tissues. It leads to the production of aldehydes, such as nonanal and decanal, which are emitted in higher levels in aging skin.

10. What differences in VOC emissions did researchers observe between younger and older individuals?
    Older individuals were found to emit more aldehydes and showed differences in the production of certain VOCs, such as a lower release of acetic acid, which is linked to an increase in skin pH.

11. Why might scientists be interested in the VOC 2-ethyl-1-hexanol, which was found on nearly all test participants?
    Scientists are interested in 2-ethyl-1-hexanol because it consistently appears in nearly all individuals' skin emissions, although its source within the human body remains uncertain.

12. What did researchers discover about the relationship between skin pH and VOC emissions?
    Researchers found that VOCs can be used to determine skin pH levels, which are typically acidic in healthy individuals. Changes in VOC emissions can indicate shifts in skin pH that might signal various health conditions.

13. Explain the significance of aldehydes like nonanal and decanal in skin emissions.
    These aldehydes are products of oxidative stress reactions in the skin and are found in higher concentrations as individuals age, suggesting they could be biomarkers for aging and related processes.

14. How did researchers design a colorimetric pH sensor using bromocresol green, and what does it indicate?
    Researchers used bromocresol green in a gel-like material applied to cellulose patches. When these patches absorbed acidic or basic VOCs, their color changed, revealing the skin's pH.

15. Why is understanding the baseline VOC profile important before using VOCs as biomarkers for health diagnostics?
    Establishing a baseline profile ensures that common, non-disease-related VOCs are distinguished from those potentially linked to health conditions. This helps in accurately identifying biomarkers for diagnosing diseases.

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.

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0	Not acceptable	So incomplete that no judgment can be made about student understanding

Additional Resources and Teaching Strategies

Additional Resources

❖ Labs and demonstrations

- ➢ In the Clean Air chemistry lab, students measure the mass and concentration of CO2 from burning a candle over time. This is then connected to the burning of fuels and the contribution to air pollution. Students also build a lego model to illustrate how a catalytic converter works. https://teachchemistry.org/classroom-resources/clean-air-chemistry

❖ Lessons and lesson plans

- ➢ Students can watch a video about VOCs from the American Lung Association and explore sources of VOCs on their website: https://www.lung.org/clean-air/indoor-air/indoor-air-pollutants/volatile-organic-compounds#:~:text=Volatile%20organic%20compounds%2C%20or%20VOCs%2C%20are%20gases%20that%20are%20emitted,they%20are%20in%20the%20air.

❖ Projects and extension activities

- ➢ Students can prototype an air quality sensor using a breadboard and then test it by measuring VOCs. https://www.teachengineering.org/activities/view/cub_air_lesson09_activity3

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 use wearable technology to monitor their health. Ask them to consider how monitoring emissions from their skin might be helpful in the future, and what challenges analytical chemists might have in developing technology to monitor skin emissions. 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 a knowledge of chemistry can help engineers develop new technology to monitor our health and diagnose medical conditions.

Chemistry Concepts and Standards

Connections to Chemistry Concepts

The following chemistry concepts are highlighted in this article:

- Intermolecular forces
- pH
- Indicators
- Molecular structure
- Isomers
- Mixtures

Correlations to Next Generation Science Standards

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

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

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
- ETS1.A: Defining and delimiting engineering problems

Crosscutting Concepts:

- Patterns
- Structure and function

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.