

**December 2016/January 2017 Teacher's Guide for**

***No Smartphones, No TV, No Computers:***

***Life without Rare-Earth Metals***

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# About the Guide

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Articles from past issues of *ChemMatters* and related Teacher’s Guides can be accessed from a DVD that is available from the American Chemical Society for $42. The DVD contains the entire 30-year publication of *ChemMatters* issues, from February 1983 to April 2013, along with all the related Teacher’s Guides since they were first created with the February 1990 issue of *ChemMatters*.

The DVD also includes Article, Title, and Keyword Indexes that cover all issues from February 1983 to April 2013. A search function (similar to a Google search of keywords) is also available on the DVD.

The *ChemMatters* DVD can be purchased by calling 1-800-227-5558. Purchase information can also be found online at <http://tinyurl.com/o37s9x2>.

# Student Questions

**Life without Rare-Earth Metals**

* 1. List eight (8) common products that use rare-earth elements.
  2. If rare-earth elements look alike and act similarly, how are they different?
  3. Why are rare-earth elements sometimes called “chemical vitamins”?
  4. Starting in the 1970s, color televisions contained minerals with rare-earth elements. Which elements were used, and what colors did they produce?
  5. Describe how the process of luminescence works.
  6. What is an alloy?
  7. Are rare-earth metals really rare? Explain.
  8. Which country has the largest supply of rare-earth metals?
  9. Which rare-earth element is used as a pink coloring agent and found in lasers used to remove acne scars and tattoos?
  10. The Toyota Prius nickel-metal hybrid battery is strengthened with which rare-earth metal?
  11. List two rare-earth elements that are used to improve magnets.

# Answers to Student Questions

**(taken from the article)**

* + 1. **List eight (8) common products that use rare-earth elements?**

*a. Some common products  
 that use rare-earth  
 elements are:*

*smartphones  
baseball bats  
televisions  
batteries  
cars  
electric guitars*

*b. High-tech products  
 include:*

*night-vision goggles  
sunglass lenses  
lasers  
magnets  
ear buds*

*c. Sporting goods  
 products include:*

*Bicycles  
baseball bats  
golf clubs  
hockey sticks*

* + 1. **If rare-earth elements look alike and act similarly, how are they different?**

*Each rare-earth element has its own atomic number and subtle differences inside the atoms that cause them to be different from each other.*

* + 1. **Why are rare-earth elements sometimes called “chemical vitamins”?**

*Rare-earth elements are sometimes called “chemical vitamins” because small amounts, as little as 0.2%, can be alloyed with other materials and vastly affect their properties.*

* + 1. **Starting in the 1970s, color televisions contained minerals with rare-earth elements. Which elements were used, and what colors did they produce?**

*Color televisions in the 1970s used minerals containing europium and yttrium to make red light, and a different europium compound to produce blue light. Terbium produces green and blue light, and terbium and europium together can produce a brilliant white light.*

* + 1. **Describe how the process of luminescence works.**

*In luminescence, electrons in atoms absorb energy and move from their lower ground states to higher, excited states. When the excited electrons release energy by returning to their lower ground states, the energy thus produced can be in the form of visible light.*

* + 1. **What is an alloy?**

*Alloys are mixtures of metals, or a mixture of a metal with another element.*

* + 1. **Are rare-earth metals really rare? Explain.**

*No, rare-earth metals aren’t really rare; they have been found all over the globe. All but one of the rare-earth elements are more abundant than gold. They are referred to as rare because, even though they are relatively common in the earth's crust, their concentration is so low that it is not economical to extract them.*

* + 1. **Which country has the largest supply of rare-earth metals?**

*China has the largest supply of rare-earth metals.*

* + 1. **Which rare-earth element is used as a pink coloring agent and found in lasers used to remove acne scars and tattoos?**

*Erbium (Er) is the rare-earth metal used as a pink colorant and in lasers to remove acne scars and tattoos.*

* + 1. **The Toyota Prius nickel-metal hybrid battery is strengthened with which rare-earth metal?**

*The Toyota Prius batteries are strengthened with lanthanum.*

* + 1. **List two rare-earth elements that are used to improve magnets.**

*Rare-earth elements used to enhance magnets include*

*a. neodymium, and b. samarium*

# Anticipation Guide

Anticipation guides help engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students’ responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

**Directions:**  *Before reading*, in the first column, write “A” or “D,” indicating your agreement or disagreement with each statement. 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. Rare-earth metals have very similar physical and chemical properties. |
|  |  | 1. Most rare-earth elements were mined in the same town in Sweden. |
|  |  | 1. All rare-earth elements are in the lanthanide row on the periodic table of elements. |
|  |  | 1. Rare-earth metals provide more strength when alloyed with other metals. |
|  |  | 1. Rare-earth elements were used in color television tubes in the 1970s. |
|  |  | 1. Rare-earth elements are used in sports equipment. |
|  |  | 1. Nanoparticles of scandium surrounded by lithium are incorporated into aluminum to create more powerful but lighter weight hockey sticks. |
|  |  | 1. Most rare-earth elements are more common than gold. |
|  |  | 1. Rare-earth elements are easy to separate from their minerals. |
|  |  | 1. The United States is the largest producer or rare-earth elements. |

# Reading Strategies

These graphic organizers are provided to help students locate and analyze information from the articles. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the articles. The use of bullets helps them do this. If you use these reading and writing strategies 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 |

***Teaching Strategies:***

1. Links to **Common Core Standards for Reading**:

* ELA-Literacy.RST.9-10.1:Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
* ELA-Literacy.RST.9-10.5: Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).
* ELA-Literacy.RST.11-12.1:Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
* ELA-Literacy.RST.11-12.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.

1. Links to **Common Core Standards for Writing**:

* ELA-Literacy.WHST.9-10.2F: Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).
* ELA-Literacy.WHST.11-12.1E: Provide a concluding statement or section that follows from or supports the argument presented.

1. **Vocabulary** and **concepts** that are reinforced in this issue:

* Chemical reactions
* Redox reactions
* Solubility
* Equilibrium
* Le Chatelier’s Principle
* Vitrification
* Hydrogen bonding
* Molecular structures
* Personal and community health
* Rare-earth metals
* Endothermic and exothermic reactions
* Conservation of energy

1. Some of the articles in this issue provide opportunities for students to consider how understanding chemistry can help them make informed choices as citizens and consumers.
2. Engagement suggestions:

* Prior to giving students the article “The Flint Water Crisis: What’s Really Going On?” use a Think-Pair-Share to find out what students already know about the Flint water crisis. During reading, students will reflect on what they thought and how the evidence from the article supports their original ideas (or not).
* Avoid telling students the title of the article, “No Smartphones, No TV, No Computers: Life without Rare-Earth Metals.” Instead, ask them where in their everyday lives they would find rare-earth metals and why they are used. After a short class discussion, give them the article to read.

1. To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles. The Background Information in the *ChemMatters* Teacher’s Guide has suggestions for further research and activities.

**Directions:** As you read the article, complete the graphic organizer below to describe what you learned about rare-earth metals, including where they are found in your everyday life.

|  |  |  |
| --- | --- | --- |
| 3 | **New things you learned about the chemistry of rare-earth metals through reading the article** |  |
| 2 | **Examples of rare-earth metals in your everyday life, including the products where they can be found and why they are used in that product** |  |
| 1 | **Question you have about rare-earth metals** |  |
| Contact! | **What one thing would you like to tell your friends about the importance of rare-earth metals?** |  |

# Connections to Chemistry Concepts

**(for correlation to course curriculum)**

1. **Metals**—The rare-earth elements are all metals. Students are familiar with common metals such as iron, copper, and silver, but emphasizing important, but less well known, metals such as the rare-earth metals may expand their understanding of metals. Teachers may include the rare-earth elements in discussions of properties of metals and in the organization of the periodic table into metals and nonmetals.
2. **Alloys**—Alloys are an example of solid-solid mixtures and can be discussed in the curriculum with types of mixtures. Because all alloys contain at least one metal, they can be discussed with students when studying the properties of metals.
3. **Atomic emission spectra**—The electrons in rare-earth compounds make energy changes and can release light, which can be used in television, smartphone, or other display devices. Teachers can include examples of rare-earth emissions when discussing electrons and quantum theory.
4. **Material science**—Rare-earth elements are used in many household products. Scientists have the ability to manipulate the properties of materials to suit human needs.
5. **Lanthanides**—The majority of rare-earth elements are classified as lanthanide elements. These elements have an f-block electron configuration.
6. **Atomic number**—While the rare-earth elements are similar to each other in some aspects, they are unique elements, each with a different atomic number.

# Possible Student Misconceptions

**(to aid teacher in addressing misconceptions)**

1. **“There are lots of other materials available that we can use to substitute for the rare-earth elements in smartphones and our other electronic technology.”** *Many rare-earth elements have NO substitutes, and others have substitutes that work only poorly, compared to the “real thing”.*
2. **“Rare-earth elements are rare.”** *At the time of their discoveries, the rare-earth elements were difficult to chemically separate and were thought to be in low abundance in the earth's crust. However, deposits of the rare-earth elements can be found in many countries, and all but promethium are more abundant than gold. These elements can be found in many large rock formations, but their abundance does not make it economical to extract them, except from places (mines) where their concentration is greater.*
3. ***"If rare-earth elements are not really rare, why are they called rare-earths****?" The history of the elements and their early production from minerals led to their misleading name. In the late 1700s when the earliest rear-earth elements were discovered, the element was called an "earth" if the pure metal could not be extracted from its mineral by heating the mineral with coal. The separation of the pure metal from its mineral (usually oxide) form took a more extensive chemical process than heat. In addition, these elements were considered rare when they were initially discovered; therefore, they were called rare-earth elements.*
4. **“There are mines for specific rare-earth elements just like there are mines for copper, gold, iron, or other metals.”** *Typically, the rare-earth elements are found in mines where the elements are in an oxide (earth) chemical compound. These metal oxides are often grouped together within the same mineral deposit. So, unlike a gold mine or a lead mine that produces primarily one metal, the rare-earth element mines produce many metals from the same site.*
5. **“Recycling rare-earth elements can conserve our supply and make them less expensive and more abundant.”** *Recycling materials is always a smart idea! Unfortunately, it is costly and difficult to recycle many of the rare-earth elements. These elements are often used as a metal additive to form alloys with other metals, and their concentrations in the alloys are low. In addition, the process of separating the rare-earth metals from the alloy is chemically challenging and expensive. Much of the e-waste from consumer electronics goes to China, India, and other countries where pieces might be reused, but currently, very little rare-earth wastes are recycled.*
6. **"The United States has rare-earth metal mines and can produce most of these metals that we need.”** *The U.S. cannot produce the quantity of rare-earth metals that we need for consumer and military uses. Currently, the U.S. has only one commercial rare-earth mine, the Mountain Pass mine, near the California/Nevada border along I-15 in between Barstow, CA, and Las Vegas, NV. The mine was closed in 2105 due to bankruptcy of the owner, Molycorp Minerals. There are no current plans for the mine to reopen.*

# Anticipating Student Questions

**(answers to questions students might ask in class)**

1. **“What are the specific uses of the rare-earth elements in smartphones?”**

*Here are a few specific uses for rare-earth elements in smartphones:*

* *praseodymium, gadolinium and neodymium are used in alloys in the magnets in the speaker and microphone of the smartphone*
* *neodymium, terbium and dysprosium are used in the vibration unit of the smartphone*
* *praseodymium and neodymium are used in glass (e.g., television screens) to reduce glare*
* *cerium (oxide) is used to polish glass, and to extract color from colored glass*
* *europium and yttrium (oxides) produce the red colors in television screens (and smartphone screens)*
* *europium also is used in blue phosphors in electronic screens*
* *lanthanum (oxide) is used in camera lenses and binoculars*

*(from the Teacher’s Guide for the April/May 2015 ChemMatters article “Smartphones, Smart Chemistry”)*

1. **“Where do most of the rare-earth metals come from?”** *Rare-earth metals can be found in almost any large rock formation in the world. Often, these rare-earth elements can be found in uranium mines, but it is not cost effective to extract them. However, mines in China currently produce over 95% of the rare-earth metals used in the world.*
2. **“Are rare-earth metals expensive?”** *All but the two rarest rare-earth elements (thulium and lutetium) are many times more abundant than gold. The prices of the more valuable rare-earth metals can cost about $1,000 per pound. In comparison, gold costs about $12,700 per pound.*
3. **“Why are rare-earth elements so important?”** *These rare-earth metals are important for many high-tech uses such as display screens (televisions and smartphones); electronics; superconducting magnets used in research and medical devices like MRIs, military equipment such as fighter jets and night-vision goggles, and the sports equipment that we love.*
4. **“If rare-earth metals are found all over the world, why does China produce the majority of these metals?”** *China is a very large country in area. In addition, China has an abundance of deposits where these rare-earth elements are concentrated. The biggest reason that China produces most of the rare-earth metals is that China's environmental mining laws are more lenient, so it is easier and cheaper to mine and extract these metals there than in other countries with higher environmental standards.*

# Activities

**Labs and Demos**

1. **Make a "gold" penny:** A common alloy activity is the formation of a brass coating on a copper penny. The Flinn Scientific version of this lab is safer because it does not use hot sodium hydroxide solution. *Alchemy: A Cross-Curricular Activity* provides student procedure, safety, disposal, teacher tips, and a discussion of the chemistry involved. [(https://www.flinnsci.com/media/620915/91343.pdf](file:///C:\Users\Bill\Documents\1%20OFFICE%20DOCUMENTS\CHEMATRS\2016-17%20CM%20TG\2%20December\TG%20Drafts\5%20SL\(https:\www.flinnsci.com\media\620915\91343.pdf))
2. **Form and test a lead-tin solder alloy:** The *Royal Society of Chemistry* provides the lab activity “Making an Alloy (Solder)”. The solder is produced by heating lead and tin in a crucible over a Bunsen burner. It can be cast in a sand mold or poured onto a porcelain tile to cool. The resulting alloy is tested for properties and compared to the lead and tin metals individually. The Web site include procedure, safety, and teaching notes. [NOTE: Care must be taken when heating the lead to avoid inhalation of fumes.] (<http://www.rsc.org/learn-chemistry/resource/res00001742/making-an-alloy-solder?cmpid=CMP00006705>)
3. **Conduct a virtual lab on the properties of elements:** Students can conduct a virtual lab, *What Properties Do Elements Have*, analyzing several elements for their density, flame color, melting point, and boiling point. Background information explains that elements are classified as metals, nonmetals, and metalloids. A video explains how elements are tested for these properties. Students then virtually test element unknowns and analyze their data. They conclude with generalizing how they collected information and arrived at identifying the elements. (<http://www.glencoe.com/sites/common_assets/science/virtual_labs/E21/E21.html>)
4. **Build, calibrate, and use a spectroscope:** In connection with the idea of luminescence, students can build, calibrate, and use a spectroscope to better understand the concept of atoms possessing specific energy levels and the electron transitions producing specific wavelengths of light as they fall to lower states. Thorough background information, construction directions, calibration of the instrument, and measurement of the energies of a polyelectronic element are provided. This lab may be best suited for more advanced students. (<http://www.smc.edu/projects/28/Chemistry_11_Experiments/Atomic_Spectra_B.pdf>)
5. **Build and use a homemade spectrometer:** Using an empty cereal box and a CD, students can build and then use their own spectrometer. The site includes a discussion of making spectral measurements and how the spectra are formed. While not included in the lesson, students could be instructed to observe and measure the spectra from different colored LEDs. (<http://www.scienceinschool.org/2007/issue4/spectrometer>)

**Simulations**

1. **Produce light by bombarding atoms with electrons:** The PhET simulation, “Neon Lights & Other Discharge Lamps”, provides students with the opportunity to explore atomic emission phenomena (luminescence) that was referenced in the Haines article. Students can manipulate the simulation to explore why discharge lamps produce only certain colors, and they can configure their own energy states to produce different colors. Additional teacher materials support this simulation. (<https://phet.colorado.edu/en/simulation/legacy/discharge-lamps>)

**Media**

1. **Video: Understanding our dependence on rare-earth metals:** This CBS *60 Minutes* episode, “Rare Earth Elements” (12:54), aired in 2015 and reported on our dependence on rare-earth metals along with their mining, processing, pollution, demand, and China's monopoly on these critical supplies. (<https://www.youtube.com/watch?v=N1HiX0HiAuo>)
2. **Video: The formation of elements by stars:** “Threshold 3: New Chemical Elements” (2:51) is a part of the Big History Project that the Kahn Academy supports. This concise video clearly shows how elements other than the primordial hydrogen and helium can be formed in stars. (<https://www.khanacademy.org/partner-content/big-history-project/stars-and-elements>)
3. **Video: Stellar nucleosynthesis:** This NOVA video clip, “The Elements: Forged in Stars” (3:42), provides a different look at how elements are formed in stars. The video is available with English or Spanish audio and closed captions. In addition, there are teacher support materials, including a classroom activity and discussion questions. (<http://www.pbs.org/wgbh/nova/physics/make-an-element.html>)
4. **Video: How an LED color TV works:** YouTube provides “How an LED TV Works” (3:00) to help students understand how LEDs are used with liquid crystals and polarizing filters to produce an image on the TV screen. (<https://www.youtube.com/watch?v=to_kXfBn2qk>)
5. **Video: How neodymium supermagnets are manufactured:** A magnet supplier visited China and narrates this video of the neodymium magnet manufacturing process. “How Supermagnets Are Made” (12:28) is an interesting look at the steps involved in creating these very strong magnets. (<https://www.youtube.com/watch?v=BHuWloNGo6c>)
6. **Video: Five magnet experiments:** *The Tech Blog* supplies five short video clips on its Web site. Three of these videos in *5 Mind-Bending Magnet Experiments That Might Surprise You* involve neodymium magnets. “Neodymium Magnet Meets Copper Pipe” (1:29) focuses on eddy (Foucault) currents, “Magnet vs Computer” (9:47) shows the effects of a powerful magnet on computer and other display devices, and “Grand Illusions” (2:40) shows the interactions of neodymium magnets with each other. The last two video clips are “Magnetic levitation, paramagnetism and diamagnetism”, (2:08) and “Ferrofluid” (15:01). (<http://www.techeblog.com/index.php/tech-gadget/5-mind-bending-magnet-experiments-that-might-surprise-you>)
7. **Video: Samurai swords:** NOVA has a video from 2008, Secrets of the Samurai Sword (56:00), available on DVD. The sword-making process goes from smelting the ore through forming the steel blade (an alloy). The transcript of the video and accompanying links is found at <http://www.pbs.org/wgbh/nova/ancient/secrets-samurai-sword.html>.
8. **PowerPoint: Metals and alloys:** “Metals and Alloys: Properties and Applications” is a 31-slide presentation which focuses on ferrous alloys (carbon steels, alloy steels, stainless steels, and cast irons) and nonferrous alloys (aluminum, copper, magnesium, nickel, titanium, refractory, and super alloys). Charts showing the various compositions of these alloys are included. ([www.me.uprm.edu/sundaram/inme%204007/INME4007-14.ppt](file:///C:\Users\Bill\Documents\1%20OFFICE%20DOCUMENTS\CHEMATRS\2016-17%20CM%20TG\2%20December\TG%20Drafts\5%20SL\www.me.uprm.edu\sundaram\inme%204007\INME4007-14.ppt))
9. **PowerPoint: Future directions for rare-earth materials:** This 12-slide presentation from 2010, “Future Directions in Rare Earth Research: Critical Materials for 21st Century Industry”, provides a brief overview of rare-earth materials and looks at the future for the uses and research needed. There are several colorful slides with current uses and trends in the presentation. (<http://energy.gov/sites/prod/files/Session_A3_Lograsso_Ames_0.ppt>)
10. **PowerPoint: Formation of the elements:** “The Genesis of Elements” is a 17-slide presentation describing the Big Bang Theory, formation of stars, and the synthesis of heavier elements starting from hydrogen and helium. Chemical equations help illustrate the accumulation of mass to form heavier elements. The final slide provides further references.

(<https://view.officeapps.live.com/op/view.aspx?src=http%3A%2F%2Fquiz2.chem.arizona.edu%2Fattachments%2FMiranda%2FRatnayaka.ppt>)

(<http://quiz2.chem.arizona.edu/attachments/Miranda/Ratnayaka.ppt>)

1. **Infographic: elements in a smartphone:** *Compound Interest* supplies an interesting infographic, “The Chemical Elements of a Smartphone”. Many of the elements used are rare-earth elements, and their uses in the smartphone are briefly identified. (<http://www.compoundchem.com/2014/02/19/the-chemical-elements-of-a-smartphone/>)
2. **Infographic: recycling elements in a smartphone:** *Compound Interest* follows up with another infographic, “The Recycling Rates of Smartphone Metals”. The parts of a smartphone (screen, battery, electronics, and casing) have the metals in them identified; it includes a short discussion of their use and their recycle rate by color code. Many of the metals are rare-earth metals. (<http://www.compoundchem.com/wp-content/uploads/2015/09/Recycling-Rates-of-Smartphone-Elements.png>)
3. **Infographic: the lanthanide elements:** *Compound Intere*st has another interesting infographic, “Element Infographics—The Lanthanides”. The rare-earth elements include all of the lanthanide elements plus a few more. These lanthanide elements are grouped by similar properties or uses. (<http://www.compoundchem.com/2014/01/13/element-infographics-the-lanthanides/>)
4. **Infographic: electric guitars:** *Compound Interest* provides a useful infographic, "The Chemistry of an Electric Guitar," which shows and briefly describes the use of samarium and neodymium in the guitar pickup magnets. (<http://www.compoundchem.com/2015/11/24/guitar/>)
5. **Interactive periodic table:** Students can sharpen their periodic table skills at the Merck Web site, <http://pse.merck.de/merck.php?lang=EN>. They can work with an interactive periodic table that provides facts about the elements, and they can also choose to play a quiz-style game online that tests their knowledge/understanding of the periodic table. Some of the questions are fact-based, and some are based on trends in properties of the elements. Any of these “games” could be used as part of your lesson on, or a review of, the periodic table.

**Lessons and Lesson Plans**

1. **Explore properties and structures of alloys:** This curriculum unit, *Investigating the Structure & Properties of Metal Alloys*, involves four activities which will take at least four days of instruction. The four activities are “Investigating the Internal Structure of Metals”, “What is Steel? – A Webquest”, “Synthesis of an Inexpensive Alloy”, and “Investigating the Effects of Various Heat Treatments on the Properties of a Metal”. The comprehensive, 54-page unit includes student and teacher materials, safety, background, references, and answers. (<http://cassidyjohns.webs.com/documents/S.Zaucha_Curriculum%20Project.pdf>)
2. **Study how light can be used to explore the solar system:** The NASA-funded *Project Spectra!* includes 17 lessons/activities using emission spectra (related to luminescence) in science and engineering activities for middle and high school students. Five of these activities center on spectrographs and may be useful to teachers. These lesson involve building and using either a "fancy" or an "open" spectrograph. The Web site provides teacher and student packets, and other materials, including a Flash interactive, apps, and worksheets. (<http://lasp.colorado.edu/home/education/k-12/project-spectra/>)
3. **A Web tutorial on luminescence:** The University of Southampton has a Web-based tutorial, *Web Tutorial–Luminescence*, with three parts and multiple sub-parts. The parts are “Fundamental Concepts”, “Fluorescence & Phosphorescence”, and “The Jablonski Diagram”. The first two parts would be most appropriate for students as it relates to the Haines article on luminescence and rare-earth elements. (<http://www.l4labs.soton.ac.uk/index.htm?http://www.l4labs.soton.ac.uk/tutorials/lum/lum.htm>)
4. **LEDs and the periodic table:** This is an entire module to introduce students to using the periodic table to customize the properties of materials. There are background information pages on LEDs, writing activities, activities with LEDs, demonstrations, and video support. Detailed teacher information and support as well as student materials are provided. The teacher materials are extremely detailed and complete for the 13-day unit. (<http://education.mrsec.wisc.edu/81.htm>)

**Projects and Extension Activities**

1. **Explore the Curie point of a magnet:** The *Exploratorium* provides an activity, “Curie Point”, which can be conducted at home. Students use a ceramic magnet, 6-V lantern battery, and other household items to heat the magnet and observe how its magnetism changes with temperature. Procedures with pictures and student questions to stimulate learning are provided. (<http://www.exploratorium.edu/snacks/curie-point>)
2. **Learn about metals:** The *Home Science Tools* Web site supplies a lab, “Metals”, where students can conduct two activities investigating properties of metals and alloys at home. The first activity directs students to study the conductivity of metals. The second uses a galvanized nail and a penny to copper plate the nail. Directions, basic safety, and a connection to metal salts used in fireworks is provided on the Web site. (<http://www.hometrainingtools.com/a/metals-101-science-explorations-newsletter>)
3. **Debate on the need for rare-earth metals versus their environmental impact:** Direct the students to elect three students to serve as judges for the debate. Allow the remaining students to choose whether to represent the side justifying the mining, processing, and use of rare-earth metals or the side defending the vast economic and environmental impact of these metals. Each group should research information including costs and long-term projections for the United States as well as for China and other rare-earth producing countries. Students should have multiple speakers in their presentation, some type of visuals or graphics, and a rebuttal time. The elected judges will decide the outcome of the debate and justify their decision. A writing extension could be assigned where students summarize both sides of the debate, the decision of the judges, and a personal reflection of what they have learned as well as their opinion of the judges' decision.
4. **Research the metallic elements in a smartphone:** You can assign each student a different metal used in the smartphone and ask them to research and find out the chemical nature of the metal’s ores, where geographically the ores are found, and how the ores are refined into metal. You may choose to ask your students to pay special attention to any issues of geopolitics or economics that relate to their assigned metal. (For example, you may ask the student assigned aluminum to consider why Jamaica is such a poor country despite producing most of the world’s bauxite aluminum ore.) You may ask your students to present their findings as a written paper, a class presentation, a poster, or in some other medium. (fromthe Teacher’s Guide for the April/May 2015 *ChemMatters* article “Smartphones, Smart Chemistry”)

# References

**(non-Web-based information sources)**

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles   
published from the magazine’s inception in October 1983 through April 2013; all available Teacher’s Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [**http://ww.acs.org/chemmatters**](http://www.acs.org/chemmatters)**. Click on the “Teacher’s Guide” tab to the left, directly under the “*ChemMatters Online"* logo and, on the new page, click on “Get the past 30 Years of *ChemMatters* on DVD!” (the icon on the right of the screen).**

**Selected articles and the complete set of   
Teacher’s Guides for all issues from the past three   
years are available free online at the same Web site, above. Click on the “Issues” tab just below the logo, *“ChemMatters Online”*.**



***30* Years of *ChemMatters !***

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One of the earliest issues in *ChemMatters* included an article on stars. Students may enjoy a look back at this article on the origin of the elements. (Finkbeiner, A. Star Born: The Origin of the Elements. *ChemMatters*, 1984, *2* (3), pp 6–9)

This article on nitinol, a nickel-titanium alloy, includes its history, crystal structure and uses, and it shows how this unique alloy behaves under different temperatures. (Kauffman G.; Mayo, I. Memory Metal. *ChemMatters*, 1993, *11* (3), pp 4–7)

Another *ChemMatters* author addresses the origin of the elements and their origin in the stars. (Thielk, D. The Birth of the Elements. *ChemMatters*, 2000, *18* (3), pp 4–5)

Students will gain a better understanding of display screens, especially liquid crystal designs, along with information on pixels, polarization, and color theory in this 2005 article. While the photos of flip phones and other older devices date the article, the information and visuals are excellent. (Fruen, L. Liquid Crystal Displays. *ChemMatters*, 2005, *23* (3), pp 6–9)

Many scholars believe that the Japanese samurai sword is a milestone in metallurgy and weaponry. This article describes the history, alloy composition, and the process of making the samurai sword. The discussion of the structure of the carbon steel alloy in the sword ties in nicely with the Haines article. (Graham, T. Secrets of the Samurai Sword Revealed. *ChemMatters*, 2005, *23* (5), pp 9–12)

The alloys used in metal coins and a description of alloys is featured in this article. (Rohrig, B. The Captivating Chemistry of Coins. *ChemMatters*, 2007, *25* (2), pp 14–17)

This article includes diagrams and a description of the atomic emission spectra of elements as it relates to fireworks, but the information may help readers understand the science behind luminescence. (Copes, J. Science at Hogwarts: Chemistry in Harry Potter's World. *ChemMatters*, 2009, *27* (1), pp 4–6)

This is an excellent explanation of the origin of elements from stars. Included in a sidebar is a section on identifying elements by their emission spectra. (Ruth, C. Where Do Chemical Elements Come From? *ChemMatters*, 2009, *27* (3), pp 6–8)

The accompanying Teacher's Guide for the October 2009 *ChemMatters* article above, Where Do Elements Come From, is a rich source of information and resources on the formation of elements, nucleosynthesis, and the life cycle of stars. Included are a student activity comparing the life cycle human to a star, additional Web sites, and video links.

A brief piece in the "Did You Know? ..." feature includes information on rare-earth metals. (Pages, P. Rare-earth Metals: Not Well-Known but Critical for High Technology. *ChemMatters*. 2010, *28* (2), p 4)

This is another look at the atomic emission spectra of elements as it applies to colored fireworks. Luminescence and spectra are explained and a chart of typical fireworks color sources is provided. (De Antonis, K. Fireworks. *ChemMatters*, 2010, *28* (3), pp 8–10)

The impurities in the metal rivets and chemistry of the alloy carbon-steel plates likely contributed to the sinking of the Titanic. This article discussed the metallic properties of the rivets and the steel alloy. (Rohrig, B. Titanic: Was It Doomed by Chemistry? *ChemMatters*, 2011, *22* (4), pp 17–19)

This is an infographic on the elements (many of them rare-earth metals) that are found in a typical smartphone. Your Smart Phone Contains Valuable Chemicals. *ChemMatters*, 2014, *32* (1), p 4)

The importance of recycling old cell phones and a life-cycle diagram of a cell phone is found in this short article. (Rohrig, B. Be Smart—Recycle that Old Cell Phone! *ChemMatters*, 2015, *33* (2), p 4)

This is an excellent resource to accompany the Haines article. Information on rare-earth metals used in the smartphones is highlighted throughout the article. Also, a discussion of Gorilla Glass (which is strengthened by the addition of potassium ions) is analogous to the formation of substitutional alloys. (Rohrig, B. Smartphones, Smart Chemistry. *ChemMatters*, 2015, *33* (2), pp 10–12)

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An interesting historical view of the rare-earth elements and their discovery is found in this 1932 article. The article provides details on the rare-earth elements and the discovery of each. It also includes photographs of people and places associated with the rare-earth elements. (Weeks, M. The Discovery of the Elements. XVI. The Rare-earth Elements. *J. Chem. Educ.*, 1932, *9* (10), pp 1751–1773; <http://pubs.acs.org/doi/pdf/10.1021/ed009p1751>; note that this link is a brief abstract only, the full article is only available to American Chemical Society members or subscribers to the journal)

While this article is designed as a laboratory experiment for high school students, the publication date of 1963 should be considered, especially with respect to safety, equipment, and whether it is currently appropriate. However, it is filled with lab procedures for, the chemistry of, and details pertaining to the lighter lanthanides. (Kauffman, G.; Takahashi, L.; Vickery, R. The Lighter Lanthanides: A Laboratory Experiment in Rare-earth Chemistry. *J. Chem. Educ.*, 1963, *40* (8), pp 433–437; <http://pubs.acs.org/doi/pdf/10.1021/ed040p433>; note that this link is a brief abstract only, the full article is only available to American Chemical Society members or subscribers to the journal)

A scholarly article from *The Journal of Chemical Education* explains luminescence in greater detail with accompanying diagrams. The article specifically refers to phosphors used in cathode ray television tubes, fluorescent lamps, and x-ray detectors. (DeLuca, J. An Introduction to Luminescence in Inorganic Solids. *J. Chem. Educ.*, 1980, *57* (8), pp 541–545; <http://pubs.acs.org/doi/pdf/10.1021/ed057p541>; note that this link is a brief abstract only, the full article is only available to American Chemical Society members or subscribers to the journal)

This article is from 1990, but the information on how the elements are formed in the stars, nucleosynthesis, is explained in detail, with diagrams, and chemical equations to help readers understand this complex process. (Viola, V. Formation of the Chemical Elements and the Evolution of Our Universe. *J. Chem. Educ.*, 1990, *67* (9), pp 723–730; <http://pubs.acs.org/doi/pdf/10.1021/ed067p723>; note that this link is a brief abstract only, the full article is only available to American Chemical Society members or subscribers to the journal)

Emphasize properties of metals by using five guided inquiry experiments with metals to develop students' understanding of chemistry concepts, including intensive and extensive properties, limiting reagents, spectator ions, reactivity series, and strengths of oxidizing and reducing agents. (Lamba, R.; Sharma, S.; Lloyd, B. Constructing Chemical Concepts through a Study of Metals and Metal Ions. *J. Chem. Educ.*, 1997, *74* (9), pp 1095–1099; <http://pubs.acs.org/doi/pdf/10.1021/ed074p1095>; note that this link is a brief abstract only, the full article is only available to American Chemical Society members or subscribers to the journal)

Take an historical look at atomic emission spectroscopy with its contributions to science and technology as well as the changes and revisions it has undergone. The components (sources, dispersion systems, and detectors) are analyzed and compared to other elemental analysis methods. (Hieftje, G. Atomic Emission Spectroscopy—It Lasts and Lasts and Lasts. *J. Chem. Educ.*, 2000, *77* (5), pp 577–583; <http://pubs.acs.org/doi/pdf/10.1021/ed077p577>; note that this link is a brief abstract only, the full article is only available to American Chemical Society members or subscribers to the journal)

Forensic cases are popular on television and in teaching science. A chemical mystery using the popular characters of Sherlock Holmes and Dr. Watson is used to solve a case based upon knowledge of simple physical and chemical properties of metals. (Rybolt, T.; Waddell, T. The Chemical Adventures of Sherlock Holmes: The Case of Three. *J. Chem. Educ.*, 2002, *79* (4), pp 448–453; <http://pubs.acs.org/doi/pdf/10.1021/ed079p448>; note that this link is a brief abstract only, the full article is only available to American Chemical Society members or subscribers to the journal)

This thorough article on luminescence is aimed at high school students. It explains the types of luminescence (triboluminescence, fluorescence, chemiluminescence, phosphorescence, and bioluminescence) and contrasts luminescence with incandescence. For readers with paid access to *JCE Online*, there are five supplemental experiments available to accompany the article. (O'Hara, P.; Engelson, C.; St. Peter, W. Turning on the Light: Lessons from Luminescence. *J. Chem. Educ.*, 2005, *82* (1), pp 49–52; <http://pubs.acs.org/doi/pdf/10.1021/ed082p49>; note that this link is a brief abstract only, the full article is only available to American Chemical Society members or subscribers to the journal)

# Web Sites for Additional Information

**(Web-based information sources)**

**Rare-earth elements**

A *ChemMatters* Teachers Guide for the article, Smartphones, Smart Chemistry has a wealth of additional information, charts, and graphics on the history, chemical and physical properties, supply and demand, and substitutes for rare-earth elements. Select the April 2015 Teacher's Guide at: <https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/teachers-guide.html>. [Note: this Teacher’s Guide will only be available free online until summer, 2018.]

For a scholarly article on the rare-earth elements go to <http://www.fieldexexploration.com/images/property/1_RareEarths_FLX_02.pdf>.

Information on the only commercial U.S. rare-earth mine, Mountain Pass, in California can be located at <http://www.theatlantic.com/technology/archive/2012/02/a-visit-to-the-only-american-mine-for-rare-earth-metals/253372/>.

The U.S. Geological Survey (USGS) has a vast array of articles, charts, reports, and other information on its Web site. Rare-earth statistics and information for each year starting with 1996 can be found at <http://minerals.usgs.gov/minerals/pubs/commodity/rare_earths/>.

The *Rare Element Resources* Web site includes links for “Rare Earth Elements”, “Critical Rare Earth Elements”, “Rare Earths at Bear Lodge” [a northeast Wyoming mine], and “Industry Related Reports”. All of these can be accessed at [http://www.rareelementresources.com/rare-earth-elements#.V\_b1leArJhG](http://www.rareelementresources.com/rare-earth-elements%23.V_b1leArJhG).

The *Rare Earth Technology Alliance* Web site lists the 17 rare-earth metals and gives a short paragraph about each. (<http://www.rareearthtechalliance.com/What-are-Rare-Earths>)

Maps of potential U.S. rare-earth production sites, rare-earth ores types, processing rare-earth minerals and a chart of rare-earth mineral deposits in the world are available at <http://geology.com/usgs/ree-geology/>.

An interactive world map identifying mineral deposits containing rare-earth elements with quality (grade) of ore, tonnage, and their mineralogy is found at <http://mrdata.usgs.gov/mineral-resources/ree.html>.

Maps of rare-earth deposits in the world as well as for other strategic minerals (platinum group, uranium, phosphorous, and lithium) along with short summaries by groups are located at <http://web.mit.edu/12.000/www/m2016/finalwebsite/solutions/deposits.html>.

A 2010 report from *The Economist* addresses the cost, supply, and importance of rare-earth elements can be found here: <http://www.economist.com/blogs/babbage/2010/09/rare-earth_metals>.

The *American Geosciences Institute* has a Web page listing the ways we use rare-earth elements. (<http://www.americangeosciences.org/critical-issues/faq/how-do-we-use-rare-earth-elements>)

*National Geographic* provides the article “Rare-Earth Elements” discussing supply, China's domination of the market, uses, and opinions regarding the instability of the rare-earth metals market. (<http://ngm.nationalgeographic.com/2011/06/rare-earth-elements/folger-text>)

*National Geographic* has 14 pictures with captions regarding China's rare-earth mining at <http://news.nationalgeographic.com/news/energy/2012/04/pictures/120403-china-rare-earth-mining-pictures/>.

The U.S.G.S. has a four-page, colorful publication describing the rare-earth elements and explaining why they are vital to our technology and lifestyles. (<http://pubs.usgs.gov/fs/2014/3078/pdf/fs2014-3078.pdf>)

A short profile of an EPA female scientist who works with rare-earth minerals is located at <https://www.epa.gov/sciencematters/meet-epa-scientist-diana-bless>.

A scholarly article, “Effects of Samarium Addition on Microstructure and Mechanical Properties of As-Cast AL-Si-Cu Alloy” is available at <http://www.ysxbcn.com/down/2013/11_en/10-p3228.pdf>.

Another scholarly article, “A Historical Geography of Rare Earth Elements: From Discovery to the Atomic Age”, is located at <https://www.bu.edu/pardeeschool/files/2015/08/Klinger-2015-Extractive-Industries-and-Society.pdf>.

For a look at why recycling rare-earth metals is rare and difficult see <http://ensia.com/features/why-rare-earth-recycling-is-rare-and-what-we-can-do-about-it/>.

**Rare-earth mining pollution**

Environmental damages associated with mining (not just rare-earth mining) identified by the type of mining, specific contaminants, and additional environmental problems are listed in this Web site. In addition, some case studies are briefly described. (<http://web.mit.edu/12.000/www/m2016/finalwebsite/problems/mining.html>)

The pollution from mines in Mongolia is described, along with pictures, at <http://www.bbc.com/future/story/20150402-the-worst-place-on-earth>.

Mining risks from toxic pollution to produce rare-earth materials is discussed in a 2013 report at <http://e360.yale.edu/feature/boom_in_mining_rare_earths_poses_mounting_toxic_risks/2614/>.

The *New York Times* reports on rare-earth mining toxic wastes and pollution at <http://www.nytimes.com/2013/10/23/business/international/china-tries-to-clean-up-toxic-legacy-of-its-rare-earth-riches.html?_r=0>.

Concern regarding possible rare-earth mining and the associated pollution in Arizona and other places is found at <http://tucson.com/business/local/big-pollution-risk-seen-in-rare-earth-mining/article_c604dd80-7a8d-5ab5-8342-0f9b8dbb35fb.html>.

The huge social and ecological impact of rare-earth mining in China is discussed in an article at <https://www.theguardian.com/sustainable-business/rare-earth-mining-china-social-environmental-costs>.

**Naming elements**

The International Union of Pure and Applied Chemistry (<https://iupac.org/> ) coordinates and affirms the naming of new elements. For additional information on the entire procedure, see <https://www.degruyter.com/view/j/ci.2016.38.issue-2/ci-2016-0205/ci-2016-0205.xml>.

The recent announcement of the temporary names and symbols of newest elements 113, 115, 117, 118 has stimulated interest in the nomenclature procedure for new elements. For an announcement on these new elements and their proposed names, see <http://cen.acs.org/articles/94/i24/Proposed-names-new-periodic-table.html>.

**LEDs, LCDs, luminescence, and light**

This site provides an in-depth explanation of LED theory and practice. Information includes color rendering index, controlling LEDs in building and street lamps, LED arrays, luminous efficacy, and electroluminescence at semiconductor junctions. (<http://electronicdesign.com/components/understanding-led-application-theory-and-practice>)

For a review of the basics of light, including light as energy, absorption and emission of light, and the wave/particle nature of light see <http://www.pha.jhu.edu/~wpb/spectroscopy/basics.html>.

Television Theory of Operation explains both the CRT (TV picture tube) and the LED types of televisions at <http://wavuti.webs.com/teleprinciples/Television%20Theory%20of%20Operation.pdf>.

A detailed explanation of how a television screen makes its picture using LCDs (liquid-crystal displays), using polarizing filters can be found here: <http://www.explainthatstuff.com/lcdtv.html>.

An excellent Web site with the history and properties of liquid crystals (which are used in color TVs) is located at <http://www.nobelprize.org/educational/physics/liquid_crystals/history/index.html>.

**Sites on metals**

NOVA has an interesting Web page, “Metal Fundamentals”, explaining basic properties of metals, defects (alloys), metal failures, and sword making. (<http://www.pbs.org/wgbh/nova/tech/metal-fundamentals.html>)

For many students, Samurai swords are of interest. NOVA provides a slideshow at <http://www.pbs.org/wgbh/nova/tech/crafting-samurai-sword.html> to show the steps involved in making this classic sword.

**Sites on element formation**

Additional information on how elements are formed in stars is located at <http://aether.lbl.gov/www/tour/elements/stellar/stellar_a.html>.

The formation of elements (nucleosynthesis) is included in a discussion of the timeline, processes, empirical evidence, and a list of additional references at <https://en.wikipedia.org/wiki/Nucleosynthesis>.

This site gives a brief overview of nucleosynthesis and it has links to more detailed explanations of the formation of elements, including the s-process and the r-process. (<http://curious.astro.cornell.edu/about-us/84-the-universe/stars-and-star-clusters/nuclear-burning/402-how-are-light-and-heavy-elements-formed-advanced>)