Extracting Earth's Elements

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Overview: There are many elements on the periodic table lending themselves to the composition of many ionic minerals in the lithosphere of the earth. However, the high school chemistry curriculum has not gone deep enough in the extraction process. Students are still performing routine chemical experiments, have not yet unlocked the potential of how those reactions have truly advanced our society. I believe the key to helping students understand ionic compounds is to give them diverse instructional approaches that bring them beyond the knowledge of everyday table salt. Overall, the aim of this unit is to investigate new chemistry techniques that have been developed over the past 15-20 years by introducing those techniques into the classroom to replace mundane experiments with experiments developed with the intent of solving a problem or meeting a need.

Rationale:

I am a teacher that loves creating new things and performing new tasks. However, I feel that the curriculum in the school district of Philadelphia really keeps chemistry teachers at the foundational level of chemistry. When I examine the curriculum, I realize that it is nearly identical to what I learned in school 15 years ago. As a teacher of a new generation of students, I feel obligated to teach students new ways of doing things. I believe it is a huge disservice to my students to offer them the exact same curriculum that I had when I was in high school, when the truth is that they deserve better. If I am not living up to that task, then that means my university degrees and professional accomplishments carry no weight or power because I have not attempted to impart even a fraction of what I have learned from my professional experiences to the next generation of high school students. Failure to impart these experiences means that I am actually sending my students back in time to a darker past instead of advancing them towards a brighter future.

Some laboratory experiments will always be considered the classics, such as the flame test lab and electrical conductivity of salts, which establishes foundation for understanding. However, if science is advancing, but the laboratory experiments in high school remain the same, then students will always be living in the past. When I was completing my bachelor's degree in chemistry, I chose to investigate the applications of synthetic hydroxyapatite coatings on biomedical implants, which required me to personally synthesize variants of the mineral. Therefore, the inspiration for the design of this unit is to teach students how to synthesize minerals or materials and investigate their applications.

The other piece of inspiration driving this unit is my students' desire for more than what the suggested textbook offers. When teaching ionic bonds, students have asked questions that break past the basic barrier of binary compounds. Some of them want to know whether multiple cations and anions can be used to create compounds. I believe that this seminar opens the door for me to comfortably introduce and teach about ionic compounds containing more than two types of ions, which involves minerals and materials. I believe that when we simply do solution chemistry and pour the chemicals down the drain after the experiments are over, we are doing a huge disservice to our students, implying that the very thing we created in class has no use or purpose but to go down the drain. I owe it to my students to show them the complete beauty of chemistry, that happens beyond the test tube.

Objectives:

Student Audience: The unit is intended for students in grade 10, who attend classes together as an advisory. Students have 60-minute class periods three days per week and 50-minute class periods twice weekly. An estimated 85% of the students will be enrolled in algebra II, while the remaining students will be enrolled in geometry. The students enrolled in geometry are in the same advisory. Grade 10 students are also committed to the completion of a personal project as a requirement for finishing the International Baccalaureate (IB) Middle Years Program (MYP). Some lessons and activities may be suitable for environmental science.

Key and Related Concepts: In IB MYP, key concepts are words used to paint a broad picture of learning expectations that can be observed within and across disciplines. There are three fundamental key concepts that IB recommended in science: *change, relationships,* and *systems*. Of the three fundamental key concepts recommended by IB (*change, relationships, and systems*), this unit will focus on the key concept of *change*.

Related concepts are more discipline-specific and allow for exploration of the key concepts in greater detail to cultivate students' conceptual understanding. The two related concepts selected for this unit's presentation are *form* and *identity*.

Conceptual Phrase: The conceptual phrase is a generic statement that summarizes a concept, is nonspecific, and can be applied across multiple content areas and topics. The conceptual phrase developed for this unit is as follows: ***Systemic changes*** *influence* ***form*** and/or ***identity***. This conceptual phrase can be translated to other topics, such as physical and chemical changes, thermodynamics, ion formation, or the redox reactions. Thus, students benefit from learning conceptual phrases because they potentially bring the familiarity of older content into new content.

Global Contexts: The global context describes the direction of the content and how students will purposefully and meaningfully engage the content. For this unit, the global context will focus on **scientific and technical innovation**, by which students will explore the natural world and its laws and how humans use their understanding of scientific principles. Students will begin the unit by learning about the basics of the periodic table and periodicity. Then students will be asked to apply the patterns observed in periodicity to the formation of compounds and minerals. Students will then be challenged to synthesize synthetic variations of minerals and explore some of the possible applications.

Inquiry Statement: The inquiry statement is comprised of the key and related concepts, the conceptual phrase, and the primary global context. It is provided to the students so that they may know the direction of the unit. The inquiry statement addresses what the student should expect to learn and why they should learn the forthcoming content. The inquiry statement derived for this unit is as follows: *Studying* ***changes*** *and their influence on* ***form*** *and* ***identity*** *of minerals have helped humans understand the applications of minerals and develop an increased awareness of environmental issues.*

Inquiry Questions: Inquiry questions are provided for students as a guide to their learning expectations. They are not necessarily exam questions, but they ought to provoke students into learning the content. Below are the several examples of inquiry questions that can be used throughout the unit.

Factual Questions:
- What are cations and anions?
- What is an ionic bond?
- What is the unit cell?
- What is a crystal lattice?
- What are the meanings of oxidation and reduction.
- What is an endangered element?
- What are minerals?

Conceptual Questions:
- What role do electrons play in the formation of an ionic bond?
- How does the periodicity of ionic radius affect the form of a unit cell?
- How is atomic size and polyhedral shapes used to create substances for water

decontamination?
- How can changing elements in minerals alter their appearance or use?

Debatable Questions:
- Which types of minerals are better to use: natural or synthetic?
- Can minerals be harvested sustainably?
- How does the extraction of salts and other precious minerals affect the environment?

The Objectives of the unit will include, but are not limited to the following:
- Identify sources of elements found in the earth.
- Discuss the availability of rare earth elements and technological applications.
- Predict and describe the spatial organization of elements when combined in compounds and polyatomic ions.
- Describe the process of synthetic mineral formation and evaluate the applications of creating synthetic minerals.

Background:

The foundation of this unit will focus on green chemistry. Research will begin with green chemistry and why this discipline is important in sustainability. Secondly, we must understand what chemical techniques scientists are using in order to promote and drive green chemistry practices. The chemical elements are neither evenly nor fairly distributed across the globe and. Thus, a teacher of this unit ought to know the relative abundances of some of the most common elements used on the planet.

Since most of our chemicals are extracted from ores mined from the earth, some of those sources have already been depleted while others are reaching exhaustion. Thus, it raises the question whether or not humanity is ready to move from the recycling of paper, plastics, and water toward recycling anything and everything. This means raising up a generation of people who are becoming environmentally responsible through the power of science literacy. Thus for this unit, one aspect that I chose to focus on is the artificial synthesis of minerals, since minerals are the original vessel of choice upon the creation of the earth to store elements until their appointed time of discovery. The mineral of choice for this study is malachite. Scientists have used chemistry to recycle elements back to a synthetic mineral in order to increase access to other rare compounds, such as metal oxides.

To prepare myself for this unit, I had to find the availabilities of elements in the earth's crust and their distribution across different geographical regions. Secondly, I needed to refresh my knowledge of coordination chemistry of compounds. Finally, I had to conduct research on the latest wet chemistry techniques developed in the past 15-20 years that produce synthetic forms of the minerals, which will provide opportunity for more diverse laboratory experiments. Overall, I want the students to experience the power of materials science in the classroom, rather than teaching about salts.

Green Chemistry

In chemistry, we know that two laws are always at work: conservation of mass and energy. This means that the amount of matter available in the earth is finite with the exception of sending equipment to explore space and occasional meteors entering our planet's atmosphere every few hundred, thousand, or million years. Commonly, politics has directed our attention toward global warming and managing our carbon and water footprints. However, with our increasing dependence on technology, is our society truly moving towards sustainable management of resources? Technology is heavily dependent on transition metals and some rare earth elements. Minerals are constantly being extracted from the earth for our technological benefit, but what will be our future.

How are we practicing green chemistry?

As of early 2016, 118 elements have been discovered and named, but 44 of those elements have been classified as "endangered elements" considering that they will be in short supply in the near future.[1] The list of elements include zinc, gallium, germanium, helium, silver, phosphorus, and all of the rare earth elements. In an effort to raise awareness of elemental exhaustion, the Royal Society of Chemistry has published a book entitled, *Element Recovery and Sustainability*.

However, we know that these elements are not disappearing based on the law of conservation of mass. They are simply being redistributed out of the earth across the human population. Thus, when an element is labeled endangered, it means that access to these elements will be extremely limited as their natural sources become depleted. For example, indium is commonly used in cell phones and only a few milligrams are needed in each device. Since so little is needed, the recycling of phones to reharvest this element is not very cost effective.[2]

[1] Endangered Elements. (n.d.). Retrieved April 01, 2017, from https://www.acs.org/content/acs/en/greenchemistry/research-innovation/research-topics/endangered-elements.html

[2] Chattopadhyay, D. (2017). Endangered elements of the periodic table. *Resonance*, *22*(1), 79-87.

Copper Minerals

Copper containing compounds have always provided excellent platforms to educate students in chemistry. This unit contains a relatively new laboratory experiment focused on copper minerals. Malachite is a mineral composed of copper, carbonate, and hydroxide ions with a chemical formula of $Cu_2CO_3(OH)_2$. It is often found with its relative, azurite, which has a composition of $Cu_3(CO_3)_2(OH)_2$. Malachite was first harvested from King Solomon's mines located in the Timna Valley of Israel, located south of Iran. However, the highest quality malachite was discovered in the Ural Mountains of Russia.

During the early and mid 19th century, malachite was primarily used as a dye for paints, which is evident in the green rooftops of homes near the Ural Mountains. On the other hand, Europeans valued malachite for its aesthetic appeal, using it to assemble mosaics containing other colorful minerals. Eventually, malachite found uses in decorative furniture and houseware items such as tabletops and silverware. Eventually, malachite deposits were depleted, causing scientists search for methods to reproduce natural malachite. It was not until the second half of the 20th century that scientists began to truly understand the chemical structure of malachite and use those physico-chemical properties to devise methods of synthesis.

Early materials science application of malachite was noted in Medieval writings. In those writings, malachite was referred to a *chrysocolla*, is a composition of the Greek words *chryso* (gold) and *colla* (glue), meaning that malachite was used to solder gold. However, the name *chrysocolla* has be reassigned to copper silicates[3].

As of 2009, scientists are still refining their search for malachite synthesis techniques. Saha et al. have sought to exploit the pH-specific adsorption behavior and adsorption capacity of malachite nanoparticles as a biomaterial for bioseparation technology and biochemical sensor development.[4] Their research has shown that BSA has a higher adsorption affinity toward bare malachite nanoparticles than toward malachite nanoparticles modified with stearic acid. Similar studies are being reported for the removal of arsenate and chromate ions.[5]

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[3] Gettens, Rutherford J., and Elisabeth West Fitzhugh. "Malachite and Green Verditer." *Studies in Conservation*, vol. 19, no. 1, 1974, pp. 2–23., www.jstor.org/stable/1505631.

[4] Saha, Bedabrata, and Gopal Das. "Malachite nanoparticle: a New basic hydrophilic surface for pH-controlled adsorption of bovine serum albumin with a high loading capacity." *The Journal of Physical Chemistry C* 113.35 (2009): 15667-15675.

[5] Saikia, Jiban, Bedabrata Saha, and Gopal Das. "Efficient removal of chromate and arsenate from individual and mixed system by malachite nanoparticles." *Journal of hazardous materials* 186.1 (2011): 575-582.

Interestingly, malachite is also under investigation as a water decontaminant. However, as mentioned in regards to the biotechnology, malachite's mechanism of water decontamination focuses on its adsorptive characteristics.

Malachite can be precipitated via the following reaction by keeping the pH of the stock solution at 7.0 ± 0.5.

$$2\ CuCl_2 + 2\ Na_2CO_3 + H_2O \rightarrow Cu_2(OH)_2CO_3\downarrow + CO_2\uparrow + 4\ NaCl$$ (Du et al.)[6]

At the end of this curriculum unit, I have provided a laboratory activity where students can synthesize malachite and other structural variants of the mineral and web resources for students to conduct research on copper minerals.

Standards: The Core Curriculum of the School District of Philadelphia is aligned to the Pennsylvania Department of Education Standards Aligned System. The standards include instruction on the following topics: chemistry, physics, and environmental science.

Strategies:

Implementing this Unit: This unit does not necessarily have to be taught as a standalone unit. The intent of this unit is to provide added variety to student learning and to create content overlap. Typically, I spend about a week allowing my students to learn about the periodic table's families and periodicities. The first classroom activity can be used as summative assessment for the periodic table, providing an opportunity for students explore the applications of endangered elements and reflect on the environmental impacts of harvesting elements from the earth. The second classroom activity will focus on using periodicity to explain how ionic compounds obtain their crystal geometries or coordinations. This activity can be taught after ionic compounds or after valence-shell electron-pair repulsion theory. Ionic compounds tend to favor octahedral and cubic geometries, while covalent compounds tend to favor tetrahedral, trigonal, and linear. Thus, you can choose to split the second activity across distinctively between those two types of bonds. The final activity allows students to act as a materials scientist and fabricate a synthetic mineral. Since many minerals are composed of polyatomic ions, the mineral synthesis also serves as a summative assessment for ionic compounds.

This unit will use a variety of strategies to help students grasp the concepts. The first strategy is breaking the timeline of the curriculum. I believe that there are topics that just need to be introduced earlier because I believe they will strengthen the understanding of the students. I do not teach International Baccalaureate (IB) diploma program chemistry,

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[6] DU, Ying-ji, et al. "Preparation of Basic Copper Carbonate Microspheres by Precipitation Method." (2015).

but materials science is an optional unit taught near the end of the IB course. Thus, concepts of materials science will be sprinkled into the curriculum earlier to add more depth and to take student understanding of ionic compounds past their limited perception of salts and into materials science applications.

The second strategy is to use the appropriate chemistry methods available to bring the materials application to life in the classroom. This will be entirely dependent upon what universities have published regarding the synthetic replicates of earth's minerals and their fabrications for materials applications.

The last strategy is to use a systems and societies approach to expose students to how the availability of minerals across the globe has influenced the environment and the economy. This too is dependent upon the research that universities have published and whether human activity and values have stimulated the search for the development of various materials derived from minerals.

Assessment Objectives**:** The IB Middle Years Program (MYP) requires that students are assessed according to four criteria. These criteria are defined as (a) knowing and understanding, (b) inquiring and designing, (c) processing and evaluating, and (d) reflecting on the impacts of science. Activities presented in this curriculum unit will primarily assess strands in criteria a and d.

Approaches to Learning

- Thinking skills: Students will be required to interpret data via graphical analysis of processed data.
- Communication: Students will frequently engage in activities that require them to communicate using non-linguistic representations their research findings concerning the availability of minerals and their uses.
- Self-management: Students will work in groups and decide the best methods for organizing and presenting information for their peers. On some occasions, complete understanding of content will only take place if the students manage their gifts and talents, and learn how to use them cooperatively for their peers to benefit.
- Research skills: Students will be required to read articles and discuss the impact of knowledge obtained about the minerals and their practical or impractical applications in society.

Classroom Activities

Activity: Endangered Element Poster Project

There are only a limited supply of elements available on the earth. Recently, chemists have been tracking the availability of elements and their consumption to find that some elements have become endangered. You will study the sources of elements and answer the following questions.

- Identify elements and their current and future availabilities to society.
- Describe the distribution of an endangered element across the earth.
- Discuss advantages and disadvantages of using other elements to substitute an element that is considered endangered.

In teams of 2-3, you are responsible for creating an infographic about an endangered element. Be sure to explain how the element is used, why is it becoming scarce, and alternatives available in the event that the element is exhausted from the planet.

List of Endangered Elements

Helium	Indium	Gallium	Silver	Uranium	Germanium
Arsenic	Zinc	Hafnium	Platinum	Phosphorus	Lithium

Recommended Websites:

Locations of Deposits	http://web.mit.edu/12.000/www/m2016/finalwebsite/solutions/deposits.html
Rare Earth Element Mines, Deposits, and Occurrences	https://mrdata.usgs.gov/ree/

Criteria to be addressed on your poster

- What countries or specific landmarks readily harvest the endangered element?
- What are some minerals where the element is most commonly harvested from?
- What are some elements that can be substituted for the endangered element?
- What are the applications of the element?
- Are there alternatives to using the endangered element?
- What are some of the advantages and disadvantages of using the alternatives?
- What advances in technology are being pursued for use of this element? What does the future hold for this element? How much longer do we have until the endangered element is depleted from the earth?
- Can the element be recycled? Should we even bother trying to recycle the element?

- Pictures describing the element; neatness, organization, and color usage.
- Bibliography submitted in a separate document.
- Use either of the following websites to format your poster:
    - Intermediate to Professional Formats
        - www.venngage.com
        - www.canva.com
        - www.piktochart.com
    - Basic to Intermediate Formats
        - Google Slides or Draw

Rubrics for Endangered Element Poster:

Criterion A: Knowing and Understanding

Criteria	**1–2**	**3–4**	**5–6**	**7–8**
Location Source	1 country (nonspecific landmark)	2 countries (nonspecific landmark)	3 countries (some specific landmarks)	3 countries (with specific landmarks)
Mineral Source	1 mineral containing EE.	2 minerals containing EE.	3 minerals containing EE.	4+ minerals containing EE.
Advantages	1 Advantage	1-2 Advantages	2 Advantages	3 Advantages
Disadvantages	1 Disadvantage	1-2 Disadvantages	2 Disadvantages	3 Disadvantages
Alternative Elements	1 suggested alternative	1-2 suggested alternatives	1 convincing alternatives	2 convincing alternatives
Future of element	No Prediction made on future use/ availability	Prediction made on future use OR availability lacking detail	Prediction made on future use/ availability lacking some detail	Prediction made on future use/ availability
Pictures of sources/visuals	No pictures	1-2 inaccurate pictures	1 picture	2 pictures
	Disorganized and rushed.	Organized, colorful, but rushed.	Organized, colorful, but slightly rushed or incomplete.	Well-organized, colorful, and looks complete.

Criterion D: Reflecting on the Impacts of Science

Achievement Level	1–2	3–4	5–6	7–8
Sub-criterion 1	**Outline** the ways in which endangered element is used to address a specific problem or issue	**Summarize** the ways in which endangered element is applied and used to address a specific problem or issue	**Describe** the ways in which endangered element is used to address a specific problem or issue	**Explain** the ways in which endangered element is applied and used to address a specific problem or issue
Sub-criterion 2	**Outline** the implications of using endangered element (and any available substitutes) to solve a specific problem or issue, interacting with a factor	**Describe** the implications of using endangered element (and any available substitutes) to solve a specific problem or issue, interacting with a factor	**Discuss** the implications of using endangered element (and any available substitutes) to solve a specific problem or issue, interacting with a factor	**Discuss and evaluate** the implications of using endangered element (and any available substitutes) to solve a specific problem or issue, interacting with a factor
Sub-criterion 3	**Apply** scientific language to communicate understanding	**Sometimes apply** scientific language to communicate understanding	**Usually apply** scientific language to communicate understanding **clearly and precisely**	**Consistently apply** scientific language to communicate understanding **clearly and precisely**
Sub-criterion 4	Document sources (1 clearly identified source).	**Sometimes** document sources correctly (2 clearly identified sources).	**Usually** document sources correctly (3 clearly identified sources).	Document sources **completely** (4 clearly identified sources).

Command term	Definition
Apply	Use knowledge and understanding in response to a given situation or real circumstances. Use an idea, equation, principle, theory, or law in relation to a given problem or issue.
Describe	Give a detailed account or picture of a situation, event, pattern, or process.
Discuss	Offer a considered and balanced review that includes a range of arguments, factors, or hypotheses. Opinions or conclusions should be presented clearly and supported by appropriate evidence.
Document	Credit sources of information used by referencing (or citing), following one recognized referencing system. References should be included in the text and also at the end of the piece of work in a reference list or bibliography.
Evaluate	Make an appraisal by weighing up the strengths and limitations.
Explain	Give a detailed account including reasons and causes.
Outline	Give a brief account or summary.
Summarize	Abstract a general theme or major point(s).

Lesson: Coordination Chemistry of Ionic Compounds

Purpose: The purpose of this lesson is to show students how the size of atoms helps predicting their crystal geometries (ionic compounds) and molecular geometries (covalent compounds). It requires students to apply their knowledge of ionic sizes to make sense of the compounds formed. The key thing students need to be warned of prior to this lesson is that ionic bonds and covalent bonds are very different. The chemical formula of an ionic compound does not foreshadow any geometries. However, the chemical formula of a covalent compound correlates well to their predicted geometries. This comes down to making sure that students know that ionic bonds rely on forces of attractions while covalent bonds rely on sharing of electrons.

Lesson Objectives: At the conclusion of this lesson, students will be able to:

- Define and calculate the radius ratio to predict the coordination of ionic compounds.
- Use periodicity to determine common geometries for different classes of compounds based on the central atom or cation.

Materials and Equipment: periodic tables, calculators, PowerPoint slides, printed or electronic worksheets

Do Now Activity: This should be a review for your students after having demonstrated mastery of periodicity.

- Think-Pair-Share: Describe what happens when to the size of an atom when it becomes a cation and an anion.
- Upon reviewing the answer, remind students that when atoms lose electrons to become cations, they become smaller. When atoms gain electrons to become anions, they become larger in in size.

Introduce Lesson:

- Review the lesson objectives with the students.
- Explain that ionic bonding works more like magnets being stuck together rather than two atoms actually forming a bond (like covalent).
- Cations will coordinate with anions to be surrounded by as many anions as possible.
- This number of anions surrounding the cation is called the coordination number.

- The coordination number is predicted by ratio of the ionic size of the cation compared to the surrounding anions.
- Introduce the following table to the students.

Table of common coordination numbers, shapes, and radius ratio classifications

Coordination Number	**Polyhedron**	**Radius Ratio (min)**
12	Irregular	> 1.000
8	Cube	0.732 – 1.000
6	Octahedron	0.414 – 0.732
4	Tetrahedron	0.225 – 0.414
3	Triangle	0.155 – 0.225
2	Line	< 0.155

- When calculating the radius ratio, the size of the cation goes into the numerator and the size of the anion goes into the denominator of the ratio. Simply calculate, and then classify according to the table.
- Complete 2-3 problems with the students as needed.
- Students should answer conclusion questions at the end of the worksheet.
- Assign additional tables for homework or create your own. Whether this lesson is given after ionic or covalent bonding, these calculations can strengthen students' understanding of patterns found in the periodic table.
- NOTE: For covalent compounds, students should be aware that the central atom in a polyatomic ion can assume a cationic form, even though the central atom will primarily be a nonmetal.
- Follow-up activities can include Colorado PhET Lab entitled "Molecular Shapes". This is a great visual aid for the covalent compounds.

Student Worksheet

Directions: Calculate the radius ratio for each ionic compound. Then determine the coordination number (CN) and the type of polyhedron formed between the ion pair.

Table 1: Common Cations and Anions

Chemical Formula	Cationic Radius	Anionic Radius	Radius Ratio	Coord. Number	Polyhedron
NaF	102	133	0.767	8	Cube
NaCl	102	181			
NaBr	102	195			
NaI	102	220			
$CaCl_2$	100	181			
$CaBr_2$	100	195			
$Ca(OH)_2$	100	133			
$Ca_3(PO_4)_2$	100	238			

Table 2: Transition Metals

Chemical Formula	Cationic Radius	Anionic Radius	Radius Ratio	Coord. Number	Polyhedron
FeO	61	140			
$FeCl_2$	61	181			
$FeCO_3$	61	178			
$Fe(OH)_2$	61	133			
$CuCO_3$	77	178	0.459	6	Octahedron
Ag_2O	115	140			
$FeCl_3$	55	181			

Table 3: Covalent Bonds

Chemical Formula	Central Ion Radius	Anionic Radius	Radius Ratio	Coord. Number	Polyhedron
$(SO_4)^{2-}$	38	140			
$(NO_3)^{1-}$	27	140			
$(PO_4)^{3-}$	58	140			
CO_2	16	140			
$(SiO_4)^{4-}$	40	140			
$(IO_4)^{1-}$	69	140			

Table 4: Rare Earth Elements

Chemical Formula	Cationic Radius	Anionic Radius	Radius Ratio	Coord. Number	Polyhedron
Sc_2O_3	38	140			
Eu_2O_3	27	140			
Er_2O_3	58	140			
LaF_3	106.1	133			
HoI_3	89.4	220			
$SmCl_3$	96.4	181			

Conclusion Questions

	Question/Prompt	Response
1	Which geometries/shapes do common ionic compounds favor?	
2	Which geometries/shapes do compounds containing transition metals favor?	
3	Which geometries/shapes do	

	common covalent compounds favor?	
4	Which geometries/shapes do rare earth elements favor?	

Lab: Chemical Recycling – Synthesis of Malachite and Related Minerals

For the Teacher:

Summary:

In this lesson, students will attempt to synthesize a semi-precious mineral. This mineral has been used for aesthetic applications in jewelry, furniture, and silverware. At the end of this lab, students should prepare a group lab report addressing either the environmental/economic impacts of mining endangered elements or the biotechnological applications of the mineral. The goal of this lab activity, in addition to all the objectives, is to show students that they can make a material that is useful for humanity and actually has an application beyond a simple demonstration that reinforces a chemistry concept.

Objectives:

At the conclusion of this lesson, students will be able to

- Predict the amount of yield from a chemical reaction.
- Describe the process of forming complex ionic compounds and minerals.
- Classify the steps in the process of forming ionic compounds as either endothermic or exothermic.

Teacher Preparation: 30-45 minutes handling materials.
Lesson: 90 minutes or 2 class periods

Materials

- 0.5M copper(II) chloride solution or copper(II) sulfate (50 mL for each group)
- 0.25M sodium carbonate solution (100 mL per group)
- Distilled water (10-20 mL per group)
- Methanol (10-20 mL per group)
- 10 mL graduated cylinder (one per group)
- 250-mL Erlenmeyer flasks (two per group)
- Hot Plate (one per group)
- Thermometer (one per group)
- Glass stirring rod (one per group)
- Funnel
- Filter paper
- Balance
- Plastic pipets

Safety

- Always wear safety goggles when handling chemicals in the lab.
- Students should wash their hands thoroughly before leaving the lab.
- When students complete the lab, instruct them how to clean up their materials and dispose of any chemicals.
- Exercise caution when using a heat source. Hot plates should be turned off and unplugged as soon as they are no longer needed.
- Copper(II) chloride and sodium carbonate are toxic if swallowed. They are also eye, respiratory, and skin irritants.
- Do not allow excess copper(II) chloride to be washed down the drain, as it is not readily biodegradable.
- Minimize the release of sodium carbonate down the drain.

Teacher Notes

This section includes any information the teacher might need, including

- This laboratory experiment is adapted from the following references:
    - Xu, Jiasheng, and Dongfeng Xue. "Fabrication of malachite with a hierarchical sphere-like architecture." *The Journal of Physical Chemistry B* 109.36 (2005): 17157-17161.
    - Du, Ying-ji, et al. "Preparation of Basic Copper Carbonate Microspheres by Precipitation Method." (2015).
- Read the supplemental material about malachite minerals and its applications.
    - Gettens, Rutherford J., and Elisabeth West Fitzhugh. "Malachite and Green Verditer." *Studies in Conservation*, vol. 19, no. 1, 1974, pp. 2–23., www.jstor.org/stable/1505631.
    - Saha, Bedabrata, and Gopal Das. "Malachite nanoparticle: a New basic hydrophilic surface for pH-controlled adsorption of bovine serum albumin with a high loading capacity." *The Journal of Physical Chemistry C* 113.35 (2009): 15667-15675.
    - Saikia, Jiban, Bedabrata Saha, and Gopal Das. "Efficient removal of chromate and arsenate from individual and mixed system by malachite nanoparticles." *Journal of hazardous materials* 186.1 (2011): 575-582.
    - Cris E. Johnson, Gordon T. Yee, and Jeannine E. Eddleton. Copper Metal from Malachite circa 4000 B.C.E. *Journal of Chemical Education* 2004 *81* (12), 1777. DOI: 10.1021/ed081p1777
    - H. S. Parekh and A. C. T. Hsu. Preparation of Synthetic Malachite. Reaction between Cupric Sulfate and Sodium Carbonate Solutions. *I&EC Product Research and Development* 1968 *7* (3), 222-226. DOI: 10.1021/i360027a015

- Provide students with access to the supplemental material (to be provided in next draft).
    - PowerPoint slides with summaries of articles will be provided with lab.
    - Students may need the information summarized in advanced as a supplement because when a search for the applications of malachite is conducted, the organic malachite green paint will appear with a significantly greater frequency than the malachite mineral.

<u>Laboratory Environment</u>

- Hot plates should be preheated to 80°C. If the hot plate does not have a built-in digital thermometer, use a hot water bath and glass thermometer calibrate a setting for heating substances at 80°C. Do not exceed temperatures of 95°C.
- The mixture must be above 80°C for the reaction to occur. The initial reaction will produce copper (II) carbonate, which is light blue in color and cloudy in its initial appearance. When there is enough energy, carbon dioxide will escape from the solution and a dark green precipitate will form leaving the solution slightly translucent. If the solution is near boiling (~95°C due to the solute lowering the boiling point of water), then the solution will still appear dark green and cloudy.
- Students should be in groups of 2-4 depending on classroom size and availability of laboratory equipment.

Preparing Stock Solutions – Teacher Setup

- Preparing 0.5M copper(II) chloride stock solution
    - From **anhydrous** source: using a balance, measure 67.2 g of copper(II) chloride. Dissolve in 1 L of distilled water.
    - From **dihydrate** source: using a balance, measure 85.2 g of copper(II) chloride. Dissolve in 1 L of distilled water.
- Preparing 0.5M copper(II) sulfate stock solution
    - From **anhydrous** source: using a balance, measure 79.8 g of copper(II) sulfate. Dissolve in 1 L of distilled water.
    - From **pentahydrate** source: using a balance, measure 124.8 g of copper(II) sulfate. Dissolve in 1 L of distilled water.
- Preparing 0.25M sodium carbonate stock solution
    - Using a balance, measure 53 g of sodium carbonate. Dissolve in 1 L of distilled water.

Copper WebQuest

- Copper. (n.d.). Retrieved April 26, 2017, from https://mineralseducationcoalition.org/minerals-database/copper/
- Copper. (n.d.). Retrieved April 26, 2017, from https://mineralseducationcoalition.org/elements/copper/

- Medical Uses of Copper in Antiquity:

https://www.copper.org/publications/newsletters/innovations/2000/06/medicine-chest.html

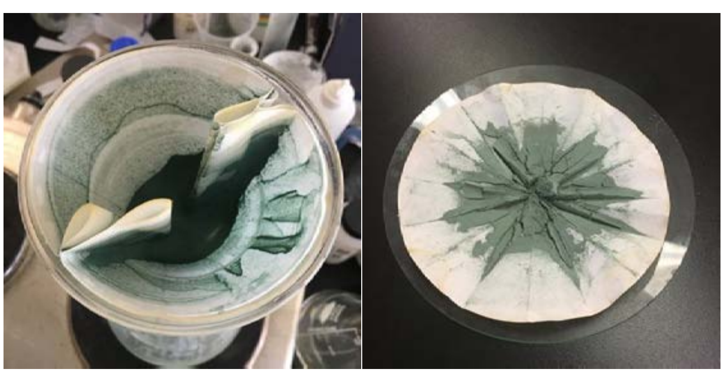
- Copper.org - Copper Facts: https://www.copper.org/education/c-facts/facts-print.html

Web Quest Prompts

1. Outline three benefits of copper usage.
2. Describe the primary method by which copper is mined.
3. Compare three environmental effects caused by mining copper.
4. Compare three approaches to providing solutions to environmental effects caused by mining the mineral.
5. Explain how copper is applied and used to address a specific problem or issue.
6. Discuss and evaluate the various implications of using copper and its application to solve a specific problem or issue.

Supplement – Pictures of Lab Setup

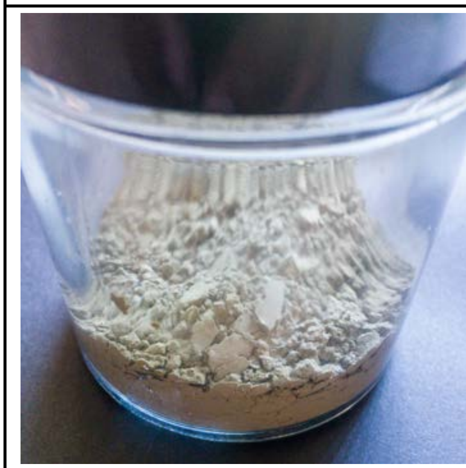
malachite precipitate at bottom of an Erlenmeyer flask


malachite powder in filter paper


malachite powder in glass jar

Optional Extension

- Interdisciplinary learning: Co-plan this laboratory experience with a biology teacher at your school. Once the students create the malachite powder, give the malachite powder to a biology teacher. Design a lesson that tests the antimicrobial properties of copper in the form of malachite.

Other Derivatives of Malachite	 Rosasite $Cu_{1.5}Zn_{0.5}CO_3(OH)_2$	 Black Rosasite $Cu_xZn_{2-x}CO_3(OH)_2$ contains higher proportion of Cu:Zn than Rosasite
	 Kolwezite $Cu_{1.34}Co_{0.66}CO_3(OH)_2$	 Cobalt Carbonate Hydroxide $Co_2CO_3(OH)_2$

For the Student
Lesson

Chemical Recycling – Synthesis of Malachite

Background

Malachite ($Cu_2(OH)_2CO_3$) is a semi-precious mineral that has been harvested from many years going back to reign of King Solomon of Israel. However, the most eye-catching malachite comes from the Ural Mountains in Russia. Copper is typically extracted from malachite and its chemical relative, azurite. Unfortunately, many of the mines containing malachite have been depleted and scientists are beginning to admire its biotechnological and biomaterial applications. To meet the demand for these revolutionary applications, chemists have developed simple methods to artificially reproduce the mineral.

The equation for the chemical reaction you will perform is as follows:

$$2\ CuCl_2 + 2\ Na_2CO_3 + H_2O \rightarrow Cu_2(OH)_2CO_3(s) + CO_2(g) + 4\ NaCl(aq)$$

$$2\ CuSO_4 + 2\ Na_2CO_3 + H_2O \rightarrow Cu_2(OH)_2CO_3(s) + CO_2(g) + 2\ Na_2SO_4(aq)$$

Since malachite is a more complex ionic compound, a simpler compound, copper(II) carbonate, will form first. When the water absorbs enough heat energy, free copper(II) ions will begin to form copper(II) hydroxide. Both compounds are light blue in their appearance so there is no way to determine exactly when copper(II) hydroxide begins to form. When enough copper(II) hydroxide accumulates and reactants begin to equilibrate and organize into the correct ratio, they will unite to form the dark green malachite.

Prelab Questions

1. According to the balanced chemical equation, calculate the amount in moles of malachite will be produced for one mole of copper salt (chloride or sulfate) used in the reaction.
2. Calculate the amount in moles of copper salt you will produce in this experiment given that you start the experiment with 50 mL of 0.5M copper salt.
3. Calculate the amount in moles of malachite that will be produced from the amount of copper salt calculated from the previous problem.
4. Calculate the theoretical yield in grams of malachite. The molar mass of malachite is 221.116 g/mol.

Problem/Objective

In this experiment, you are going to replicate an experiment that materials scientists began in the 1960s, but have recently perfected in the past 10 years. You will synthesize malachite particles.

Materials

- 0.5M copper(II) chloride solution or copper(II) sulfate (50 mL for each group)
- 0.25M sodium carbonate solution (100 mL per group)
- Distilled water (10-20 mL per group)
- Methanol (10-20 mL per group)
- 10 mL graduated cylinder (one per group)
- 250-mL Erlenmeyer flasks (two per group)
- Hot Plate (one per group)
- Thermometer (one per group)
- Glass stirring rod (one per group)
- Funnel
- Filter paper
- Balance
- Plastic pipets

Safety

- Always wear safety goggles when handling chemicals in the lab.
- Wash your hands thoroughly before leaving the lab.
- Follow the teacher's instructions for cleanup of materials and disposal of chemicals.
- Exercise caution when using a heat source. Hot plates should be turned off and unplugged as soon as they are no longer needed.
- Copper(II) chloride and sodium carbonate are toxic if swallowed. They are also eye, respiratory, and skin irritants.
- Do not allow excess copper(II) chloride to be washed down the drain, as it is not readily biodegradable.
- Minimize the release of sodium carbonate down the drain.

Procedure

1. Obtain 100 mL of 0.25M sodium carbonate in a beaker.
2. Obtain 50 mL of 0.5M copper(II) chloride in a beaker.

Measure 5 mL of 0.5M copper(II) chloride in a 10-mL graduated cylinder. Add it to your Erlenmeyer flask.

Stir vigorously using a glass stirring rod. If a glass stirring rod is not available, gently swirl the Erlenmeyer flask.

Add copper(II) chloride solution in 5-mL portions. Stir vigorously after each addition with a glass stirring rod (or with gentle swirling). Continue adding your copper-containing solution in 5-mL increments until you use all 50 mL.

Measure the mass of a sheet of filter paper. Record this mass in the data table.

When all solutions have been added to your Erlenmeyer flask and you see a dark green precipitate your reaction is complete.

Using a balance, measure the mass of a sheet of filter paper.

Using a second 250-mL Erlenmeyer flask, glass funnel, and filter paper, filter the precipitate using a glass funnel and filter paper.
Using a plastic pipette, rinse your filter paper containing the malachite precipitate with ~10 mL of distilled water.
Repeat the rinse with ~10 mL of methanol.
Give your glass funnel to your teacher for overnight drying and storage.
On the following day, obtain your filter paper covered with malachite and measure the mass of the dried filter paper containing malachite powder. Record this mass in the data table.
Continue to perform the calculations

Results/Data/Observations

Mass of Filter Paper (g)	Mass of Dried Filter Paper with Malachite Powder (g)	Experimental Mass of Malachite Powder (g)	Percent Yield of Malachite Powder

Calculations
Calculate the mass of malachite powder by subtracting the mass of the filter paper from the mass of the filter paper containing malachite powder. Record in the data table.
Calculate the percent yield of malachite powder using the theoretical yield calculated from the prelab questions and your experimental mass of malachite powder. Record the results in the data table.

Conclusion
Conduct research on copper as an endangered element. To what extent has mining affected the environment and the economy?
Conduct research on malachite used as a biomaterial. Use the articles provided by the teacher. Do not be confused with malachite green dye, which is an organic dye.

Bibliography (Reading List):

Teacher Resources

Endangered Elements. (n.d.). Retrieved April 01, 2017, from https://www.acs.org/content/acs/en/greenchemistry/research-innovation/research-topics/endangered-elements.html

Chattopadhyay, D. (2017). Endangered elements of the periodic table. *Resonance*, *22*(1), 79-87.

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Saha, Bedabrata, and Gopal Das. "Malachite nanoparticle: a New basic hydrophilic surface for pH-controlled adsorption of bovine serum albumin with a high loading capacity." *The Journal of Physical Chemistry C* 113.35 (2009): 15667-15675. Potential application of malachite synthesis.

Saikia, Jiban, Bedabrata Saha, and Gopal Das. "Efficient removal of chromate and arsenate from individual and mixed system by malachite nanoparticles." *Journal of hazardous materials* 186.1 (2011): 575-582. Potential application of malachite synthesis.

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Xu, Jiasheng, and Dongfeng Xue. "Fabrication of malachite with a hierarchical sphere-like architecture." *The Journal of Physical Chemistry B* 109.36 (2005): 17157-17161.

Cris E. Johnson, Gordon T. Yee, and Jeannine E. Eddleton. Copper Metal from Malachite circa 4000 B.C.E. *Journal of Chemical Education* 2004 *81* (12), 1777. DOI: 10.1021/ed081p1777. Background reading material on malachite mineral.

H. S. Parekh and A. C. T. Hsu. Preparation of Synthetic Malachite. Reaction between Cupric Sulfate and Sodium Carbonate Solutions. *I&EC Product Research and Development* 1968 *7* (3), 222-226. DOI: 10.1021/i360027a015

Student Resources

The Chemistry Behind the Minerals. https://www.youtube.com/watch?v=dS8za4jGcUA&spfreload=5

Locations of Deposits. (n.d.). Retrieved July 06, 2017, from http://web.mit.edu/12.000/www/m2016/finalwebsite/solutions/deposits.html. Website is an excellent resource for learning about the availability of endangered elements across the globe.

Program, M. R. (n.d.). Rare earth element mines, deposits, and occurrences. Retrieved July 06, 2017, from https://mrdata.usgs.gov/ree/ . Website contains GIS maps, databases, and search engines tailored for rare earth element research.

Copper. (n.d.). Retrieved April 26, 2017, from https://mineralseducationcoalition.org/minerals-database/copper/

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Medical Uses of Copper in Antiquity. (n.d.). Retrieved July 06, 2017, from https://www.copper.org/publications/newsletters/innovations/2000/06/medicine-chest.html

Copper.org - Copper Facts. (n.d.). Retrieved July 06, 2017, from https://www.copper.org/education/c-facts/facts-print.html

Appendix – School District of Philadelphia Standards

Anchor Descriptor	Core Standard
3.1.12.C Assess and apply patterns in science and technology.	● Assess and apply recurring patterns in natural and technological systems. ● Compare and contrast structure and function relationships as they relate to patterns. ● Assess patterns in nature using mathematical formulas.
3.4.10.A Explain concepts about the structure and properties of matter.	● Explain the repeating pattern of chemical properties by using the repeating patterns of atomic structure within the periodic table. ● Explain the formation of compounds and their resulting properties using bonding theories (ionic and covalent) ● Recognize formulas for simple inorganic compounds
3.5.10A Relate earth features and processes that change the earth.	● Describe and identify major types of rocks and minerals.
3.5.10.B Explain sources and uses of earth resources.	● Compare the locations of strategic minerals and earth resources in the world with their geologic history using maps and global information systems.
3.5.12.B Analyze the availability, location, and extraction of earth resources.	● Describe how the location of earth's major resources has affected a country's strategic decisions. ● Analyze the impact of resources
3.8.12.C: Evaluate the consequences and impacts of scientific and technological solutions.	3.8.12.C.2: Analyze scientific and technological solutions through the use of risk/benefit analysis. 3.8.12.C.3: Analyze and communicate the positive or negative impacts that a recent technological invention had on society. 3.8.12.C.4: Evaluate and describe potential impacts from emerging technologies and the consequences of not keeping abreast of technological advancements (e.g., assessment alternatives, risks, benefits, costs, economic impacts, constraints).
3.2.C.A6 Scientific Investigations	● Compare and contrast scientific theories. ● Know that both direct and indirect observations are used by scientists to study the natural world and universe. ● Identify questions and concepts that guide scientific investigations.

	• Formulate and revise explanations and models using logic and evidence. • Recognize and analyze alternative explanations and models. • Examine the status of existing theories. • Evaluate experimental information for relevance and adherence to science processes. • Judge that conclusions are consistent and logical with experimental conditions. • Interpret results of experimental research to predict new information, propose additional investigable questions, or advance a solution. • Communicate and defend a scientific argument.

Appendix – Next Generation Science Standards

Anchor Descriptor	**Core Standard**
HS. Structure and Properties of Matter	HS-PS2-6. Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
HS. Waves and Electromagnetic Radiation	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.

NGSS Standards

- HS-PS1-5: Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.
- HS-PS2-6: Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
- 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.
- HS-ETS1-3: Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

Appendix – Common Core Standards

Anchor Descriptor	**Core Standard**
ELA/Literacy	RST.9-10.7 – Translate qualitative or technical information expressed in words in a text into a visual form and translate information expressed visually or mathematically into words.
Mathematics	**MP.2** – Reason abstractly and quantitatively. (HS-PS4-1), (HS-PS4-3) **HSN-Q.A.1** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-PS1-3),(HS-PS1-8),(HS-PS2-6) **HSN-Q.A.2** Define appropriate quantities for the purpose of descriptive modeling. (HS-PS1-8),(HS-PS2-6)