Minerals in Society

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Problem Statement

The learning of science is most captivating and compelling when educators can make a connection between the classroom content and their student's daily lives. Relating a chemical process or abstract concept to a student's lived experiences makes the learning personal, relevant and more accessible. This is especially necessary in the chemistry classroom where many concepts explore microscopic realities (atoms, protons, electrons, atomic radius, etc.) that are difficult to conceptualize. Although I use many strategies to connect the classroom content to important realities in my student's lives, few are able to make do so. For the majority of these students, chemistry remains theoretical, foreign and uninteresting. This unit is intended to help high school students develop a greater connection to chemistry and a sense of its importance in their lives.

My students (like most young adults) do however, live in a world dominated by continuously evolving technology that demands a constant investment of attention, time and energy. Most spend all of their free time engaged with electronic devices that are made possible by our advances in materials science, wireless communications, and miniaturized microchip technologies. Few are aware of the powerful impact science and our understanding of minerals has made on their lives. Focusing on these artifacts and the compounds that make them possible may provide a much needed connection between the chemistry learned in class and the worlds they inhabit.

Rationale

The importance of minerals is evidenced by the names given to the great eras (the Bronze Age, Iron Age, Steel Age) in the evolution of human civilization (Wolfe, 1984). While the agricultural revolution radically altered our nomadic lifestyles, it is the improvements in manufacturing made during the industrial revolution and the scientific technological discoveries of the computer-information age that have created the world as we now know it (Morse & Glover, 2000). While there are many non-mineral resources that have facilitated mankind's development, it is our ability to mine, extract and exploit the physical and chemical properties of minerals that has made the evolution of our modern world possible. Nearly every artifact of importance in our world contains minerals. Some are native elements (such as aluminum, copper, or silicon), some are precious gems (rubies, emeralds, diamonds), others are components of essential rocks (feldspars in granite, calcium carbonate in limestone,) others are important industrial minerals (gypsum, cement, soda ash); the list is endless (Kogel, Trivedi, Barker, & Krukowski, 2006). Every product from toothpaste, to rechargeable batteries, to the displays on our smart devices, are made possible by minerals.

I have chosen to create a unit on the minerals in our world because such an exploration will provide a vivid connection between chemical principles and the worlds my students inhabit. These content areas are color (as a result of the absorption / release of energy); the role of *d* orbitals in producing color (crystal field theory): coordination chemistry (as it relates to the arrangement of ions in minerals), molecular geometry (as it relates to the 3 dimensional shapes of molecules (known as VSEPR), and electrochemical reactions. A unit on the chemistry of the minerals will provide a forum in which I can explore each of these topics as each helps to explain the physical properties that make minerals important in modern society.

Proposed Unit of Study

Curriculum Unit:

The chemistry content knowledge that informs the Minerals in Our World unit covers a wide range of concepts in the chemistry curriculum. Since these concepts are not taught sequentially, the teaching of the unit take place during the latter part of the school year. I will however introduce the unit and the concept of minerals at the start of the school year when we begin our exploration of the elements of the periodic table. I will then continue to highlight topics relevant to the unit as the chemistry curriculum unfolds. This is important as one of the goals of the unit is to provide a real world context to the chemistry curriculum. The complete unit will be taught during the early weeks of May.

Following is an outline of my chemistry curriculum that includes relevant topics from the minerals unit. The outline is meant to provide a time line and a context for the individual topics throughout the year. Topics from the Mineral in our World unit are italicized.

The unit will also serve as review of the year's work given the scope of the concepts covered in the unit.

CHEMISTRY CURRICULUM

Elements and Compounds in Society:
- *Important Minerals our Society*
- *What are minerals?*

The Periodic Table:

Element Distribution in the Crust:

Metals, Non Metals, Transition metals, Rare Earth Elements
- *What are Minerals? Mineral Abundance*
- *Types of Minerals: (Native Elements, Ores Minerals, Industrial Minerals, Gems)*

Atomic Theory

Atomic Structure and Electron Distribution

Electromagnetic Spectrum and Electron Motion
- *The Bohr Model and the Hydrogen Emission Spectra:*
- *What is Color?*

Electron Configuration
- *Electron Configuration of Transition Metals and Rare Earth Elements*

The Octet Rule, Types of Bonding:

Ionic and Polyatomic Compounds
- *Minerals, and Solid Solution: Silicates, Oxides, Feldspars, etc.*

Unit Cells: Packing in Ionic Compounds

Unit Cell Packing
Density Calculation and Coordination Number
VSEPR and Molecular Geometry
Coordination number and Molecular Geometry
Tetrahedral and Octahedral Geometries
Colors in Minerals
Ligand and Orbital Destabilization
Crystal Field Theory
Types of Chemical Reactions
Single Displacement
Double Displacement
Oxidation – Reduction
Stoichiometry
Solution Stoichiometry: Molarity
Electrochemical Reactions

Overview of the Minerals in Our World Unit

The unit will begin with a review of the chemistry of minerals, their importance in our lives and the various classification systems we use to categorize them. Upon completion of the first three days of the unit, students will select two minerals as topics of their research paper. Students will be expected to note relevant data on their mineral during the remaining days of the unit.

Once we have explored the chemistry of minerals, the class will analyze how electrons are distributed within atoms and how their movement creates color. We will review the Bohr model in order to analyze the hydrogen emission spectra and relate the colors to the motion of electrons between energy levels. Following this we will use our understanding of electron configuration to analyze the structure of transition metals. Our work will go beyond the configuration of the representative elements and explore electron interactions within the d orbitals of the transition metals as the source of colors in minerals. I would like my students to explore an abbreviated form of crystal field theory as it helps to explain why transition metals play such an important role in producing the color of gemstones.

Given the importance that minerals have played in our history, I will end the unit with individual research projects on minerals. Students will research two minerals and create a presentation based on their research. This ending project would provide a summative assessment of my student's understanding of the chemistry and social significance of minerals.

Objectives: Students Will Be Able to (SWBAT):

- Describe the chemical structure of various classes of minerals
- Describe how geological processes transform minerals and alter their physical / chemical properties
- Evaluate the role of minerals in modern society
- Explain the relationship between electron configuration and color in transition metal complexes
- Research the social, economic, and cultural importance of minerals

Standards Used in the Unit

Common Core Literacy Standards:

RST.9-10.7 Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. (HS-PS1-1)

RST.11-12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

RST.11-12.9 Synthesize information from a range of sources into a coherent understanding of process, phenomenon, or concept, resolving conflicting information when possible.

WHST.11-12.8 Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. (HS-PS1-3)

WHST.9-12.9 Draw evidence from informational texts to support analysis, reflection, and research. (HS-PS1-3)

Next Generation Science Standards

HS-PS1-1 Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

HS-PS1-2. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

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

HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

HS-PS4-1 Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.

Background

Mineral Composition and Structure

Minerals are defined as naturally occurring inorganic solids with specific crystalline structures and definite chemical composition. Some minerals consist of a single element: however, most are ionic compounds consisting of a metallic cation and a mono or polyatomic anion in specific ratios. For example, pyrite: FeS, is composed of the Fe^{2+} cation and the Sulfide S^{2-} anion, while Gypsum ($CaSO_4$-$2H_2O$) is composed of the calcium cation Ca^{2+} the sulfate polyatomic anion $SO_4{}^{2-}$, and two waters of hydration. Note that ratio of ions gives the mineral an overall neutral charge.

Although the ratio of cations to anions maintains the mineral's charge neutrality, differing ions can substitute for one another in a given mineral. Minerals with this type of variable composition are known as solid solutions. In a solid solution specific sites in the minerals structure are occupied by differing elements or chemical groups. An example of this is the solid solution of the mineral dolomite ($Ca^{2+,}$ Mg^{2+}, $(CO_3)_2$). In this instance the carbonate anion has a 2^- oxidation state, which necessitates a cation with a 2^+ charge. Either a calcium cation (Ca^{2+}) or a magnesium cation (Mg^{2+}) can bond with the carbonate and provide charge neutrality. The resulting compounds ($CaCO_{3:}$ aragonite or calcite) and ($MgCO_{3:}$ magnesite) are called the end members of the solid solution.
In this example, ions of similar charge and size created the two end members. If, however the ions are of different charges and / or sizes, coupled substitutions occur in order to maintain the mineral's charge neutrality. For example, in the solid solution for the mineral plaglioclase feldspar, ($NaAlSi_3O_8$ - $CaAl_2Si_2O_8$), the end members are (albite $NaAlSi_3O_8$) and (anorthite $CaAl_2Si_2O_8$). In anorthite a $Ca^{2+}$and an Al^{3+} replaced the Na^{1+} and Si^{4+} in the albite: Note that the overall charge of the substituting ions (5^+) maintains the mineral's charge neutrality. These and other types of substitutions create a wide range of solid solutions (Nelson, 2013) that produce the more than 4,000) differing mineral: each with a unique chemical composition and crystalline structure.
A mineral's chemical composition and physical structure depends on the number of ions, the charges on each constituent of the mineral, and their geometrical arrangement of the elements contained within the mineral. Although minerals can form through a variety of geological processes, the rock cycle and the motion of tectonic plates are the two processes that provide the heat and pressure needed to synthesize the vast variety of minerals within the earth. While tectonic forces are able to metamorphose minerals within existing rocks, it is within igneous rocks that most minerals are initially formed.

The Rock Cycle

A rock can be defined as any large continuous portion of the lithosphere that has specific physical and chemical properties. These properties depend on the proportions and geometrical arrangement of the minerals of which they are composed (Tarbuck, 2006). Although there are many differing ways to classify and analyze rocks, they are generally classified into three broad categories: igneous, sedimentary, and metamorphic. Although rocks can form at any point in the cycle, igneous rocks are considered to be the beginning of the rock cycle.
Igneous rocks are formed within the mantle of the earth where they exist in a molten state known as magma. Within the magma differing elements, ions and gases (mainly water vapor) combine to form the minerals that aggregate to form rock.
The relative abundance of ions and elements present in the melt, and the physical conditions (heat, pressure, water content) of the magma determines the mineral's chemical composition. Where the magma cools, (inside the earth: intrusive) or (outside the earth: extrusive) and the rate of cooling affects the rate of crystallization which in turn determines the crystalline structure of the mineral.
Sedimentary processes can alter the composition of the minerals in rocks and create new mineral combinations. There are two major categories of **sedimentary rocks**: clastic and chemical. **Clastic sedimentary** rocks form as a result of weathering processes that erode and break up rocks and other substances into smaller particles. Sediments become rock through the process of compaction (where the weight of overlying material compresses particles into a solid phase). Sediments can also be cemented together by minerals in water such as calcite, hematite, or silica. As water passes through buried sediment, these minerals precipitate out of the solution and bind the sediments together. The processes of compaction and cementation can result in the formation on new secondary minerals within the sedimentary rocks (teachers guide), however most clastic

sediments retain the mineral composition of their parent rock. **Chemical sedimentary** rocks result when the rock minerals that are dissolved in water and carried to receiving bodies of water where dissolved ions can combine with new ones to form new minerals. As conditions change, these new minerals precipitate out of solution and are deposited as sediments. With time, these sediments become sedimentary rock (Tarbuck, 2006). The properties of the minerals and the size of the sediment determine the physical and chemical properties of the resulting sedimentary rock. If sedimentary rocks become buried deep within the earth, the extreme pressure and heat will occasion radical changes in the chemical composition of the minerals within them.
Metamorphism can also occur during tectonic events where plates either converge or diverge (at subduction zones). During these events, tremendous pressure and heat are able to alter the chemical composition and crystalline structure of the minerals within the rocks that form the tectonic plates. These geological processes provide the conditions that create the physical and chemical properties that make minerals such an important part of our society. It is our knowledge and ability to exploit the properties that have made minerals central to nearly every important product in modern society
Minerals are typically identified by their physical properties; (luster, color, streak, hardness, cleavage, specific gravity, and crystal form), it is however, the combination of the chemical composition and crystalline structure that gives each mineral its distinct chemical and physical properties. It is our knowledge and ability to exploit the properties that have made minerals central to nearly every important product in modern society. Given the vast array of minerals,

Mineral Classification:

Mineral Class	Description	Representative Formula	Representative Minerals
Native Elements	Single Elements usually mined from ore minerals: see Ore Minerals Table	Cu, Al, Fe,Ti	Copper, Aluminum, Iron, Titanium,
Silicates	Silicon and Oxygen: Largest group of minerals: They are made from the two most abundant elements in the crust, thus silicates comprise more than 90% of the weight of the crust. Silicates are divided into 7 groups based on the connectivity of the silicate tetrahedral.	SiO_4, $KAlSi_3O_8$, $KAl_2(AlSi_3O_{10})(F,OH)_2$,	K-Feldspars, Muscovite, Olivine, Biotite, Amethyst, Garnets, Agates, Beryl, Tourmaline, Talc,
Oxides	Metals combined with Oxygen	Fe_3O_4, TiO_2, Al_2O_3	Hematite, Rutile, Corundum,
Sulfides	Metals combined with Sulfur	Cu_2S, PbS, (Zn, Fe)S	Chalcocite, Galena, Sphalerite
Sulfates	Metals combined with Sulfur and Oxygen	$BaSO_4$, $CaSO_4$	Barite, Gypsum,
Halides	Metals combined with Halogens	NaCl, $CaCl_2$, HF	Sodium Chloride, Calcium Fluoride, Hydrogen Fluoride
Carbonates	Carbon and Oxygen combined with a metal or semi metal	$CaCO_3$, $MgCO_3$, $Cu_2CO_3\ (OH)_2$	Calcite, Magnesite, Malachite

Phosphates	Phosphorous and Oxygen combined with metals or semi metals	$Ca_5(PO_4)_3(OH)$, $CuAl_6(PO_4)_4(OH)_8 \cdot 5H_2O$	FluoroApatite, Turquoise,
Mineralloids	Organic compounds with no specific crystalline structure		Opal, Amber, Mother of Pearl

Minerals can be further classified as ore minerals, industrial minerals, and gems. These categories will be used in the accompanying unit as the classifications may be more accessible to my students. The category of industrial minerals and gems are especially useful because they group minerals that are in my student's everyday lives.

Important Ore minerals: Metallic minerals (such as aluminum, copper, and magnesium) are extracted from ores. Ore minerals such as bauxite, rutile, hematite, and chalcopyrite are the sources of our most important metals.

Ore Minerals and their Metals

Metal	Ore Mineral	Mineral Formula
Aluminum (Al)	Bauxite	Gibbsite: $Al(OH)_3$
		Boehmite γ– AlO(OH)
		Gibsite -α–AlO(OH)
Chromium (Cr)	Chromite $(Mg,Fe)(Cr_2O_4)$	Magnesiochromite: $MgCr_2O_4$)
		Hercynite $FeAl_2O_4$
Copper	Chalcopyrite	$CuFeS_2$
	Bornite	Cu_5FeS_4
	Chalcocite	Cu_2S
Gold (Au)	Native Gold	Au
Iron	Hematite	Fe_2O_3
	Magnetite	Fe_3O_4
	Limonite	$FeO(OH)\text{-}nH_2O$
Lead	Galena	PbS
Magnesium	Magnesite	$MgCO_3$
	Dolomite	$Ca\,Mg(CO_3)_2$
Mercury	Cinnabar	HgS
Molybdenum	Molybdenite	MoS
Nickel	Pentlandite	$(Fe,Ni)_9S_8$
Platinum	Native Platinum	Pt
Silver	Native Silver	Ag
	Argentite	Ag_2S
Tin	Cassiterite	Sn_2O
Titanium	Ilmenite	$FeTiO_3$
	Rutile	TiO_2
Tungsten	Wolframite $(Fe,Mn)WO_4$	Ferberite (Fe^{2+}
		Hübnerite (Mn^{2+}
	Scheelite	$CaWO_4$
Uranium	Uranitnite	UO_2 (UO_3)
Zinc	Sphalerite	(Zn,Fe)S

Major Industrial Minerals

The classification of industrial minerals is especially relevant to this unit as they will be familiar to most students because they are used in a wide range of domestic and industrial applications. Industrial minerals can be defined as (Schumaker, Snyder, & Katz, 1975)

> rocks or earth materials that are utilized because of their characteristic physical and/ or chemical properties and not because of their metal content and which are energy sources
>
> (Christidis, 2011.p.2)

Clays, gypsum, potash, mica, calcium carbonate, talc, and zeolite are a few well known industrial minerals.

Industrial Minerals and their Uses in the Home

Use in the Home	Mineral
Glass, light Bulbs	Silica, Sand
Ceramic Tiles	Kaolin,
Ceramic Plates & Mugs	Feldspars, Alumina
Paint	Titanium Dioxide
Detergents, Soaps	Soda Ash, Phosphates
Kitchen Surfaces	Limestone (Marble)
Oven Glass	Petalites
Sheetrock	Gypsum
Cat Litter	Sepiolite, Bentonite
Salt	Halite
Water Purification	Zeolites
Displays, Smartphones	Rare Earth Elements
Gems	Ruby (corundum), emerald (beryl)
Pencil lead	Graphite

Gemstones

There are countless number of minerals that are prized for their radiance and beauty. These minerals are considered gems (or gemstones). There are too many to list in this unit guide, so I will list a subset of gems used as birthstones. In some months a separate gem is used for the corresponding sign of the Zodiac. These will be listed along with the birthstone for that month. A more comprehensive list will be made available during the research phase of this curriculum unit.

Birthstones

Month	**Gemstone**
January	Garnet
February	Amethyst
March For Aries	Aquamarine Bloodstone
April For Taurus	Diamond Sapphire
May For Gemini	Emerald Agate

June For Cancer	Opal, Mother of Pearl, Alexandrite Emerald
July For Leo	Ruby Onyx
August For Virgo	Peridot, Spinel Carnelian
September For Libra	Sapphire Chrysolite
October For Scorpio	Tourmaline Beryl
November	Yellow Topaz, Citrine
December For Capricorn	Turquoise, Blue Topaz, Blue Zircon Ruby

Source: https://www.gemselect.com/gem-info/birthstones.php

Gems are an important class of minerals that are prized for their color. The color in these minerals is the result of the complex interaction between light, their chemical structure, and the arrangement of electrons within atomic orbitals. To fully understand the colors of minerals, one must describe the interaction of electromagnetic radiation and the electronic structure of atoms.

Atomic Structure and Color

Atoms of given elements have a unique number of protons (their atomic number) and a corresponding number of electrons (which equal the atomic number in neutral atoms). Electrons are arrayed around the nucleus of the atom in orbitals that correspond to the electron's energy state. The electron configuration of an atom describes the arrangement of its electrons within the differing orbitals.

Color and Light

Color is the result of the differential absorption of light as it interacts with the valence electrons distributed throughout an elements atomic orbitals. Visible light is an array of electromagnetic radiation (with wavelengths between approximately 400 and 700 nanometers) that can be observed by human beings. The colors we are all familiar with (R O Y G B I V) compose the visible spectrum of light. As white light passes through an object, some of the energies (corresponding to specific wavelengths and frequencies), are absorbed by the object, the unabsorbed energies pass through the object and are perceived as color.

Quantized Energy and Color

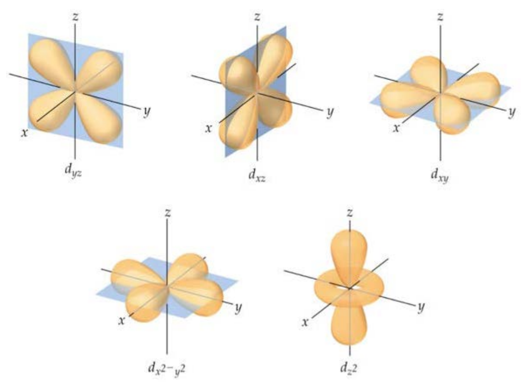
The electrons within an atom are arranged in orbitals of differing energies. Transition from an orbital of a given energy to one of a higher (or lower) energy requires a specific amount of energy. Modern atomic theory states that energies within atoms are quantized thus electrons can only transition between energy level when the energy absorbed corresponds to the specific quantized energy gap between orbitals. This energy difference can be correlated to the energy of a given wavelength of light. If the energy needed for a transition to a higher energy level corresponds to a specific wavelength of light. If the energy corresponds (exactly) to the energy gap between orbitals, then that energy is absorbed by the electron and it is "excited" to a higher energy level. Electrons in the excited energy state will eventually fall back to the ground state and release the absorbed energy. If the emitted energy is in the visible range of the electromagnetic spectrum, then they will be perceived as the “color” of the object.

Transition metals and color

The color in minerals is the result of the presence of transition metals. Idiographic minerals emit colors because they contain a transition metal as part of their innate chemical structure. The color of allochromatic minerals results from the inclusion of a transition metal that is not part of its chemical structure. These “impurities” help explain the varying colors in minerals that would otherwise be colorless. For example, corundum Al_2O_3 is normally colorless, but the addition chromium (Cr^{3+}) to its structure produces the intense red color of a ruby. There are several theoretical constructs (color centers, metal-metal charge transfer and crystal field theory) that can be used to explain how the motion of electrons within the transition metals occasion a mineral’s color (Nassau, 1978). Of these, crystal field theory is best suited to explain how the interaction between ligands and metal complexes produce the colors associated with given transition metals (Miessler & Tarr, 1999).

Atomic Orbitals and Color

Transition metals are a group of 38 elements located in the middle of the periodic table (groups 3 through 12). They are known as the ‘d’ block elements because their valence electrons are distributed throughout the five d orbitals. Scandium is the first transition metal with an electron in a d orbital (there are five d orbitals): thus it’s electron configuration is [Ar] $4s^2$ $3d^1$. The other nine elements of this period will fill the remaining d orbitals. As atoms increase in atomic number, so do the number of valence electrons and the variety and spatial orientations of the atomic orbitals that they inhabit. Atoms with a large number of available energy levels allow a wider range of electronic transitions and are therefore able to produce a wide array of colors. Transition metals are known as coloring agents because their valence electrons are able to move freely between the various unoccupied d orbitals.

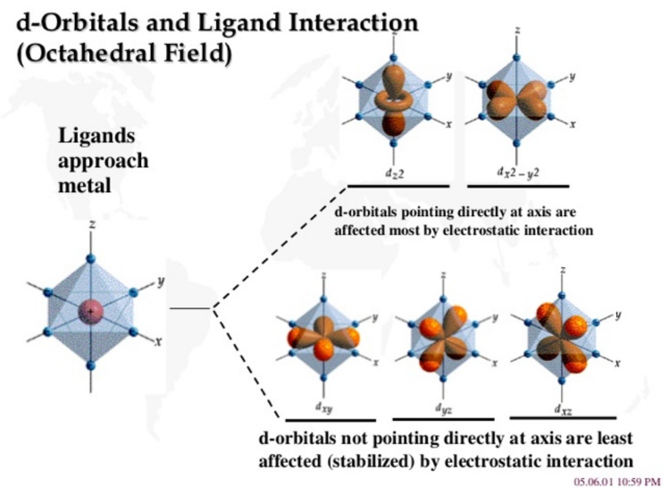


Each of the d orbitals with the exception of the horus ($d_z{}^2$) is composed of two large lobes (each oriented along one of the three coordinate axes (x,y,z) Although the orbitals have differing geometries and spatial orientations they are described as degenerate as they all possesses the same amount of energy. The transition metals in minerals are located within metal complexes that have either a tetrahedral or octahedral molecular geometry. In each of these types of complexes, the transition metals are bonded with ligands (chemical species that form dative bonds (also known as coordinate covalent bonds) with the metal complex.

Electron Configuration and Color

Electrons within the complex occupy any one of the d orbitals. Initially the orbitals are said to be “degenerate” as they all have equal energy. This situation changes when ligands (positioned along the axes of the octahedral) do not interact with the transition metal’s d orbitals. This is normally the case with 3 of the d orbitals (the d_{yz}, d_{xz}, and the d_{xy}) whose lobes are not in an orientation that would occasion an interaction with the ligand's electrons. This is not the case with the d_{x2-y2} or the d_{z2} orbitals who are oriented in such a way as to interact directly with the ligand's electrons. The repulsive interactions between the ligand and the electrons in the d orbitals increases the energy of the d_{z2} and the d_{x2-y2} and lowers the energy of the d_{yz}, d_{xz}, and the d_{xy} creating a split in the energy of the orbitals.

Thus the interaction of the ligands and the metal's orbitals increases the number of possible electronic transitions. As a result, a thus we have a 2 -3 split with two orbitals in a high energy state (termed *eg* level) and three in a lower energy state: (termed the t*2g* level) (see figure 2).

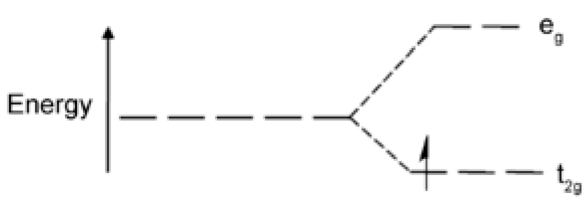


The energy difference between the orbitals orbitals is known the crystal field splitting energy (D_O). The energy needed to excite electrons to these new energy states (and the corresponding wavelength of absorbed light) is specific to each metal. These variations give rise to the variety of colors associated with minerals containing transition metals.

Source: https://image.slidesharecdn.com/

An example of this splitting is analyzed for chromium found in the ruby mineral. Rubies are made from the mineral corundum (Al_2O_3) where chromium has displaced some of the Al in the crystal structure. The chromium ion has lost 3 valence electrons (Cr^{3+}) thus it is in the d^3 state. When light interacts with the complex, the electrons in the Cr^{3+} absorb some of the energy and move from a lower t*2g* orbital into the excited *eg* orbital. The transitioning electrons will absorb some of the light's energy (corresponding to given wavelengths of color). The remaining wavelengths of light (in this instance the color red) will pass through the mineral where they will be observed as the color red.

Figure 2 Crystal Field Splitting Energy



Curriculum Unit

Curriculum Unit

Day One and Day Two	**Topic: Minerals in Society**
Essential Question: What is the importance of minerals in society? What is the importance of minerals in your daily life?	
Objective: SWBAT Describe the role of minerals in society IOT Analyze their role in modern society	
Narrative: This class will introduce students to the role that minerals have society and in their daily life. The class will establish the goals for the unit, the criteria for the final research paper, as well as the working definitions and categories of minerals. The class (as do all in this unit) will include previously taught content as background knowledge. **Strategies**: Classroom discussion, video analysis, guided reading, and PowerPoint presentation on minerals in our world. **Background Content:** Definition of mineral, mineral categories, mineral formulae, **Direct Instruction:** Students will describe the elements / minerals found in Smartphones and relate them to the periodic table. Instructor will review content on minerals, types of minerals, ore minerals, gemstones. **Classroom Activity:** The class begins with the question: What is the most important object that you use every day? The answer will likely be a Smartphone or other piece of technology. The class will then view a video titled "Do You know what is in your Smartphone? Students will list the elements used in the typical phone and explain their function. The elements will be defined as minerals that make modern life possible. The class will then analyze the poster: "Mineral Resources: Out of the ground and into your life" from the USGS. The class will discuss the minerals, their categories, and their function in our society. Once the discussion is completed, we will review our definitions of minerals, industrial minerals, ore minerals, and gemstones as important classes of minerals. Students will be asked to select three minerals that they will research during the unit: one of the minerals will be used for their final research paper. The class will end with a directed reading assignment, which will be completed as homework. The text "Life Without Rare Earth Metals" will introduce the rare earth metals as a group of important minerals. Students will complete a set of guided questions as homework. **Extension**: Rare Earth Element Technology Alliance Website:	
Materials[1]: You Tube Video: What's in your Smartphone? Lists of the following categories of minerals: Native Elements, Ore minerals, Industrial minerals, and gemstones. There may be overlap in the lists as the categories are somewhat fluid.	

Day Three and Four	**Topic: Minerals in Society and Mineral Properties**
Essential Question: What is the importance of minerals in society? What are the chemical and physical properties that make minerals valuable?	
Objective: SWBAT: Describe mineral properties IOT Evaluate how minerals affect our daily lives.	
Narrative: The class continues the topics of the first lesson with a review of the homework questions on rare earth metals. Teacher will begin the lesson with a demonstration of talc. Teacher will ask students what	

[1] Source information and links to all resources is located in the Resource Section of Appendix A.

the mineral has to do with talcum powder. A discussion will ensue on the properties of the mineral (and the sandpaper) and the importance of these minerals in society. Following the demonstration, the class will engage in an activity on the identification of minerals using a mineral identification key and samples of a variety of minerals. Students should become familiar with properties such as luster, hardness, streak, cleavage, and color. Students will classify the minerals as native elements, industrial, either ore minerals, or gems. **Strategies:** Discussion of assigned questions and a description of important minerals in society. The list will remain as resource for final projects. Mineral identification activity with a focus on mineral properties and how they relate to a mineral's use. **Background Content:** Mineral properties **Direct Instruction**: Students will list mineral properties and note how to use the materials in the mineral identification kit. Teacher will explain the hardness scale, streak plate, the use of the dilute acid and the remaining tools in the kit. Each student group will receive a mineral sample, an identification kit and instructions. The activity will be concluded on Day 3 if needed. **Classroom Activity**: Mineral identification key info is in the appendix. copy it to here.
Materials: A sample of talc and a variety of differing grades of sandpaper. Mineral identification kit (specified in mineral key): Mineral samples kit: One set of large minerals for demonstration and 6 smaller kits for student groups.

Day Five	**Topic: Classification of Minerals**
Essential Question: How does the classification of minerals improve our understanding of their properties?	
Objective: **SWBAT** Describe the similarities in the chemical composition of mineral groups IOT create an efficient classification system.	
Narrative: There are over 4000 known minerals. In order to **Strategies**: Describe the chemical composition and structure of representative minerals and classify them based on chemical structure. The class will work collaboratively to classify a representative list of minerals. Students will use the DANA classification system. Once completed the class will decide on the use of alternative classification systems. **Background Content:** Chemical composition and properties of minerals: (information from mineral identification activity can be used to inform inquiry). DANA classification system, and alternative classification systems: (industrial minerals, ore minerals, and gemstones) can be used. **Direct Instruction**: DANA classification system criteria. Definition of industrial minerals, gemstones and ore minerals to be used as alternative classification systems. **Classroom Activity**: Students will be given a list of minerals to classify. Some minerals from the previous day's activity will be included. Students will list the criteria for each mineral class. Each group will select a mineral class and then select minerals from the list that belong to the class. Once completed the class will discuss the relevance of classification systems and decide if an alternative system would be more efficient. The groups will then use alternative systems to reclassify our list of minerals. Once complete the class will determine which classification system is more efficient for our unit. At the end of the class students will select two minerals from different classes for their research project.	
Materials: List and pictures of relevant minerals from each of the 8 classes and a description of the classification criteria for each of the classification systems. Information should be displayed as part of a PowerPoint presentation. Extension: Students should begin their research project on this day. Criteria for the project are located in the Teacher Resources section of the Appendix.	

These first days of the unit cover content that focuses specifically on minerals. The following days focus on the chemistry of minerals. It is important to note that not all of the relevant chemistry concepts are covered in this unit as they were studied as part of the year curriculum. The reader is encouraged to review the yearly chemistry curriculum provided earlier in this document should they need to include more of the chemistry chemistry curriculum in this unit

Day Six and Seven	**Topic: Electron Distribution and Color**

Essential Question: What is the relation between the motion of electrons and the colors of the emission spectra of elements?

Objective: SWBAT use the Bohr model of the atom to explain the emission spectra of hydrogen gas. Students will also calculate the energy and wavelength of emitted light using Bohr's equation.

Narrative: An important property of minerals is color. We will begin the investigation of color in minerals by examining the Bohr model and the equations that predict the wavelengths of the emission spectra of the gas. The lesson is an introduction to how the motion of electrons affects the color we perceive from objects. In this lesson color is the result of the electron's transition between energy levels in the atom. The concept of quantized energy is important as it will be used to explain why minerals absorb some wavelengths of light and transmit others. These analogous explanations of color will be examined in these lessons.
Although we are using Bohr's model to describe the "location" of electrons, students will use the quantum mechanical model and electron configuration to describe the distribution of electrons in transition metals. In the ensuing lesson students will use the interactions of ligands with these electrons to explain the colors of transition metal complexes.

Strategies: Students will observe the bright line emission spectra of hydrogen gas using spectroscopes. Students will then use a series of equations to verify the wavelength and energy of the emitted light.

Background Content: Bohr's atomic model: Bohr's equations and the equations that relate frequency, wavelength, and energy.

Direct Instruction: Teacher will show the electromagnetic spectrum, and describe the relationship between wavelength, frequency and the speed of light.

Classroom Activity: Students will review the Bohr model of the atom, the principles that describe electron motion between atomic orbitals, and Bohr's equations that describe the energy associated with those transitions.

Materials: Hydrogen gas discharge tube, power source, hand held spectroscopes, emission spectra chart, PowerPoint presentation of Bohr's model of the atom.

Day Eight and Nine **Topic: Analysis of Color in Transition Metal Complexes**

Essential Question; How does the motion of electrons in the d orbitals of transition metals contribute to the perceived color?

Objective: SWBAT describe the electron configuration of transition metals IOT analyze the colors of transition metal complexes.

Narrative: In previous lessons students learned that color we perceive results from the interaction of electrons with differing wavelengths of electromagnetic radiation. The colors associated with transition metal complexes is the result of the motion of electrons in d orbitals. Crystal Field Theory provides an explanation of the reason why transition metal complexes absorb (and transmit) given wavelengths of light. In this class students will engage in an activity that explores this concept using a series of solutions containing Co^{3+} ions. Students will combine the solutions with differing compounds to determine the effect that differing ligands have on the color of the solution. Students will use a color wheel to estimate the wavelength of the light absorbed then use the equation $\Delta E = hc / \lambda =$ □to calculate the crystal field splitting energy. Students will perform a similar analysis of the other solutions in order to determine the effect that different ligands have on the splitting energy. Once completed the class will compare observations and determine how and why the differing ligands affected the splitting energy.

Strategies: Group analysis of concepts related to electron configuration, and crystal field theory. Group lab activity, and group discussion of lab data and associated calculations.

Background Content: Color wheels, electron configuration of transition metals, oxidation states of metals, shape and orientation of d orbitals, equations relating energy, wavelength, and frequency.

Direct Instruction: Review of electron configuration of transition metals, the shapes and orientations of d orbitals, and oxidation states of metals. Instructions on the preparation of the cobalt complexes and instructions for the mixing of solutions and completion of the lab.

Classroom Activity: Students will begin the class by determining the electron configuration of transition metals. Students will also predict the oxidation state of the metals and draw the corresponding electron configurations. Students will draw a diagram of the five d orbitals then explain how the orbitals react to the approach of the ligand in the complex. Once completed students will set up to begin the lab. This activity will take at least two class periods to complete.

Materials: Materials for laboratory are listed in the lab located in the Teacher Resources section of the Appendix. Laboratory is located at: https://www.lahc.edu/classes/chemistry/arias/Lab9Coordsp11.pdf Source: (Arias, 2016)

Day Ten and Eleven	**Synthesis and Evaluation of Malachite**
Objective: SWBAT synthesize the mineral malachite and verify its purity.	
Narrative: To this point students have yet to experience the synthesis of a mineral. This laboratory provides this opportunity. The procedure is relatively simple and can be completed in one class period. The samples will dry until the next class period when verification tests can be conducted. **Strategies**: Laboratory activity. **Direct Instruction**: Explanation of laboratory procedure and set up of equipment. **Classroom Activity**: Students will complete the synthesis of malachite. Students will use tools from their mineral identification kits, and the calculations of density to determine the purity of their sample.	
Materials: Necessary chemicals and equipment is described in the materials section of the lab. Lab procedure is located at: http://www.chymist.com/malachite.pdf. Source: (Schumaker, Snyder, & Katz, 1975)	

Day 12	**Summary Research Topic**
Objective: SWBAT Construct a research paper that evaluates the role of minerals in society and in their everyday life.	
Narrative: This summary research will serve as a summative assessment for our unit. Students will be given a set of guided questions to use a scaffold for their research project. Students will be asked to prepare an oral report to accompany their paper. **Classroom Activity**: Students will begin the research paper during the final two days of the unit. They will then be given a week to complete the research paper.	
Materials: Guided questions, research paper criteria and grading rubric.	

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APPENDIX

Teacher Resources

Day One:
Smartphone Video:
WHAT'S in your Smartphone Video:
https://www.youtube.com/watch?v=66SGcBAs04w
Mineral Poster:
Poster for first day:
https://pubs.usgs.gov/of/2001/0360/pdf/of01-360.pdf
Life without Rare Earth Elements:
http://www.acschemmatters-digital.org/acschemmatters/december2016?pg=14#pg14

Life Without Rare Earth Elements Teacher's Guide Available at:
https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/teachers-guide.html
Select December 2016 to access materials. Guide contains guided reading questions and many other resources on the topic of rare earth metals.

Extensions:

Rare Earth Elements Technology Alliance: A series of web pages promoting the use of rare earth elements in our society. A very comprehensive resource that can be used as resource for research papers:
http://www.rareearthtechalliance.com/NewsRoom

The Economics of the North American Rare Earth Industry:
http://www.rareearthtechalliance.com/Resources/The-Economic-Benefits-of-the-North-American-Rare-Earths-Industry.pdf

Rare Earth Elements Vital to Modern life and Technologies
https://pubs.usgs.gov/fs/2014/3078/pdf/fs2014-3078.pdf

Day Two

Mineral Identification Lab: This laboratory provides background information on mineral properties and how to use the tools in a mineral identification kit. The instructions will be used along with the mineral identification key to analyze the properties of minerals. Details each property with illustrations and example: The lab is located at:
https://www.saddleback.edu/faculty/jrepka/notes/GEOmineralLAB_1.pdf

Mineral Identification Key and Guide: This guide describes the materials for an identification kit and suggests samples to be used in the activity. The guide is located at: http://www.minsocam.org/msa/collectors_corner/id/mineral_id_keyi1.htm: This key is cited in the unit as: (Plante, Peck, & Von Bargen , 2003): The guide contains a virtual dichotomous key that will help identify a sample. The site includes an extensive data base of mineral samples that can be used to supplement the activity.

Mineral Identification Activity Teacher Guide: This guide details a series of mineral activities.
The guide can be used as background knowledge for the mineral identification activity. The mineral sample suggested provide the opportunity to examine all of the relevant properties of minerals. The guide is located at:
http://www.msnucleus.org/membership/

Mineral Structure Data Base: Complements J. Smyth's book with illustrations of each type of structure. Provides unit cell coordination numbers, illustrations of unit cell and data for calculating the density of minerals.
http://ruby.colorado.edu/~smyth/min/minerals.html

Day Three:
Mineral Identification Kit is located at:
http://www.minsocam.org/msa/collectors_corner/id/mineral_id_keyi1.htm

A second identification lab activity with pictures.
https://www.saddleback.edu/faculty/jrepka/notes/GEOmineralLAB_1.pdf

Laboratory Procedures

Day Eight and Nine Laboratory
Synthesis and Analysis of Coordination Complexes
This laboratory complements the discussion on crystal field splitting energy. Students will make and observe the colors of solutions of transition metal complexes. They will use the observed colors to estimate the crystal field splitting energy of the complexes. Laboratory procedure is located at:
https://www.lahc.edu/classes/chemistry/arias/Lab9Coordsp11.pdf

Day Ten and Nine Laboratory
Synthesis of Malachite
http://www.chymist.com/malachite.pdf

Additional Teacher Resources

Gem Select: Extensive data base on gems. Indexed alphabetically: provides history of gem, how gems are jeweled, along with a complete table of the gems properties.
https://www.gemselect.com/gem-info/info.php

Mineral Resources Data Base: A series of databases on mineral nationally and internationally. Included is a database that lists domestic production and consumption trends for the mineral commodities since 1996. Data is organized alphabetically and by categories such as: Aggregates minerals, agricultural minerals, precious metals and gems, nonferrous and ferrous metals, and construction materials:
https://minerals.usgs.gov/minerals/pubs/commodity/

Birthstones: Organized by month. Cultural history and lore of each stone.
https://www.americangemsociety.org/en/birthstones

Geology of Rubies: Detailed history of ruby chemistry.
https://www.americangemsociety.org/en/birthstones

Mineralogy Data Base:
http://webmineral.com/
Extensive data base on minerals. Over 4700 minerals are indexed and classified in a variety of systems (including Dana classification). All physical and chemical data are

organized on webpages and organized on periodic table. Extensive listing of all compounds containing given minerals.

Smartphones Smart Chemistry from: a summary of longer article from April 2015Chemmatters article.
https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/past-issues/archive-2014-2015/smartphones.html
Complete Article is located at:
https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/teachers-guide.html
Select April 2015 to download Teacher Guide: article pages 75 – 110.

Appendix B

Ore Minerals and Metals

Metal	Uses	Ore Mineral	Mineral Formula
Aluminum (Al)		Bauxite	Gibbsite: $Al(OH)_3$

	Aircraft, Canning,		Boehmite □□□□ lO(OH)
			Gibsite -□□ AlO(OH)
Chromium (Cr)		Chromite $(Mg,Fe)(Cr_2O_4)$	Magnesiochromite: $MgCr_2O_4)$
			Hercynite $FeAl_2O_4$
Copper		Chalcopyrite	$CuFeS_2$
		Bornite	Cu_5FeS_4
		Chalcocite	Cu_2S
Gold (Au)		Native Gold	
Iron		Hematite	Fe_2O_3
		Magnetite	Fe_3O_4
		Limonite	$FeO(OH)\text{-}nH_2O$
Lead		Galena	PbS
Magnesium		Magnesite	$MgCO_3$
		Dolomite	$Ca\ Mg(CO_3)_2$
Mercury		Cinnabar	HgS
Molybdenum		Molybdenite	MoS
Nickel		Pentlandite	$(Fe,Ni)_9S_8$
Platinum		Native Platinum	
Silver		Native Silver	Ag
		Argentite	Ag_2S
Tin		Cassiterite	Sn_2O
Titanium		Ilmenite	$FeTiO_3$
		Rutile	TiO_2
Tungsten		Wolframite $(Fe,Mn)WO_4$	Ferberite $(Fe^{2+}$
			Hübnerite $(Mn^{2+}$
		Scheelite	$CaWO_4$
Uranium		Uranitnite	UO_2 (UO_3)
Zinc		Sphalerite	(Zn,Fe)S