Charlotte Teachers Institute
Collaborative Teacher Education

Lights all Around Us

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Cato Middle College High School

This curriculum unit is recommended for: Honors Chemistry I/ Grades 10th - 12th

Keywords: fluorescence, electrons, visible light, chemical bonds, chemical reactions, exothermic reaction, endothermic reaction, thermochemistry, chemistry

Teaching Standards: See Appendix 1 for detailed explanation of standard addressed in this unit.

- Chm.1.1.3 Explain the emission of electromagnetic radiation in spectral form in terms of the Bohr model.
- Chm.2.2.1 Explain the energy content of a chemical reaction.
- Chm.2.2.2 Analyze the evidence of chemical change.
- Chm.3.1.1 Explain the factors that affect the rate of a reaction (temperature, concentration, particle size and presence of a catalyst).

Synopsis:
Chemistry is one of those subjects that has a bad or scary reputation. On or even before the first day of class students will tell me that they are not expecting to do well in the course. This curriculum unit is designed to make chemistry accessible and relatable to all students. Using the unifying concept of light emission, this unit will link various North Carolina chemistry standards to everyday experiences. All of the topics and activities were selected with simplicity in mind, and every teacher should be able to incorporate all or part of this curriculum unit into their course with relative ease. The topics addressed in this unit include: electron emissions, the visible light spectrum, chemical bonds, chemical reactions, thermochemistry and solutions. This unit includes a lesson on electron emissions that focuses on how the movement of electrons can produce visible light. Students will also investigate how chemical bonding relates to chemical reactions; while being challenged to explore how luminescence can be used to improve society.

Rationale

Chemistry is one of those subjects that has a bad or scary reputation. On or even before the first day of class students will tell me that they are not expecting to do well in the course. I try to counteract this by making the class fun with stories and weekly labs or hands-on activities. While this makes the class more enjoyable, I feel that students still fail to see how chemistry is relevant or applicable to their everyday life. Not only does this curriculum unit make chemistry interesting, it will also demonstrate how chemistry is relevant to their everyday life.

Most high school students have heard of luminescence. If you were to ask any of them to describe luminescence they would probably tell you that it glows and any examples would probably revolve around glow in the dark objects. While this is not wrong, it is very simplified and it limits luminescence to party favors and face paint. You may not realize it, but luminescence is a part of our everyday lives. When you turn on a light with an LED bulb, that is luminescence. When you go to the store and pay with a fifty dollar bill and the cashier puts the bill in a light box, that is luminescence. Our cell phones, televisions, detergents, credit cards, drivers license, tickets, clothing, beverages, writing utensils, and so much more all luminate in some way.

It is no secret that this age group is obsessed with technology. While they are knowledgeable in how to use technology effectively, they probably have new thought twice about the science behind the technology. This unit is designed to bridge the knowledge gap between technology and luminescence and activate their curiosity about luminescence. As students progress through the course they will use concepts that they learn in class to explain luminescence.

Student and School Background

Cato Middle College High School is a magnet high school located in east Charlotte on the campus of Central Piedmont Community College- Cato Campus. Admission is based on GPA (2.5 minimum) and standardized test scores (SAT, ACT or ACCUPLACER). Students at Cato are dual enrolled in CMS and CPCC. The school serves approximately 220 students (100 11th grade, 100 12th grade, 20 13th grade). The majority (67%) of the students belong to a minority ethnic group (33% black, 33% hispanic). Thirty-three percent of the students are classified as intellectually gifted. As a result all of the students in my Honors Chemistry class are high achieving. We are a 1:1 school so all students have access to technology, and teachers are encouraged to incorporate technology into our daily lesson plans.

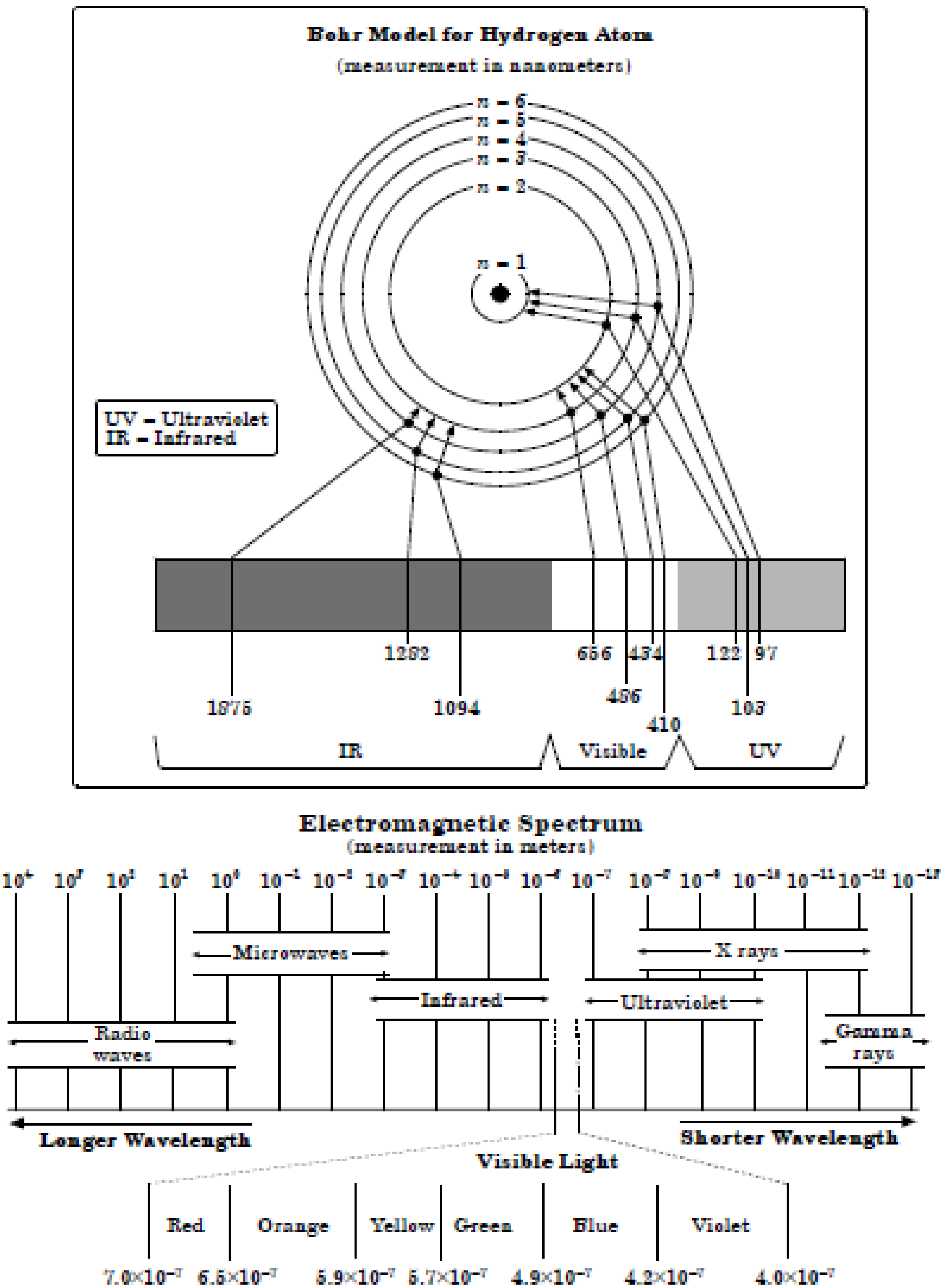
Curriculum Objective

From an early age students are introduced to the physical sciences. In elementary school they learn about chemical versus physical changes, they begin to learn about the different states of matter, and they might even begin to learn about visible light. Once they get to middle school they start learning about the atom and they are introduced to protons, neutrons and electrons. Students also obtain basic knowledge of acids and bases; most middle schoolers can tell you that acids have a low pH and bases have a high pH. In the typical high school chemistry class students will revisit and learn more about all of these concepts. While before they just learned the states of matter and phase changes in chemistry they will learn about the energy associated with the phase change, and how to determine if the change is endothermic or exothermic. Instead of just identifying a chemical change they will learn about what causes the chemical reaction and how to predict the outcome of such a reaction. Students learn that the electron is not just that negatively charged thing in the atom, but it is responsible for a lot of phenomena we see in our everyday world; including light. Using hands on activities, students will connect several chemistry standards including, electron emissions, chemical reactions, chemical bonds, and solutions to fluorescence.

Content Background

Electron Emissions

All matter is made of atoms and is composed of three subatomic particles; protons, neutrons and electrons. The nucleus of the atom has positively charged protons and neutrons that do not have a charge. Electrons orbit around the nucleus of an atom and they have a negative charge. According to Niels Bohr, an atom has a finite number of allowable energy states. The lowest energy state is referred to as the ground state and when an atom gains energy it is said to be in an excited state.[1] In 1913 Bohr created the Bohr model and he used this model of a hydrogen atom to illustrate what happens to electrons when an atom absorbs and releases energy. Based on his model, Bohr suggested that electrons revolve around the nucleus in circular orbits and the smaller the orbits, the lower the energy state of the atom. As electrons move further away from the nucleus the orbit becomes larger, therefore the energy state will increase. Bohr assigned quantum numbers (n) to the orbits.[8] The orbit that is closest to the nucleus is $n = 1$, the next orbit is $n = 2$, and so on. When a hydrogen atom is in the ground state the single electron is in the $n = 1$ orbit and no energy is emitted. However, when energy is added to the atom from an outside source the electron is able to move to a different orbital, and now the atom is in an excited state. The amount of energy absorbed by the atom will determine to which orbit the electron is able to move.[1] The more energy the atom absorbs, the further away from the nucleus an electron is able to move.[8] The excited state of an atom is only temporary and eventually the atom must return to the ground state when the electron returns to the initial orbit. The process of an electron releasing energy returning to the original orbit is referred to as relaxation or emissions.[1] The law of the conservation of energy states that energy cannot be created or destroyed; meaning that any energy absorbed by an electron will eventually be released. Typically this energy is lost as a photon with a specific wavelength. The wavelength of the photon will determine if it is visible light, and if it is visible the wavelength will determine the color of light emitted. The wavelength of light is inversely proportional to the energy release from the electron.[1, 8] The image in Figure 1 is taken from the North Carolina Department of Public Instruction reference tables for chemistry.[k] This figure illustrates electrons returning to the ground state release energy of varying wavelengths. The wavelength will determine the type of photon that is emitted, and if the wavelength falls within the visible light spectrum it will be visible to the naked eye.



North Carolina Department of Public Instruction Chemistry Reference Guide, p.8

Figure 1.[k]

Chemical Bonds

Thousands of chemical compounds exist, we probably interact with hundreds on a daily basis. All of these compounds are formed from the 118 known chemical elements that are held together by chemical bonds.[1] Atoms form chemical bonds with other atoms in order to achieve stability by creating a full valence shell of electrons. Based on the composition of the compound, chemical bonds are classified as either ionic, covalent or metallic.[2, 9] Ionic bonds are present in compounds composed of metals and nonmetals, while covalent bonds are between two nonmetals.[9] The bond between sodium (Na, a metal) and chlorine (Cl, a nonmetal) in sodium chloride (NaCl) is a simple and popular example of an ionic bond. During the reaction to create NaCl, a sodium atom donates a valence electron to a chlorine atom and becomes a positive ion (cation). When the chlorine atom accepts the donated electron it becomes a negatively charged ion (anion).[1] The electrostatic force that holds these oppositely charged particles together is referred to as an ionic bond; the compounds that contain ionic bonds are ionic compounds.[9] While electrons are transferred to form ionic bonds, when two nonmetals come together the electrons are shared and a covalent bond is formed.[2] Chlorine gas (Cl_2) has a covalent bond. Both oxygen (O) atoms have seven valence electrons and need one more electron to become stable. As these two chlorine atoms approach each other, the electrons of one atom are attracted to the positively charged nucleus of the other atom. As the two atoms continue to move closer to each other the attraction continues until the maximum attraction is achieved; this attraction is referred to as a covalent bond and the compound can be called a covalent compound or a molecule.[1]

When a single pair of electrons is shared between atoms a single bond is created. In many molecules atoms have to share more than one pair of electrons and double or triple bonds may result. If two pairs of electrons are shared between atoms (O_2 for example) a double bond is formed and if three pairs are shared, a triple bond is the result (N_2 has a triple bond). Not all covalent bonds are created equal. These three types of bonds have different strengths. The strength of a covalent bond is directly related to the length of the bond. Single bonds are about 1.43×10^{-10} m, the length of a double bond is roughly 1.21×10^{-10} m and triples bonds are around 1.10×10^{-10} m in length. As you can see, as the number of shared pairs of electrons increases, the bond length will decrease. Shorter bonds are stronger than longer bonds, thus triple bonds are stronger than double bonds, which are stronger than single bonds.[10]

All bond types have different strengths which cause the compounds or molecules to have different properties/ characteristics. Energy is needed to break chemical bonds, and the amount of energy needed will depend on the composition of the compound/ molecule and the type of bonds present. The amount of energy required to break a bond is directly proportional to the strength of the bond. This also correlates to the melting and boiling points of a compound; stronger bonds require more energy which causes the compound/ molecule to have a high melting or boiling point.[10] Since ionic bonds are generally stronger than all covalent bonds, more energy is required to break ionic bonds and they will have higher melting and boiling points; and among covalent bonds triple bonds require the greatest amount of energy and covalent compounds with single bonds will have the lowest melting and boiling points.[1]

Chemical Reactions

When atoms, compounds or molecules come together a chemical reaction can happen. During a chemical reaction substances are rearranged to form a new substance. When a chemical reaction occurs the substances involved experience a chemical change. Evidence of a chemical reaction includes temperature change, color change, odor, bubbles, or production of a solid precipitate. There are five types of chemical reactions, and based on the type of reaction you can predict the products of the reaction. The five types of chemical reactions are: synthesis, decomposition, single-replacement, double-replacement and combustion reactions. A single reaction may be classified as more than one type of reaction.[1]

A synthesis reaction occurs when two elements or two compounds (A and B) combine to create one new compound (AB).

$$A + B \rightarrow AB$$

The exact opposite of a synthesis reaction is a decomposition reaction. During this reaction a single compound (AB) breaks down into two or more elements or compounds (A and B).

$$AB \rightarrow A + B$$

In a combustion reaction O_2 combines with a substance and releases energy in the form of heat and light. A combustion reaction can be a simple synthesis reaction like in the combustion of coal: $C(s) + O_2(g) \rightarrow CO_2(g)$, or it can be more complex like the combustion of methane: $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$.

Many reactions involve the replacement of an element or molecule in a compound. These are referred to as replacement reactions. A reaction in which the atom of an element replaces the ion in a compound is called a single replacement reaction.

$$A + BX \rightarrow AX + B$$

When there is an exchange of ions between two compounds, this is called a double replacement reaction.

$$AX + BY \rightarrow AY + BX$$

The NCDPI Reference Table for Chemistry does a good job at outlining how to predict the products of a chemical reaction.

Chemical reactions are always happening around us, and just like when you follow a recipe, a specific ratio of each reactant is required in order to form your product. As long as an appropriate amount of each reactant is present a reaction will occur; however, once one of the reactants is no longer available the reaction will stop. The reactant that runs out is referred to as the limiting reactant and the other reactant is the excess reactant(s).[6]

In addition to the availability of reactants, there are several other factors that can impact the rate of a reaction: concentration, surface area, temperature and catalysts. The rate of reaction will increase as the concentration of the reactants increases. This happens because if there are more particles of the reactants moving around, it is more likely that they will collide, thus causing a chemical reaction. When the surface area increases so will the reaction rate, because there are now more surfaces for the reactants to interact.[6] An example of this is the time it takes to dissolve a sugar cube versus loose sugar in coffee. If you were to dissolve sugar in two cups of coffee, one cold and one hot, you will notice that the sugar dissolves faster in the warm coffee. This is because when molecules are heated they begin to move faster which makes them more likely to collide with each other so the reaction proceeds quicker.[1] The addition of a catalyst or enzyme to a system will increase the reaction rate because the catalyst lowers the amount of energy needed for the reaction to occur.[6]

Acids and Bases

The terms acid and base are frequently used to describe the chemical characteristics of chemical solutions. Physically speaking, acids have a sour taste and basic solutions (base) are bitter and feel slippery.[1] Chemically speaking acids and bases are classified by the concentration of hydrogen (H^+) or hydroxide (OH^-).[3] The relative amounts of these ions will determine if a chemical solution is acidic, basic or neutral. Acidic solutions contain more hydrogen ions than hydroxide ions; a basic solution has more hydroxide ions than hydrogen; and a neutral solution will contain an equal concentration of hydrogen and hydroxide ions.[7]

According to the Arrhenius model acids contain hydrogen and will ionize to produce hydrogen ions in aqueous (aq) solution. For example, when hydrogen chlorine gas (HCl) dissolves in water, the molecule ionizes to form H^+ ions.[1]

$$HCl(g) \rightarrow H^+(aq) + Cl^-(aq)$$

Bases on the other hand contain a hydroxide group and produces a hydroxide ion in an aqueous solution. For example when NaOH dissolves in water it will dissociate and form a OH^- ion.[1]

$$NaOH(s) \rightarrow Na^+(aq) + OH^-(aq)$$

According to the Bronsted-Lowery model, acids are hydrogen ion donors and bases accept hydrogen ions. In the example below, when HCl dissolves in water it donates a H^+ ion to water. In this case water acts like a base because it accepts the hydrogen ion to become H_3O.[1]

$$HCl(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + Cl^-(aq)$$

Hydrogen ions (H^+) are usually found in very small amounts in solutions; so small that the concentrations need to be expressed in scientific notation. To make these numbers easier to work with chemists developed the pH scale. This logarithmic scale is an easy way to state the concentration of H^+ in a solution. The pH scale runs from 0 to 14.0. Acidic solutions have pH values below 7, basic solutions have a pH greater than 7 and solutions with a pH of 7.0 are considered neutral.[7]

Thermochemistry (endothermic and exothermic reactions)

As mentioned above, chemical reactions can cause a temperature change. This change is the result of heat either leaving or entering a system. As you already know, during a chemical reaction energy is required to break the bonds of the reactants, and energy is released as new bonds are formed in the products. In some chemical reactions more energy is released when the new bonds are formed in the products than was needed to break the bonds of the reactants. This is known as an exothermic reaction, and heat is being lost. Conversely, if more energy is required to break the reactant bonds than is released once the products are formed, an endothermic reaction has occurred and heat is absorbed.[4, 5]

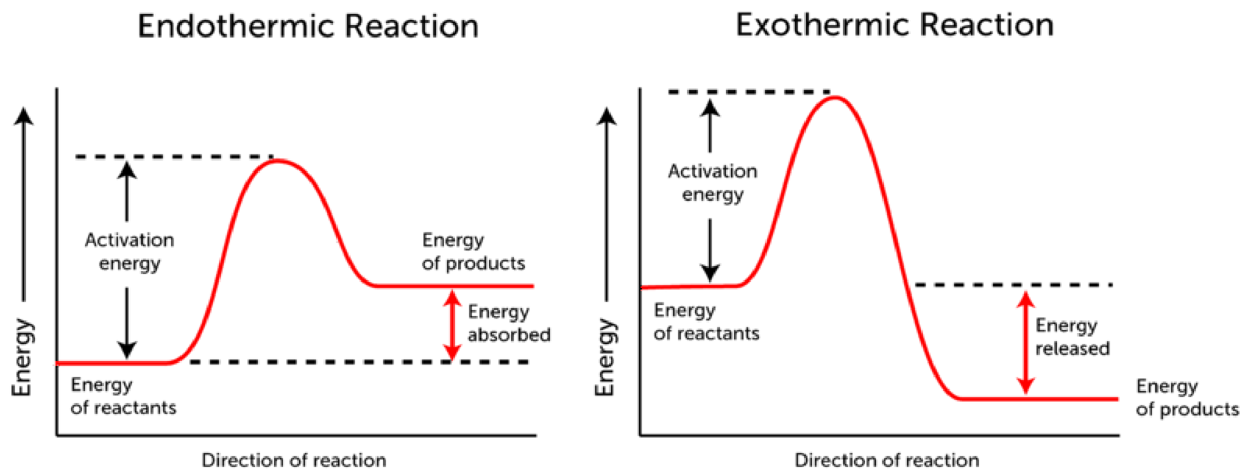


Figure 2.

This figure depicts the activation curves of endothermic and exothermic reactions. Take note that overall in endothermic reactions energy is absorbed, while energy is released in exothermic reactions.

Both endothermic and exothermic reactions are demonstrated as a substance changes phases. Freezing (liquid to solid), vaporization (liquid to gas) and sublimation (solid to gas) are all examples of endothermic reactions. Since these processes take in more energy (heat) than they release, they feel cool to the touch. Exothermic processes include; melting (solid to liquid), condensation (gas to liquid) and deposition (gas to solid). Exothermic reactions release more heat than they take in, and are hot to the touch.[4, 5]

Light Emissions

In simple terms, light is merely a stream of photons. If the photon has a wavelength that falls between 400 nm and 700 nm, it is part of the visible light spectrum and it is detectable by the human eye.[11] When objects, atoms or molecules produce light this is referred to as light emission. Matter emits light because molecules (either electrons or molecules or atoms) become excited for a brief period and when they return to the ground state they release energy in the form of a photon.[1] Molecules can be excited in a variety of ways if they become excited without heat or cold this is known as luminescence. The absence of heat distinguishes luminescence from incandescence. Traditional light bulbs are classified incandescent because they require heat to emit light. There are several types of luminescence and they are categorized based on what causes the molecules to become excited.[12]

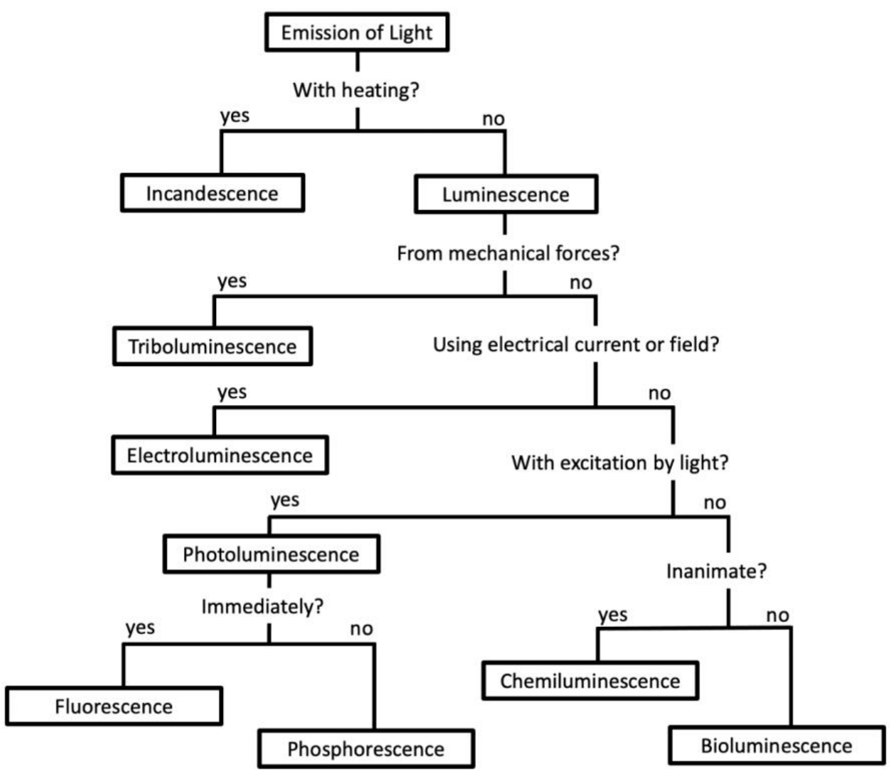


Figure 3.

The flowchart above helps distinguish between that various types of light emission.

Electroluminescence

Electroluminescence occurs when light is emitted after molecules are stimulated by an electrical current.[13] Small electrical currents provide energy to the molecules, causing them to become temporarily excited. As the molecules return to their ground state they emit a photon that can be seen if the wavelength is within the visible light spectrum. A light-emitting diode or LED is a commonly used example of electroluminescence. Inside LED lights there is a semiconductor material that allows electrical current to pass through. As the current flows through molecules become excited, then return to the ground state emitting electromagnetic radiation in the form of visible light.[14]

Photoluminescence

Photoluminescence occurs when light is emitted after molecules are excited by another light source. Depending on the type of material the time between when a photon is absorbed to excite a particle and when the photon is emitted can range from milliseconds to hours.[15] Glow in the dark products are examples of photoluminescence. In order for a glow in the dark item to work properly, it first must be exposed to visible, UV or infrared light. As the item is exposed to light, the molecules absorb the photons and become excited. The molecules are only excited for a brief period of time, and as they return to their ground state they release photons. If the wavelength of the photon falls within the visible light spectrum, you will see light. If the light is emitted immediately it is fluorescence and if it is delayed that falls under the category of phosphorescence. Safety reflective tape fluoresce while glow in the dark face paint, nail polish and some clothing usually phosphoresce.[15]

Chemiluminescence and Bioluminescence

Chemiluminescence and bioluminescence are very similar in that they both are the result of a chemical reaction. Just like in all other types of luminescence, light is emitted when molecules are excited and return to the ground state. In the case of chemiluminescence and bioluminescence a chemical reaction occurs which excites molecules for a short period of time, then the molecules return to their ground state and emit energy in the form of a photon.[16] If the chemical reaction and light emission happens in an animate object like a firefly, then it is classified as bioluminescence. If it occurs in an inanimate object then it is chemiluminescence. As mentioned previously, fireflies are an excellent example of bioluminescence. Fireflies light up as a result of a chemical reaction inside their body. Fireflies have a chemical in their body known as luciferin. Luciferin is oxidized by luciferase, and this chemical reaction excites molecules in the firefly, and when the molecule releases energy as it returns to the ground state light is emitted.[17] Glow sticks are an example of chemiluminescence. Most glow sticks contain a hydrogen peroxide solution and a glass tube that holds a phenyl oxalate ester and fluorescent dye. As long as these two solutions remain separate no reaction will occur; however, when the glow stick is activated (by cracking the glow stick), the two solutions mix and a chemical reaction will occur. The chemical reaction excites the atoms in the dye and the atoms begin to emit light as they return to ground state. The color emitted depends on the dye used.[18]

Teaching Strategies

Claim-Evidence-Reasoning (CER)

This strategy is specifically mentioned in this CU as students are analyzing the flame test; however, it can be applied throughout this unit both formally and informally. When using CER, students make a claim and then cite specific evidence for the claim, and then they must explain the evidence using content knowledge. In this CU CER is used formally and students are asked to record their thoughts; however, it can be used effectively in an informal way and be incorporated into your classroom norms. CER is a great strategy to encourage students to use evidence to support their conclusions. It also scaffolds the task of making drawing conclusions and provides the framework for students to use prior knowledge to explain their evidence.

Gallery Walk

This strategy is specifically used in Option 2 of the electron emissions activity. The gallery walk gives students the opportunity to formally share their thoughts, and other students have the chance to challenge their ideas. This process of challenging and defending causes both sides to think critically.

Know-Want to know-Learned (KWL)

This CU introduces KWL just prior to students building their own solar cell. In this activity students activate their prior knowledge by writing down everything they know about a topic. As they are recalling old information they may notice knowledge gaps or become curious about something in particular and they realize there are things they want to know. By acknowledging and writing down what they want to know students are establishing a purpose for the activity. At the end students are asked to write down what they learned, this forces them to summarize what happened and to explain everything in their own words. This is a great tool for a teacher to assess student comprehension, and to identify any misconceptions.

Closed reading with document based questions

As mentioned previously, this curriculum unit is designed for honors students, and at this level I really stress and work on their ability to acquire information, and make connections on their own. Prior to the glow stick investigation students will read and annotate a pre-selected article and watch a short video. Then they will answer several text-dependent questions to gauge their understanding.

Class Discussion

This requires little participation from the teacher and provides the opportunity for students to teach each other. As students discuss a topic you can assess their understanding and uncover gaps in their knowledge. Class discussion can be used frequently throughout the curriculum especially at the end of each activity.

INSTRUCTION GUIDE

Topic: Electron Emissions

In this lesson students will explore how different metals emit different colors of light when heated. This activity can be used to get students engaged about light and emissions. Prior to this lesson students should have an understanding of subatomic particles, and they should know that electrons orbit around the nucleus of an atom.

Essential Questions:

- Why do metal ions produce different colors of light when exposed to a flame?

Objective:

- To observe the colors emitted by various metal ions
- Students will be able to link the color emitted to the frequency and wavelength of emitted photons

Classroom management: There are two versions of this lesson outlined below. Option 1 can be completed in one 90 minute class session and at least two 90 class sessions are needed for Option 2. This lesson has a lab component that will require access to a gas hook-up. If you do not have access to gas there are several YouTube videos like this one from Kimberly Stites that your students can watch in lieu of actually conducting the lab.[a] Please be mindful that the majority of your students have little to no experience using a Bunsen burner, so I suggest modeling the set up for them and reviewing lab safety procedures. Option 1 can follow a lesson on electron emissions and absorptions or students can conduct the lab investigation prior to learning about the electron emission spectra. Similar to Option 1, Option 2 can follow instruction; however, it is designed to be inquiry based and may work best if students are able to make their own conclusions first.

Option 1

This option is mostly focused on the Flame Test lab detailed in Appendix 2. As mentioned above this activity requires access to gas, and it works best if students are in pairs or small groups. In the provided lab protocol seven different chlorides (sodium, calcium, strontium, lithium, copper and barium) are tested, however; you can substitute the chlorides for nitrates, carbonates or another binary compound that contains a metal. For the best results use powdered samples, the concentration of the metal is too low in most liquid solutions to detect a color change. At the beginning of the lab, have students read the introduction and discuss the information with their partner/ group. If you want feel free to give students guiding questions such as:

- Where are electrons located in an atom?
- What does it mean to say an electron is excited?
- What does it mean to say an electron is grounded?
- What can excite electrons?
- Blue light is more energetic than red light, what does that imply about the wavelengths of blue versus red light?
- Which color on the ROY G BIV spectrum is the most energetic? and the least?

Once students finish discussing the introduction with their partner/ group, they can work through the lab at their own pace. Inform students that some metals may produce similar colors, so it is important that they are as descriptive as possible when identifying colors in the flame.

Option 2

Option two focuses on inquiry and argument-based instruction. Similar to Option 1, this option uses the Flame Test lab detailed in Appendix 2**.** On day one students will conduct the lab just as they would in Option 1; however, this option works best if students are not given the guiding questions beforehand and analysis questions should also be withheld until day 2 or Day 3. After students complete the lab, they should discuss their thoughts and observations with their partner/ group. Each group should create a Claim-Evidence-Reasoning (CER) poster detailing the following:

- Lab objective: What question were you trying to answer in this lab?
- Claim: Based on your current knowledge, what can explain what you observed?
- Evidence: Provide detailed and specific observations. DO NOT explain anything!
- Reasoning: Explain your evidence using your claim.

Everything above should be completed on Day 1. On Day 2 students will have a Gallery Walk. During the Gallery Walk one group member will man the poster and explain it to their classmates, while the remaining group members visit posters from other groups. Following the gallery walk students will discuss the various claims within their groups, and they can use this time to alter their own claim. You can end Day 2 here or you may continue. On Day 3 students will get back into their groups and answer the analysis questions using their poster.

Below are the colors each metal should produce once heated.

Flame Test	
Ion	***Flame Color*** *(be descriptive)*
Sodium, Na^{+1}	Bright yellow
Potassium, K^{+1}	Lilac
Calcium, Ca^{+2}	Orange-red
Barium, Ba^{+2}	Green
Strontium, Sr^{+2}	Bright red
Lithium, Li^{+1}	Magenta
Copper, Cu^{+2}	Blue-green/ teal

Explanation

When the metal ions are heated the electrons absorb energy from the flame and become excited. Once the electrons are excited, they move to a higher energy level. This transition is only temporary and the electrons will return to their original energy state. As the electron returns to the ground state it releases energy in the form of visible light. The color of light corresponds to the wavelength of light and amount of energy released. Use this activity to really stress the process of electrons absorbing energy to become briefly excited and then returning to the ground state after they release energy. This concept is the foundation for this curriculum unit. Following the lab activity, have a class discussion about the various types of light emissions. Make sure to explain that this activity was an example of incandescent light because heat was required. Briefly introduce the other forms outlined in Figure 3 so students have a reference point for future lessons, have students explore on their own using the optional activity in Appendix 3.

Topics: Light Emissions and Fluorescence (optional)

The purpose of this curriculum unit is to encourage students to make connections between *luminescence and their everyday life. In this activity (found in Appendix 3) students will identify the various types of luminescence they have encountered. This activity is most effective when used in groups or with a partner. Together students will study the flowchart and work together to identify examples. To make sure students are fully engaged, I recommend prohibiting students from using the internet or outside sources for examples. As students are working, circulate the room to check for understanding. Fifteen minutes should be enough time for students to complete the chart; then have students share and explain their examples with the class.*

Topic: Chemical Bonds

This is an application lesson where students will learn how a dye-sensitized solar cell works. At this point in the course students should be able to differentiate between ionic and covalent bonds, and they should understand that ionic bonds result from a transfer of electrons between two atoms. Students should know that electrons are negatively charged and can emit energy when moving from an excited state to a ground state. Students should also know that salt crystals are held together by electrostatic attraction.

Essential Questions:

- How does the presence of a dye lead to the production of electrical energy?

Objective:

- To gain an understanding of how the properties of electrons, metals, and chemical compounds interact with one another to convert light into electricity through use of a dye sensitized solar cell (DSSC).

Classroom management: This lesson is designed to take 3 class days (2 partial 90-minute class and 1 full 90-minute class). However, it can be condensed into just 2 partial classes. A student handout adapted from Cornell Center for Molecular Research is found in Appendix 4.[b] Due to the technical nature of this activity I highly recommend you assemble your own solar cell ahead of time for troubleshooting purposes. Cornell Center for Molecular Research created a video that details how to construct the solar cell.[c] The video will help you familiarize yourself with the solar cell. Jimmy O'Dea of Cornell Center for Molecular Research also prepared a Google Slides presentation that you can share with your students.[d] Solar Army also shared a similar activity that is fully aligned to the Next Generation Science Standards.[e]

Prior to the lab activity give students the opportunity to share what they know about solar energy, solar panels and solar cells. This can be done via a KWL activity. Students are divided into groups and share everything they know and what they want to know about solar energy. Ask students to think about the role chemistry (and bonding specifically) may play in solar energy. Each group can share their thoughts with the class; use this discussion as an opportunity to talk about the importance of solar energy and why it may be necessary to invest in this technology. The lab activity will take place during Days 2 and 3. A student handout adapted from Cornell Center for Molecular Research is found in Appendix 4.[b] Due to the technical nature of this activity I highly recommend you assemble your own solar cell ahead of time for troubleshooting purposes. Cornell Center for Molecular Research created a video that details how to construct the solar cell.[c] The video will help you familiarize yourself with the solar cell.

Day 1
The activity for Day 1 is intended to take no longer than 30 minutes. Through a Know-Want to know-Learned (KWL) activity you can get your students thinking about solar energy, and how it may be linked to chemistry. Students are divided into groups and share everything they know and what they want to know about solar energy. Have someone in the group record all of the responses so they can reflect on them later. Ask students to think about the role chemistry (and bonding specifically) may play in solar energy. Each group can share their thoughts with the class; use this discussion as an opportunity to talk about the importance of solar energy and why it may be necessary to invest in this technology. On Day 3 students will come back to their KWL and add what they learned. Since this is an introductory activity, I suggest that it be done at the end of the class prior to starting the lab component.

Day 2
This is another partial day activity. On Day 2 students will begin the lab. While it may be possible to complete the entire lab in one class period; it is better to break it up into two days so students can really make connections and fully understand what they are doing and seeing. On Day 2 students will coat their slides with nano Titanium Dioxide (TiO_2) and prep the Carbon--coated Counter Electrode. Depending on your class size you may opt to prepare the TiO_2 solution ahead of time. Pay special attention and make sure students correctly apply TiO_2 to the slides.

Day 3
This activity is designed to take a full class period. Students will assemble their solar cells and test them indoors and outdoors (to ensure data is consistent make sure students take their readings in the exact same location). Following the lab, students can work on the analysis questions in their groups. These questions are designed to get students thinking, and are scaffold to have them connect what they observed to concepts they already know. At this point in time students will not have the knowledge base to answer technical questions. After students have worked through the questions use the previously mentioned presentation to explain what occurred. Then have students go back to their group and connect their original assumptions to what they just learned. Using what they have learned and the light emission flowchart, ask them to identify the type of fluorescence observed. As an extension activity have students test their solar cells in areas with varying amounts of light, or have students attach several cells together and see how that impacts their readings. You can even save these cells for a day with drastically different weather and measure your voltage again.

Topic: Chemical Reactions and Thermodynamics
This lesson focuses on chemiluminescence, and students will explore how chemical reactions can lead to fluorescence. Prior to this lesson students have learned that mixing compounds together may lead to the creation of new compounds via chemical reactions. During this lesson students will observe how temperature impacts reaction rates.

Essential Questions:
- How does temperature affect the reaction rate?
- How does temperature affect kinetic energy of molecules?
- How does kinetic energy affect the rate of a reaction?

Objective:
The purpose of this lab is for students to explore the effect of temperature on the rate of a chemical reaction.

Classroom management: This lesson can be completed in one class period. At the beginning of class students will read a ThoughtCo article “How Do Glowsticks Work?” and watch the accompanying video.[f] The provided guided notes sheet in Appendix 5 will help students pull out the main points of the article and video. Next students will conduct a quick investigation where they will explore the effect of temperature on the rate of a chemical reaction. For optimal results make sure each group has three glows sticks that are the same color. Also, make sure students use hot water, but not boiling water as glow sticks are known to burst in boiling temperatures.

Activity:
The student lab handout provided in Appendix 6 is adapted from procedures outlined in articles from California Institute of Technology and University of Oregon.[g,h] Both documents thoroughly explain the science behind this lab, and provide extension activities. You also may want to watch the Glowstick Reaction Rate videos from Sully Science.[i,j] At the completion of the lab discuss the effect that temperature has on the rate of chemical reactions. Discuss how the energy of activation barrier is overcome. Ask students which light stick will use up the reactants first. Discuss the concept that the intensity of light is proportional to the reaction rate. The faster the rate of reaction, the sooner all the reactants are consumed and the reaction ceases. Explain to students that this is an example of chemiluminescent, and introduce the various types of fluorescence. Encourage students to make connections with other things in their everyday life and in nature. To help draw deeper connections show your students this video dolphins swimming off the coast of Newport Beach;[l] and ask questions similar to the following:

- What type of luminescence is displayed here?
- What is causing the light emission?
- How is it similar to what you just observed in your lab?
- How is it different from what you just observed?

Appendix 1

Chemistry Course Standards

- Chm.1.1.3 Explain the emission of electromagnetic radiation in spectral form in terms of the Bohr model.
    - Students will be able to describe the process that creates atomic spectra.
    - Students will be able to describe the relative energies, wavelengths and frequencies of ultraviolet, visible, infrared, microwave, X-ray, and radio waves.
    - Students will be able to distinguish between absorption (excitation) and emission of energy.
    - Students will be able to describe the properties of light. (i.e. wavelength, frequency and energy)
    - Students will be able to determine the wavelength, type of energy, and color of visible light if applicable for a given electron transition.

Through this curriculum unit students will experience the electron emission through the flame test lab. In this activity students will learn how electrons can become excited by absorbing energy provided from heat. However, electrons are only excited for a brief amount of time before the energy is lost and emitted as a photon. Based on the color of light emitted, students will be able to determine the wavelength, frequency and relative energy of the emitted photon.

- Chm.2.2.1 Explain the energy content of a chemical reaction.
    - Students will be able to explain collision theory – molecules must collide in order to react, and they must collide in the correct or appropriate orientation and with sufficient energy to equal or exceed the activation energy.
    - Students will be able to interpret potential energy diagrams for endothermic and exothermic reactions including reactants, products, and activated complex–with and without the presence of a catalyst.
- Chm.2.2.2 Analyze the evidence of chemical change.
    - Students will be able to contrast physical and chemical changes.
- Chm.3.1.1 Explain the factors that affect the rate of a reaction (temperature, concentration, particle size and presence of a catalyst).
    - Students understand qualitatively that reaction rate is proportional to number of effective collisions.
    - Students will be able to explain how temperature (kinetic energy), concentration, and/or pressure affects the number of collisions.
    - Students will be able to explain how a catalyst lowers the activation energy, so that at a given temperature, more molecules will have energy equal to or greater than the activation energy.

Using glowsticks students will explore chemical reactions and different variables that can alter the rate of reaction. With this activity students will investigate how temperature affects reaction rates. They will also learn about what factors are needed in order to initiate a reaction.

Appendix 2

Introduction: When electrons are heated to high temperatures, some of their electrons are excited to higher energy levels. These excited electrons eventually fall back to lower energy levels, their ground states, releasing the excess energy in packages of light called photons. The color of the emitted light depends on its energy. Blue light is more energetic than red light, for example. Remember ROY G BIV. When heated, each element emits a characteristic pattern of light energies, which is useful for identifying the element. The characteristic colors of light produced when substances are heated in the flame of a gas burner are the basis of flame tests for several elements.

In the experiment, you will perform flame tests for several metallic elements.

OBJECTIVES: 1. To observe the colors emitted by various metal ions
2. To evaluate flame testing as a method of detection of metals
3. To identify an unknown element by comparing the color of the flame it produces to that of known elements

MATERIALS:

- Q-tips (non-plastic) swabs coated with each of the following:
  - Sodium chloride, NaCl
  - Potassium chloride, KCl
  - Calcium chloride, $CaCl_2$
  - Strontium chloride, $SrCl_2$
  - Lithium chloride, LiCl
  - Copper (II) chloride, $CuCl_2$
  - Barium chloride, $BaCl_2$
- Meker/Bunsen burner
- Safety goggles
- Crucible tongs
- Beaker of water

PROCEDURE: **As the experiment is performed, record the observations in the Data Table 1.**

1. Obtain a Q-tip coated with each of the 7 metallic solutions. Do not let the Q-tips touch.
2. Wearing safety goggles and using proper lab burner procedures, light the burner.
3. Using crucible tongs, hold the Q-tip in the flame and QUICKLY note the color of the flame. DO NOT ALLOW THE Q-TIP TO CATCH FIRE, AS THE FLAME WILL OBSCURE THE RESULTS.
4. Extinguish the Q-tip in the beaker of water.
5. Obtain a Q-tip coated in an unknown solution form the teacher. (It will be one which has already been observed in this lab activity.) Record the observations and predict the identity of the metal in solution.

Data Table 1

Flame Test	
Ion	***Flame Color*** *(be descriptive)*
Sodium, Na^{+1}	
Potassium, K^{+1}	
Calcium, Ca^{+2}	
Barium, Ba^{+2}	
Strontium, Sr^{+2}	
Lithium, Li^{+1}	
Copper, Cu^{+2}	
Unknown metal ion	

QUESTIONS:

1. List the elements that gave the most easily identified colors. Which are least easily identified?

2. Which element gives the most intense color?

3. Are flame tests valuable for detecting specific metal ions present in a mixture of metal ions? **Explain.**

4. The energy of colored light increases in the order red, orange, yellow, green, blue, indigo, violet. (ROY G BIV) List the metallic elements used in the flame tests in INCREASING order of energy of light emitted.

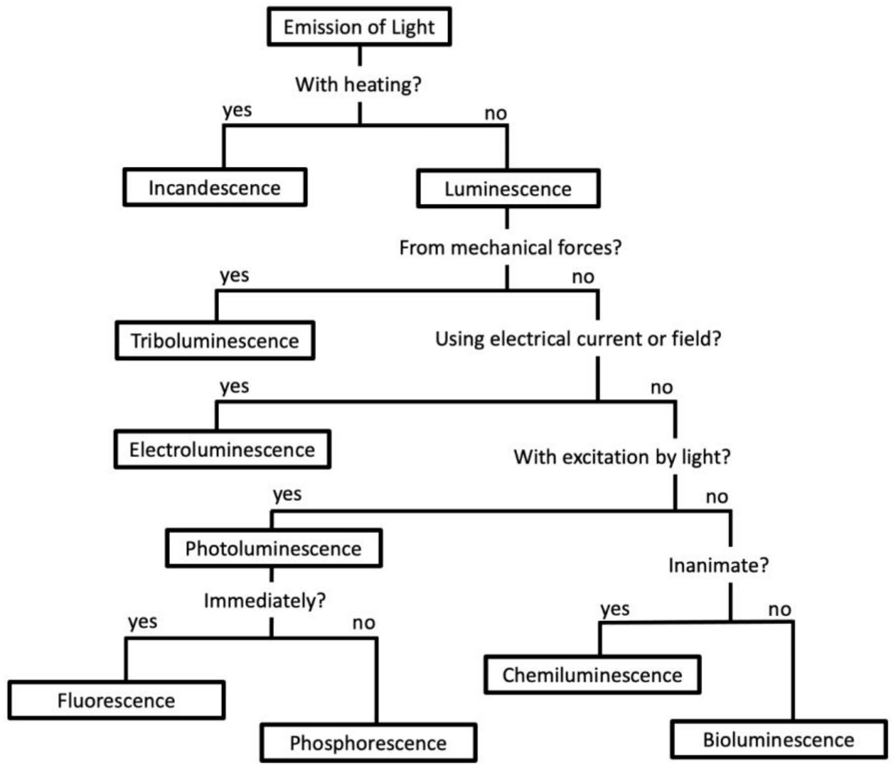
5. Explain how the colors observed in the flame test are produced. *Be specific.*

6. Which metal released the greatest amount of energy?

Appendix 3

Everyday Light Emissions

Everyday you interact with light in some way without giving it a second thought. It's probably one of those things that you take for granted until the power goes out at night. Even though all light illuminates our world, not all light is not created equally. Use the flowchart below to differentiate between the different types of light. Brainstorm within your group and try to come up with at least 2 examples of each type of emissions.



Type of Light Emission	Examples
Incandescence	
Triboluminescence	
Electroluminescence	
Photoluminescence	
Fluorescence	
Phosphorescence	
Chemiluminescence	
Bioluminescence	

Appendix 4

Blackberry Juice Solar Cell

Introduction:

The United States is heavily dependent on the use of fossil fuels for energy production. As our supply of fossil fuels decreases and global concern for the environment increases, the focus has shifted to more sustainable energy sources such as hydropower, geothermal, biomass, wind and solar. In recent years solar energy has increased in popularity; however, not all solar cells are created equal. Some types of solar cells are more efficient than others, and scientists are always working to create a solar cell that is highly efficient and has little environmental impact. Dye sensitized solar cells (DSSC) also known as Grätzel cells are simple and cheap to manufacture, sustainable and are relatively efficient (about 10-14 %) even under low flux of sunlight.

Objective:

To gain an understanding of how the properties of electrons, metals, and chemical compounds interact with one another to convert light into electricity through use of a dye sensitized solar cell (DSSC).

Materials:

- Multimeter
- Alligator clip (2)
- Plastic dish (2)
- Distilled water (in a wash bottle)
- Ethanol (in a wash bottle)
- Graphite pencil
- Small binder clips (2 per cell)
- 2 conductive glass slides
- Iodide electrolyte solution
- Beaker
- Glass stirring rod
- Measuring Cylinder
- Scale
- Blackberries, raspberry, or blueberries (do not use strawberries)
- Paper towels

Procedure:

Coat slides with nano Titanium Dioxide

1. Nano Titanium Dioxide (TiO_2) solution: add 10 mL vinegar gradually to 6 g Titanium Dioxide, stirring until smooth and lump free (about 5 minutes).
2. Test one of the conductive glass slides with a multimeter to determine which side is conductive
3. Using Scotch tape mask about 3 mm on two sides of the conductive slide.
4. Using a glass pipet or eye dropper, drop 3 drops of the TiO_2 solution in a row on one side of the slide.
5. Use a glass slide cover to evenly spread the TiO_2 solution (spread the solution in one direction in one pass).
6. Allow the slide to dry for a few minutes before removing the tape.
7. Place the slide directly on a hotplate for about 30 minutes.
    a. Make sure the slides turn yellow and then white again.
    b. Prepare Carbon-coated Counter Electrode while you wait
8. Let the slide slowly cool for 30 minutes.

Carbon-coated Counter Electrode

1. Use a graphite pencil to coat the entire surface of the conductive side of the second slide.

Stain Titanium Dioxide with Dye

1. Crush a blackberry (blueberry or raspberry) in a large test tube using a glass stirring rod.

2. Pour a few the juice dye into a shallow clean dish, and place the TiO_2 coated slide face down in the juice for 5 minutes.
3. Rinse the slides in water, then in ethanol, using a wash bottle, and blot dry with a tissue.

Assembling the Solar Cell

1. Place the graphite coated slide face down on top of the dry dye soaked TiO2 coated side of the second slide. The slides should be placed slightly offset to allow enough room on the end to place an alligator clip.
2. Use two binder clips to hold the two slides together.
3. Now with an eyedropper add 1-2 drops of liquid Iodide/Iodine electrolyte solution to the crease between the two slides. The solution will be drawn into the cell by capillary action and will stain the entire inside of the slides.
4. Attach the alligator clips to the two overhanging edges of the slide and attach the clip leads to your multi-meter with the negative terminal attached to the TiO_2 coated slide and the positive terminal attached to the graphite coated slide.
5. Measure both the current and voltage of the cell in direct sunlight and indoors.

Data Table

	Classroom	**Outdoors** Weather conditions:
Voltage (V)		
Current (mA)		

Analysis Questions:

1. Under what conditions did you measure the highest voltage?

2. Based on your previous knowledge of electrons, what is responsible for the energy detected by the multimeter?

3. What is the relationship between electrons, UV radiation and voltage and current readings?

4. What is different about the two conditions that could account for the variation in voltage?

5. The blackberry juice contains a light absorbing pigment called anthocyanin. What role does this pigment play in the solar cell?

6. How is this process similar to photosynthesis?

7. What do you think will happen if you used spinach (or another green plant) instead of blackberries?

8. Based on your previous knowledge of properties of chemical elements, what was the purpose of the TiO_2 solution?

9. What type of light emission is demonstrated by the DSSC?

Appendix 5

How Do Lightsticks Work?: *Chemiluminescence In Action*	
Question	Response
Does a glow stick release energy? How do you know?	
How does temperature affect the glow of a glow stick?	
When you bend a glow stick it begins to glow. In your own words explain what is happening.	
What do you think temperature does to the movement of molecules? Be specific.	

How Do Lightsticks Work?: *Chemiluminescence In Action*	
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What do you think temperature does to the movement of molecules? Be specific.	

Appendix 6

Temperature and the Rate of a Chemical Reaction

Purpose:
The purpose of this lab is for students to explore the effect of temperature on the rate of a chemical reaction.

Pre-Lab Questions:
1. In your own words EXPLAIN the Kinetic Molecular Theory (KMT).

2. What is the collision theory?

3. How do both the KMT and the collision theory relate to chemical reactions?

Hypothesis:

Materials:
- 3 glow sticks
- 3 250 mL beakers
- thermometer

Procedure:
1. Add ice cubes to one of the beakers, and fill up to 200 mL of water
2. Add 200 mL of water to the remains 2 beakers (add hot water to one beaker)
3. Record the temperature of each beaker
4. Wait for all of your classmates to record their temperatures. Once all temperatures are recorded you teacher will turn off the lights
5. Break and shake each glow stick
6. Submerge one glow stick into each beaker.
7. After 3 minutes observe the relative brightness of each glow stick and rank them 1 through 3. (1= weak, 3= strong)
8. Rank the glow sticks based on how quickly they reach their brightest glow. (1= quickest, 3= slowest)
9. Create a graph using the data you collected. Remember to label your graph correctly and include a key.

Data Table

	Water Temperature (°F)	Brightness	Speed
Cold			
Room Temperature			
Hot water			

Graph

Question:

1. Which beaker contained the brightest glow stick?

2. What was the water temperature in that beaker?

3. Which beaker contained the glow stick that reached maximum brightness first?

4. What was the water temperature in that beaker?

5. How does the water temperature affect the rate of the chemical reaction occurring in a glow stick? Explain this result using your knowledge of the Kinetic Molecular Theory of Heat.

6. What evidence do you have that a chemical reaction took place?

7. What type of luminescence is demonstrated by the glowstick?

Teaching Resources

a. *MegaLab - Flame Test - Li, Na, K, Ca, Sr, Ba, Cu*. *YouTube*, 2012. https://www.youtube.com/watch?v=NEUbBAGw14k&t=5s.
   - This video is a helpful resource to familiarize yourself with the flame test, or it can be shown to students in lieu of conducting the lab. This is great for remote learning.

b. Johnson, Jill, Stephanie Chasteen, Louisa Smieska, Ryan Dwyer, Brian Calderon, and James O'Dea. Solar Cells: Juice From Juice. Cornell Center for Molecular Research , 2014. https://www.ccmr.cornell.edu/wp-content/uploads/sites/2/2015/11/Solar-Cells.pdf.
   - This document provides additional information about DSSC and contains an alternative protocol to the one provided in this curriculum unit.

c. *Solar Cells*. YouTube, 2015. https://youtu.be/G94_Ec1mY-k.
   - This video should not be shared with students. It is a great resource to help understand how to construct the DSSC. Consider this a "must watch" before you facilitate this lab for the first time.

d. O'Dea, Jimmy. "How the Berry Solar Cell Works." 2015. https://docs.google.com/presentation/d/1ocDqTU8UeAVYd4aEbSyGCes_as03nIvLZaZXwyQy-HE/edit#slide=id.gc8dcee370_1_0.
   - This slideshow can either be used solely for your benefit or shared with students. This fully explains the science behind DSSC.

e. "DSSC." The Solar Army, 2014. http://thesolararmy.org/jfromj/activities/dssc/.
   - This site shares an activity similar to the one outline in this CU that is fully aligned to NGSS.

f. Helmenstine, Anne Marie. "How Do Glowsticks Work?" ThoughtCo, 2019. https://www.thoughtco.com/how-do-lightsticks-work-607878.
   - This article briefly explains the science behind glowsticks and can be used as a close reading assignment in class.

g. Caltech.edu. Temperature and the Rate of Chemical Reactions. Cool Cosmos. Accessed October 24, 2020. https://coolcosmos.ipac.caltech.edu/system/media_files/binaries/68/original/Temperature_and_Glow_Sticks.pdf?1375754120.
   - This is an alternative protocol to the one provided in this CU.

h. "Lightstick Reaction Rates versus Temperature." Chemdemos. Accessed October 25, 2020. https://chemdemos.uoregon.edu/demos/Lightstick-Reaction-Rates-versus-Temperature.
   - This is an alternative protocol to the one provided in this CU.

i. *Glowstick Reaction Rate 0809 #1*. *YouTube*, 2009. https://www.youtube.com/watch?v=fBtCTcRYEUk.
   - This video should not be shared with students. It is a great resource to help understand how to conduct the glowstick activity.

j. Glowstick Reaction Rate 0809 #2. YouTube, 2009. https://www.youtube.com/watch?v=RH8TcwsHsvc.
   - This video should not be shared with students. It is a great resource to help understand how to conduct the glowstick activity.

k. "Chemistry Reference Table_2012.Pdf." Google Drive. Google. Accessed November 15, 2020. https://drive.google.com/file/d/1yXvQ03OIxgYafg1sq0cZZHxrAf0k5QOA/view.
   - This reference table outlines the electromagnetic spectrum and types of chemical reactions

l. Dolphins Swim in Bioluminescent Waves in Newport Beach. YouTube, 2020. https://www.youtube.com/watch?v=GQ08UJ8QNtg.
   - This is a video of dolphins swimming through the water of Newport Beach at night. As they swim the water glows blue due to the bioluminescence of some of the aquatic organisms.

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12. *A Brief History of Fluorescence and Phosphorescence before the Emergence of Quantum Theory* Bernard Valeur and Mario N. Berberan-Santos J. Chem. Educ., 2011, 88 (6), pp 731–738
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18. Harris, Tom. "How Light Sticks Work." HowStuffWorks Science. HowStuffWorks, June 30, 2020. https://science.howstuffworks.com/innovation/everyday-innovations/light-stick.htm.