A Chemistry Unit on Stoichiometry for Grades 10-12

**Lesson Overview**

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| Lesson | Lesson Title and Description |
| 1 | **Does stoichiometry rule?**  *We use the Law of Conservation of Matter to explain the stoichiometric relationships of a chemical reaction. This is our recipe to create the type of product that we want. If the recipe calls for 2 eggs, but we decide to use 3 eggs, can we still create our product? How will the change effect our product?* |
| 2 | **Making an explosive compound!**  *Using our recipe, it’s now time to add our compounds and create an environment for them to react.* |
| 3 | **Using Auto Ignition to force metal ions to combine!**  *Viscosity of a solution can play and important part in the ability of the solution to interact with other substances. Can we find the right viscosity to create optimal conditions for our reaction?* |
| 4 | **Collecting our products, application of chemical and physical properties.**  *Bang!!!! And a cloud of dust! So we were able to make our reaction happen, but how do we collect we made. Solubility becomes our friend again as we work to separate our products.* |
| 5 | **How did we do??? Analysis to see what is in the products!**  *So we made something, but what did we make. It’s time to go high tech and find some ways to analyze our products to find out what we made and how much of it we made.* |

**Phenomenon:** **We have learned to predict the outcome of a chemical reaction based on oxidation states of ions trying to achieve balanced charge, which supports** the **law of conservation of mass** and the **law of constant composition which are the basis for Dalton’s Atomic Theory. Recipes provide the same functions for bakers where the ingredients can be predicted to make a specific type of product. Recipes can be altered to create different properties in the types of food they create. Can the rules of stoichiometry and the claims of Dalton’s Atomic Theory be altered in the same way to create different properties in the products that are created?**

**Storyline:**

This unit explores the relationships of ions combining to create specific products and the possibilities that are created when we are able to use highly energetic reactions to combine ions in different ratios. The flexibility of metal ion bonds can be used to create combinations that allow scientists and engineers to create complex ion substances that utilize beneficial properties of several different ions in one product.

The future of energy production and energy use in the world is dependent on the ability to store and access energy in for form of electricity and batteries. Batteries offer the benefits of being able to store energy for and long time and the ability to be recharged and reused. Batteries offer challenges due to the costs and types of materials that they are made of, the amount of energy they can store, and the weight and size of the batter. Lithium ion batteries have been utilized widely in the world for a wide variety of applications. The continued improvement of Lithium ion technology involve making batteries lighter, smaller and more efficient. To accomplish this, Lithium ion compounds that utilize several metal ions with specific useful properties must be created.

**Performance Expectations**

**SCIENCE**

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| **Performance Expectation** | | **Lessons** |
| 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. (SEP: 2; DCI: PS1.A, PS2.B; CCC: Patterns) | 1,4 |
| 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. (SEP: 6; DCI: PS1.A, PS1.B; CCC: Patterns) | 1,2 |
| HS-PS1-5 | Construct an explanation based on evidence about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. (SEP: 6; DCI: PS1.B; CCC: Patterns) | 2,3,4 |
| 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.\* (SEP: 6; DCI: PS1.B, ETS1.C; CCC: Stability/Change) | 3,4 |
| HS-PS1-7 | Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. (SEP: 5; DCI: PS1.B; CCC: Energy/Matter, Nature of Science/Consistency) | 1,2,5 |

**MATHEMATICS**

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| **9-2.N.Q.1** | Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. | 1,2 |

**Three Dimensional Learning Matrix**

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| Lesson | Disciplinary  Core Idea | Practices | Crosscutting Concept |
| 1 | Structure and properties of matter.  (PS1.A) | SEP 1: Asking questions and defining problems.  MP4: Model with mathematics | Patterns; Scale, Proportion and Quantity; Stability and Change; Systems and System Models; Structure and Function |
| 2 | Structure and properties of matter.  (PS1.A) | SEP 3:  Planning and Carrying Out Investigations | Cause and Effect |
| 3 | Structure and properties of matter.  (PS1.A)  Relationship between energy and forces. (PS3.C) | SEP 2:  Developing and using models.  MP4: Model with mathematics. | Scale, Proportion and Quantity |
| 4 | Conservation of energy and energy transfer. (PS3.B)  Relationship between energy and forces. (PS3.C) | SEP 6:  Constructing explanations and designing solutions. | Energy and Matter |
| 5 | Structure and properties of matter.  (PS1.A) |  | Scale, Proportion and Quantity |

**Materials List**

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| **For Unit** | * LiNO3 * Mn(CH3COO)2\*4H2O * Ni(NO3)2\*6H2O * Co(NO3)2\*6H2O * C2H5NO2 * 150 ml beakers * Pyrex covers * Filter paper * Test tubes w/stoppers * Poker Chips |

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| **Lesson 1** |  |
| Three Dimensional Teaching and Learning | **Overview:**  *Students will be introduced to the unit phenomenon, adjusting a Recipe, with an analogy and an application to the actual experiment. We use the Law of Conservation of Matter to explain the stoichiometric relationships of a chemical reaction. This is our recipe to create the type of product that we want. If the recipe calls for 2 eggs, but we decide to use 3 eggs, can we still create our product? How will the change effect our product?*  **Performance Expectation:**  **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-PS1-7** Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.  **Science and Engineering Practice:** Developing and using models, Using mathematics and computational thinking.  **Crosscutting Concept:** Scale, Proportion and Quantity; Stability and Change; Systems and System Models; Structure and Function    **Objectives:**  Students will   * Apply the concepts of stoichiometry to a system to determine relationships of reactants and products |
| Background Information | Conservation of mass and the Law of definite proportions work together for us to solve for amounts of reactants needed to create specific amounts of products. Chemical formulas are determined using oxidation relationships between ions. We can write a specific formula for a complex ionic compound and use a high energy environment to create it from a set of know reactants. |
| Materials | For each pair of students:  Poker chips  Access to online Chemical Equation Balancer |
| Prior Knowledge | The performance expectations for this lesson require students to demonstrate grade-level proficiency in writing chemical formulas and balanced chemical equations. |
| Launch (10-15 minutes) | |
| Engagement and Communication of Student Expectations | 1. Begin by having students determine the recipe for a Double-Double-Cheese-Cheese-Burger-Burger-please-please. Have them assign a color of poker chip for each ingredient and build a DDCCBBpp. 2. Have them write out the recipe in the format of a chemical equation using coefficients and two letter abbreviations for each ingredient. |
| Explore (15-20 minutes) | |
| Procedure | 1. Show students the list of ingredients (reactants) and the formula for the products along with any extra products.   C2 H5 NO2 +LiNO3 + Cr(NO3)2 +Ni(NO3)2 + Mn(CH3COO)2 LiNiMnCoO2 +H2O +N2 + CO2   1. Have students balance the equation using a reactants and products chart. Let them go through a couple iterations of the coefficients before showing them the Online Chemical Equation Balancer. Discuss situations where the technology is beneficial for complex equations. 2. Have the students get out their DDCCBBpp poker chip models. Have them add one burger patty to the sandwich. Using the same recipe as before, what implications does this have on the reactants? Is it possible? What would have to change? Give 3 mins for small group discussion, 5 mins for large group discussion. 3. Give students a formula for 6-2-2 NMC   Li Ni(.6)Mn(.2)Co(.2)O2  Explain how the formula can show the molar relationships of each component of the Formula  1 mole Li, .6 mole Ni, .2 mole Mn, .2 mole Co, 2 mole O   1. Calculate the mass percentage of each component in the formula.      |  |  |  |  | | --- | --- | --- | --- | | 1 gLiNi(.6)Mn(.2)Co(.2)O2 | 1 mole LiNi(.6)Mn(.2)Co(.2)O2 | .6 mole LiNO3 | 68.9 g LiNO3 | |  | 96.93 g LiNi(.6)Mn(.2)Co(.2)O2 | 1 mole LiNi(.6)Mn(.2)Co(.2)O2 | 1 mole LiNO3 |   Have groups determine the amount of another reactant.     1. Put the equation on the board and have students put up their calculated amount. 2. But what about Glycine? How can we ensure it is not the limiting reactant? |
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| Summarize (10 minutes) | |
| Communicate | **Can we use stoichiometry to predict our reactants and products if we are not using oxidation states to determine chemical formulas?**  **Would we expect the 6-2-2 NMC to have the same properties of 1-1-1 NMC?**  **What happens to the stoichiometric relationships of the metal ions to the product if we change the reactants into Hydrates?** |
| Terminology and Concepts to Solidify | **NMC** –Lithium Nickle Manganese Cobalt Oxide  **Hydrate—** Compounds that are bonded to water molecules as a solid crystal. |
| Connection to Big Ideas (Phenomena) | Stoichiometry can apply to any reaction beyond the basic forms we studied and cover a broad range of chemical reactions |
| Follow  Up/Practice | **Balance the equation with hydrates. Calculate the amount of reactants needed to make 1g of Li Ni(.6)Mn(.2)Co(.2)O2 using Mn, Ni, and Co Hydrate compounds.** |
| Assessment | Students will be able to work through and explain the calculations for amounts of reactants required for the reaction. Students will turn in a copy of their calculations. |

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| **Lesson 2** | **Making NMC according to a specific formula** |
| Three Dimensional Teaching and Learning | **Overview:**  *So we have our recipe, and we have our ingredients, but can we make our solution. Every time I make something in the kitchen, the evidence is left all over the counter, sometimes on the walls, and occasionally on the ceiling. To make a specific product, we need to carefully measure and prepare our reactants. Precision and accuracy will determine the quality of our product.*  **Performance Expectations:**  **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-PS1-5** Construct an explanation based on evidence about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs..  **HS-PS1-7** Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction..  **Science and Engineering Practices:**  **SEP 3**: Planning and Carrying Out Investigations  **SEP 4**: Analyzing and Interpreting Data  **Crosscutting Concepts:** Cause and Effect, Patterns  **Objectives:**  Students will   * Verify calculations using collaboration with other groups * Measure reactants to specified accuracy account for significant figures and equipment accuracy * Combine materials in approved reaction vessel and set in oven for drying. Proper labeling and safety procedures need to be utilized. |
| Background Information  for performance expectation | As students verify their answers with other groups, consensus should be reached about the validity of measurements. Each reactant is massed and added to an approved labeled vessel. Vessel is set in oven for drying overnight. |
| Materials | For the classroom: For the classroom:   * LiNO3 * Mn(CH3COO)2\*4H2O * Ni(NO3)2\*6H2O * Co(NO3)2\*6H2O * C2H5NO2 * 150 ml beakers * Digital Scale * Weigh Papers |
| Prior Knowledge | In Lesson 1, students calculated a derived chemical formula and related it to the reactants needed to create it. In this lesson they take those numbers and verify their validity. Chemicals are measured and added to the 150 ml beaker. After all of the dry chemicals are added, 15ml of dH2O are added to the mixture to create the solution. |
| Launch (10-15 minutes) | |
| Engagement and Communication of Student Expectations | Students in their groups can discuss the calculation of the 1-1-1NMC with each other to determine the validity of their answers. Then have each group put the mass of one of the reactants on the board. Discuss the relevancy and accuracy of each measurement. Discuss possible errors. |
| Explore (30 minutes) | |
| Procedure | 1. Each group needs a balance and weigh paper. Discuss the rules about measuring the mass of a chemical and about cross contamination. 2. Each group will mass out a set of all five reactants and add them to the labeled 150ml bleaker. 3. After adding the reactants, have students add 15 ml of d H2O to the mixture and stir. 4. Use the Ultrasonic Stirrer to finish mixing the chemical. 5. Place solution in oven at 500C overnight. |
| Questions | **Driving Question:**  How did the reactants change when placed in the beaker?  How did the reactants change when water was added to the beaker?  Why did the ultrasonic stirrer dissolve the solution?  Why do we want to dry the solution overnight? (think products and reactants)  **Probing Questions:**  Why do we want to dry the solution overnight? (think products and reactants) |
| Summarize (10 minutes) | |
| Communicate | What were the biggest challenges of preparing the reaction?  Do the actions we took today support the concept of a chemical reaction or physical change?  Did it appear that all of the reactants combined, or were there leftovers?  What parts of the lab support the laws of constant composition, what parts appear to violate that? |
| Terminology and Concepts to Solidify | **Ultrasonic-** of or involving sound waves with a frequency above the upper limit of human hearing. |
| Connection to Big Ideas (DCI) | The law of constant composition says there are definite ratios in which elements combine to make compounds. We can structure specific compounds according to a recipe when we use properties of compounds in inorganic chemistry |
| Follow  Up/Practice | What do you think the compounds will look like after spending the night in the oven? |
| Assessment | Students will turn in their 6-2-2 NMC and 1-1-1 NMC calculations. |

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| **Lesson 3** | **3-2-1 We have ignition.** |
| Three Dimensional Teaching and Learning | **Overview.** *We have allowed our compounds to set over night, there are several changes that have happened, some we can see, others we cant. Now we can use the properties of the glicine and the metal ion compounds to conduct a high energy reaction that can combine our reactants.*  **Performance Expectations**  **HS-PS1-5.** Construct an explanation based on evidence about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.  **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.  **Science and Engineering Practice:**  Planning and Carrying Out Investigations, Constructing explanations and designing solutions.  **Crosscutting Concept:** Cause and Effect  **Objectives:**  Students will   * Provide energy to their reactants in a controlled environment to create an auto-ignition reaction that acts as a catalyst for a high energy REDOX reaction. |
| Background Information | The reaction that will happen is dependent on several conditions. Students will make a full set of observations before the reaction and after the reaction to determine and evaluate the reaction. |
| Materials | For each pair of students:   * Reaction vessel with reactant solution * Pyrex cover plate * Corning 420-D Hotplate * Fume hood * Safety goggles * glove |
| Prior Knowledge | Students use their five senses to experience the world around them. The observations we are able to make help us determine the factors that are effecting our substances and our reaction. |
| Launch (10 minutes) | |
| Engagement and Communication of Student Expectations | 1. Have students look at substances that were left in the oven overnight. 2. Make a list of the properties of the substance to determine if anything had changed overnight. 3. Why do you think we “dried” the solution overnight? |
| Explore (30 minutes) | |
| Procedure | 1. Have students place their solution on the hot plate at 200oC for 15 minutes with a Pyrex cover plate in the fume hood. 2. Observe what is happening in the beaker as the solution is heated. If moisture collects on the Pyrex lid, remove the lid and dry the lid with a chem wipe. 3. After 15 minutes, increase the temperature to 400oC and continue observing any changes. Make sure the door to the fume hood is closed. 4. Continue heating until auto-ignition. Note the time that auto-ignition occurs. Have someone in your group video the reaction with slow motion. 5. After the auto-ignition reaction, turn off the hot plate and use thermal gloves to place the reaction vessel and coverplate to the side of the fume hood to cool. |
| Questions | **Driving Question:**  What happens to a substance as it its heated? What changes in a chemical reaction as we heat the substance?  **Probing Questions:?**   * What changes as the solution is heated to 200oC? * How does the substance change as we heat it to 400oC? * What evidence do we have that a chemical reaction has occurred? * Where are our products, can we account for all of them? |
| Summarize (10 minutes) | |
| Communicate | 1. The reaction happened quickly, why is it important to take data and make observations during the process? 2. Why is a slow motion video useful for a reaction like this? |
| Terminology and Concepts to Solidify | **Auto-ignition** – The **autoignition temperature** or kindling point of a substance is the lowest **temperature** at which it spontaneously ignites in normal atmosphere without an external source of **ignition**, such as a flame or spark. This **temperature** is required to supply the activation energy needed for **combustion.** |
| Connection to Big Ideas | Students will begin to make a clear connection between the **cause and effect** relationship between a normal chemical reaction and a high energy reaction. Students will be able to explain how energy of activation can effect a reaction. |
| Follow  Up/Practice | Students need to account for the final locations of products and reactants after the auto-ignition. What evidence do they have for their assumptions? |
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| **Lesson 4** | **It’s all about the products!** |
| Three Dimensional Teaching and Learning | **Overview**  *The purpose of any chemical reaction is to illicit change due to the process of the reaction or to make a product that has a specific use. In our reaction, we are trying to create a specific product, so we need to collect that product from our reaction process.*  **Performance Expectations**  **HS-PS1-2.** 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-PS1-5.** Construct an explanation based on evidence about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs..  **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.  **Science and Engineering Practice:**  **SEP 3:** Planning and Carrying Out Investigations  **SEP 4:** Analyzing and Interpreting Data  **Crosscutting Concept:** Cause and Effect; Patterns  **Objectives:**  Students will   * Describe materials based on their chemical and physical properties * Use chemical and physical properties to design a process to separate the materials. |
| Background Information | Planning and carrying out investigations to answer questions or test solutions to problems in high school builds on prior experiences and progresses to simple investigations, based on fair tests, which provide data to support explanations or design solutions.  Simple tests can be designed to gather evidence to support or refute student ideas about causes and effects.  Students will learn that the basic chemical and physical properties of substances are always intrinsic tools that can be used when working with them. |
| Materials | For each pair of students:   * Reaction vessel and lid from lesson 3. * Glass funnel * Filter paper * dH2O * scale or balance * Lab oven |
| Prior Knowledge | In the previous lesson, students made observations about the properties of materials and made assumptions about what was left in the reaction vessel. Now we need to devise a plan to collect our products. |
| Launch (10 minutes) | |
| Engagement and Communication of Student Expectations | 1. Recap what students predicted and assumed about where all of our products ended up and what properties they have. Also a list of the observations and properties of the reactants. 2. In the lists of properties, what separates our product NMC from everything else? 3. How can we utilize that difference to recover our product? What evidence will support that we have effectively separated the substances? |
| Explore (30 minutes) | |
| Procedure | 1. Have students make a funnel separation apparatus. What measurements should be taken? 2. Have students perform the separation noting changes to the products, the precipitate and the filtrate. Where are our products, what evidence do we have to support that? 3. When filtration is finished, have students place filter paper in the pyrex cover plate and put in the lab oven overnight to dry. 4. Make observations of the appearance of the precipitate and the filtrate. |
| Questions | **Driving Question:**  “Why can the substances be separated using water and a filtration set up?”  **Probing Questions:**   * What happens if product gets past your filter? * Does everyone’s filtrate look the same? * Does everyone’s product look the same? * Is it important how you handle the materials? |
| Summarize (10 minutes) | |
| Communicate | 1. Facilitate student discourse about their investigations. Did everyone reach the same conclusion? 2. How can we get the product back from the filter paper? 3. How much product should we recover? 4. How do we know what we made? |
| Terminology and Concepts to Solidify | **Filtrate** – a liquid which has passed through a filter.  **Precipitate-** (a substance) to be deposited in solid form from a solution |
| Connection to Big Ideas | Once we have made our products, we still can use chemistry tools to process and work with our substances to isolate and purify our products. Reactions are many times multistep operations. |
| Follow  Up/Practice | After a couple nights in the oven, students can collect their product and place it in a glass vial. Measurements of mass of the vial should be recorded empty and after product is added. Those numbers can be used for students to evaluate their atom economy, efficiency, and percent yield. |
| Assessment | Have students compare the mass of their product to their original stoichiometry. Have them use that as evidence to support a short written summary on how they created their product and the possible factors that effected the creation of the product. Have them suggest ideas to increase the yield of the process. |

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| **Lesson 5** | **So, what did we really make** |
| Three Dimensional Teaching and Learning | **Overview:**  *Having our product is only part of the process. We need to analyze our product to determine the quality of our product. We also need to know how our product will be used.*  **Performance Expectations:**  **HS-PS1-7** Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.  **Science and Engineering Practices:**  **SEP 6:** Designing Solutions  **SEP 1:** Asking Questions and Defining Problems  **Crosscutting Concept:** Technology  **Objectives:**  Students will   * Utilize technology to analyze the quality of product using properties that are not accessible to our standard senses. * Compare their results to know standards to determine the composition of their products * Utilize products similar to theirs to build a Lithium ion battery. * Develop an understanding of the role of batteries in energy use in our world. |
| Background Information | The performance expectation for this lesson integrates traditional science content with engineering. Chemistry is part of a process where our understanding of chemical and physical properties can be utilized to meet the needs of society. Equipment and researchers at South Dakota School of Mines and Technology are working on problems like this in Rapid City. |
| Materials | XRDM for NMC analysis  Battery material provided by SDSMT |
| Prior Knowledge |  |
| XRDM analysis | |
| Engagement and Communication of Student Expectations | Students will participate in the XRDM analysis of materials produced in Lesson 4 |
| Explore | |
| Procedure | 1. Mortar and Pestle |
| Questions | **Driving Question:**  **Probing Questions:** |
| Summarize | |
| Communicate |  |
| Terminology and Concepts to Solidify | **Engineer/Engineering-** An engineer designs solutions to human problems by creatively applying principles of science, mathematics or technology.  **Engineering Design Process-** Engineers use an iterative cycle of steps to solve a human or societal problem. |
| Connection to Big Ideas | **ASK-PLAN-BUILD-TEST-REFINE**  Engineers use science and technology to solve problems and design solutions. The Engineering Design Process is cyclical and adaptable. Students are given a design challenge, and then begin to look for solutions by **asking questions**. Ideally, students will brainstorm with their teams and create detailed **plans**. As teams begin to **build** or create solutions, **testing** and **refining** begin. Students will naturally work toward a solution while utilizing multiple stages of the Engineering Design Process, often simultaneously. |
| Follow  Up/Practice |  |
| Assessment |  |