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IMPROVING STUDENT COMPREHENSION OF
STOICHIOMETRIC CONCEPTS

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Connie Lynn Bannick Kemner

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Major Professor's Signature

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IMPROVING STUDENT COMPREHENSION OF STOICHIOMETRIC CONCEPTS

By

Connie Lynn Bannick Kemner

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ABSTRACT

IMPROVING STUDENT COMPREHENSION OF STOICHIOMETRIC CONCEPTS

By

Connie Lynn Bannick Kemner

Stoichiometry is a mathematical Chemistry concept. One use of stoichiometry is to determine how much product can be formed from a given amount of reactants.

The purpose of this study was to teach a variety of stoichiometric concepts to high school students. During the unit, students learned to do conversions related to balanced chemical equations, determine which reactant was the limiting reactant, and to determine percent yield. This was accomplished using lecture, class discussion, working through sample problems as a class, and a variety of laboratory activities. The majority of the unit was spent doing activities with the goal that students would be more engaged than if they were simply doing homework problems. Data were collected using pre-unit and post-unit surveys, pre-unit and post-unit tests, and answers from student work.

Test averages from the current year and 2005-2006 year were compared. Although the averages were not significantly different, the grades were higher this year. Also, based on student comments and teacher observations, the students seemed to enjoy the unit more and retained the information longer compared to previous years.

ACKNOWLEDGEMENTS

Special thanks go to my husband, Mark, for helping whenever I needed it and having the patience to do so.

Thank you also to my parents who have always taught me that I can do whatever I put my mind to doing.

One last thank you goes to Dr. and Mrs. Boyd Ellis who were generous enough to allow me to live in their home while I did much of my degree work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

I chose to improve the stoichiometry unit where students are asked to mathematically interpret chemical equations. By the end of the unit, students should be able to:

- Define the term stoichiometry.
- Use moles of one substance to determine moles of another substance.
- Use the grams of one substance to find the grams of another substance.
- Use the grams of one substance to find the liters of another substance.
- Use the liters of one substance to find the grams of another substance.
- Use the liters of one substance to find the liters of another substance.
- Use the grams of two reactants to determine the amount of product that can be made.
- Use lab data along with the expected amount of product to determine the percent yield.

This unit is generally taught during the middle of the second semester (mid-March through mid-April). At this point, students have learned about the atom, the periodic table, how to do basic conversions using dimensional analysis, how to balance chemical equations, and the mole concept. Following this unit is one on how kinetic-molecular theory applies to the different states of matter and a unit on solutions, acids, and bases. At the end of the year, students complete a written final exam and a project exam that incorporates all of the key ideas from the second semester.

I chose to work on this topic because it has been a source of frustration for many of my students over the past several years. The complaints are generally based on the mathematics involved that students often believe do not make sense. I model how to solve the problems and involve the students in practicing the skills needed to solve the problems, but that is not always enough. I feel that I am doing too much talking during the unit which bores the students and me. In addition, I would like the students to be more actively engaged in activities as that should lead to better understanding. If things go well, some of them may even decide that stoichiometry and related problems can be fun.

Stoichiometry is often a difficult topic for students taking an introductory Chemistry course. This may be because the topic is too abstract or it may be because the language used is done so in a way that is unfamiliar (Huddle, 1996). I believe that both of these are contributing factors for my students. One way to eliminate the language barrier is to break down large words into their components. To ease the issue of abstractness, it helps to work on making the process of stoichiometry as simple as possible (Poole, 1989). Another way to help students with this abstract topic is to teach them to translate the symbolic information given in a chemical equation into something more tangible (Koch, 1995). In my classroom, I try to model the process of doing stoichiometric conversions and then guide students through some sample problems to familiarize them with the concepts before asking them to attempt problems on their own. I also try to incorporate lab activities so they have a hands-on experience. They can measure masses of reactants and products then compare them to the results of their conversions.

Beyond the issue of difficulty, the students are not always given enough opportunities to make their own connections to stoichiometric concepts. Lecture material and a few worksheets supplemented by a lab activity or two were not sufficient. This lecture driven method works for some learners but not all of them (Lawrence, 1984). This is because not all students learn the same way. Some are more auditory so the spoken word works well for them. Others have a need to move and interact with the subject matter or with other students (Dunn and Griggs, 2000). In my classroom, I try to vary activities from day to day so that students are not sitting through lecture several days a week. Even during lectures, I try to spend time modeling and coaching students in their learning.

Since it is not always practical to design individual lessons every day for each student, it is important to use activities that involve different methods of learning like labs where there is hands-on learning being coupled with what they can observe visually. Developing such lessons allows students to develop other learning styles instead of relying on just one (Bold, 2004). By addressing different learning styles, lessons can be more meaningful for all students (Boyles, 1997). It also more closely simulates the real world as learning outside of the classroom is not all auditory, all visual, or all kinesthetic (Jensen, 2005). Including more hands-on activities that involve more than just the art of observation allows students to become involved and give them a sense of actually doing science instead of being a mere bystander to the process (Zemelman, 2005). Allowing students to interact with the material through their sense of touch, taste, and/or smell in addition to what they can observe visually can also assist students in their learning experiences (Reiff, 1992). This is where lab activities can be useful. Students now have chemicals reacting and changing right before their eyes. Whenever it is safe, I give students permission to touch or smell the chemicals so that they have more sensory input from the activity. By giving students this first-hand experience with the subject matter instead of relying on rote learning, their learning process may be improved (Huddle, 1996). In addition to lab activities, another form of hands-on learning is through the use of manipulatives (Dunn and Griggs, 2000). Internet-based assignments may also be useful, especially if there is access to programs and activities to help them to visualize more abstract topics (Arasasingham, 2005). Throughout the year, I schedule time for students to work with computers. On computer days, students are given a task and some suggested websites to visit. This seems to make learning more fun as the students are much more involved with computer projects than they are when they are asked to read the text to find the same information. These projects culminate with the students presenting their findings to the class through media presentations. This allows the students to go from the role of being a learner to being a teacher and I step aside during their teaching. My interaction at that point is to ask clarifying questions and make sure that they address any questions their classmates might have.

If a student can see a connection between an activity and their everyday life, they are more likely to consider it a relevant task (Sumrall, 1991). This experiential learning allows the student to connect ideas from this unit to prior learning as well as to new topics (Sternberg, 2000). When students are allowed to make sense of the topic they are more likely to remember the information, not just for the upcoming test, but for some time into the future (Herron, 1996). Throughout the year, I try to give students chances to connect with the material through labs that mimic real-world situations. One such activity is the dehydration of gypsum and plaster of Paris. Groups are asked to act as a chemical analysis company and determine the composition of each material. In the process, they must create invoices, develop procedures, and create reports to discuss their findings. This lab takes a few days to complete, but students are generally involved and active throughout the process. Through the use of a lab that utilizes using everyday materials, students should be able connect aspects of their learning to their own lives.

The learning process can also be improved by allowing students to work in groups of two to five students each. This gives an outlet to those students who have trouble interacting with adults. They may now interact with their classmates in a more relaxed atmosphere. This allows the students to divide up the task and work more effectively (Dunn and Dunn, 2000). It also allows them to do some thinking aloud and get feedback from their classmates or from the instructor (Jeon, 2005). After attending several brain-based learning workshops at our school a few years ago, I reorganized my classroom so that students are seated in small groups instead of the traditional rows. Students are now being encouraged to interact with each other and are able to do so without the disruptions I used to have when they were in rows because they are in closer proximity to the person they need to address.

For the thesis project, I set out to develop a stoichiometry unit that would address different methods of learning, include a variety of hands-on activities, allow students to be experiential learners, and place students into small learning groups. To accomplish this, I planned some teacher-led activities such as lecture and note-taking along with some student-centered activities. These activities would alternate throughout the unit. Each segment of the unit would start with a lecture and note-taking activity to give students background information and an introduction to the skills they would develop in that segment. The segment would then bring in student-centered, hands-on activities. This would be the basis for turning the stoichiometry unit into a more interactive unit for the students (Hassard 2005). If all went well with the unit, this year's students would have a better understanding of stoichiometry than those in previous years and that understanding would stay with them. This could be measured by comparing data from this year's students to data from previous years for the unit test as well as final exam and project data.

Lake Shore High School is a public school for students in ninth through twelfth grades in Saint Clair Shores, Michigan. The school had an enrollment of 1,098 students for the second count of the 2006-2007 school year. Our school is a school of choice and there were 145 students in the building taking advantage of that opportunity. A majority (89.43%) of the students who attend Lake Shore are identified as White. The remaining students are identified as Black (4.55%), Asian (1.09%), Hispanic/Latino (1.09%), American Indian (3.20%), and Multi-Racial or No response (0.64%). More than a quarter (28.23%) of our students received free or reduced price lunches. The unit was presented to five sections of Chemistry with a total of 136 students. That represents one senior, 28 juniors, and 107 sophomores. The students taking Chemistry generally reflected the previously listed ethnic breakdown. The data in this study were generated by 34 students who submitted signed consent forms as well as from anonymous pre- and post-surveys (Appendices B & C). This number is low compared to the number of students in taking Chemistry classes. Possible reasons for low participation were that the consent forms were not given until the end of the unit, at the request of the review board, which ended just before Spring Break so there were many students focused on the break rather than schoolwork and students in our school are not likely to return any materials if they are not going to receive credit for doing so. Despite the low number of students participating in the study, the group reflected the wide range of abilities present in the entire five sections of Chemistry students.

IMPLEMENTATION OF THE UNIT

Prior to the 2007-2008 school year, there were a number of labs being done during the stoichiometry unit, but I felt that some of them were not working well in terms of student understanding and some were almost too long to complete during a single class period. This was one reason I chose to improve this unit. The other reason was because this unit was the one that presented the most difficulty for students in previous units. The main goal of my research was to find shorter, and perhaps less involved, labs that would engage students and increase their abilities to comprehend stoichiometric concepts. I also wanted to develop a device that could assist my students in the process of learning stoichiometry. This device would have conversion factors on it that my students could manipulate while they were practicing the various types of stoichiometric calculations. When I arrived on campus for the summer research, I started looking for activities that would support the learning of stoichiometry by actively engaging students in classroom activities. My research (internet, alternate textbooks, and modification of current activities) resulted in the development or adaptation of eleven activities (Appendix A). Near the end of the research course, I went back to my initial idea of developing a manipulative to assist students with the various conversion factors involved in stoichiometric problems. I found some mailing tubes, dowel rods, and fun foam in the store room and began forming the first manipulative. After some sawing, gluing, and boring holes with a hot object, I had one working manipulative (Appendix D, Figure 16). That one manipulative took a lot longer to put together than I thought it might, so I sat down to think about how I could simplify it. I then created a modified version that took much less time to build (Appendix D, Figure 17). This modified version would later be replicated so that I had a set to use in class.

This year, the stoichiometry unit was taught following a unit on balancing equations and one on the mole concept that also introduced dimensional analysis. This represents a change over previous years where the balancing equations unit was in the middle of the mole concept and stoichiometry units. The change was done because I thought this order might be more beneficial to the students. The intended benefit for the students was that the dimensional analysis would still be fresh in their minds as they began to learn about stoichiometry and the units would transition better. There were initially eleven activities planned for this unit (Appendix A). In the end, seven of these activities were used and the final stoichiometry unit outline which includes objectives for each activity is included in Table 1.

Table 1 - Unit outline with objectives

Topics	Activities	Objectives
• What is Stoichiometry? • Mole-Mole Problems	• Lecture • Class Discussion & Practice Problems	• Define the term stoichiometry. • Use moles of one substance to determine moles of another substance.
• Basic Types of Stoichiometry Problems	• Lecture • Class Discussion & Practice Problems	• Use the grams of one substance to find the grams of another substance. • Use the grams of one substance to find the liters of another substance. • Use the liters of one substance to find the grams of another substance. • Use the liters of one substance to find the liters of another substance.
• How to Use Stoichiometry	• Stoichiometry Scavenger Hunt (internet-based)	• Define the term stoichiometry. • Use moles of one substance to determine moles of another substance. • Use the grams of one substance to find

		the grams of another substance.
• Stoichiometric Conversions in the Laboratory	• Al + $CuCl_2$ Lab	• Use moles of one substance to determine moles of another substance. • Use the grams of one substance to find the grams of another substance.
• Limiting Reactants • Percent Yield	• Post-lab Quiz – Cu + $AgNO_3$ Lab • Limiting Reactants & Percent Yield	• Use the grams of two reactants to determine the amount of product that can be made. • Use lab data along with the expected amount of product to determine the percent yield.
• Stoichiometric Conversions in the Laboratory • Using Lab Data to Calculate Percent Yield	• Percent $NaHCO_3$ in a Tablet Lab	• Use the grams of one substance to find the grams of another substance. • Use lab data along with the expected amount of product to determine the percent yield.
• Using Lab Data to Calculate Percent Yield	• Stoichiometry Quiz #2 • Determination of Percent Yield Lab	• Use the grams of one substance to find the grams of another substance. • Use lab data along with the expected amount of product to determine the percent yield.
• Using Lab Data to Determine Which Reaction Occurred	• Decomposition of Baking Soda Lab	• Use the grams of one substance to find the grams of another substance.
• Using Lab Data to Calculate Percent Yield	• Determining Mass of CO_2 Lab	• Use the grams of one substance to find the grams of another substance. • Use lab data along with the expected amount of product to determine the percent yield.
• Using Stoichiometry to Make the Ideal Air Bag	• Stoichiometry Quiz #3 • Air Bag Activity (part I)	• Use the grams of one substance to find the grams of another substance.
• Using Stoichiometry to Make the Ideal Air Bag	• Air Bag Activity (part II)	• Use the grams of one substance to find the grams of another substance.
	• Review	• Define the term stoichiometry. • Use moles of one substance to determine moles of another substance. • Use the grams of one substance to find the grams of another substance. • Use the grams of one substance to find

		the liters of another substance. • Use the liters of one substance to find the grams of another substance. • Use the liters of one substance to find the liters of another substance. • Use the grams of two reactants to determine the amount of product that can be made. • Use lab data along with the expected amount of product to determine the percent yield.
	• Stoichiometry test	• Define the term stoichiometry. • Use moles of one substance to determine moles of another substance. • Use the grams of one substance to find the grams of another substance. • Use the grams of one substance to find the liters of another substance. • Use the liters of one substance to find the grams of another substance. • Use the liters of one substance to find the liters of another substance. • Use the grams of two reactants to determine the amount of product that can be made. • Use lab data along with the expected amount of product to determine the percent yield.
	• Post-Unit Survey	

The unit started with each student being asked to complete an anonymous Pre-Unit survey (Appendix C) and a Pretest (Appendix E). This was to assist in determining student abilities from previous units and their attitudes about science as well as school in general. The first two days were spent going over basic stoichiometry information. These two class days were similar to previous years where most students took notes and practiced using the math. From there, I began introducing activities that were developed during the research summer. There was one more day of lecture in the middle of the activities. During this lecture, we covered how to determine the limiting reactant and how to calculate percent yield. This included taking notes and working through some sample problems. While discussing limiting reactants, we talked about how not using the stoichiometric ratio of chemicals during a lab activity would result in wasted materials as one reactant would be in excess. After students took their Posttests (Appendix E), they finished the unit by completing a Post-unit Survey (Appendix C).

Following is a description of the activities and assessments used during the unit. A qualitative analysis accompanies each activity description.

Activities

1. ***Stoichiometry Scavenger Hunt*** (Appendix D)

   This activity required students to work in pairs while doing some internet research related to the stoichiometry concept and how to solve stoichiometric problems. Students visited selected internet sites, recorded information, and completed related problems. To assist students with the problem completion, students were allowed to use the stoichiometry manipulatives (Appendix D). The students were very engaged during the Stoichiometry Scavenger Hunt and worked well during the class period. Those who chose to use the stoichiometry manipulatives reported positive experiences and several would go on to use them for other assignments during the unit. When asked how they liked the activity, I received several comments of "It's easy." Generally, students had little trouble with the research aspect of the assignment. The difficulties were mostly related to the mathematical problem solving which was still very new to them.

2. ***Aluminum + Copper (II) Chloride Lab*** (Appendix D)

This lab required students to place a coil of aluminum wire into a solution of copper (II) chloride and filter out the solid copper that was produced from the single replacement reaction. If groups carefully followed the procedure, they would have a mass of copper product that would closely resemble, if not match, the stoichiometric calculations that were based on the amount of aluminum and copper (II) chloride consumed in the reaction. The biggest problem encountered during this part of the lab was that students either did not read the lab in advance or were not carefully reading during the activity. The filtered product was to be dried overnight and massed during the next class period. This lab was adequately effective, but it was not as good as I expected. This was likely because there were several students who had not read through the lab prior to class and those groups had difficulty finishing on time. The lab results for this lab did not turn out as well as I hoped. One big problem was that students were having trouble completing the calculations and this was likely due to the newness of the stoichiometry concept. Another problem came from students not being able to clearly see a color change in the aqueous solution.

3. ***Percent $NaHCO_3$ in a Tablet Lab*** (Appendix E)

For this lab, students were given an effervescent tablet containing sodium hydrogen carbonate and determined the individual masses of the tablet and a beaker of water. After the reaction was completed, they found the mass again so they could determine the amount of carbon dioxide produced and use their knowledge of stoichiometric conversions to determine the amount of sodium hydrogen carbonate originally in the tablet. They then compared their answer to the amount listed on the package and found their percent yield. This lab took very little time to complete, so there was time for students to work on their calculations during class and get help when needed. There were no major difficulties with this lab and students were generally able to complete the activity to a satisfactory level. By this time, students were gaining a little confidence in their abilities and were not as frustrated as they were with the previous lab.

4. ***Determination of Percent Yield Lab*** (Appendix D)

   Students measured an amount of sodium hydrogen carbonate and used stoichimetric conversion to determine how much sodium chloride could be produced by reacting hydrochloric acid with sodium hydrogen carbonate. They then heated the resulting mixture to drive off the water and leave behind sodium chloride crystals. Groups who carefully followed the procedure would have typical sodium chloride crystals at the end of the lab. Not all groups were able to produce typical crystals. Some had powdered product that was white, yellow, or light brown which I suspect may have been related to students using a heat setting that was too high, using too much hydrochloric acid, or possibly having some sort of other contamination in their beakers. For this reason, I would like to try the lab again and change the heating portion to allow the liquid to evaporate over a couple of days before using the hot plate. After the product formed, students measured the mass and determined percent yield by comparing their product mass to the mass they calculated using stoichiometry. This was another activity that most students were able to complete satisfactorily.

5. ***Decomposition of Baking Soda Lab*** (Appendix D)

Students measured the mass of a small amount of baking soda (sodium hydrogen carbonate) in a crucible. The crucible was then heated for three to five minutes to assist in the decomposition process. When the crucible was cool, the mass was taken again. The crucible was heated for another brief period, cooled, and measured. This process was repeated until the mass changed by no more than one one-hundredth of a gram which signaled that the decomposition process was completed. While completing the heating and cooling cycles, students were asked to translate three word equations into balanced formula equations. Based on the starting amount of baking soda and the balanced equations, they were asked to calculate how much solid product could be formed. When they finished the heating and cooling cycles, they were asked to compare their measured data to the calculations so they could determine which of the three reactions took place when the baking soda was heated. Students had little trouble with the technique involved in the Decomposition of Baking Soda Lab and this was due mainly to them spending almost a week using the same skills to dehydrate gypsum and plaster of Paris. That gave them more confidence in their abilities and a willingness to attempt the lab. The biggest problem students had was in determining which reaction occurred. It appears that they are too accustomed to doing cookbook-style labs where they simply get data that they do not have to analyze. Most students completed this activity satisfactorily.

6. ***Determining Mass of CO_2 Lab*** (Appendix D)

   Students were asked to determine the mass of a small amount of sodium hydrogen carbonate as well as the mass of 100 milliliters of vinegar (a solution of acetic acid and water). They then had to pour the vinegar into the sodium hydrogen carbonate slowly so that the fizzing did not result in a loss of any liquid product. They were asked to use stoichiometry to determine the expected amount of carbon dioxide based on their starting amount of sodium hydrogen carbonate. Students used the actual and expected values to calculate the percent yield for the reaction. At this point, students had several experiences with the mathematical aspects of the unit and were having little difficulty. The main concern was that many groups were reporting more than 100 percent as their yield. This may have occurred because the students used a spoon to stir that was removed when taking the mass readings and there may have been some liquid clinging to the spoon which would make it appear that more carbon dioxide was produced.

7. ***Air Bag Activity*** (Appendix D)

   This activity was the least structured of all the activities in this unit. Students were given a purpose, materials list, an unbalanced formula equation, and a goal of creating an airbag that was neither over- nor under-inflated. They needed to balance the equation for the reaction between vinegar (acetic acid) and baking soda (sodium hydrogen carbonate), determine the volume of their plastic bag, determine how much baking soda was needed to produce enough carbon dioxide to fill the bag, and develop a procedure for inflating the bag. The students had most of the period to complete the first part of the activity and have their procedure approved. In the following lab period, the groups went into the lab to test their procedure and modify it as needed. When they were satisfied with their results, they asked me to observe as they completed the reaction. I then did a pinch test on the inflated bag to determine if it was over-inflated, under-inflated, or perfectly inflated. Based on student responses (see Results Section, Figure 11) to an anonymous Post-Unit Survey (Appendix C), this may have been one of the most effective activities of the unit. Students worked together and had good dialogue while completing the various tasks.

This activity was the most enjoyable for me and it was the activity most frequently reported as being the student's favorite. As the students began the lab, there was both excitement and frustration over having to write their own procedure. Some students were very detailed in how they thought it would be best to fill the bag with carbon dioxide. Others felt that it was too hard to write their own procedure and spent a fair amount of time complaining instead of working productively. By the time they actually completed the reaction to fill the bag, the groups were all back on track and working well. It was fun to watch as they tried to determine if their bag was inflated properly and how they were going to modify their technique so that the bag inflated to a level that I would judge as "just right." For those groups whose bag did not earn the "just right" label, I talked with them to see if they could give reasons why the bag was either over- or under-inflated. Some groups said it was the bag as some bags seemed to develop tiny holes in the seam after a couple of uses. Others said that they did not seal the bag quickly enough. This was the one activity where students really connected with the material and began to go beyond what I asked of them. Several made a connection between the activity and the air bags found in automobiles which caused them to ask if the chemicals we used were really in automotive air bags. Rather than simply saying no, I responded with other questions that led them to answer the question for themselves.

Assessments
During the unit students were given the following assessments:

1. ***Pre- and Post-Unit Surveys*** (Appendix C)

   These items were not graded because they were turned in anonymously.

2. ***Unit Pretest*** (Appendix E)

   All students who submitted a Pretest that showed effort earned four points. Students who did not submit a Pretest earned no points.

3. ***Homework Problems***

   All homework assignments were graded on a four point scale based on the effort shown by the student. A student who attempted all of the problems and showed work would earn four points. A student who attempted more than half of the problems and showed work would earn three points. A student who attempted half of the problems and showed work would earn two points. A student who attempted less than half of the problems and showed work would earn one point. A student who failed to submit an assignment earned zero points.

4. ***Lab Activities*** (Appendix D)

   Labs were graded similar to homework assignments, but were also scanned for correctness of concepts in the extended response questions.

5. ***Quizzes and Unit Posttest*** (Appendix E)

   Mathematical problems on quizzes and tests were graded based on having correct work shown and an answer with an appropriate number of significant digits and correct units.

RESULTS/EVALUATION

Pre-/Posttest Evaluation

For this unit, all students were given a Pretest and a Posttest (Appendix E) which contained eleven common questions. The raw data for the students who submitted completed consent forms are recorded in Appendix F. Two of the consenting students did not return a pretest, so it was assumed that all questions were incorrectly answered. For the remaining students, 25 of the remaining 32 improved their scores for those questions. Of the 34 students, 27 passed the posttest with a score of 70 percent or better (Appendix F). As is shown in Figure 1 below, there was improvement from pretest to posttest for all but questions one, two, and ten.

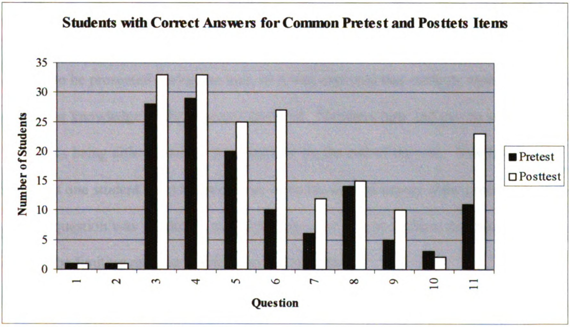

Figure 1 – Student response scores for pretest & posttest questions

Questions one and two were about translating word equations into formula equations which was a necessary skill for the stoichiometry unit, but this material was not taught or re-taught during the unit. Questions three through five asked the students to write in the correct coefficients to balance the given chemical equations. This skill was presented two units prior which is the reason for the number of students who were able to successfully answer those questions on the pretest. The skill was used frequently throughout the unit which would account for more students being able to answer the questions on the posttest. Question six asked students to describe coefficients in chemical equations. This is another skill from a prior unit. Although it was not explicitly re-taught during the unit, but student data show that there was more mastery of the concept at the end of the unit. This is most likely because there was reinforcement of the concept as students worked on the various assignments. Questions seven and eight asked students to describe processes they learned in the two previous units that would be needed in the stoichiometry unit. Questions nine through eleven asked students about doing stoichiometric conversions, limiting reactants, and percent yield. These three skills were all to be presented during the unit, so it was expected that students would have little to no prior knowledge of the concepts involved. Numbers nine and eleven saw increases in students being able to answer the questions by the end of the unit. Number ten saw a decline of one student. I had expected an increase, so I am unsure if the problem is in the way the question was worded as many of them were able to perform the calculations and identify the limiting reactant in a later posttest question.

Pre-/Post-Unit Survey Evaluation

Prior to the unit, students were asked to take a survey that included how they felt about their abilities to do four types of conversions that were presented in the previous unit – 1) grams to moles of a substance, 2) moles to grams of a substance, 3) liters to moles of a substance, and 4) moles to liters of a substance (Appendix C). As seen in Figure 2, there were just over half who responded that they felt that they could either usually or always perform the conversions.

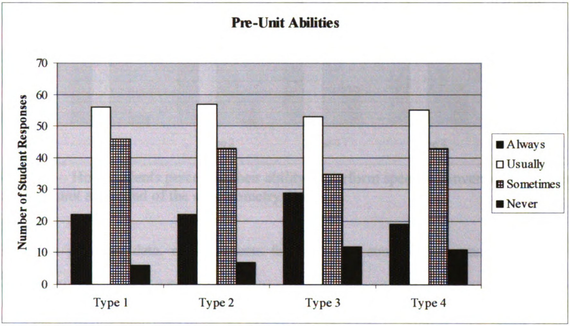

Figure 2 – How students perceived their ability to perform specific conversions from the previous unit

By the end of the unit, students were exposed to more of these types of conversions and more of them responded that they could either usually or always perform the conversions (Figure 3).

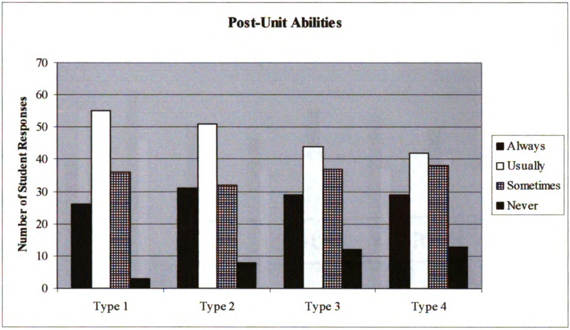

Figure 3 – How students perceived their ability to perform specific conversions from the previous unit at the end of the stoichiometry unit

Based on post-unit data, most students felt that they could either usually or always perform the seven types of stoichiometric calculations presented in the unit – 1) convert from moles of one substance to moles of another substance, 2) convert from grams of one substance to grams of another substance, 3) convert from grams of one substance to liters of another substance, 4) convert from liters of one substance to grams of another substance, 5) convert from liters of one substance to liters of another substance, 6) determine which reactant is the limiting reactant, and 7) calculate percent yield (Figure 4).

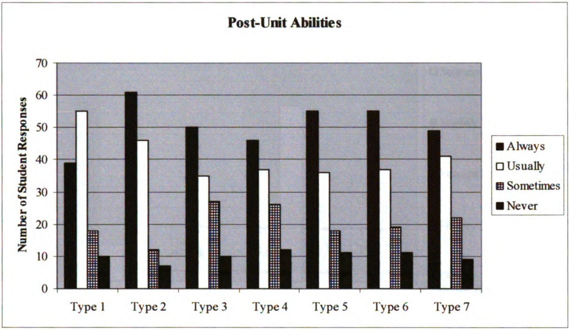

Figure 4 – How students perceived their ability to perform calculations presented during the stoichiometry unit

The Pre-Unit Survey also asked students for information about their current attitudes towards school and their post-graduation plans. Most (128 out of 132 respondents) students indicated that they plan to continue their education past graduation from high school and many (124 respondents) plan to attend a college or university to do so.

I also wanted to know how students felt about science classes and how they approached things like studying, problem solving, or having trouble in a class. The survey results suggest that science is not a popular subject at Lake Shore High School (Figure 5).

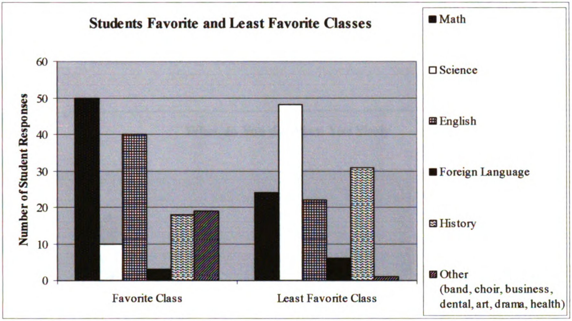

Figure 5 – Students favorite and least favorite classes

The survey indicates that students find in class work to be the most helpful part of science class and quizzes and tests to be the least helpful part (Figure 6).

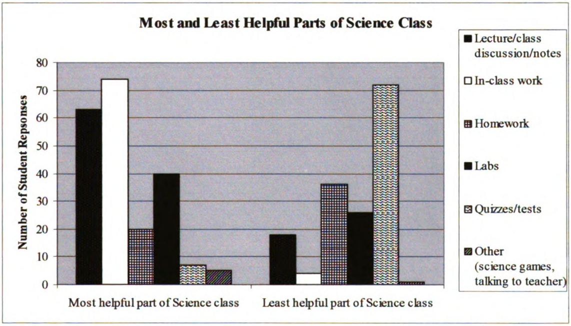

Figure 6 – Student ranking of the most and least helpful parts of science classes

According to the survey data, the students' number one choice for studying is in a quiet place at home, but listening to music is a close second choice (Figure 7).

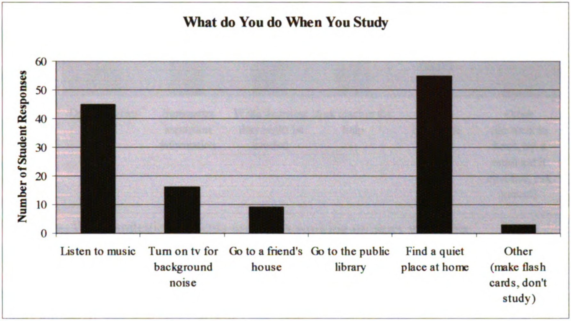

Figure 7 – What students do when they study

Based on survey results, the students have good problem solving skills – writing out needed formulas, summarizing information, and drawing pictures (Figure 8).

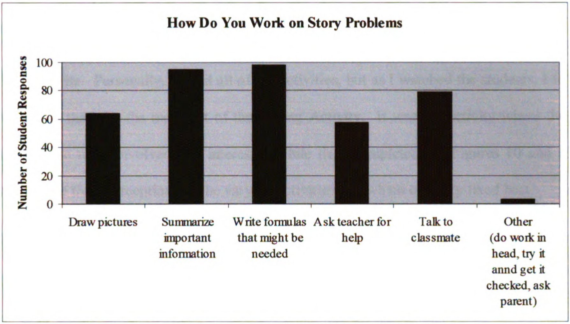

Figure 8 – What strategies students use when working on story problems

Students indicated that they are most likely to talk to a friend when they have trouble in a class (Figure 9).

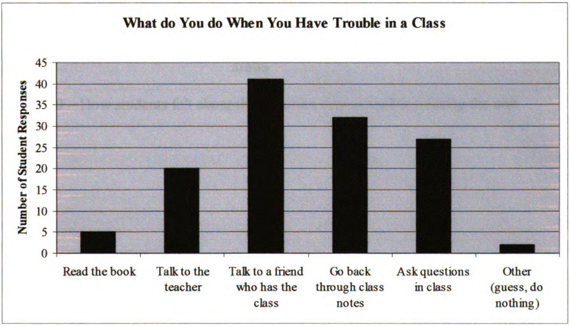

Figure 9 – What strategies students use when they have problems in a class

At the end of the unit I wanted to know how the students felt about the various activities they completed. I also thought it would be interesting to see which activity would be their favorite. Personally, I liked all of the activities, but as I watched the students, I felt as though they got the most out of the Airbag Activity. It was the activity where they seemed the most involved and interested while they completed it. Figures 10 and 11 summarize their perceptions of the varying activities and which one they liked best.

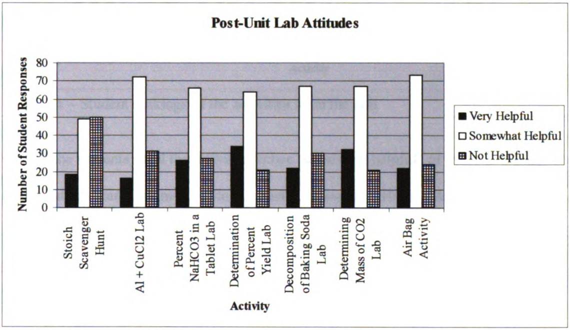

Figure 10 – How students felt about the activities they completed during the unit

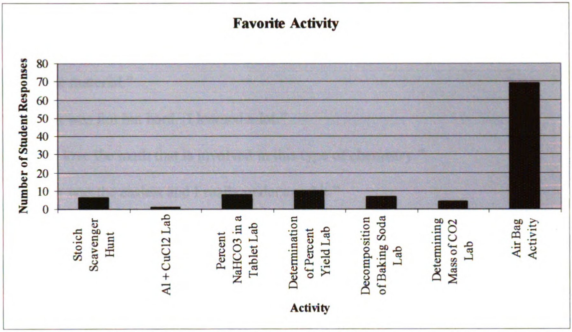

Figure 11 – Student rankings of the activities from the unit

Most of the students rated the activities either "somewhat helpful" or "very helpful." The lowest ratings came from the Stoichiometry Scavenger Hunt. Although I liked the Airbag Activity the best, I was surprised to see that so many students chose that as their favorite. This was because there seemed to be more frustration with this activity than any of the labs that had procedures in place for students to follow.

The open response section of the survey showed that students had a range of things to say about the unit when it was finished. (All survey responses were anonymous.)

> "It was a lot of math."
>
> "It's too hard."
>
> "I need more help with it."
>
> "I think that the labs should be a little more spaced out. Instead of every day, I think it should be every other day."

"This was hard, but you taught it well."

"This unit got better towards the end of the unit when I mostly understood the material."

"It was fun but hard. I learned a lot."

"I love the math that is involved in this type of chemistry."

"It was the easiest and I really understood it."

"There is one thing and that is this is the most I have learned in a unit a while and I actually felt like I accomplished something."

"This unit was the easiest for me so far, it was good to finally fully understand everything I did. It made me more confident in the class."

The comments about the unit being hard and having a lot of math are similar to previous years. Although there were several comments written on the survey indicating that the unit was difficult, it appears as though most students feel comfortable with the calculations presented in the unit as there are fewer than fifteen "Never" responses to any statements regarding the stoichiometric calculations (Figure 4). I generally do not get many about the unit being the easiest or enjoying the unit. Those last few comments made this entire process worthwhile as that was one of my goals – to get at least a few students with an appreciation for how stoichiometry works. The students commenting on the ease of the unit were likely to be students who responded either "Always" or "Usually" to the statements regarding the stoichiometric calculations (Figure 4).

Activity Evaluation

Despite the amount of work students were asked to do in this unit, a majority of them were able to complete the activities to a satisfactory level of three or four points on a four point scale (Appendix F). The scores for the activities are summarized in Table 2.

Table 2 – Activity scores

Avtivity	Range of Scores	Average Score
Pretest	0 to 4	4
Scavenger Hunt	0 to 4	4
Al + CuCl2 Lab	0 to 4	3
Percent NaHCO3 in a Tablet Lab	0 to 4	3
Determination of Percent Yield Lab	0 to 4	3
Decomposition of Baking Soda Lab	0 to 4	3
Determining the Mass of CO2 Lab	0 to 4	3
Airbag Activity	0 to 4	3

The first quiz of the unit (Appendix E) was a follow up to the Aluminum + Copper (II) Chloride Lab (Appendix D). Students were given sample lab data to analyze and were asked to answer questions similar to the ones on their lab. Many students (21 of 34) had scores of 60% or less (Figure 12) which is likely because the required stoichiometry skills were still new to them. Only one student was able to successfully answer all five questions and earn 100%.

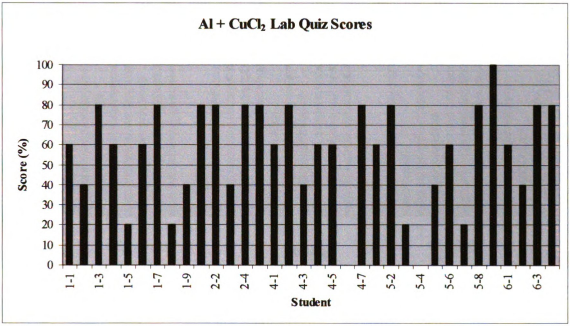

Figure 12 – Student scores for Al + $CuCl_2$ Lab Quiz

Stoichiometry Quiz #2 (Appendix E) saw an improvement in scores (Figure 13). More than half of the students (19 of 34) were able to earn scores of 70% or better and eight were able to earn a score of 100%. By this point, students had more time to work with the various stoichiometric conversions.

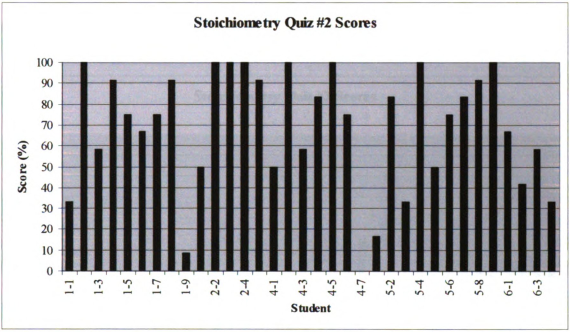

Figure 13 – Student scores for Stoichiometry Quiz #2

Stoichiometry Quiz #3 (Appendix E) showed a drop in scores (Figure 14). Only eleven of thirty-four students were able to achieve a score of 70% or better. This quiz incorporated the concepts of limiting reactant and percent yield. Again, the concepts were relatively new compared to the stoichiometric conversions that were presented on the prior two quizzes. Despite the newness, two students were able to achieve perfect scores.

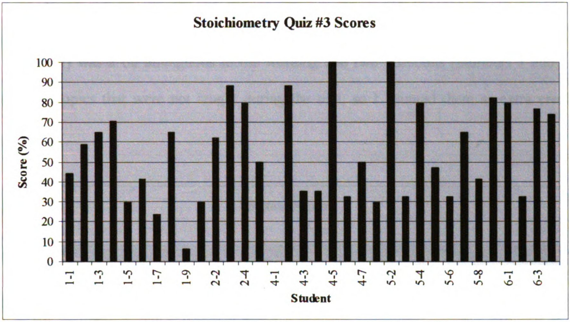

Figure 14 – Student scores for Stoichiometry Quiz #3

Of the thirty-four students who participated in the study, only seven failed to achieve a score of 70% or better (Figure 15) on the Stoichiometry Unit Test (Appendix E). The test average for the participating students was 81% compared to an overall average of 75% for the five sections of Chemistry. The greatest difficulties for the students were found in the limiting reactant and percent yield questions. Most were able to accomplish the stoichiometric conversions, but several had trouble incorporating the additional concepts. Two students earned perfect scores and one student was able to earn a score of 107%. The reasons for a student being able to earn more than 100% were because one question (number 7) was a bit ambiguous in the wording and two questions (numbers 1 and 2) were on topics that were not taught during the unit, so I counted them as extra credit questions.

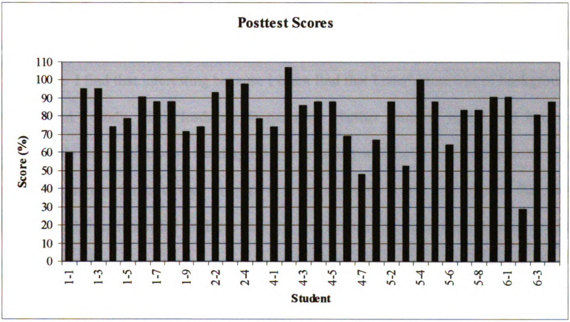

Figure 15 – Student scores for Stoichiometry Unit Test

DISCUSSION AND CONCLUSION

At the start of the unit I asked students to complete the Pre-Unit Survey (Appendix C). On average, the results were as I expected. Based on the comments I hear in class and in the halls, it was no surprise that science would be ranked as the students' least favorite subject (Figure 5). What I did not expect was that fifty respondents would list math as their favorite subject (Figure 5). I also did not expect to see lecture and note taking ranked as the second most helpful part of science class, especially since I often hear that lecturing and note taking needs to be reduced in the classroom (Figure 6). I would have expected that students would rank labs as a helpful part of class, but there seems to be some debate on that as it was ranked third on the most helpful and least helpful lists (Figure 6). I was also interested to see the results of what students do when they study (Figure 7). The number of students who study with other noises in the room (music, television, or friends) surpassed the number of those who say they need a quiet space (Figure 7). I find that interesting because I often find that I need some sort of background noise when I study. This leads me to question whether students would find it more comfortable and conducive to learning if there is background noise in the classroom. The student responses for how they attempt to work on story problems indicates that they have a good foundation for problem solving, but I often find that students have trouble when assigned story-type problems in class (Figure 8). This leads me to question if they are having trouble determining which information is important and which formulas might be applicable seeing as summarizing and formula writing are the two most popular strategies listed. I also thought it was noteworthy that the students ranked talking to a teacher as fourth on the list of things to do when they have trouble in a class while talking to a friend was their first choice (Figure 9). I understand that they are generally more comfortable with talking to a peer. This makes me want to find ways to seem more approachable to students as talking to classmates can sometimes backfire as that student may unknowingly be passing on erroneous information and making the problem worse instead of better.

My summer research resulted in a number of activities which were implemented this year. However, this unit did not go quite as I expected when I was doing the research. My initial thoughts were to edit the old labs that I felt were useful and add new ones. In my attempt to include more activities to engage students, I think I may have gone too far and tried to add too many activities. I quickly became overwhelmed with the work involved in getting labs set up and broken down every day. I also worried about whether I was trying to get the students to do too much in such a short time. I did not hear many complaints, but I noticed that there was a decrease in the number of assignments being submitted after the first few activities. To ease the problem, I eliminated the following activities from the unit: Fizzy Drinks, S'more Stoichiometry, Making Chalk, and the Balloon Lab (Appendix D). Many of the activities that were used involved the same basic reaction of vinegar and baking soda. This is a reaction that students often see in science class in one of the lower grades, so there is a familiarity. This freed students from being concerned about what kind of product they should get so they could concentrate more on the task of analyzing the reaction to see how stoichiometric concepts applied in each activity.

Looking back, I think that I would have tried to complete fewer labs, but take more time to discuss results. Judging by student responses for the extended response questions on the Post-Unit Survey (Appendix C), several of them agreed with me. The lab activities that were attempted went mostly as planned. Some did not give the best results as far as the data that the students generated, but that is always a possibility with any lab activity.

Even though I did not do as many activities as I initially planned, I feel that the activities that we completed were useful. Students had more ownership of the concepts because they were working with data they generated instead of worksheets that provided numbers the students could not visualize. Many students commented during the unit that they enjoyed doing the labs and the Post Unit Survey (Appendix C) indicated that they felt that most of the labs were either somewhat helpful or very helpful (Figure 10). There was an increase in the test average for this unit from the 2004-2005 school year (69%) to the 2006-2007 school year (75%). In addition, students were still able to remember some of the activities from the unit as they completed their end of the year project. This project asked students to build a torpedo-type boat from a plastic bottle then use their knowledge of semester topics to create an adequate amount of carbon dioxide, from a reaction of baking soda and vinegar, to propel the boat down a ten-foot section of rain gutter. A large part of the project involved using stoichiometry to convert the desired amount of carbon dioxide into starting amounts of baking soda and vinegar. I also noticed a slight increase on the section of the final exam with the stoichiometry questions from the 2004-2005 school year (75%) to the 2006-2007 school year (76%).

Next year, I plan to space out the labs for this unit a little better and eliminate or edit some. I may eliminate the *Stoichiometry Scavenger Hunt* as I feel that the lab activities reinforce the concepts better. This is likely because the students are working with the chemicals instead of working with something that looks like it came from their textbook. I will probably keep the *Aluminum and Copper (II) chloride Lab*, but change it so that there is more time to discuss the required calculations as it is one of the first labs and the students needed more support at that time. The *Percent $NaHCO_3$ in a Tablet Lab* is another lab that I plan to keep because it was easy for the students to complete the procedure and it gave expected results. The *Determination of Percent Yield Lab* is likely to be eliminated because it did not give expected results and the required types of calculations are repeated in other labs. I will keep the *Decomposition of Baking Soda Lab*, but I think it might be useful to take a little more time introducing it and going over the goal of the activity. If I keep the *Determining the Mass of CO_2 Lab*, it will need to be edited as the results were not very good – many students had yields of more than 100%. I think that could be solved by changing the procedure so that students take all mass readings with the spoon in the beaker to see if they get results that are closer to 100% yield without being over 100%. The *Airbag Activity* is one that will definitely be kept. Although it frustrates students to have to develop their own procedure, this activity served multiple purposes. Asking students to write their own procedure gives them ownership in the activity and they express more satisfaction when they are finished. This activity also gives students a foretaste of their final exam project and many of this year's students went back to it to assist in their thinking for the project. Some students read through the introductory material for the carbon dioxide boats and almost immediately mentioned that they had seen this information somewhere. After a little discussion with their partners, several groups recognized that they were using the same materials as the *Airbag Activity* and set out to find copies so they could write the balanced chemical equation for baking soda and vinegar. For groups who made this connection, I noticed that they were less frustrated as they did not have to spend time searching for the equation. This meant they could take more time determining how much carbon dioxide they wanted then do the conversions to determine how much of the starting materials they needed.

In the end, I was pleased with the overall results of the unit compared to previous years. The students were more engaged in the learning process. There were more positive comments about the unit. Students performed better both at the end of the unit and at the end of the year. In addition, I enjoyed teaching more this year. The combination of these things made this a worthwhile endeavor.

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APPENDICES

APPENDIX A - UNIT OUTLINES

Proposed outline of activities from research summer

Day	Topic/activity	Text section	Homework	Notes
M	Stoichiometry Pretest & Survey $Mg + HCl$ demonstration What is Stoichiometry Beginning Stoichiometry Problems (mole-mole)	9.1, 9.2	Mole-mole worksheet	
Tu	Types of Stoichiometry Problems		Stoichiometry worksheets	
W	Stoichiometry Scavenger Hunt			
Th	Percent $NaHCO_3$ in a Tablet Lab			
F	**Stoichiometry Quiz #1** $Al + CuCl_2$ Lab			
M	Discover It Demonstration Limiting Reactants & Percent Yield	9.3	Cookie stoich worksheet – baking optional	
Tu	**Post-lab Quiz** – $Cu + AgNO_3$ Lab Fizzy Drinks S'more Stoichiometry Activity			
W	Decomposition of Baking Soda			
Th	**Stoichiometry Quiz #2** Determining Mass of CO_2 Lab			
F	Determination of Percent Yield Lab			
M	Making Chalk Lab			
Tu	**Stoichiometry Quiz #3** Balloon Lab			
W	Air Bag Activity			
Th	Review			
F	**Stoichiometry test**			

Outline of activities as presented in class

Date	Topic/Activity	Text Section	Homework	Notes
3/19	What is Stoichiometry Beginning Stoichiometry Problems (mole-mole)	9.1, 9.2	Mole-mole worksheet	
3/20	Types of Stoichiometry Problems		Stoichiometry worksheets	
3/21	Stoichiometry Scavenger Hunt			
3/22	Al + $CuCl_2$ Lab			½ day - PT conferences
3/23	**Post-lab Quiz** – Cu + $AgNO_3$ Lab Limiting Reactants & Percent Yield	9.3		
3/26	Percent $NaHCO_3$ in a Tablet Lab			
3/27	**Stoichiometry Quiz #2** Determination of Percent Yield Lab			
3/28	Decomposition of Baking Soda Lab			
3/29	Determining Mass of CO_2 Lab			
3/30	**Stoichiometry Quiz #3** Air Bag Activity (part I)			
4/2	Air Bag Activity (part II)			
4/3	Review			
4/4	**Stoichiometry test**			
4/5	Post-Unit Survey		Get consent form signed	½ day

APPENDIX B – CONSENT FORM

Improving Student Comprehension of Stoichiometric Concepts
Parent Consent and Student Assent Form

I am currently enrolled as a graduate student in Michigan State University's Department of Science and Mathematics Education (DSME). My thesis research is on improving student comprehension of stoichiometric concepts (which are the mathematics of chemical equations). Some components of the unit are determining the amount of product that can be formed in a reaction and determining percent yield of the reaction or how much of the expected amount was obtained in an experiment.

Data for the study will be collected from standard student work generated in the course of teaching this unit such as pre and post tests, lab activities, quizzes, and surveys. I am asking for your permission to include your child's data in my thesis. Your child's privacy is a foremost concern. During the study, I will collect and copy student work. These assignments will have the student's name removed prior to use in the study. All of the work being collected will be stored in a locked cabinet until my thesis is finished and will be shredded after that time. In addition, your child's identity will not be attached any data in my thesis paper or in any images used in the thesis presentation. Your child's privacy will be protected to the maximum extent allowable by law.

Participation in the study is completely voluntary. Students who do not participate in the study will not be penalized in any way. Students who do not participate in the study will still be expected to participate in class and complete assignments. Students who participate in the study will not be given extra work to complete. You may request that your child's information not be included in this study at any time and your request will be honored. There are no known risks associated with participating in this study. Participation in this study may contribute to determining the best way to present stoichiometric concepts to high school students.

If you are willing to allow your child to participate in the study, please complete the attached form and return it to me by February 28th, 2007. Please seal it in the provided envelope with your child's name on the outside of the envelope. The envelopes will be stored in a locked cabinet and opened after the unit is completed. Any work from a student who is not to be included in the study will be shredded.

If you have any questions about the study, please contact me by e-mail at CKemner@lsps.org or by phone at (586) 385-8896. Questions about the study may also be directed to Dr. Merle Heidemann at the DSME by e-mail at heidema2@msu.edu, by phone at (517) 432-2152, or by mail at 118 North Kedzie, East Lansing, Michigan 48824. If you have any questions or concerns regarding your rights as a study participant, or are dissatisfied at any time with any aspect of this study, you may contact - anonymously, if you wish - Peter Vasilenko, Ph.D., Director of the Human Subject Protection Programs at Michigan State University, by phone at (517) 355-2180, by e-mail at irb@msu.edu, by fax at (517) 432-4503, or by mail at 202 Olds Hall, East Lansing, MI 48824.

Thank you,

Mrs. Connie Kemner
Chemistry Teacher
Lake Shore High School

I voluntarily agree to allow ________________________________ to participate in this study.

(print student name)

Please check all that apply.

_______ I give Mrs. Kemner permission to use data generated from my child's work in chemistry class to be used in the thesis project. All data from my child will remain confidential.

_______ I do not wish to have my child's work used in this thesis project. I acknowledge that my child's work will be graded in the same manner regardless of participation in the study.

_______ I give Mrs. Kemner permission to use pictures of my child during her work on this thesis project. My child will not be identified in these pictures.

_______ I do not wish to have my child's picture used at any time during this thesis project.

___________________________________ ________________

(Parent/Guardian signature) (date)

I voluntarily agree to participate in this thesis project.

___________________________________ ________________

(Student signature) (date)

APPENDIX C - SURVEYS

Stoichiometry: Pre-Unit Survey

Circle the answer that fits you best. You are not required to put your name on this assignment.

1) Do you plan to continue your education after graduating from Lake Shore?
   Yes　　No　　Not sure

2) If you answered yes to the previous question, please indicate where you will continue your education.
   College/University　　Trade School
   Military　　On-the-job training/Apprenticeship

3) If you plan to continue your education, will you need to take another chemistry course?
   Yes　　No　　Not sure

4) Do you plan to have a career that is related to science?
   Yes　　No　　Not sure

5) If you answered yes to the previous question, please list what career you are considering.

6) My favorite class is
   Math　　Science　　English　　Foreign Language
   History/Social Studies　　Other (please list which one) __________________

7) My least favorite class is
   Math　　Science　　English　　Foreign Language
   History/Social Studies　　Other (please list which one) __________________

8) My usual grade in math classes is
   A　　B　　C　　D　　F

9) My usual grade in science classes is
   A　　B　　C　　D　　F

10) When you have trouble in a class, what do you do? Please number your choices with 1 being the first thing you do and 6 being the last thing you would try.
   ____ Read the book　　____ Talk to the teacher
   ____ Talk to a friend who has the class　　____ Go back through the class notes
   ____ Ask questions in class
   ____ Other (please describe) ____

11) When you study, which of the following do you do? Please number your choices with 1 being the thing you are most likely to do and 6 being the thing you are least likely to do.

____ Listen to music
____ Turn on the tv for background noise
____ Go to a friend's house
____ Go to the public library
____ Find a room in the house that is quiet
____ Other (please describe) ____

12) When you are assigned story problems, do you do any of the following? Circle all that apply.

Draw pictures
Summarize the important information
Write formulas that might be needed
Ask the teacher for help
Discuss the problem with someone else in the class
Other (please describe) ____

13) Which part of science class is most helpful to you?

Lecture/Class discussion
In-class work
Homework
Labs
Quizzes/Tests
Other (please describe) ____________________

14) Which part of science class is least helpful to you?

Lecture/Class discussion
In-class work
Homework
Labs
Quizzes/Tests
Other (please describe) ____________________

15) What is your favorite part of science class?

Lecture/Class discussion
In-class work
Homework
Labs
Quizzes/Tests
Other (please describe) ____________________

16) What is your least favorite part of science class?

Lecture/Class discussion
In-class work
Homework
Labs
Quizzes/Tests
Other (please describe) ____________________

17) Please shade the box that most fits how you feel.

I can convert from grams of a substance to moles of the same substance.	**Always**	**Usually**	**Sometimes**	**Never**
I can convert from moles of a substance to grams of the same substance.	**Always**	**Usually**	**Sometimes**	**Never**
I can convert from liters of a substance to moles of a substance.	**Always**	**Usually**	**Sometimes**	**Never**
I can convert from moles of a substance to liters of a substance.	**Always**	**Usually**	**Sometimes**	**Never**

Stoichiometry: Post-Unit Survey

Answer each of the following questions. You are not required to put your name on this assignment.

1) Please shade the box that most fits how you feel.

I can convert from grams of a substance to moles of the same substance.	**Always**	**Usually**	**Sometimes**	**Never**
I can convert from moles of a substance to grams of the same substance.	**Always**	**Usually**	**Sometimes**	**Never**
I can convert from liters of a substance to moles of a substance.	**Always**	**Usually**	**Sometimes**	**Never**
I can convert from moles of a substance to liters of a substance.	**Always**	**Usually**	**Sometimes**	**Never**
I can convert from moles of one substance to moles of another substance.	**Always**	**Usually**	**Sometimes**	**Never**
I can convert from grams of one substance to grams of another substance.	**Always**	**Usually**	**Sometimes**	**Never**
I can convert from grams of one substance to liters of another substance.	**Always**	**Usually**	**Sometimes**	**Never**
I can convert from liters of one substance to grams of another substance.	**Always**	**Usually**	**Sometimes**	**Never**
I can convert from liters of one substance to liters of another substance.	**Always**	**Usually**	**Sometimes**	**Never**
I can determine which reactant is the limiting reactant.	**Always**	**Usually**	**Sometimes**	**Never**
I can calculate percent yield.	**Always**	**Usually**	**Sometimes**	**Never**

2) Rate the activities and labs from this unit by shading the box that most fits how you feel.

Air Bag Activity	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**
Al + $CuCl_2$ Lab	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**
Balloon Lab	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**
Decomposition of Baking Soda	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**
Determination of Percent Yield Lab	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**
Determining Mass of CO_2 Lab	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**
Discover It (Paper Clip) Activity	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**
Fizzy Drinks	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**
Making Chalk Lab	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**
Percent $NaHCO_3$ in a Tablet Lab	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**
S'more Stoichiometry Activity	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**
Stoichiometry Scavenger Hunt	**Very Helpful**	**Somewhat Helpful**	**Not Helpful**

3) From the list of activities/labs in the previous question, select your favorite and describe why you liked it best.

4) Is there anything else about this unit that you would like to say?

APPENDIX D - ACTIVITIES

Stoichiometry Scavenger Hunt

Adapted from: http://www2.gsu.edu/~mstjrh/stoichiometry.html

Name: ________________________ Partner(s):__________________________

Please visit the listed websites, follow the directions, and answer the questions. In order to earn credit for the assignment, you must show all work (using the method shown in class) for mathematical problems on a separate sheet of paper.

Website #1:

http://dbhs.wvusd.k12.ca.us/webdocs/Stoichiometry/Stoichiometry.html

1) Read "What is stoichiometry?"
   a) What does the word stoichiometry mean?

   b) In your words, why are stoichiometric calculations important?

   c) To whom might stoichiometric calculations be important?

2) Read the following sections:
   a) Molar Ratios
   b) Given Moles, Get Moles
   c) Given Grams, Get Moles and Given Moles, Get Grams
   d) Given Grams, Get Grams

3) Go to Stoichiometric Problems (found at http://dbhs.wvusd.k12.ca.us/webdocs/Stoichiometry/Stoichiometry-Worksheet.html)
   a) Do 1a, 1b, 2, 3, 4

The answers are provided on this site; use them to check your answers only. Keep in mind you MUST show your work to earn credit.

Website #2:
http://library.kcc.hawaii.edu/external/chemistry/everyday_combustion.html

1) Read the information on fuels and answer the following questions.
   a) Fuels such as gasoline, propane, diesel, etc. primarily consist of what two elements?

   b) What is the molar ratio of C_3H_8 to water?

   c) If 4 moles of C_3H_8 reacted according to the reaction given for propane, how many moles of carbon dioxide would result?

   d) How many grams of water would be produced if an initial amount of 50.0 g of oxygen gas reacted with unlimited amounts of C_3H_8?

Stoichiometry Manipulatives

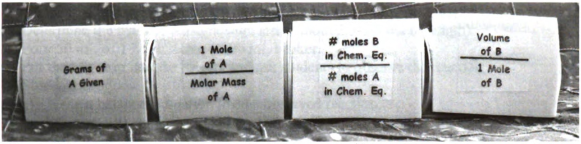

Figure 16 – Manipulative, first version (segments of a mailing tube connected by a dowel rod with fun foam and plastic conversion panels, segments labels are "Grams of A Given," "1 Mole of A/Molar Mass of A," "# moles B in Chem. Eq./# moles A in Chem. Eq.," and "Volume of B/1 Mole of B" respectively)

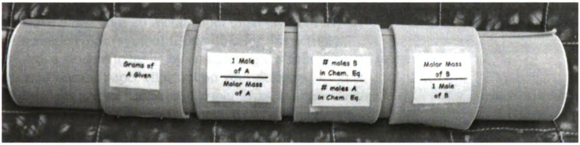

Figure 17 – Manipulative, second version (a whole mailing tube covered in construction paper with fun foam bands containing conversion panels attached by clear contact paper, segments labels are "Grams of A Given," "1 Mole of A/Molar Mass of A," "# moles B in Chem. Eq./# moles A in Chem. Eq.," and "Molar Mass of B/1 Mole of B" respectively)

Teacher Demonstrations

Mg + HCl

Adapted from Addison-Wesley's Chemistry (© 2000, page 241)

1) Determine the mass of a magnesium strip (about 2.5-3.5 cm in length).
2) Pour 50 mL of 1 M HCl into a 100 mL beaker.
3) Put the Mg strip into the beaker and ask students to observe the reaction.
4) Student questions:
   a) Write a balanced equation for the observed reaction.
   b) Interpret the equation (explain the coefficients) in terms of moles, mass, and particles.

Discover It

Adapted from Addison-Wesley's Chemistry (© 2000, page 236)

1) Have a bag with 20 metal paper clips (symbol M) and 20 plastic-coated paper clips of a single color (symbol C) availble for this activity.
2) Ask a student to assist by completing the following directions.
   a) Pour the paper clips out on your desktop.
   b) Join pairs of matching paper clips to make diatomic molecules of each reactant (M and C). Put the completed molecules back into the bag.
   c) Without looking at the molecules, take out 15 molecules from the bag.
   d) Line up the M_2 and C_2 molecules in two adjacent, vertical columns.
   e) Pair up the reactant molecules in the 1:3 M_2 to C_2 ratio as shown in the equation of $M_2 + 3\ C_2 \rightarrow 2\ MC_3$. (Students might do better if they have a visual representation on the board of what is expected in this step.)
   f) Make the molecules "react" by taking them apart and forming product molecules.
3) Student questions:
   a) How many reactant molecules of each type were drawn from the bag?
   b) How many molecules of the product were able to be formed?
   c) Which reactant molecule did you run out of first?
   d) How many reactant molecules were left over after the reaction and what type were they?

***This could be used as a class activity instead by giving bags to groups and comparing data from the groups at the end of the activity.

Acid & Marble Chip Demo

Adapted from Holt's Chemistry: Visualizing Matter (© 2000, pages 367-368)

~15 minutes

1) Place a Petri dish on the overhead projector and add 1 M HCl until the dish is half full. Record reactant formula on the board.
2) Have a student to determine the mass of 5-10 marble chips to the nearest thousandth of a gram. Record reactant formula on the board along with the mass.
3) Add the marble chips to the Petri dish.
4) Student questions:
   a) What gas is in the bubbles being generated? ***CO_2***
   b) How do you know the reaction is done? ***No more bubbles are generated***
   c) Look at what's left in the Petri dish.
      i) What is the excess reactant? ***Probably $CaCO_3$***
      ii) What is the limiting reactant? ***Whatever is used up, probably HCl***
   d) How could you find the theoretical yield of CO_2? ***Dry the marble chips, get the new mass, use stoichiometry to convert from grams of marble to grams of carbon dioxide***
   e) How could you find the actual yield of CO_2? ***Do the reaction again & collect the gas being generated***
   f) How could you find the percent yield of CO_2? ***Divide the actual yield by the theoretical yield and multiply by 100***
   g) How does this demonstration show the effect of acid rain on marble? ***Acid causes damage to the marble – this explains some of the destruction of marble monuments***

Safety:

Wear goggles. Keep students 3 or more meters from the reaction. Avoid getting acid on your skin. Avoid breathing the acid fumes

Disposal:

Decant the liquid and wash any remaining chips with distilled water. Place the wash water with the leftover reaction liquid. Test the pH of the solution. If it is 3 or less, neutralize it with 1 M NaOH and pour the liquid down the drain with plenty of water. Save the chips for a future use.

Aluminum + Copper (II) Chloride Stoichiometry Lab

Adapted from: http://departments.oxy.edu/tops/Stoichiometry/stoichstudent.htm

Purpose

Determine the stoichiometric relationship of two reactants.

Materials

- Aluminum wire
- Electronic balance
- $CuCl_2 \bullet 2\ H_2O$
- Screw-top test tube
- Wash bottle with distilled water
- Tweezers
- Paper towel
- Filter paper
- Funnel
- 250 mL beaker

Procedure

All masses need to be recorded to the nearest 0.01 g.

Day 1

1) Loosely coil a small piece (between 5.0 and 10.0 cm) of Al wire around a pencil. Remember that your coil needs to fit into the test tube. Determine the mass of the wire coil.
2) Determine the mass of your test tube and lid.
3) Place a pea-sized amount of $CuCl_2 \bullet 2\ H_2O$ in your test tube, reseal it, and determine the mass.
4) Use your wash bottle to add the water to the test tube. Add enough water to fill the tube to the 5 or 6 mL line. Make sure the cap is on tight and shake the tube to make sure the solid is completely dissolved. If there is still solid left in the test tube you may, add another milliliter of distilled water. Record the color of the solution. (It may help to put the test tube on a piece of white paper to see the color.)
5) Place the wire into the $CuCl_2$ solution, replace the cap, and shake gently. Observe the reaction for 10 minutes, occasionally shaking gently to remove Cu crystals from the wire.
6) Take a small piece of paper towel and a filter paper. Use a pencil to put the initials of your group members on both items. Determine the mass of the filter paper.
7) Fold the filter paper to fit into your funnel. Place the filter paper and funnel into a 250 mL beaker.
8) Empty contents of test tube into the filter paper. (Make sure the liquid does not reach the top of the filter or you may lose some of your product.) Use the tweezers to pull the wire out of the filter. Use the wash bottle to rinse any remaining copper from the wire into the filter. Put the wire on the paper towel and place it in the area indicated by your instructor.
9) Use the wash bottle to rinse any remaining copper from the test tube into the filter. Record the color of the final solution in the beaker. (It may help to put the beaker on a piece of white paper to see the color.)
10) When all of the liquid is out of the filter paper, carefully remove the filter, unfold it, and place it on the paper towel with your wire.
11) Clean up and put away all materials.

Day 2

1) Determine the mass of the wire. Return the wire to your instructor.
2) Determine the mass of your dried filter paper and crystals. Record your data.
3) Clean up and put away all materials.

Data Table

Initial mass of Al wire	
Mass of $CuCl_2$	
Color of $CuCl_2$ solution before reaction	
Color of solution at end of reaction	
Final mass of Al wire	
Mass of filter paper	
Mass of filter paper + Cu crystals	

Questions

Answer the following questions on a separate sheet of paper. You must show your work to earn credit for the questions involving calculations.

1) Use the information from your data table to calculate:
   a) the mass of Al reacted.
   b) the mass of $CuCl_2 \bullet 2\ H_2O$ in solution.
   c) the mass of Cu crystals

2) Use the information from Question 1 to determine:
   a) the moles of Al reacted.
   b) the moles of $CuCl_2$ reacted.
   c) the moles of Cu crystals produced.
   (***Remember to convert mass of $CuCl_2 \bullet 2\ H_2O$ to moles of $CuCl_2 \bullet 2\ H_2O$ and moles of $CuCl_2 \bullet 2\ H_2O$ to moles of $CuCl_2$)

3) Write the mole ratio:
   a) of Cu to Al.
   b) of Cu to $CuCl_2$.

4) Write the balanced equation for the single-replacement reaction of Al with $CuCl_2$.

5) According to the balanced chemical reaction in Question 4, what is the mole ratio of Cu produced to Al reacted?

6) How does the Cu to Al mole ratio in Question 5 compare with the mole ratio determined in Question 3? If it did not match, discuss what might have happened in the lab that would change the mole ratio. (Be specific.)

7) What happened to the color of the solution as the reaction took place? If it changed colors, suggest one reason why this would happen.

Percent $NaHCO_3$ in a Tablet

Adapted from: http://www.cms.k12.nc.us/allschools/providence/keenan/chem/labs/nahco3.pdf

Purpose

Determine the percent of $NaHCO_3$ by mass in an effervescent tablet (e.g., Alka Seltzer).

Background Information

Effervescent tablets (vitamin tablets, lemonade, etc.) contain sugar, flavoring, and food coloring as well as tartaric acid and sodium bicarbonate. When such a tablet is added to water, the sodium bicarbonate reacts with the tartaric acid to form sodium tartrate, carbon dioxide and water. The sodium bicarbonate content of the tablet can be experimentally determined from the amount of carbon dioxide generated.

Materials

- Balance
- Graduated cylinder
- 125 mL beaker
- Watch glass
- Stirring rod
- Balance paper or weigh boat
- Effervescent tablet

Procedure

Record all experimental data in the given data table. Record masses to the nearest 0.01 g.

1) Add approximately 50 mL water to the beaker using a graduated cylinder. Find the mass of the beaker, watch glass, stirring rod, and water. Record your data.
2) Tare a piece of clean paper or weigh boat. Add the tablet to the balance. Record your data. ***Do not place the tablet directly on the balance pan!***
3) Add the tablet to the water and cover immediately with the watch glass. Let it react. When the fizzing has subsided somewhat, stir (with a glass stirring rod) to increase the rate of the reaction. You want to remove as much CO_2 as possible. Be careful not to lose any of the water that has accumulated on the underside of the watch glass. Do NOT place the watch glass down on the counter top or on a paper towel.
4) Remass the beaker, stirring rod, watch glass, and water solution. Record your data.
5) Record your Trial 1 data on the board.
6) Copy two other columns of data to complete your data table.

Data Table

	Trial 1	Trial 2	Trial 3
Mass of beaker, stirring rod, watch glass and 50 mL water (before reaction)			
Mass of effervescent tablet (before reaction)			
Mass of beaker, stirring rod, watchglass, 50 mL water and tablet (before reaction)			
Mass of beaker, stirring rod, watchglass, 50 mL water and tablet (after reaction)			
Mass of CO_2 emitted			
Calculated mass of $NaHCO_3$ in original tablet			
Percent $NaHCO_3$ in original tablet			
Theoretical mass of $NaHCO_3$ in tablet			
Error, g			
Relative error, %			

Questions

You must show your work on a separate sheet of paper to earn credit for the calculations. Record your final answers in the data table.

1) Balance the equation.

$$\_\_ NaHCO_3 + \_\_ H_6C_4O_6 \rightarrow \_\_ Na_2C_4H_4O_6 + \_\_ CO_2 + \_\_ H_2O$$

2) Calculate the mass of the CO_2 generated.

3) Using stoichiometry, calculate the mass of $NaHCO_3$ in the tablet.

4) Calculate the percent by mass of $NaHCO_3$ that was in the tablet prior to the reaction.

5) Check the package to find the mass of $NaHCO_3$ that is in each tablet. Record the data.

6) Calculate your error in grams.

   Error = Measured Amount – Theoretical Amount

7) Calculate the percent error.

   % error = [(Measured Amount – Theoretical Amount)/ Theoretical Amount] × *100*

8) Discuss potential reasons for error in this lab. (Be specific.)

Determination of Percent Yield

Adapted from:

http://www.cms.k12.nc.us/allschools/providence/keenan/chem/labs/detn_of_percent_yield.pdf

Purpose

Determine the theoretical and experimental yields of NaCl and calculate the percent yield.

Materials

- 250 mL beaker
- Balance
- $NaHCO_3$
- 1 M HCl solution
- 50 mL beaker
- Pipette
- Hot plate

Procedure

Record all experimental data in the given data table. Record masses to the nearest 0.01 g.

1) Mass the 250 mL beaker. Record your data.
2) Mass no more than 0.50 grams of $NaHCO_3$ into the beaker. Record the exact amount being used.
3) Put approximately 25 mL of 1 M HCl into the 50 mL beaker.
4) Use a pipette to slowly add 10 drops of HCl to the $NaHCO_3$. Gently swirl the liquid to thoroughly mix the acid into the $NaHCO_3$.
5) Repeat the previous step until no bubbles form while swirling the beaker.
6) Place the beaker on the hot plate and heat it for about 15 minutes or until it seems that all of the water is gone from the beaker. Do not turn the hot plate higher than setting 3. (While you wait for the water to evaporate, start working on the Questions. Work in the lab area so that you can continue to monitor your experiment.)
7) After heating on level 3 for 15 minutes, turn the setting to level 1 and heat for another 5-10 minutes to ensure that all water is gone from the beaker.
8) Cool the beaker for 5 minutes. Do this by placing a piece of paper towel on the counter and set the beaker on the towel.
9) When the beaker is cool, mass the beaker and product. Record your data.
10) Clean up your lab area.
11) Record your Trial 1 data on the board.
12) Copy two other columns of data to complete your data table.
13) Finish answering the questions.

Data Table

	Trial 1	Trial 2	Trial 3
Mass of beaker			
Mass of beaker and $NaHCO_3$			
Mass of $NaHCO_3$			
Mass of beaker, watch glass and product			
Mass of product (actual yield)			
Theoretical yield of NaCl (calculated)			
Percent yield of NaCl			

Questions

You must show your work to earn credit for the calculations. Record your final answers in the data table.

1) Calculate the mass of $NaHCO_3$ used in this experiment.

2) The equation for the reaction is as follows. If it is not balanced, you need to balance it before going to the next question. If it is balanced, please indicate that by putting a large check mark to the left of the equation.

$$\_\_\ NaHCO_3 + \_\_\ HCl \rightarrow \_\_\ NaCl + \_\_\ H_2O + \_\_\_\ CO_2$$

3) Calculate the actual yield of product.

4) Use stoichiometry to calculate the theoretical yield of NaCl starting with your mass of $NaHCO_3$.

5) Calculate the percent yield of NaCl.

6) If your percent yield was not 100%, give one reason why this may have happened. Be specific.

Kitchen Stoichiometry

Adapted from: http://jchemed.chem.wisc.edu/Journal/Issues/2000/Dec/PlusSub/V77N12/p1608A.pdf

Background

Stoichiometry is the mathematics of chemical equations. This concept also applies to recipes. Just as there is a correct ratio of reactants to get a desired set of products, there is a correct ratio of ingredients to get a desired finished product. In this lab, you will use pre-sweetened powered drink mix, citric acid, baking soda, and water to create a carbonated beverage.

Materials

- 5 medium cups
- 2-3 small cups
- ½ tsp measuring spoon
- ½ cup measuring cup
- Distilled water
- Coffee stirrer or straw
- 2 paper muffin cups
- Citric acid ($H_3C_6H_5O_7$)
- Baking soda ($NaHCO_3$)
- Balance

Procedure

1) Use a marker to label your medium cups A through E.
2) Measure 1 ½ tsp of drink mix and put it into cup A. Repeat for cups B through E.
3) Add ½ cup of water to cup A. Use the coffee stirrer to mix the ingredients. Pour small samples for each group member. Taste the beverage and record your observations. Keep the rest of the beverage in cup A as a control when you sample the other trials.
4) Label a muffin cup "citric acid." Find the mass of this cup and record the value. Use the balance and the "citric acid" cup, measure approximately 0.50 grams of citric acid. Add the citric acid to cup B.
5) Add ½ cup of water to cup B. Use the coffee stirrer to mix the ingredients. Pour small samples for each group member. Taste a very small amount of the beverage and record your observations. Pour the remaining beverage into the sink and discard cup B.
6) Label a muffin cup "baking soda." Find the mass of this cup and record the value. Use the balance and the "baking soda" cup, measure approximately 0.50 grams of baking soda. Add the baking soda to cup C.
7) Add ½ cup of water to cup C. Use the coffee stirrer to mix the ingredients. Pour small samples for each group member. Taste a very small amount of the beverage and record your observations. Pour the remaining beverage into the sink and discard cup C.
8) Using the appropriate muffin cups and the balance, measure no more than 0.50 grams of baking soda and citric acid. Add the baking soda and citric acid to cup D.
9) Add ½ cup of water to cup D. Use the coffee stirrer to mix the ingredients. Pour small samples for each group member. Taste a very small amount of the beverage and record your observations. Pour the remaining beverage into the sink and discard cup D.
10) Balance the chemical equation for the reaction between citric acid and baking soda.

$$\_\_\_\ H_3C_6H_5O_{7\,(aq)} + \_\_\_\ NaHCO_{3\,(aq)} \rightarrow \_\_\_\ Na_3C_6H_5O_{7\,(aq)} + \_\_\_\ H_2O_{(l)} + \_\_\_\ CO_{2\,(g)}$$

11) Use stoichiometry to determine how much citric acid is required to react completely with 0.50 grams of baking soda. Show your work to your instructor and ask the instructor to initial your lab sheet before completing the next step.
12) Measure 0.50 grams of baking soda and the amount of citric acid from the previous step using the balance and the appropriate muffin cups. Add the baking soda and citric acid to cup E.
13) Add ½ cup of water to cup E. Use the coffee stirrer to mix the ingredients. Pour small samples for each group member. Taste the beverage and record your observations. Compare the results of cup E to the results of Cup A.
14) Clean your lab area. Pour any remaining liquid into the sink. Discard the cups, coffee stirrers, and muffin cups.

Data Table

Cup	Total amount of citric acid	Total amount of baking soda	Taste of beverage
A			
B			
C			
D			
E			

Questions

Answer the following questions on a separate sheet of paper. You must show your work to earn credit for the questions involving calculations.

1) Show your work for the amount of citric acid needed in cup E.

Instructor's initials __________

2) Why do citric acid and baking soda not react until water is added?
3) Why is fizzing observed in cup C?
4) How will the drink taste if too much citric acid is used? How it taste if too much baking soda is used?
5) Fizzies drink tablets use the reaction you performed in class to make carbonated beverages when added to water. Why do the tablets use aspartame sweetener instead of sugar?
6) What are some other practical uses of stoichiometry?

The Stoichiometry of S'mores

Adapted from: http://devacaf.caes.uga.edu/main/lessonPlan/SMoreLP.pdf

Introduction

In this activity, you will explore the principles of stoichiometry by building S'mores.

Materials

- Chocolate bar (C_2)
- Marshmallows (M)
- Whole graham crackers (G_2)
- Paper plate
- Napkins
- Electronic balance

Procedure

Record all experimental data in the given data table. Record masses to the nearest 0.01 g.

1) Mass one of each reactant – one chocolate square, one marshmallow, and one graham cracker square. Use a napkin to keep your food items from touching the balance.

2) Perform a **synthesis reaction** and form a S'more. Keep all edible items on the plate. Write the balanced equation for the reaction below. Use following symbols for each reactant: C = chocolate square, M = marshmallow, and G = graham cracker.

3) Cause the reaction to go to completion by forming as many of the products as you possibly can. Mass and record **ONE** of the representative products (one S'more).

4) Count the number of products you were able to form. ________

Data Table

Mass of chocolate square (C)	
Mass of marshmallow (M)	
Mass of graham cracker square (G)	
Mass of one completed S'more	
Number of completed S'mores	
Number of left over chocolate pieces	
Number of left over marshmallows	
Number of left over graham crackers	

Questions

Answer each of the following questions in complete sentences.

1) Is there a relationship between the mass of a S'more and the masses of the reactants used to make it? If so, what is the relationship? What law have you studied in this course that might define this relationship?

2) A limiting reactant is the material responsible for a reaction reaching completion. In the reaction, what was the limiting reactant?

3) What reactants, if any, were left after building as many whole S'mores as possible?

Decomposition of Baking Soda

Adapted from: **Chemistry: Visualizing Matter** (© 2000 Holt, Rinehart, & Winston)

Introduction

Baking soda (sodium hydrogen carbonate) is used to make sure that baked goods rise. This happens because the compound breaks down and one or more gases are generated in the process. The evidence of the generated gas is the holes or bubbles in the finished baked good. Your job is to experimentally determine the correct chemical reaction for the decomposition of baking soda. The choices are the following reactions.

- Solid sodium hydrogen carbonate reacts to form solid sodium hydroxide and gaseous carbon dioxide
- Solid sodium hydrogen carbonate reacts to form solid sodium oxide, gaseous carbon dioxide, and water vapor.
- Solid sodium hydrogen carbonate reacts to form solid sodium carbonate, gaseous carbon dioxide, and water vapor.

Materials

- Crucible and lid
- Crucible tongs
- Balance
- Ring stand
- Ring
- Pipestem triangle
- Bunsen burner
- Plastic spoon
- Baking soda
- Spatula

Procedure

All masses need to be recorded to the nearest 0.01 g.

1) Measure the mass of the crucible. Record your data.
2) Set up the ring stand, ring, and Bunsen burner. Place the triangle on the ring.
3) Set the crucible on the triangle and heat it for 5 minutes. Use the crucible tongs to remove the crucible from the triangle and set it on the wire mesh to cool for 5 minutes.
4) Measure the mass of the crucible. (Remember to use crucible tongs to handle the crucible to prevent fingerprints that change the mass reading.) Record your data. If your crucible mass does not vary by more than 0.01 g, you may continue. If it changed by more than 0.01 g, repeat step 3 until the mass changes by no more than 0.01 g.
5) Put enough baking soda into the crucible so that the bottom is covered. Measure the mass of the crucible and baking soda. Record your data.
6) Place the crucible on the triangle. Position the lid so that any gas being generated can escape.
7) Heat the crucible for 5 minutes. (The bottom should glow red-orange during the heating.) Use the crucible tongs to remove the crucible from the triangle and set it on the wire mesh to cool for 5 minutes. While it cools, use the spatula to break up any lumps that form.
8) Use the back of your hand to test the crucible for heat being generated. If you can comfortably hold you hand just above the crucible, it is cool enough to continue. If not, wait another 1-2 minutes. When the crucible is cool, measure the mass and record your data.

9) Heat the crucible for another 5 minutes. Use the crucible tongs to remove the crucible from the triangle and set it on the wire mesh to cool for 5 minutes.
10) Repeat step 8. If the mass changes by no more than 0.01 g, you are finished. If the mass changes by more than 0.01 g, repeat steps 8 and 9 until the mass changes by no more than 0.01 g.
11) Clean up your lab area. Rinse the solid product out of the crucible and flush it down the drain with plenty of water. Put the used crucible and lid in the "dirty crucible" box.

Data Table

Before Reaction		***After Reaction***	
Mass of empty crucible		Mass of crucible and solid product	
Mass of crucible and baking soda		Mass of solid product	
Mass of baking soda			

Questions

Answer the following questions on a separate sheet of paper. You must show your work to earn credit for the questions involving calculations.

1) Translate each of the given word equations into balanced formula equations.
2) Calculate the mass of baking soda prior to the reaction.
3) Calculate the mass of the solid product.
4) Use stoichiometry to convert the original mass of baking soda to mass of sodium hydroxide.
5) Use stoichiometry to convert the original mass of baking soda to mass of sodium oxide.
6) Use stoichiometry to convert the original mass of baking soda to mass of sodium carbonate.
7) Compare your measured mass of product with your expected masses of sodium hydroxide, sodium oxide, and sodium carbonate. Which chemical reaction occurred in the crucible?
8) If the crucible was not heated long enough, would you expect the mass of the solid product to be higher or lower than stoichiometry would predict? Explain your answer.

Determining the Mass of CO_2

Adapted from: http://teacherslounge.editmc.com/Stoichiometry

Purpose

Perform a chemical reaction to analyze stoichiometry and determine percent yield.

Materials

- 250 mL beaker
- 100 mL Graduated cylinder
- Balance
- 1-2 g $NaHCO_3$ (sodium bicarbonate)
- 100 mL CH_3COOH (acetic acid)
- Spoon or stirring rod

Procedure

Record all experimental data in the given data table. Record masses to the nearest 0.01 g.

1) Take the mass of the empty beaker and graduated cylinder and record the data in the chart below.
2) Place 1-2 g $NaHCO_3$ in the 250 mL beaker and record the actual mass used in the data table.
3) Measure 100 mL CH_3COOH in the graduated cylinder and get the mass.
4) Slowly pour all of the CH_3COOH into the beaker with the $NaHCO_3$. You must do this slowly because if any of it fizzes over you have to start over. Be very careful!
5) Stir the reaction solution for at least 5 minutes to make sure it has reacted completely.
6) Take the mass of the beaker and the final products in the beaker. Record the data.
7) Clean up your lab area.

Data Table

Before Reaction

Mass of empty beaker	
Mass of beaker + $NaHCO_3$	
Mass of $NaHCO_3$	
Mass of empty graduated cylinder	
Mass of graduated cylinder + CH_3COOH	
Mass of CH_3COOH	

After Reaction

Mass of beaker and products	
Mass of products	

Questions

You must show your work on a separate sheet of paper to earn credit for the calculations.

1) Calculate the mass of $NaHCO_3$ used in this reaction and record the answer in the data table.

2) Calculate the mass of CH_3COOH used in this reaction and record the answer in the data table.

3) Calculate the apparent mass of products formed in this reaction and record the answer in the data table.

4) Calculate the mass of CO_2 that was formed. (Although you can't measure the CO_2 directly because it was released as a gas and became part of the air in this room, you can calculate it by using the Law of Conservation of Mass.)

   (mass of $NaHCO_3$) + (mass of CH_3COOH) = (mass of $NaCH_3COO$ + H_2O) + (mass of CO_2)

   ____________ + ______________ = __________________ + mass of CO_2

5) The equation for the reaction is as follows. If it is not balanced, you need to balance it before going to the next question. If it is balanced, please indicate that by putting a large check mark to the left of the equation.

$$\_\_\_\ NaHCO_{3\,(s)} + \_\_\_\ CH_3COOH_{(aq)} \rightarrow \_\_\_\ NaCH_3COO_{(aq)} + \_\_\_\ H_2O_{(l)} + \_\_\_\ CO_{2\,(g)}$$

6) Use stoichiometry to calculate the expected yield of CO_2 from the initial amount of sodium bicarbonate.

7) Calculate the percent yield for your reaction.

8) If your percent yield was not 100%, give one reason why this may have happened. Be specific.

9) Using your expected amount of CO_2, determine how many moles of acetic acid were actually used in this reaction. Does this number match the amount you get when converting the mass of acetic acid used to moles? If it does not, give a possible reason for the discrepancy.

Balloon Lab

Adapted from: **Chemistry** (© 2000 Prentice Hall)

Materials

- Balance
- Graduated cylinder (1 per group)
- 50 mL beaker (1 per group)
- 125 mL Erlenmeyer flask (1 per group)
- Balloon (1 per group)
- Ruler (1 per group)
- String (1 piece per group)
- Magnesium ribbon (3 pieces of varied sizes)
- 50.0 mL 1.0 M HCl for each trial

Procedure

Record all experimental data in the given data table. Record masses to the nearest 0.01 g.

1) Use tweezers to take three pieces of magnesium ribbon from the supply table and put it into the beaker. They should all be different sizes.

2) Use the balance and determine the mass, in grams, of one piece of magnesium. (Do not place the magnesium directly on the balance pan.) Record the mass of the magnesium.

3) Place the magnesium into the balloon.

4) Use the graduated cylinder to measure exactly 50.0 mL of hydrochloric acid.

5) Pour the hydrochloric acid into the Erlenmeyer flask.

6) Carefully stretch the end of the balloon over the mouth of the flask. Do not allow the magnesium to fall into the acid while you are adding the balloon to the flask. Try to keep as much air out of the balloon as possible.

7) Gently lift the balloon to drop the magnesium into the acid. Write down what you observe.

8) Use the string and a ruler to measure the circumference of your balloon in centimeters.

9) Repeat steps 2 through 8 for the other pieces of magnesium.

Data Table

	Trial 1	Trial 2	Trial 3
Mass of Mg			
Circumference of balloon			

Questions

Answer the following questions on a separate sheet of paper. You must show your work to earn credit for the questions involving calculations.

1) What was the purpose of this lab?

2) Write a balanced chemical equation for the reaction you observed.

3) Use stoichiometry to calculate the volume (in cm^3) of hydrogen you should have created from 50.0 mL of 1.0 M HCl. (100. mL of 1.0 M HCl = 0.100 moles)

4) Use stoichiometry to calculate the volume (in cm^3) of hydrogen you should have created from each piece of magnesium.

Trial 1 ________________ Trial 2 ________________ Trial 3 ________________

5) What volume (in cm^3) of hydrogen did you actually produce in each trial? (HINTS: How can you determine the radius of a sphere if you know the circumference? What is the formula for the volume of a sphere?)

Trial 1 ________________ Trial 2 ________________ Trial 3 ________________

6) What was the limiting reactant in each trial – magnesium or hydrochloric acid?

Trial 1 ________________ Trial 2 ________________ Trial 3 ________________

7) What was your percent yield for each trial?

Trial 1 ________________ Trial 2 ________________ Trial 3 ________________

Making Chalk

Adapted from: http://colossus.chem.umass.edu/genchem/summer/chem111/111_Experiment_4.htm

Introduction

In this lab, you will perform a reaction that involves the formation of a precipitate as well as a second product that remains in an aqueous solution. The precipitate in this lab is chalk (calcium carbonate) and the reaction involved is shown below.

$$Na_2CO_{3(aq)} + CaCl_{2(aq)} \rightarrow CaCO_{3(s)} + 2\ NaCl_{(aq)}$$

At the end of the lab, you will use limiting reactant concept. In this experiment you are given the concentration and the volume of the two solutions that you mix. Therefore you can calculate the moles of Na_2CO_3 and the moles of $CaCl_2$ that are reacted. You will use these values to determine which reactant is the limiting reactant and to predict the amount of $CaCO_3$ (calcium carbonate or chalk) that should be produced. Finally, you will calculate the percent yield for the chalk that you produce. If you are careful, you should expect a percent yield of 80% or more.

Materials

- 2 graduated cylinders
- 0.50 M $CaCl_2$ solution
- 1.5 M Na_2CO_3 solution
- 2 100 mL beakers
- Filter paper
- Funnel
- 2 foil muffin cups
- Balance
- Hot plate
- Spatula
- Tweezers

Procedure

Record all experimental data in the given data table. Record masses to the nearest 0.01 g.

NOTE: This lab is not extremely difficult, but it requires that you make good use of your class time. If you do not read the procedure and make sure you understand the instructions before the lab period, you may be in danger of not finishing the activity.

1) Use a graduated cylinder to measure approximately 22 mL of 0.50 M $CaCl_2$ solution. Record the exact amount being used.
2) Use a graduated cylinder to measure approximately 11 mL of 1.5 M Na_2CO_3 solution. Record the exact amount being used.
3) Pour the liquids from both graduated cylinders in to a clean 100 mL beaker. If you do not immediately observe the formation of a precipitate, gently swirl the beaker and one should quickly form.
4) Gravity filter the white solid. This is done by folding a piece of filter paper into quarters and making a cone. Place this inside your glass funnel. Hold the funnel over the second beaker and pour the solution into the center of the filter paper taking care not to let it get above the level of the filter paper. Wash the sides of the beaker with a small amount of distilled water from your wash bottle and filter this liquid through the filter paper. There will still be some while solid inside the beaker, but it is not worth the time and effort to continue the wash and filter process to remove it.

5) Label one foil cup T1 for trial #1. Find the mass of the foil cup and record the value.
6) Set up a hot plate.
7) Carefully remove the filter paper from the funnel. Gently scrape the product from the filter paper and place it on the foil cup you massed in the previous step. Try to get off as much as you can without tearing or scraping off some of the filter paper. Discard the filter paper. Place the foil cup on the hot plate and leave it for 10 minutes. (Do not use a heat setting higher than 7.)
8) Repeat steps 1-7 using approximately 25 mL of 0.50 M $CaCl_2$ and 1.5 M Na_2CO_3. (Label this foil cup T2 for trial #2 before getting the mass.) Be sure to record the actual amounts being used.
9) While the products are drying, begin work on the questions at the end of the lab.
10) After the product heats for 10 minutes, use the tweezers to remove the foil cup from the hot plate. Place it on the counter and allow it to cool to the touch. When the foil cup is cool, take it to the balance and get the mass. Record your data.
11) Return the foil cup to the hot plate and heat it for another 5 minutes. At the end of the 5 minutes, use the tweezers to remove the foil cup from the hot plate. Place it on the counter and allow it to cool to the touch. When the foil cup is cool, take it to the balance and get the mass. Record your data.
12) Repeat the previous step until you get two masses that are within 0.02g of each other. If you follow the procedure closely, two or three heatings should be sufficient.
13) Clean your lab area.

Data

	Trial #1	**Trial #2**
Amount of 0.50 M $CaCl_2$ used		
Amount of 1.5 M Na_2CO_3 used		
Mass of Foil Cup		
Mass of Foil Cup and $CaCO_3$ after heating 1 time		
Mass of Foil Cup and $CaCO_3$ after heating 2 times		
Mass of Foil Cup and $CaCO_3$ after heating 3 times		

Questions

You must show your work to earn credit for the calculations.

1) Determine the number of moles of $CaCl_2$ and Na_2CO_3 that were used in each trial. Calculate the number of moles of $CaCO_3$ expected in each trial. Show your work and record the values in the table below.

   Helpful conversion factors:

   *when calculating moles of $CaCl_2$, there are 0.50 moles/1 liter in the solution you used

   *when calculating moles of $CaCO_3$, there are 1.5 moles/1 liter in the solution you used

	Trial #1	**Trial #2**
Moles of $CaCl_2$ used		
Moles of Na_2CO_3 used		
Moles of $CaCO_3$ expected		

2) Was there a limiting reactant in either trial? If so which one was it?

   Trial 1: **Trial 2:**

3) Determine the % yield of $CaCO_3$ for each trial. Show your work in the space below.

% Yield for Trial 1: ____________ **% Yield for Trial 2: ____________**

Airbag Activity

Purpose
To use stoichiometry to create the ideal airbag

Materials
- Zip-top sandwich bag
- Graduated cylinder
- Balance
- Weigh boat
- Baking soda
- 50.0 mL Vinegar

Instructions
1) **Balance the equation for the reaction between baking soda and vinegar.**

$$\_\_\_ \ NaHCO_3 + \_\_\_ \ C_2H_4O_2 \rightarrow \_\_\_ \ CO_2 + \_\_\_ \ H_2O + \_\_\_ \ NaC_2H_3O_2$$

2) **Determine the volume of your sandwich bag in milliliters.**

Our bag holds ______________ milliliters

3) **For this lab, vinegar will be your excess reactant. Use stoichiometry to determine the amount of baking soda that will produce enough carbon dioxide to fill the bag.** Record your calculations at the end of this page. (Use a separate sheet if you need more space.)

Baking soda needed: ___________ grams

4) Write a procedure on the back of this sheet that you will follow when creating your airbag. Before you continue, you must get your instructor's approval for your **calculations and procedure.**

Instructor's initials _______

5) Follow your procedure to create an airbag. When you are ready to start the reaction, ask your instructor to observe your reaction. A pinch test will be conducted by the instructor at the end of your reaction to determine if the bag was over-inflated or under-inflated.

Result of pinch test: over-inflation under-inflation

6) **Determine whether or not all of the reactants were consumed in the reaction.**

7) Clean up your lab area.

Calculations

Procedure
(Use a separate sheet of paper if you need additional space.)

Questions and Conclusions

1) Did you have any left-over reactants? How did you know? (Be specific.)

2) How is the reaction in this experiment similar to an air bag in a car? How is it different?

3) How does figuring out the correct ratio of reactants help manufacturers of real air bags?

4) If you were asked to do this lab again,
   a. is there any extra information you would want to have? (Be specific.)

   b. what would you change in your procedure? (Be specific.)

APPENDIX E - ASSESSMENT

Stoichiometry Pre-Test

Translate each of the following word equations to a formula equation. You do not have to balance the equation. (1 pt each)

1) Aqueous sodium carbonate reacts with aqueous calcium chloride to produce solid calcium carbonate and aqueous sodium chloride.

2) Solid magnesium reacts with aqueous hydrochloric acid to produce aqueous magnesium chloride and hydrogen gas.

Balance each of the following equations. (1 pt each)

3) __ $NaHCO_3$ + __ $C_2H_4O_2$ → __ CO_2 + __ H_2O + __ $NaC_2H_3O_2$

4) __ $NaHCO_3$ + __ HCl → __ $NaCl$ + __ H_2O + ___ CO_2

5) __ $NaHCO_3$ + __ $H_6C_4O_6$ → __ $Na_2C_4H_4O_6$ + __ CO_2 + __ H_2O

Answer each of the following questions in complete sentences. (1 pt each)

6) In a chemical equation, what do the numbers before the chemical formulas represent?

7) If you are converting from grams to moles, what conversion information do you need?

8) If you are converting from moles to liters, what conversion information do you need?

9) If you are converting from grams to liters, what conversion information do you need?

10) If you are given two reactants for an experiment, how can you determine which one is the limiting reactant?

11) What is the difference between actual yield and theoretical yield?

Stoichiometry Lab Quiz

Adapted from: http://departments.oxy.edu/tops/Stoichiometry/stoichpre-post.htm

Use the data below when answering the following questions.

mass of dry test tube	22.202 grams
mass of test tube and $AgNO_3$	23.842 grams
mass of copper before reaction with $AgNO_3$	5.030 grams
mass of copper after reaction with $AgNO_3$	4.730 grams
mass of silver produced by the reaction	1.020 grams

1) The mass of $AgNO_3$ reacted is __________.
   a) 1.640 grams
   b) 0.300 grams
   c) 87.173 grams
   d) 1.020 grams

2) The moles of $AgNO_3$ (169.91 grams/mole) reacted is ____________.
   a) 0.09412 mole
   b) 0.00189 mole
   c) 0.5133 mole
   d) 0.009652 mole

3) The mass of copper reacted is ___________.
   a) 1.600 grams
   b) 0.300 grams
   c) 87.170 grams
   d) 1.200 grams

4) The moles of copper (atomic mass 63.55 grams/mole) reacted is ________.
   a) 0.0285 moles Cu
   b) 0.00472 moles Cu
   c) 1.37 moles Cu
   d) 0.0161 moles Cu

5) Based on your answers to questions 1 through 4 and the remaining data, the balanced equation should be ______________________________.
   a) $AgNO_3 + Cu \rightarrow Ag + CuNO_3$
   b) $AgNO_3 + 2Cu \rightarrow Ag + Cu_2NO_3$
   c) $2AgNO_3 + 2Cu \rightarrow 2Ag + 2CuNO_3$
   d) $2AgNO_3 + Cu \rightarrow 2Ag + Cu(NO_3)_2$

Stoichiometry Quiz #2

Solve the following stoichiometry problems. You may need to balance the equations. You must show your dimensional analysis work to earn credit. Give your answers with the correct significant digits, chemical formulas, and units.

1. How many grams of water can be prepared from 16.4 liters of hydrogen reacting with oxygen?

   $H_2 + O_2 \rightarrow H_2O$

2. How many grams of iron are needed to produce 143 grams of iron (III) sulfide?

   $Fe + S \rightarrow Fe_2S_3$

3. 36 liters of chlorine gas react with hydrobromic acid at STP to yield how many liters of bromine gas?

   $HBr_{(g)} + Cl_{2\,(g)} \rightarrow HCl_{(g)} + Br_{2\,(g)}$

Stoichiometry Quiz #3

Solve the following stoichiometry problems. You may need to balance the equations. You must show your dimensional analysis work to earn credit. Give your answers with the correct significant digits, chemical formulas, and units.

1. Given 111.7 g Fe & 160.35 g S, how many grams of product can be formed?

   $Fe + S \rightarrow Fe_2S_3$

2. Given 3.5 g copper & 6.0 grams silver nitrate, how many grams of silver can be formed?

   $Cu + AgNO_3 \rightarrow Cu(NO_3)_2 + Ag$

3. 5.00 grams of copper are mixed with an excess of silver nitrate. In the end, 15.2 grams of silver are recovered. What is the percent yield?

   $Cu + AgNO_3 \rightarrow Cu(NO_3)_2 + Ag$

Stoichiometry Test

☺ Yes, you may write on this one! ☺

Translate each of the following word equations to a formula equation. You do not have to balance the equation. (1 pt each)

1) Aqueous sodium carbonate reacts with aqueous calcium chloride to produce solid calcium carbonate and aqueous sodium chloride.

2) Solid magnesium reacts with aqueous hydrochloric acid to produce aqueous magnesium chloride and hydrogen gas.

Balance each of the following equations. (1 pt each)

3) __ $NaHCO_3$ + __ $C_2H_4O_2$ → __ CO_2 + __ H_2O + __ $NaC_2H_3O_2$

4) __ $NaHCO_3$ + __ HCl → __ $NaCl$ + __ H_2O + ___ CO_2

5) __ $NaHCO_3$ + __ $H_6C_4O_6$ → __ $Na_2C_4H_4O_6$ + __ CO_2 + __ H_2O

Answer each of the following questions in complete sentences. (1 pt each)

6) In a chemical equation, what do the numbers before the chemical formulas represent?

7) If you are converting from grams to moles, what conversion information do you need?

8) If you are converting from moles to liters, what conversion information do you need?

9) If you are converting from grams to liters, what conversion information do you need?

10) If you are given two reactants for an experiment, how can you determine which one is the limiting reactant?

11) What is the difference between actual yield and theoretical yield?

Write the letter of the appropriate answer on the line next to the definition. (1 pt each)

12) _____ Starting materials in a chemical reaction

13) _____ Total amount of product produced in a chemical reaction

14) _____ Determining the grams of products from a given number of grams of reactants

15) _____ Substance that determines how much product may be formed

16) _____ Determining the liters of products from a given number of grams of reactants

17) _____ Maximum amount of product to be formed in a chemical reaction

18) _____ Determining the grams of products from a given number of liters of reactants

19) _____ Avogadro's number of particles

20) _____ Determining the liters of products from a given number of liters of reactants

21) _____ Comparison of expected and actual amounts of product

A. Actual yield

B. Limiting reactant

C. Mass→mass conversion

D. Mass→volume conversion

E. Mole

F. Percent yield

G. Reactants

H. Theoretical yield

I. Volume→mass conversion

J. Volume→volume conversion

Answer the following question. Remember to do each of the following:

- **balance the chemical equation (1 pt)**
- **show all dimensional analysis work (including units) (2 pts)**
- **give an answer with the appropriate units and number of significant digits (2 pts)**

(Remember to keep all digits when calculating molar masses.)

22) How many moles of nitrogen are needed to produce 3.9 moles of ammonia?

N_2 + H_2 → NH_3

Answer three of the following questions. Remember to do each of the following:

- **balance the chemical equations (1 pt)**
- **show all dimensional analysis work (including units) (2 pts)**
- **give an answer with the appropriate units and number of significant digits (2 pts)**

(Remember to keep all digits when calculating molar masses.)

23) How many liters of oxygen are needed to produce 78.93 g of water?

H_2 + O_2 → H_2O

24) How many grams of lithium hydroxide can be produced from 4.0 grams of lithium?

Li + H_2O → LiOH + H_2

25) How many grams of silver oxide are needed to produce 5400 liters of oxygen?

Ag_2O → Ag + O_2

26) 92.8 liters of butane can be used to produce how any liters of carbon dioxide?

$$C_4H_{10} \quad + \quad O_2 \quad \rightarrow \quad CO_2 \quad + \quad H_2O$$

Answer the following question. Remember to do each of the following:

- **show all dimensional analysis work (including units) (4 pts)**
- **give answers with the appropriate units and number of significant digits (4 pts)**
- **tell which reactant was the limiting reactant (1 pt)**

(Remember to keep all digits when calculating molar masses.)

27) A chemistry student was working on an experiment to produce copper from copper (II) sulfate and iron filings. The materials available for the experiment were 7.82 grams of iron and 45.9 grams of copper (II) sulfate. How much copper could be produced?

$$Fe + CuSO_4 \rightarrow Cu + Fe\ SO_4$$

Answer the following question. Show your work. Give your answer with the correct number of significant digits and appropriate units. (3 pts)

28) If the student in the previous question produced 6.31 grams of copper at the end of the experiment, what was the percent yield?

APPENDIX F – STUDENT DATA

Table 3 – Student Scores for Activities (hours 1, 2, & 4)
*Possible scores for each assignment are in bold beneath the title

Student	Gender	Grade	Pretest	Scavenger Hunt	Al + CuCl2	% NaHCO3 in Tablet	Determination of % Yield	Decomposition of Baking Soda	Determining the Mass of CO2	Airbag Activity
			4	4	4	4	4	4	4	4
1-1	F	10	4	3	3	2	3	1	3	4
1-2	F	10	4	3	2	2	4	1	3	4
1-3	F	10	4	3	4	3	4	4	3	2
1-4	M	10	4	4	3	2	1	3	0	0
1-5	F	10	4	3	4	4	4	3	3	4
1-6	F	10	4	0	0	0	0	4	4	4
1-7	F	11	4	3	4	2	4	3	4	4
1-8	F	10	4	3	4	4	4	3	3	4
1-9	F	10	4	0	0	0	0	0	0	4
2-1	M	10	4	4	4	4	4	4	4	4
2-2	M	10	4	4	0	0	3	0	4	0
2-3	F	10	4	4	4	4	4	4	4	4
2-4	M	10	4	4	4	4	4	4	4	4
2-5	M	10	4	4	4	4	4	4	4	4
4-1	F	11	4	4	3	3	3	3	3	4
4-2	F	10	4	4	4	4	4	4	4	4
4-3	F	10	0	4	4	3	3	3	4	4
4-4	F	10	4	3	4	3	4	3	3	4
4-5	F	10	4	4	4	4	4	4	4	4
4-6	M	10	4	4	4	2	3	4	4	4
4-7	F	11	0	4	0	1	0	1	3	0

Table 4 – Student Scores for Activities (hours 5 & 6)
*Possible scores for each assignment are in bold beneath the title

Student	Gender	Grade	Pretest	Scavenger Hunt	Al + CuCl2	% NaHCO3 in Tablet	Determination of % Yield	Decomposition of Baking Soda	Determining the Mass of CO2	Airbag Activity
			4	**4**	**4**	**4**	**4**	**4**	**4**	**4**
5-1	M	10	4	4	1	1	3	3	3	3
5-2	F	10	4	4	3	2	3	3	3	4
5-3	M	11	4	4	4	4	4	3	4	4
5-4	F	11	4	4	4	4	3	4	3	4
5-5	M	10	4	4	3	4	4	4	3	4
5-6	M	10	4	3	4	4	4	3	3	4
5-7	M	10	4	4	4	4	3	4	4	4
5-8	M	11	4	4	4	4	4	4	4	4
5-9	M	10	4	4	4	1	3	1	3	0
6-1	F	10	4	4	3	4	3	4	4	4
6-2	F	10	4	4	0	0	3	3	4	4
6-3	F	10	4	4	4	4	4	3	4	4
6-4	M	10	4	4	4	4	3	4	4	4

Table 5 – Student Scores for Quizzes and Posttest (hours 1, 2, & 4)
*Possible scores for each assignment are in bold beneath the title

Student	Gender	Grade	Al + $CuCl_2$ Lab Quiz	Stoichiometry Quiz #2	Stoichiometry Quiz #3	Test Grade
			5	**12**	**17**	**42**
1-1	F	10	3	4	7.5	25
1-2	F	10	2	12	10	40
1-3	F	10	4	7	11	40
1-4	M	10	3	11	12	31
1-5	F	10	1	9	5	33
1-6	F	10	3	8	7	38
1-7	F	11	4	9	4	37
1-8	F	10	1	11	11	37
1-9	F	10	2	1	1	30
2-1	M	10	4	6	5	31
2-2	M	10	4	12	10.5	39
2-3	F	10	2	12	15	42
2-4	M	10	4	12	13.5	41
2-5	M	10	4	11	8.5	33
4-1	F	11	3	6	0	31
4-2	F	10	4	12	15	45
4-3	F	10	2	7	6	36
4-4	F	10	3	10	6	37
4-5	F	10	3	12	17	37
4-6	M	10	0	9	5.5	29
4-7	F	11	4	0	8.5	20

Table 6 – Student Scores for Quizzes and Posttest (hours 5 & 6)
*Possible scores for each assignment are in bold beneath the title

Student	Gender	Grade	Al + $CuCl_2$ Lab Quiz	Stoichiometry Quiz #2	Stoichiometry Quiz #3	Test Grade
			5	**12**	**17**	**42**
5-1	M	10	3	2	5	28
5-2	F	10	4	10	17	37
5-3	M	11	1	4	5.5	22
5-4	F	11	0	12	13.5	42
5-5	M	10	2	6	8	37
5-6	M	10	3	9	5.5	27
5-7	M	10	1	10	11	35
5-8	M	11	4	11	7	35
5-9	M	10	5	12	14	38
6-1	F	10	3	8	13.5	38
6-2	F	10	2	5	5.5	12
6-3	F	10	4	7	13	34
6-4	M	10	4	4	12.5	37

Table 7 – Student response scores for pretest questions (hours 1, 2, & 4)
*A score of 0 indicates the student incorrectly answered the question. A score of 1 indicates the student correctly answered the question.

Pretest

Student	Gender	Grade	1	2	3	4	5	6	7	8	9	10	11	# correct
1-1	F	10	0	0	1	1	0	0	1	1	1	0	0	5
1-2	F	10	0	0	1	1	1	1	1	1	0	0	0	6
1-3	F	10	0	0	1	1	1	1	1	1	1	0	1	8
1-4	M	10	0	0	1	1	1	0	0	1	0	0	0	4
1-5	F	10	0	0	1	1	1	1	0	0	0	0	0	4
1-6	F	10	0	0	1	1	0	0	0	1	0	0	0	3
1-7	F	11	0	0	1	1	1	0	0	0	0	0	1	4
1-8	F	10	0	0	1	1	0	0	0	0	0	0	1	3
1-9	F	10	0	0	1	0	0	0	0	0	0	0	0	1
2-1	M	10	0	0	1	1	1	0	0	0	0	0	0	3
2-2	M	10	0	0	1	1	1	1	0	0	1	1	1	7
2-3	F	10	1	0	1	1	1	1	0	0	0	0	0	5
2-4	M	10	0	0	1	1	1	0	0	1	0	0	0	4
2-5	M	10	0	0	1	1	1	0	0	1	0	0	1	5
4-1	F	11	0	0	0	0	0	1	0	0	0	0	0	1
4-2	F	10	0	0	0	1	0	1	0	0	0	1	1	4
4-3	F	10	did not turn in pretest											0
4-4	F	10	0	0	0	1	0	0	0	0	0	0	0	1
4-5	F	10	0	0	1	1	0	0	0	1	0	0	0	3
4-6	M	10	0	0	1	1	0	0	0	1	0	0	0	3
4-7	F	11	did not turn in pretest											0

Table 8 – Student response scores for pretest questions (hours 5 & 6)
*A score of 0 indicates the student incorrectly answered the question. A score of 1 indicates the student correctly answered the question.

Pretest

Student	Gender	Grade	1	2	3	4	5	6	7	8	9	10	11	# correct
5-1	M	10	0	0	0	1	1	0	0	1	0	0	0	3
5-2	F	10	0	0	1	1	1	0	0	0	1	0	0	4
5-3	M	11	0	0	1	1	1	0	0	0	0	0	0	3
5-4	F	11	0	0	1	1	1	1	0	1	0	0	1	6
5-5	M	10	0	0	1	1	1	1	0	0	0	0	0	4
5-6	M	10	0	0	1	1	1	0	0	0	0	1	1	5
5-7	M	10	0	0	1	1	1	0	0	0	0	0	1	4
5-8	M	11	0	0	1	1	0	0	1	1	1	0	0	5
5-9	M	10	0	1	1	1	1	1	0	1	0	0	1	7
6-1	F	10	0	0	1	1	0	0	0	0	0	0	0	2
6-2	F	10	0	0	1	0	0	0	0	0	0	0	0	1
6-3	F	10	0	0	1	1	1	0	1	1	0	0	1	6
6-4	M	10	0	0	1	1	1	0	1	0	0	0	0	4

Table 9 – Student response scores for posttest questions (hours 1, 2, & 4)
*A score of 0 indicates the student incorrectly answered the question. A score of 1 indicates the student correctly answered the question.

Posttest

Student	Gender	Grade	1	2	3	4	5	6	7	8	9	10	11	# correct
1-1	F	10	0	0	1	1	1	1	1	1	0	0	1	7
1-2	F	10	0	0	1	1	1	1	0	1	1	1	0	7
1-3	F	10	0	0	1	1	1	1	1	0	0	1	1	7
1-4	M	10	0	0	1	1	1	1	0	1	1	1	0	7
1-5	F	10	0	0	1	1	1	1	0	0	0	1	1	6
1-6	F	10	0	0	1	1	1	1	1	0	0	1	0	6
1-7	F	11	0	0	1	1	0	0	0	0	0	1	1	4
1-8	F	10	0	0	1	1	0	0	1	1	1	1	1	7
1-9	F	10	0	0	1	1	1	1	1	0	0	1	1	7
2-1	M	10	0	0	1	1	1	1	1	0	1	1	0	7
2-2	M	10	0	0	1	1	1	1	0	0	1	1	1	7
2-3	F	10	1	1	1	1	1	1	0	1	0	0	0	6
2-4	M	10	0	0	1	1	1	1	1	1	1	1	1	9
2-5	M	10	0	0	1	1	0	1	0	1	0	1	1	6
4-1	F	11	0	0	1	1	0	1	0	0	0	0	1	4
4-2	F	10	0	0	1	1	1	0	0	0	0	1	1	5
4-3	F	10	0	0	1	1	1	1	1	1	0	1	1	8
4-4	F	10	0	0	1	1	1	0	0	0	1	1	0	5
4-5	F	10	0	0	1	1	0	1	0	0	1	0	0	4
4-6	M	10	0	0	1	1	0	0	0	1	0	0	0	3
4-7	F	11	0	0	1	1	1	1	0	0	0	0	1	5

Table 10 – Student response scores for posttest questions (hours 5 & 6)
*A score of 0 indicates the student incorrectly answered the question. A score of 1 indicates the student correctly answered the question.

Posttest

Student	Gender	Grade	1	2	3	4	5	6	7	8	9	10	11	# correct
5-1	M	10	0	0	1	1	0	0	0	0	0	0	1	3
5-2	F	10	0	0	1	1	1	1	0	0	0	1	1	6
5-3	M	11	0	0	1	1	1	1	0	0	0	1	0	5
5-4	F	11	0	0	1	1	1	0	0	1	0	0	1	5
5-5	M	10	0	0	1	1	1	1	1	0	0	0	0	5
5-6	M	10	0	0	0	0	0	1	0	0	0	0	1	2
5-7	M	10	0	0	1	1	0	1	0	1	0	1	1	6
5-8	M	11	0	0	1	1	1	1	0	0	0	1	1	6
5-9	M	10	0	0	1	1	1	1	1	1	1	0	1	8
6-1	F	10	0	0	1	1	1	1	0	1	0	1	0	6
6-2	F	10	0	0	1	1	1	1	0	0	0	1	1	6
6-3	F	10	0	0	1	1	1	1	1	1	1	0	1	8
6-4	M	10	0	0	1	1	1	1	1	1	0	1	1	8