PERCENT NaHCO₃ IN A MIXTURE

OBJECTIVE(S):

- Use inquiry-based learning to perform an experiment
- Introduce and apply Green Chemistry Principles
- Determine the percent composition of a mixture using stoichiometry of reaction
- Use a gravimetric method of analysis

INTRODUCTION:

Inquiry-Based Learning

Traditional experiments used in the chemistry curriculum tend toward a “cookbook” format where all of the steps and procedures are clearly outlined. However, this type of format does not lend itself well to thinking outside the box or trying to improve problem-solving skills in a laboratory environment. Inquiry based learning involves active participation (investigating, asking questions, working actively together to reach a conclusion) in addition to honing our problem-solving skills.

When students graduate and get a job, they may find that the work environment is very different from the “college” environment. Most of the time you will be presented with problems with no clear answer or procedure and one may need to be developed through trial and error. In addition, it requires good communication skills, both oral and written, when trying to problem-solve as many times you are working with others. It is our hope that this experiment will provide you with more experience in how to communicate with others in a group environment as well as improving your written and content skills when writing a final report.

Green Chemistry

Green and sustainable chemistry is a fairly new and emerging field within the chemistry community. According to the Environmental Protection Agency, “Green chemistry consists of chemicals and chemical processes designed to reduce or eliminate negative environmental impacts. The use and production of these chemicals may involve reduced waste products, non-toxic components, and improved efficiency. Green chemistry is a highly effective approach to pollution prevention because it applies innovative scientific solutions to real-world environmental situations.” Industry, government and academia are embracing this concept due to its many benefits to society and the environment. For example using less toxic substances, reusing products produced, and reducing wastes has a positive impact on our environment as well being an important cost-saving strategy. Savings include reducing the cost of removal of hazardous wastes, reducing exposure of toxic chemicals to workers by using safer materials and processes, reusing products for other purposes, etc. It is anticipated that familiarity with green chemistry principles and processes will be an asset to your work skills in the future.

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There are twelve key principles to Green Chemistry, some of which will be addressed in this experiment.

1. **Prevention**  
   It’s better to prevent waste than to treat or clean up waste afterwards.

2. **Atom Economy**  
   Design synthetic methods to maximize the incorporation of all materials used in the process into the final product.

3. **Less Hazardous Chemical Syntheses**  
   Design synthetic methods to use and generate substances that minimize toxicity to human health and the environment.

4. **Designing Safer Chemicals**  
   Design chemical products to affect their desired function while minimizing their toxicity.

5. **Safer Solvents and Auxiliaries**  
   Minimize the use of auxiliary substances wherever possible make them innocuous when used.

6. **Design for Energy Efficiency**  
   Minimize the energy requirements of chemical processes and conduct synthetic methods at ambient temperature and pressure if possible.

7. **Use of Renewable Feedstocks**  
   Use renewable raw material or feedstock whenever practicable.

8. **Reduce Derivatives**  
   Minimize or avoid unnecessary derivatization if possible, which requires additional reagents and generate waste.

9. **Catalysis**  
   Catalytic reagents are superior to stoichiometric reagents.

10. **Design for Degradation**  
    Design chemical products so they break down into innocuous products that do not persist in the environment.

11. **Real-time Analysis for Pollution Prevention**  
    Develop analytical methodologies needed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.

12. **Inherently Safer Chemistry for Accident Prevention** Choose substances and the form of a substance used in a chemical process to minimize the potential for chemical accidents, including releases, explosions, and fires.

The chemistry department has been working towards “greener” experiments by using less toxic or nontoxic chemicals, and by reducing the volume of waste. In this experiment, we will utilize the concept of atom economy, reduction of wastes, and reuse of products produced during the experiment. The reactant, sodium bicarbonate, is the major ingredient in baking soda and is quite benign. In addition, the products of the decomposition of sodium bicarbonate, sodium carbonate (found naturally dissolved in water), gaseous water and carbon dioxide are all benign. Although carbon dioxide is a greenhouse gas, the amounts produced in this reaction are minimal compared to the amounts produced by the combustion of fossil fuels worldwide.

Atom economy is a way to assess how much of the original reactant gets converted to product. The higher the atom economy, the greater amount of the reactant is converted to product. It is a measure of the efficiency of the reaction by showing what fraction or percent of the starting material is converted to products. This concept is better applied to synthesis type of reactions that are frequently found in
organic chemistry. However, we will utilize it for this experiment to get more familiar with this concept as you will likely encounter this concept again if you take organic chemistry at Mt. SAC. For the reaction

\[
\text{reactants} \rightarrow \text{desired products + undesired products} \quad (1)
\]

**Atom economy** is defined as

\[
\text{Atom Economy} = \frac{\text{mass of desired products}}{\text{mass of all reactants}} \times 100\% \quad (2)
\]

The goal is to maximize your desired products and minimize the undesired products and get the highest atom economy as possible. Atom economy by itself does not necessarily mean a reaction is “green” as the reactants or desired products may be toxic or have long-term negative impacts on human health or on the environment.

An example using atom economy may be helpful. Let us say that you want to produce pure iron metal using the thermite reaction:

\[
\text{Fe}_2\text{O}_3 (s) + 2 \text{Al (s)} \rightarrow 2 \text{Fe (s)} + \text{Al}_2\text{O}_3 (s)
\]

The masses can be found using the molar masses of each substance and the amount of moles based on the stoichiometry of the reaction.

The mass of all reactants is calculated as follows:

\[
\text{Mass of reactants} = (1 \text{ mol Fe}_2\text{O}_3)(159.687 \text{ g/mol Fe}_2\text{O}_3) + (2 \text{ mol Al})(26.982 \text{ g/mol Al})
\]

\[
= 213.651 \text{ g of reactants}
\]

The mass of the desired product, Fe, is calculated as follows:

\[
\text{Mass of desired product} = (2 \text{ mol Fe})(55.845 \text{ g/mol Fe}) = 111.69 \text{ g Fe}
\]

The theoretical atom economy therefore is

\[
\text{Atom Economy} = \frac{\text{mass of desired products}}{\text{mass of all reactants}} = \frac{111.69 \text{ g}}{213.651 \text{ g}} \times 100\% = 52.277\%
\]

The amount left over, in this case 47.772% of the total or 101.96 g Al$_2$O$_3$, is essentially waste products that provide no benefit (end use, toxicity, etc).

Note that atom economy is not the same as percent yield. The above calculation was performed assuming 100% yield. (Even the direct decomposition of Fe$_2$O$_3$ to Fe and O$_2$ has only a 69.9% atom economy.)

**Background on the Experiment**

The purpose of the experiment is to determine the percent by mass of NaHCO$_3$ in a mixture containing NaHCO$_3$ and Na$_2$CO$_3$ by designing an experiment based on the work of others using an inquiry-based approach.
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approach. Looking at the work of other scientists is a natural process as scientists will read published literature to determine what has already been accomplished on a particular research topic. Then, scientists will try these experiments out themselves to see what results they get compared to published results as well as refine and improve upon the experiment to obtain better results whenever possible. The “published literature” that you will utilize to write your experiment will be in the form of three different lab reports theoretically generated by students. These reports will have deficiencies that are consistent with what instructors see in some student reports. Scientists also communicate informally through email, phone and at conferences and meetings. You will have an opportunity to do this too as it will be necessary to discuss the experiment with other students to help you develop and refine the experiment.

To help you prepare for this experiment some further background on the chemistry taking place in the experiment is helpful. When a mixture of NaHCO$_3$ and Na$_2$CO$_3$ is heated to high temperature, NaHCO$_3$ decomposes into Na$_2$CO$_3$, CO$_2$ gas and H$_2$O gas. Note that Na$_2$CO$_3$ does not decompose upon heating.

\[
2 \text{NaHCO}_3 \xrightarrow{\text{heat}} \text{H}_2\text{O} + \text{CO}_2 + \text{Na}_2\text{CO}_3
\]

The Law of Conservation of mass states that the total mass of reactants equals the total mass of products. Therefore, the total mass of the original mixture should equal the total mass of sample after the reaction.

\[
\text{Mass of the original mixture} = \text{Mass after reaction}
\]

\[
\text{Mass of the original mixture} = g \text{NaHCO}_3 + g \text{Na}_2\text{CO}_3
\]

\[
\text{Mass after reaction} = g \text{Na}_2\text{CO}_3 \text{produced when NaHCO}_3 \text{decomposed} + g \text{Na}_2\text{CO}_3 \text{in original mixture} + g \text{H}_2\text{O} + g \text{CO}_2
\]

Note that the measured mass of the final mixture, however, will be less than the measured mass of the original mixture because the products H$_2$O and CO$_2$ are gases that will drift away.

The purpose of this experiment is to determine the percent of NaHCO$_3$ in the original mixture.

\[
\%\text{NaHCO}_3 = \frac{\text{mass NaHCO}_3}{\text{mass original mixture}} \times 100\%
\]

There are several approaches to determining the percent NaHCO$_3$ in a mixture, all of which involve determining the mass of NaHCO$_3$ in the original mixture to substitute into the above equation (note that the denominator in the above equation is measured directly).

An example of each approach will be provided below using the following sample of student data:

| Table 1: Sample of Student Data Using a Mixture of NaHCO$_3$ and Na$_2$CO$_3$ |
|-------------------------------|-------------------------------|
| **Initial Mass of Mixture** | **Final Mass of Mixture** |
| Before heating | After Heating |
| 3.1637 g | 2.1477 g |

The two approaches lead to equivalent results and you may choose either approach to analyze your data.
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First Approach

The first approach involves assigning variables to the masses of each component of the original mixture and using stoichiometry and molar masses to generate two equations that can be solved simultaneously.

Determine Equation 1: Mass of Sample in Original Mixture (before heating)

<table>
<thead>
<tr>
<th>Explanation</th>
<th>Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Let “x” be equal to the mass of NaHCO₃</td>
<td>x = mass of NaHCO₃</td>
</tr>
<tr>
<td>Let “y” be equal to the mass of Na₂CO₃</td>
<td>y = mass of Na₂CO₃</td>
</tr>
<tr>
<td>Write an equation that represents the mass of the original mixture before heating.</td>
<td>Mass of original mixture = x + y</td>
</tr>
<tr>
<td>Actual mass of original mixture = 3.1637 g</td>
<td>Therefore, 3.1637 g = x + y</td>
</tr>
</tbody>
</table>

Determine Equation 2: Mass of Sample After Heating

<table>
<thead>
<tr>
<th>Explanation</th>
<th>Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Let “y” equal the mass of Na₂CO₃ in the original mixture</td>
<td>y = mass of Na₂CO₃ in original mixture</td>
</tr>
<tr>
<td>Let “z” equal the mass of Na₂CO₃ produced from the decomposition of NaHCO₃ upon heating</td>
<td>z = mass of Na₂CO₃ produced from NaHCO₃ in the original mixture that decomposes upon heating</td>
</tr>
<tr>
<td>The sample is now heated and CO₂ and H₂O gases are evolved leaving only pure solid Na₂CO₃. Write an equation that represents the mass of the sample after heating (all as Na₂CO₃)</td>
<td>Mass of sample after heating = y + z</td>
</tr>
<tr>
<td>Actual mass of sample after heating = 2.1477 g</td>
<td>Therefore, 2.1477 = y + z</td>
</tr>
<tr>
<td>Recall that “x” represents the mass of NaHCO₃ in the original sample. When NaHCO₃ is heated, it decomposes to produce Na₂CO₃ solid and gaseous water CO₂. Define “z” in terms of “x” so that you have a second equation with “y” and “x” terms.</td>
<td>x = mass of NaHCO₃ in original sample</td>
</tr>
<tr>
<td>“x” g of NaHCO₃ is converted to Na₂CO₃ upon heating.</td>
<td>z = [ \left( \frac{x}{84.008 \text{ g NaHCO}_3} \right) \left( \frac{1 \text{ mol NaHCO}_3}{84.008 \text{ g NaHCO}_3} \right) \left( \frac{1 \text{ mol Na}_2\text{CO}_3}{2 \text{ mol NaHCO}_3} \right) \left( \frac{105.99 \text{ g NaHCO}_3}{1 \text{ mol Na}_2\text{CO}_3} \right) \approx 0.63083 x ]</td>
</tr>
<tr>
<td>Write second equation that represents the mass of sample after heating in terms of “x” and “y”</td>
<td>2.1477 = y + z</td>
</tr>
<tr>
<td>Substitute z = 0.63803 x into equation so that</td>
<td>2.1477 = y + 0.63083 x</td>
</tr>
</tbody>
</table>
Simultaneously solve the two equations:

<table>
<thead>
<tr>
<th>Solve Equation 1 and Equation 2 simultaneously and calculate “x”</th>
<th>Equation 1 rearranged:  ( y = 3.1637 - x )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equation 2:  ( 2.1477 = y + 0.63083 \times )</td>
<td>Substitute rearrange Equation 1 into Equation 2 and solve for “x”:</td>
</tr>
<tr>
<td>( 2.1477 = (3.1637-x) + 0.63083x )</td>
<td>0.36917 ( x = 1.016 )</td>
</tr>
<tr>
<td>( x = 2.75212 \text{ g NaHCO}_3 )</td>
<td></td>
</tr>
</tbody>
</table>

Find % NaHCO_3 in the original sample

\[
\% \text{ NaHCO}_3 = \frac{2.75212 \text{ g}}{3.1637 \text{ g}} \times 100 = 86.99\%
\]
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**Second Approach**

The second approach focuses on the mass of sample lost by the evolution of CO$_2$ and H$_2$O gases and uses stoichiometry to relate this value back to the mass of NaHCO$_3$ reacted.

<table>
<thead>
<tr>
<th>Explanation</th>
<th>Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Review the stoichiometry of the reaction.</td>
<td>2 NaHCO$_3$(s) $\rightarrow$ H$_2$O(g) + CO$_2$(g) + Na$_2$CO$_3$(s)</td>
</tr>
<tr>
<td>The number of moles of H$_2$O and CO$_2$ produced are equal. Let “y” represent moles of either H$_2$O or CO$_2$. Using stoichiometry, you can define moles of NaHCO$_3$.</td>
<td>Moles of H$_2$O = moles of CO$_2$</td>
</tr>
<tr>
<td>Let y = moles H$_2$O = moles CO$_2$</td>
<td></td>
</tr>
<tr>
<td>Review Sample</td>
<td>Mass of mixture before heating = g NaHCO$_3$ + g Na$_2$CO$_3$</td>
</tr>
<tr>
<td></td>
<td>Mass after heating = g Na$_2$CO$_3$</td>
</tr>
<tr>
<td></td>
<td>Mass difference before and after heating = g CO$_2$ + g H$_2$O</td>
</tr>
<tr>
<td>Use experimental data to determine the mass lost (released as gaseous H$_2$O and CO$_2$)</td>
<td>Mass of mixture before heating = 3.1637 g</td>
</tr>
<tr>
<td></td>
<td>Mass after heating and reaction complete = 2.1477g</td>
</tr>
<tr>
<td></td>
<td>Mass lost after reaction = (mass before heating – mass after heating)</td>
</tr>
<tr>
<td></td>
<td>Mass lost after reaction = 3.1637 - 2.1477 g =1.016g</td>
</tr>
<tr>
<td></td>
<td>Mass lost after reaction = mass H$_2$O + mass CO$_2$ produced</td>
</tr>
<tr>
<td></td>
<td>Mass H$_2$O + mass CO$_2$ produced = 1.016 g</td>
</tr>
<tr>
<td></td>
<td>$g$ H$_2$O + $g$ CO$_2$ = 1.016 g lost</td>
</tr>
<tr>
<td></td>
<td>where $g$ H$_2$O = ($y$ mol H$_2$O)(18.016 g/mol H$_2$O)</td>
</tr>
<tr>
<td></td>
<td>and $g$ CO$_2$ = ($y$ mol CO$_2$)(44.01 g/mol CO$_2$)</td>
</tr>
<tr>
<td>“y” can be found by using molar mass of H$_2$O and CO$_2$</td>
<td>1.016 g = [$y$ mol H$_2$O] [$\frac{18.016 g H_2O}{1 mol H_2O}$] + [$y$ mol CO$_2$] [$\frac{44.01 g CO_2}{1 mol CO_2}$]</td>
</tr>
<tr>
<td></td>
<td>1.016 = 18.016 $y$ + 44.01 $y$</td>
</tr>
<tr>
<td></td>
<td>1.016 = 62.026 $y$</td>
</tr>
<tr>
<td></td>
<td>$y$ = 0.01638 moles</td>
</tr>
<tr>
<td>Find moles of NaHCO$_3$ in original sample</td>
<td>Based on the stoichiometry of the reaction</td>
</tr>
<tr>
<td></td>
<td>2$y$ = moles NaHCO$_3$</td>
</tr>
<tr>
<td></td>
<td>2$y$ = 2(0.01638) = 0.03276 mol NaHCO$_3$</td>
</tr>
<tr>
<td>Find mass of NaHCO$_3$</td>
<td>$g$ NaHCO$_3$ in original sample</td>
</tr>
<tr>
<td></td>
<td>= [0.03276 mol NaHCO$_3$] [$\frac{84.008 g NaHCO_3}{1 mol NaHCO_3}$]</td>
</tr>
<tr>
<td></td>
<td>= 2.7521 g NaHCO$_3$</td>
</tr>
<tr>
<td>Find mass % NaHCO$_3$ in original sample</td>
<td>Mass % = $\frac{mass NaHCO_3}{mass original mixture}$ x 100% = $\frac{2.7521 g}{3.1637 g}$ x 100 = 86.99%</td>
</tr>
</tbody>
</table>

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In this experiment, you will be given a mixture containing NaHCO₃ and Na₂CO₃ and tasked with determining the %NaHCO₃ using experimental procedures that you develop and calculations similar to those outlined above.

PRE-LAB QUESTIONS:

1. Write the balanced chemical equation for the decomposition of sodium bicarbonate solid upon heating.
2. Determine the theoretical atom economy using the balanced chemical equation in question 1 (water and carbon dioxide are the undesired products and sodium carbonate is the desired product).
3. If a 5.002 g sample of a NaHCO₃/Na₂CO₃ mixture was heated then left to cool, what is the mass of NaHCO₃ in the original mixture if the final mass after heating was 4.1250 g?

CHEMICALS AND MATERIALS
Mixture of NaHCO₃ and Na₂CO₃

EQUIPMENT TO BE CHECKED OUT
Bunsen burners
Strikers or matches

SAFETY
Be careful when working around flames and hot objects. Be sure to turn off the gas after using the Bunsen burner.

WASTE DISPOSAL
Place wastes from the heated samples into the “Heated Samples: Na₂CO₃ only” plastic container. If any excess unheated mixture remains, heat it to constant mass and place in the “Heated Samples: Na₂CO₃ only” plastic container.

EXPERIMENTAL PROCEDURE:

When you come to the lab, your instructor will ask you to form groups of 2 to 3 people to work on developing a procedure and performing the experiment based on other’s lab reports. There are three different lab reports (#1, #2, and #3). Write down the number of your lab report in your notebook. Your instructor will only give you one lab report. Try to obtain as much information as possible from the lab report to help you develop the procedure for your experiment. Information found in the other two lab reports will also be helpful in designing your experiment. However, you may only ask questions of the groups who have the other lab reports but you are not allowed to read or look at these other reports. You will have the remainder of the first lab period to develop the procedure for your experiment based on information obtained from your report and from discussions with other students. You may ask for guidance from the instructor, but the instructor may or may not give you the information you are requesting. It is up to your instructor to determine what information and/or confirmation of the procedure that he/she will give. Hopefully, you will notice that there are deficiencies in each of these
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lab reports as well as some small errors. From these observations, it should help you develop a better lab report after you have performed the experiment and after you have analyzed the results. **Again, the lab reports given to you are NOT examples of what instructors or the scientific community necessarily want. The hope is that you will recognize mistakes and the shortcomings of these lab reports to help you critical thinking skills and make you aware of things NOT to do in reports that you write.**

You will perform the experiment during the second period of class.

**Safety and Lab Procedures**

You will be using a crucible and cover, crucible tongs, and a Bunsen burner in this experiment. Your instructor will review the use of a Bunsen burner during the lab period which you perform the experiment. The crucible and cover is used to heat your mixture of NaHCO₃ and Na₂CO₃. It is made of porcelain and easily withstands high temperatures upon direct heating. If your crucible or cover is cracked, obtain another one from the stockroom. Clean the crucible and cover with soap and a brush, and use DI water for final rinsing. You will also need a ring stand, ring clamp, clay triangle, and crucible tongs (to move your crucible and cover when hot). Place the ring on the ring stand and then place the clay triangle on the ring. Your crucible/cover should rest inside the clay triangle without falling through while leaving the bottom of the crucible exposed in order to directly heat it using the Bunsen burner. DO NOT touch the crucible/cover after heating. Handle only with crucible tongs. You may place the crucible/cover on the ceramfab square on the benchtop to cool. NEVER set a hot crucible/cover directly on the benchtop. Check to see if the crucible/cover is cool by placing your hand NEAR the crucible to see if there is heat emanating from it. A hot crucible looks just like a cold crucible so be very careful not to burn yourself. When you have to weigh the crucible/cover, place it on top of something sturdy (watchglass or ceramfab square) while stabilizing with the crucible tongs before moving it to the balance room and be careful not to bump into others.

**Clean-up**

Place any of the residue left over from heating the mixture into the “Heated Samples” or “Na₂CO₃” container. If there is any unheated mixture left over, heat it to constant mass and then place into the “Heated Samples” or “Na₂CO₃” waste container. The Na₂CO₃ left from the experiment will be used again for this experiment and may be used to neutralize acid spills that may occur in the lab.

**DATA ANALYSIS:**

Use the information from the published lab reports and/or from the answer to the prelab question to do the calculations. Your instructor will provide guidelines as to how he/she wants the final results presented (full lab report, partial lab report, notebook pages, etc.).
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POST-LAB QUESTIONS:

1. If your reaction were to not go to completion, how would this affect the results? What type of error is this, random or systematic? Explain your answers in detail.

2. Which lab report did you receive? _____ What problems did you encounter when reading it? List some ways that the student could have improved the report.

3. The following questions relate to your discussion with other students
   a. Did you find it difficult to talk to others about the contents of the other lab reports? Why or why not?
   b. If you found it difficult to talk to other students, could the instructor have done something to better facilitate this process?
   c. What were some of the benefits of talking to the other students?
   d. Do you think it is important and practical to learn how to effectively communicate science to others? Why or why not?
   e. When a scientist wants to publish his or her results, it must be reviewed first by several scientists who are working in a similar field. After the reviews are done and evaluated, it is then determined whether or not the article will be published. Do you think this is an important and necessary process to get an article published based on your experience from this experiment? Why or why not?

4. Which Green Chemistry Principles are reflected in this experiment? Explain your choices.

5. Although doing an experiment based on inquiry is difficult, do you see some benefits from it? Explain your answer.

6. What did you like most about this experiment? What did you like the least?

7. Please list some ways the experiment could be improved in its content and delivery.

REFERENCES:

Written by Jody Williams Tyler

http://www.epa.gov/greenchemistry/

http://www.epa.gov/sciencematters/june2011/principles.htm