Teaching Lab Report Writing Through Inquiry: A Green Chemistry Stoichiometry Experiment for General Chemistry

Lab Documentation Supplementary Material for Online Publication, *Journal of Chemical Education*

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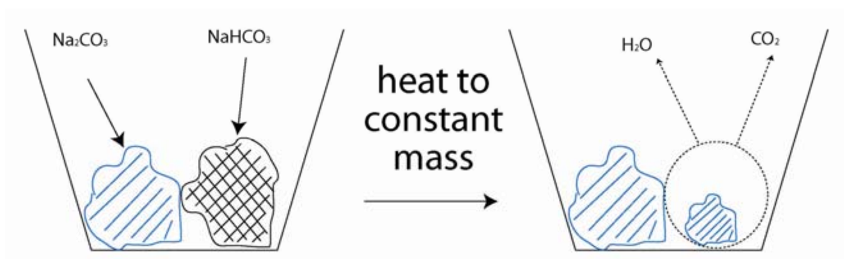
DETERMINATION OF THE COMPOSITION OF A MIXTURE

PRELAB ASSIGNMENT

The following problems are similar to calculations you will do and questions you will answer based on your own experimental data once you complete this experiment. After reading the Introduction on pages 3-5, answer questions 1-4 and bring them to lab with you. Show your work.

A mixture of sodium carbonate and sodium bicarbonate is heated. Sodium carbonate does not undergo a chemical reaction.



The sodium bicarbonate decomposes into sodium carbonate, carbon dioxide and water. Note that while in the cartoon the sodium carbonate and sodium bicarbonate are separated, in reality they will be mixed together.

1. Write a balanced chemical equation for the reaction that occurs. Remember that only one of the substances reacts (see cartoon above)!

2. What is the theoretical atom economy of this reaction? Sodium carbonate is the desired product and water and carbon dioxide are the undesirable wastes.

3. A student heats 5.128 g of the sodium carbonate/sodium bicarbonate mixture to a constant mass of 4.256 g. Determine the mass of sodium bicarbonate present in the mixture.

4. What is the percent by mass of sodium bicarbonate in the mixture, based on your answer to #3 above?

Answers: 1) coefficients of the correctly balanced reaction are 2-1-1-1 2) 63.08 3) 2.362 g, 4) 46.05%

Introduction

Green chemistry is a relatively new approach to chemical production and research in chemistry. The principles of green chemistry emphasize the reduction of hazards to human health and the larger environment as well as the conservation of nonrenewable natural resources, like petroleum. Green chemists achieve these goals through informed design of chemicals and chemical processes. They use their extensive knowledge of chemistry to create substances that serve a current need in industry or society and are safe to produce, can be produced without creating excess waste, and do not harm people or other organisms once they are no longer in use. Green chemistry has the power to transform all areas of chemistry into a far safer enterprise, while simultaneously challenging widely held perceptions that chemistry on the large scale is a polluting, “dirty” industry and a drain on limited natural resources. This approach to chemistry is exciting, modern, and ethically conscious.

Many experiments used in student laboratory courses are not “green.” Some use toxic materials, others create excess waste, and still others use unnecessary amounts of natural resources. Some might do all three or may violate other tenets of green chemistry. A green chemistry approach to teaching laboratory chemistry meets the same goals as a more traditional approach. Students still do experiments that teach the same concepts, techniques, and skills, but the experiments use green materials and processes.

In this experiment, you will learn about the mass and mole relationships of reactants and products in a chemical reaction, and you will practice communicating with other students in the laboratory both orally and in writing in the way that scientists do. The experiment has been designed in accordance with green chemistry principles. All solid wastes produced in this experiment will be collected and used again next semester for the same experiment. The only gaseous wastes generated by the reaction in the experiment are carbon dioxide and water, which are not harmful.

Green chemistry is based on twelve overarching principles. Three of these principles are addressed in this experiment. **Prevention** is an extremely important part of the green chemistry philosophy. One of the main things that distinguishes green chemistry from the environmental chemistry of the past is the latter’s focus on treatment and cleanup of waste after it is created. Very often, current (non-green) cleanup efforts involve merely placing hazardous waste in containers for indefinite storage or simply diluting them with water or other safe substances and then releasing them into the environment. Frequently these policies of containment and dilution fail because of spills, long-term build-up of toxic materials in the environment, and other problems. By contrast, green chemistry emphasizes the crucial role of prevention as an easier, cheaper and ultimately safer way of avoiding harm from chemical waste. After all, if hazardous waste is never created, then it never has to be stored, treated, or otherwise dealt with. There are often many different ways of creating a chemical to serve a particular purpose. Green chemists consider all the alternatives available, and the long-term effects of each alternative, before selecting a chemical reaction to carry out.

Atom economy is a very important measure used in assessing how “green” a chemical process is. Although the atom economy calculation is usually applied to organic synthesis processes, it can be calculated for any chemical reaction. All chemical reactions have the form

$$\text{Reactants} \rightarrow \text{Products}$$

The products of the reaction can either be desired products or undesirable waste. Green chemistry seeks to minimize undesirable waste (or not generate it in the first place, if possible). You can think of a reaction instead as

$$\text{Reactants} \rightarrow \text{(Desirable Products)} + \text{(Undesirable Waste)}$$

The atom economy calculation measures what part of the original input is converted to desirable products. In essence, atom economy measures how well the process conserves input.

$$\text{Atom economy} = \frac{\text{Mass of all desired products}}{\text{Mass of all reactants}} \times 100\%$$

Atom economy can be calculated from actual laboratory data or it can be a theoretical prediction. The theoretical atom economy for a reaction can be calculated using molar masses instead of actual masses measured in the laboratory. For example, for the reaction

$$Fe_2O_3 + 3\ CO \rightarrow 2\ Fe + 3CO_2$$

the desired product is iron metal, and the undesirable waste is carbon dioxide.

The theoretical sum of the molar masses of the reactants is:

$$\begin{aligned}
&\text{Mass of all reactants} \\
&\quad = \text{mass of } 1\,mol \text{ of } Fe_2O_3 + \text{mass of } 3\,mol \text{ of CO} \\
&\quad = \left(1\,mol\ Fe_2O_3 \times \frac{159.7\ g}{mol}\right) + \left(3\,mol\ CO \times \frac{28.02\ g}{mol}\right) \\
&\quad = 243.8\ g
\end{aligned}$$

The theoretical mass of the desired product is:

$$\begin{aligned}
&\text{Mass of desired product} \\
&\quad = \text{mass of } 2\,mol \text{ of Fe} \\
&\quad = 2\,mol\ Fe \times \frac{55.85\ g}{mol} \\
&\quad = 111.7\ g
\end{aligned}$$

Therefore, the theoretical atom economy is:

$$\begin{aligned}
\text{Atom economy} &= \frac{\text{Mass of all desired products}}{\text{Mass of all reactants}} \times 100\% \\
&= \frac{111.7\ g}{243.8\ g} \times 100\% \quad = 45.82\%
\end{aligned}$$

In principle, a reaction with higher atom economy is preferable to one with lower atom economy, because higher atom economy means less waste produced for a given amount of product produced. However, it is important to realize that atom economy is only one measure of a reaction's greenness. Atom economy tells what fraction of the original materials ends up in the desired product, but says nothing about what the original materials or desired product are and whether they are green or not. A reaction that uses highly toxic materials can have high atom economy, and that reaction still would not be green.

The **use and production of non-toxic materials** whenever possible is another vital principle in green chemistry. The toxicity of a material is a measure of both the potential harmful effects of that material on people or other organisms, and the amount of the material required to produce harm. A small amount of a highly toxic material can severely harm or kill a person, while a non-toxic material causes no harm to people even in fairly large doses. Different substances range over a continuum from extremely toxic to entirely non-toxic. The toxicity of many thousands of substances has been studied. Green chemists use this information to select the reactants and products that are lowest in toxicity while still allowing them to achieve their goals. In the past, chemists frequently considered many factors when developing a process, such as availability and cost of materials, but they often ignored toxicity. By contrast, green chemists are mindful of toxicity at each step of any process.

Putting green chemistry into practice is more complex than just understanding these three principles, as well as the nine other fundamental principles not discussed here. Often, one of the alternative chemical reactants and pathways to a particular goal is not obviously preferable to other options in terms of greenness. For example, one choice may be better in terms of atom economy, while another is preferable regarding the toxicity of wastes. In such cases, green chemists carefully analyze the relative merits and drawbacks of each choice before making decisions.

References

Anastas, P.T. and Warner, J.C. (1998). Green Chemistry: Theory and Practice. New York: Oxford University Press.

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Kirchhoff, M., and Ryan, M.A. (Eds). (2002) Greener Approaches to Undergraduate Chemistry Experiments. Washington DC: American Chemical Society.

Lancaster, M. (2002). Green Chemistry: An Introductory Text. Cambridge, UK: Royal Society of Chemistry.

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LABORATORY TASK

Your task during the laboratory period is to attempt to replicate the work of a student who did this experiment in this class last year, ***using the same unknown sample as you will use***. That student's lab report will be provided on the day of the lab for you to use as you plan and carry out your experiment. Other students in your class will receive the lab reports of different students, and thus they may have different information than you do. In order to have a better understanding of the experiment, you and your classmates may discuss information with each other during the lab period, but you may not read each other's lab reports.

Communicating science is a critical part of doing science. Scientists engage in communication when they discuss their experiments informally at meetings or over the phone or email, present their research formally at conferences, and publish their work in peer-reviewed journals. Lab reports that students write in science courses are intended to help students learn how to communicate science in writing. Questions 1-3 below ask you to evaluate some aspects of scientific communication that you engaged in as part of this laboratory exercise. There is a standard format for scientific articles in journals. Ordinarily, the format includes the following sections:

- Introduction – includes a justification for why the work is important, and a review of relevant prior work by others
- Materials and Methods
- Results – includes data and calculations
- Discussion – possible errors are analyzed, implications of the results are explained, and future directions for the work are projected
- Conclusion

Question 4 is a typical component of a Results section. Question 5 asks you to provide the kinds of explanations typical in Discussion sections of articles. Answer the following questions and turn them in by the end of the laboratory period, along with your data and calculations.

IMPORTANT SAFETY NOTE: Do not ever heat a closed container!

Questions to Answer

1) How could the student whose report you received have improved his or her lab report?

2) Why do scientists, and science students like yourself, write lab reports?

3) What did you learn from talking with other groups during the lab that you would not have been able to learn if you weren't able to talk with other groups?

4) Use your data to calculate the following quantities. Show calculations to support and explain your answers:
   a) The total **mass of water and carbon dioxide** lost in each trial.
   b) The **mass of water** lost in each trial.
   c) The **moles of water** lost in each trial.
   d) The **mass of sodium bicarbonate** originally present in the sample in each trial.
   e) The **percent composition by mass** of the original sample in each trial.

5) How does this experiment illustrate the Green Chemistry principles of *prevention* and *use and production of non-toxic materials*?

Each student must turn in his or her own lab report by the end of the laboratory period.

Don't forget to ***turn in pages 7-10 and your pre-lab*** as your lab report before you leave the

Name: ____

Lab Partner(s): ____

Number of Lab Report Provided (in upper right hand corner): 1 2 3 (circle one)

DETERMINATION OF THE COMPOSITION OF A MIXTURE

Use this space to present your data.

Name: ____

Lab Partner(s): ____

Number of Lab Report Provided (in upper right hand corner): 1 2 3 (circle one)

Answer the following questions.

1) What could the student whose report you received have improved his or her lab report?

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e) The **percent composition by mass** of the original sample in each trial.

5) How does this experiment illustrate the Green Chemistry principles of *prevention* and *use and production of non-toxic materials*?

<u>Determination of the Composition of a Mixture</u>

Lab Report #1

Goal

Determine the relative amounts of sodium carbonate and sodium bicarbonate in a mixture of the two substances.

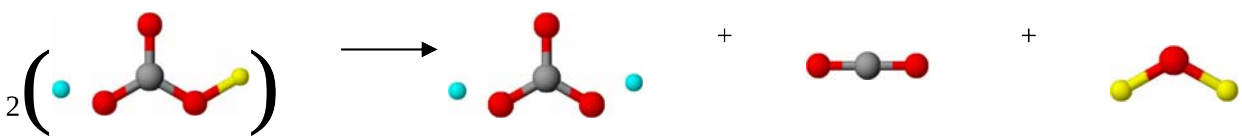
Data

Mass mixture

Trial	Before heating	After 1st heating	After 2nd heating
1	4.622 g	3.189 g	3.189 g
2	5.045 g	3.770 g	3.766g

Calculations

$2\ NaHCO_3\ (s) \rightarrow Na_2CO_3\ (s) + CO_2\ (g) + H_2O\ (g)$



$2\ mol \times \frac{84.01\ g}{mol} = 168.0\ g$ | $105.99\ g$ | $44.01\ g$ | $18.02\ g$

<u>Trial 1</u>

Mass lost: 4.622 g – 3.189 g = 1.433 g

Mass lost was all the gases ($CO_2 + H_2O$)

Theoretically, moles of CO_2 = moles of H_2O, because both have a coefficient of 1 in the balanced equation.

If y = moles of CO_2 = moles of H_2O, then

$$y \times \frac{18.02\, g\ \ H_2O}{1\, mol\ H_2O} + y \times \frac{44.01 g\ \ CO_2}{1\, mol\ CO_2} = \text{mass lost} = 1.433 g$$

$$18.02\, g\ y + 44.01 g\ y = 1.433 g$$

$$y = .02310\ \text{mol}$$

From the balanced equation, the coefficient of $NaHCO_3$ is 2, so moles $NaHCO_3 = 2y$

$$2y = .04620\, mol\ NaHCO_3$$

$$.04620\, mol\ NaHCO_3 \times \frac{84.01\, g\ NaHCO_3}{1 mol\ NaHCO_3} = 3.881 g\ NaHCO_3$$

$$\% NaHCO_3 \text{ in mixture} = \frac{g\ NaHCO_3}{g\ \text{mixture}} \times 100\%$$

$$= \frac{3.881 g\ NaHCO_3}{4.622 g\ \text{mixture}} \times 100\% = 83.97\%$$

<u>Trial 2</u>
Mass lost: 5.045 g – 3.767 g = 1.638 g

$$y \times \frac{18.02\,g\ \mathrm{H_2O}}{1\,mol\ \mathrm{H_2O}} + y \times \frac{44.01 g\ \mathrm{CO_2}}{1\,mol\ \mathrm{CO_2}} = \text{mass lost} = 1.638\,g$$

$$18.02\,g\ y + 44.01 g\ y = 1.638\,g$$

$$y = .02641\,mol$$

$$2y = .05282\,mol\ \mathrm{NaHCO_3}$$

$$.05282\,mol\ \mathrm{NaHCO_3} \times \frac{84.01\,g\ \mathrm{NaHCO_3}}{1\,mol\ \mathrm{NaHCO_3}} = 4.437\,g\ \mathrm{NaHCO_3}$$

$$\%\mathrm{NaHCO_3}\ \text{in mixture} = \frac{4.437\,g\ \mathrm{NaHCO_3}}{5.405\,g\ \text{mixture}} \times 100\% = 87.95\%$$

Average for both trials:

% $NaHCO_3$ = (83.97% + 87.95%)/2 = 85.96%

Conclusion

My results show that this mixture was originally 85.96% sodium bicarbonate and 14.04% sodium carbonate by mass.

Possible sources of error include impurities in the mixture, which could affect the calculated percent of sodium bicarbonate to be too high if the impurity would be affected by heating. For example, if some of the sodium carbonate in the mixture was in the form of sodium carbonate monohydrate rather than the anhydrous form of the salt, the water of hydration would have been driven off by the heating steps. I assumed that all water lost was originally from the sodium bicarbonate in my calculations, and thus I would have calculated that the sodium bicarbonate was present in a greater amount relative to the amount of sodium carbonate than it actually was. On the other hand, if the mixture was contaminated by a substance that was inert in heating, such as sodium chloride, my calculated value for the mass of sodium bicarbonate would have been unaffected, and so would my percent sodium bicarbonate. However, my percent sodium carbonate would be too high, because I assumed that all of the inert mass was sodium carbonate.

Another possible source of error is insufficient time cooling the dish before taking mass measurements. Because the water vapor and carbon dioxide products are still escaping the crucible during cooling, if the mass measurement is taken too early, some of those products will be included in the mass. This would result in the calculated mass of the final solid being too high, and thus the amount of mass lost would be too low. This error would cause my calculated number of moles of sodium bicarbonate to be too low.

Because I do not know the actual percent composition of this mixture, I am unable to determine the accuracy of my results.

Determination of the Composition of a Mixture
Lab Report #2

Goal

Determine the mass ratio of a mixture of sodium bicarbonate and sodium carbonate.

Procedure

Heat mixture to a constant mass.

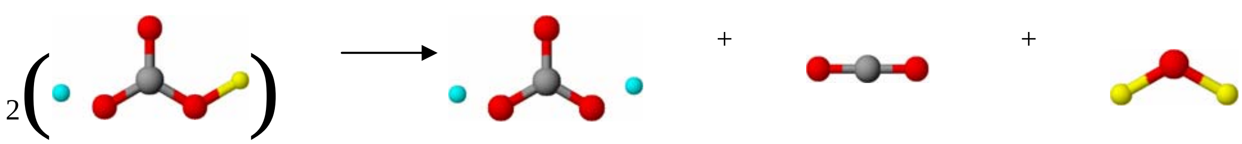
Data

Mass mixture

Trial	Before heating	After 1st heating	After 2nd heating
1	4.473 g	3.058 g	3.057 g
2	5.455 g	3.515 g	3.510g

Calculations

$2\ NaHCO_3\ (s) \rightarrow Na_2CO_3\ (s) + CO_2\ (g) + H_2O\ (g)$



$$2\ mol \times \frac{84.01\ g}{mol} = 168.0\ g \qquad 105.99\ g \qquad 44.01\ g \qquad 18.02\ g$$

Trial 1

$$\text{Experimentally, mass } Na_2CO_3 \text{ originally present} + \text{mass } NaHCO_3 \text{ originally present} = 4.473\ g$$

$$NaHCO_3 \text{ originally present} \times \frac{1\ mol\ NaHCO_3}{84.01\ g NaHCO_3} \times \frac{1\ mol\ Na_2CO_3}{2\ mol\ NaHCO_3} \times \frac{105.99\ g\ Na_2CO_3}{1\ mol\ Na_2CO_3} = Na_2CO_3 \text{ produced}$$

$$Na_2CO_3 \text{produced} + Na_2CO_3 \text{ originally present} = \text{ending mass of } Na_2CO_3 = 3.057\ g$$

Let mass of $NaHCO_3$ originally present = x; then mass of Na_2CO_3 originally present = 4.473*g* - x

$$\mathrm{x}\ g\ \mathrm{NaHCO_3} \times \frac{1\,mol\ \mathrm{NaHCO_3}}{84.01\,g\mathrm{NaHCO_3}} \times \frac{1\,mol\ \mathrm{Na_2CO_3}}{2\,mol\ \mathrm{NaHCO_3}} \times \frac{105.99\ g\ \mathrm{Na_2CO_3}}{1\,mol\ \mathrm{Na_2CO_3}} + \left(4.473g - \mathrm{x}\ g\ \mathrm{Na_2CO_3}\right) = 3.057\,g$$

Rearranging algebraically:

$$0.6309\,\mathrm{x} + 4.473\,g - 1.000\mathrm{x} = 3.057\,g$$

Solving for x:

$$\mathrm{x} = 3.836\,g\ \mathrm{NaHCO_3}\ \text{originally present}$$

$$\%\,\mathrm{NaHCO_3} = \frac{\mathrm{NaHCO_3}\ \text{originally present}}{\text{original mass of mixture}} \times 100\% = \frac{3.836\,g}{4.473\,g} \times 100\% = 85.76\%$$

<u>Trial 2</u>

Mass $NaHCO_3$ originally present + Mass Na_2CO_3 originally present = initial mass of mixture = 5.455 *g*

Again, let *g* $NaHCO_3$ originally present = x

Then *g* Na_2CO_3 in original mixture = 5.455 *g* – x

mass Na_2CO_3 produced + mass Na_2CO_3 originally present = ending mass of mixture = 3.510 *g*

Inserting these values into the same algebraic equation as in Trial 1 (see above) gives:

0.6309 x + 5.455 *g* – 1.000x = 3.510 *g*

x = 5.267 *g* $NaHCO_3$

% $NaHCO_3$ = (5.267 *g*/5.455 *g*) x 100% = 96.55%

<u>Average for both trials</u>

(85.76 + 96.55)%/2 = 91.16%

Conclusion

My results show that this mixture was originally 91.16% sodium bicarbonate and 8.84% sodium carbonate by mass. I think we spilled some of the mixture after we measured its mass and before we heated it during one of the trials. Also, the balance might have been off.

Determination of the Composition of a Mixture
Lab Report #3

Goal

Determine the relative amounts of sodium carbonate and sodium bicarbonate in a mixture of the two substances.

Materials and Methods

Bunsen Burner
Crucible
Electronic balance
Mixture of sodium carbonate and sodium bicarbonate

Procedure:
1. Measure initial mass of mixture.
2. Heat gently 5 minutes.
3. Heat strongly 5 minutes.
4. Cool, re-measure mass.
5. Repeat steps 3-4 until a constant mass is reached.

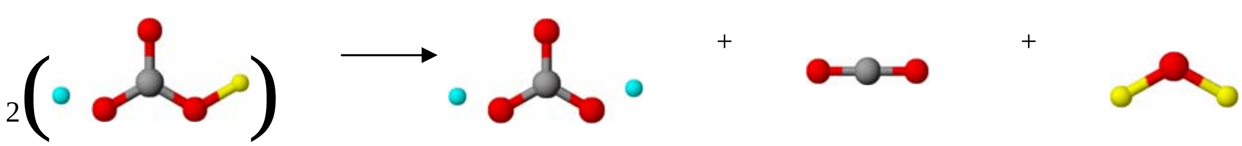
Data

Mass of mixture

Trial	Before heating	1st time after heating	2nd time after heating
1	3.575 g	2.495 g	2.493 g
2	4.218 g	2.926g	2.925 g

Calculations

$2\ NaHCO_3\ (s) \rightarrow Na_2CO_3\ (s) + CO_2\ (g) + H_2O\ (g)$



$2\,mol \times \frac{84.01\,g}{mol} = 168.0\,g$ 105.99 g 44.01 g 18.02 g

Trial 1

Mass lost was all the gases
Experimentally, total mass lost = mass of CO_2 + mass of H_2O = 3.575 g – 2.493 g = 1.082 g

Theoretically,

$$\text{Fraction of original NaHCO}_3\text{ present that was lost} = \frac{\text{mass of }H_2O\text{ and }CO_2\text{ produced}}{\text{mass of }NaHCO_3\text{ originally present}}$$

$$= \frac{1\,mol\ H_2O\text{ and }1\,mol\ CO_2}{2\,mol\ NaHCO_3}$$

$$= \frac{18.02\,g\ H_2O + 44.01\,g\ CO_2}{168.0\,g\ NaHCO_3}$$

$$= \frac{18.02\,g\ H_2O + 44.01\,g\ CO_2}{168.0\,g\ NaHCO_3} = 0.3692$$

Experimentally,

$$\text{Fraction of original NaHCO}_3\text{ present that was lost} = \frac{\text{mass of }H_2O\text{ and }CO_2\text{ produced}}{\text{mass of }NaHCO_3\text{ originally present}}$$

$$0.3692 \qquad = \qquad \frac{1.082\ g}{x}$$

Solving algebraically for *x*,

$$x = \frac{1.082\ g}{0.3692} = 2.932\ g$$

So, 2.932 g of $NaHCO_3$ must have been present in the original sample

Therefore,

$$\%NaHCO_3\text{ in original sample} = \frac{\text{part of original sample that was }NaHCO_3}{\text{mass of entire original sample (that contained mix of }NaHCO_3\text{ and }Na_2CO_3)} \times 100\%$$

$$= \frac{2.932\ g}{3.575\ g} \times 100\% = 82.01\%$$

<u>Trial 2</u>
Mass lost = Mass of CO_2 + H_2O = 4.218 g – 2.924 g = 1.294 g
The mass lost still represents = 0.3692 by mass of the original $NaHCO_3$ present (see earlier calculation of this)
1.294 g mass lost/ (.3692 g mass lost/ g $NaHCO_3$ present) = 3.504 g $NaHCO_3$ present
% $NaHCO_3$ = (3.504 g/ 4.218 g) × 100% = 83.07 %

<u>Average for both trials</u>
% $NaHCO_3$ = (82.01% + 83.07%)/2 = 82.54%

Conclusion

According to our results and calculations, the % composition of sodium bicarbonate in the mixture is between 82.01% and 83.07%. This discrepancy is small (1.06%) and thus these results are reasonably precise. Because I do not know the actual percent composition of this mixture, I am unable to determine the accuracy of my results.

Teacher's Guide for Determination of the Composition of a Mixture Lab

Overview and Introduction

Students are asked to replicate a green chemistry experiment to determine the percent composition of a mixture of sodium bicarbonate and sodium carbonate by following one of three sample lab reports, rather than by following a typical lab handout with a step-by-step procedure. Each sample lab report contains a different defect. Sample lab #1 is missing a materials and methods section, sample lab #2 contains widely discrepant results for the two experimental trials, and sample lab #3 contains an inadequate discussion section with no mention of experimental errors.

Prior to the laboratory session, students will have received an overview of this experiment, written material explaining basic tenets of green chemistry and how they apply to this experiment, and a pre-lab assignment in which they are required to carry out calculations similar to those needed in the experiment. During the laboratory session, students should carry out at least two separate trials in which they heat a small sample of a mixture of sodium carbonate and sodium bicarbonate to a constant mass. After they complete their experimental trials, students will report their results, detail their experience replicating another scientist's written work, and explain how this experiment constitutes green chemistry by answering six questions in writing. Their answers to these questions must be turned in by the end of the laboratory session.

Goals

In doing this experiment, students will:

- Determine the percent composition by mass of a mixture by heating to a constant mass.
- Discover the critical information needed in a written lab report.
- Learn and apply three introductory principles of green chemistry.

Answers to Pre-lab Questions

1. Write a balanced chemical equation for the reaction that occurs.

   $2\ NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$

2. Calculate the theoretical atom economy of the chemical reaction that occurs during today's experiment.

   (105.99g/168.02g) x 100% = 63.08%
   Theoretical atom economy is the mass of 1 mole of sodium carbonate divided by the mass of 2 moles of sodium bicarbonate expressed as a percentage.

3. A student heats 5.128 g of the sodium carbonate/sodium bicarbonate mixture to a constant mass of 4.256 g. Determine the mass of sodium bicarbonate present in the mixture.

   2.362g
   There are several ways students can solve question #2. They can calculate the mass lost as a fraction of the original mass of sodium bicarbonate present (as in sample lab #3), they can use algebra and stoichiometry to determine the mass of sodium bicarbonate that was converted to sodium carbonate (as in sample lab #2), or they can use algebra and the molar masses of water

and carbon dioxide to determine the number of moles of sodium bicarbonate originally present (as in sample lab #1). None of these methods is preferable. All that is important is that the student has shown their reasoning in a clear way, and that they have determined the correct answer.

4. What is the percent by mass of sodium bicarbonate in the mixture, based on your answer to #3 above?

   46.05%

Teaching Tips in the Laboratory

1. Set out the following materials: mixture of $NaHCO_3$ [CAS #144-55-8] and Na_2CO_3 [CAS #497-19-8] (approximately 85% $NaHCO_3$ is ideal), transferring scoops, analytical balances, crucibles, Bunsen Burners, ringstands, ring clamps.

2. Remind students not to heat covered containers.

3. There are no significant chemical hazards in this experiment. Normal laboratory precautions are sufficient.

4. Also set out two waste containers, one labeled “Heated Samples” and one labeled “Unused Mixture”. Instruct students to place the solid product that remains after heating in the first container and any mixture they take but do not heat (or do not heat to constant mass) in the second bin. After the laboratory session, the contents of the “Unused Mixture” container should be heated to constant mass and then combined with the contents of the “Heated Samples” container. This solid will be saved and stored, to be used the next time this experiment is done.

5. Give each student one of the three sample lab reports. Remind students that they may talk with each other, but may not read each other’s sample lab reports.

6. The procedure for the lab is to heat samples of the mixture to constant mass. The materials and methods section in the sample labs vary significantly in their degree of detail. Students may be confused about how to carry out the experiment or what materials to use. The goal of the lab is for students to figure out both how to do the experiment and why it is important to make the materials and methods section of a lab report clear and unambiguous. Most students will quickly realize that they need to heat approximately three to six grams of the sodium bicarbonate/sodium carbonate mixture in a crucible to a constant mass. However, should a student remain confused after several minutes, or begin to carry out a completely different procedure, the instructor must redirect that student to help him or her determine the correct procedure.

Answers to Post-Lab Questions

1) How could that student whose report you received have improved his or her lab report?

   Answers depend on which sample lab (1, 2, or 3) the student received. In all cases, the student may reasonably suggest that another calculation method is simpler or preferable, or may not, depending on his or her own personal preference.

Sample lab report #1 contains no materials and methods section at all. The student should note this omission and the difficulty it causes when someone else tries to replicate the experimenter's work.

Sample lab report #2 essentially ignores the widely discrepant results of the two trials and contains a very poor error analysis section given this large discrepancy. The student should note this shortcoming and explain the need to address the discrepancy, rather than simply average the two values obtained.

Sample lab #3 contains an extremely brief procedure in the materials and method section, so the student should note that more detail in this section would be better. In addition, there is no discussion of errors or ways to improve the lab report, which should be included in all lab reports.

2) Why do scientists, and science students like yourself, write lab reports?

Answers will vary. Reasonable answers include the following:

- To communicate results to other scientists or to instructors (in the case of students)
- To allow other scientists to attempt to confirm an experiment's findings
- To learn how to be a scientist (in the case of students)
- To allow other scientists to build on experimental findings in their own work.

3) What did you learn from talking with other groups during the lab that you would not have been able to learn if you weren't able to talk with other groups?

Answers will vary depending on the student's experience in the lab. Possible answers include:

- What procedure or materials to use
- What certain words or phrases mean (e.g. "constant mass" or "discrepancy")
- How to understand the experimenter's calculation section
- What other students' results were

4) Use your data to calculate the following quantities. Show calculations to support and explain your answers:

a) The total **mass of water and carbon dioxide** lost in each trial.
b) The **mass of water** lost in each trial.
c) The **moles of water** lost in each trial.
d) The **mass of sodium bicarbonate** originally present in the sample in each trial.
e) The **percent composition by mass** of the original sample in each trial.

Answers will vary. Sample data and calculations based on that data are shown below.
The mixture was 85% $NaHCO_3$ by mass.

DATA TABLE		
Before heating	1st time after heating	2nd time after heating
3.575 g	2.495 g	2.493 g
4.218 g	2.926g	2.925 g

Below are the calculation results based on the sample data.

Calculations Table		
Calculation	1^{st} trial	2^{nd} trial
a) total mass lost (g)	1.082	1.293
b) mass water lost (g)	0.3143	0.3756
c) moles water lost	0.01744	0.02084
d) mass sodium bicarbonate originally present (g)	2.931	3.502
e) percent sodium bicarbonate by mass	81.98	83.03

These results are calculated as explained below. There are several ways to successfully complete these calculations and no method is preferred so long as students show their work and arrive at the correct answers. The method used below involves using the ratio of the molecular weights of the products (water and carbon dioxide) to determine the moles of one of the products (water). This result is then used with the mole ratio from the balanced chemical reaction to determine the number of moles of sodium bicarbonate originally present in the mixture. Finally, this result is used to calculate the mass of sodium bicarbonate originally present and then the percent composition by mass. A slight variation of this method is found in student sample lab report #1. A second method, which is shown in sample lab report #2, involves expressing the masses of the two mixture components in terms of a single variable in two separate algebraic equations and then solving the equations simultaneously to determine the masses of the two components in the original sample. A third method is shown in sample lab report #3, and this involves finding the ratio of the sum of the molecular weights of the products (one mole each of water and carbon dioxide) to the molecular weight of the reactant (two moles of sodium bicarbonate) and using this fraction to determine the mass of reactant that was originally present.

a) mass before heating – mass after final (usually 2^{nd}) heating = total mass lost

b) $$total\ mass\ lost \times \left(\frac{18.02 g/mol\ H_2O}{(18.02 g/mol\ H_2O + 44.01 g/mol\ CO_2)} \right) = mass\ water\ lost$$

c) $$mass\ water\ lost \times \left(\frac{1 mol\ H_2O}{18.02 g\ H_2O} \right) = moles\ water\ lost$$

d) $$moles\ water\ lost \times \left(\frac{2 mol\ NaHCO_3}{1 mol\ H_2O} \right) \left(\frac{84.01 g\ NaHCO_3}{1 mol\ NaHCO_3} \right) = mass\ NaHCO_3\ originally\ present$$

e) $$\left(\frac{mass\ NaHCO_3\ originally\ present}{original\ mass\ mixture} \right) \times 100\% = \% NaHCO_3\ in\ mixture$$

5. How does this experiment illustrate the Green Chemistry principles of *prevention* and *use and production of non-toxic materials*?

Prevention:

- The sodium carbonate generated will be reused rather than discarded
- The amounts of materials used are relatively small

Use and production of non-toxic materials

- The reactants used are non-toxic
- The wastes produced (water and carbon dioxide) are harmless

STUDENT NAME:____________________________________ LAB SECTION:_________

Green Chemistry Stoichiometry Lab Grading Rubric

	A *Excellent*	**B** *Good*	**C** *Satisfactory*	**D/F** *Unsatisfactory*	# of points
Pre-lab #1	Correct balanced reaction written with phases shown. (1)	Correct balanced reaction written, but some or all phases missing. (0.85)	Correct formulas for all reactants and products, but not balanced. (0.75)	One or more formulas is wrong. (0)	/1
Pre-lab #2	Correct answer with work, including molar masses and formulas, clearly shown. (1)	Correct answer with some calculations shown. (0.85)	Formula written down but not correctly calculated. (0.75)	Answer only. (0.6)	/1
Pre-lab #3	All calculations are shown in a logical, readable manner that leads to correct answer (see student sample labs for examples). (2)	Calculations leading to the correct answer are shown, but parts are difficult to follow (1.7)	Some but not all calculation steps are shown or attempted, but they do not lead to the correct answer (1.5)	No calculations shown. (1.2)	/2
Pre-lab#4	Answer from #3 in numerator, starting mass in denominator, calculations shown. (1)	Correct formula used but wrong data chosen. (0.85)	Formula written down, no calculations. (0.75)	No work. (0)	/1
Data/ Experiment	Clearly labeled data with units, including mass of vessel, shown for at least two trials with at least two after-heating masses for each trial. (3)	Clearly labeled data shown for at least two trials with at least two after-heating masses for each trial. (2.55)	Data shown for at least two trials, but data may be poorly organized or two heating steps may not be present. (2.25)	Data for two trials not shown. (1.8)	/3
Post-lab #1	Complete, clear explanation of both the improvement given in teacher guide and why the improvement is necessary. (2)	Complete, clear explanation of the improvement given in teacher guide. (1.7)	Suggests an improvement similar to that in teacher guide, but explanation is vague. (1.5)	Does not make a reasonable suggestion for improvement. (1.2)	/2
Post-lab #2	At least two of the reasons given in the teacher guide are clearly stated. (2)	One of the reasons given in the teacher guide is clearly stated. (1.7)	Reason given is related to that in teacher guide, but explanation is vague. (1.5)	Does not give a valid reason. (1.2)	/2
Post-lab #3	Student clearly states two things he or she learned from others. (1)	Student clearly states one thing he or she learned from others. (0.85)	Student offers a vague statement about others. (0.75)	Student says he or she learned nothing from others. (0.6)	/1
Post-lab #4	All values are correctly calculated and all work is clearly shown. (5)	All but one value is correctly calculated and work is clearly shown. (4.25)	At least two values are correctly calculated, all steps are attempted and work is shown. (3.75)	All calculations not attempted or all values or all but one incorrect. (3)	/5
Post-lab #5	At least one correct reason for prevention and one for non-toxic materials is given and clearly explained. (2)	At least one correct reason for prevention and one for non-toxic materials is given. (1.7)	At least one correct reason for prevention or one for non-toxic materials is given. (1.5)	No correct answers given. (1.2)	/2
				TOTAL	/20