Experiment 4 – Decomposition of Sodium Bicarbonate

Materials Needed to Complete This Experiment (https://youtu.be/slxKzfdkpIA) Note to Student: Please review this video before you begin the lab.

- Baking soda, $NaHCO_3$
- Oven-proof glass or ceramic dish that has a mass of less than 165 grams
- Scale that holds up to 200.0 g with 0.01 g accuracy
- Oven
- 100 mL graduated cylinder, 25 mL graduated cylinder
- Distilled water
- Plastic wrap or piece of plastic
- Recommended: oven mitts or hot pads for removing materials from the oven, trivets for placing hot items on the counter
- Paper, scissors and tape

Common Lab Procedures/Skills in This Lab (new skills in bold)

1. Decompose sodium bicarbonate (https://youtu.be/dn1vspcpndq)
2. Record the mass*
3. Mix well without spilling (no inversion)*
4. Mix well without spilling (with inversion)*
5. Preparing a solution of known concentration*
6. Transfer the remaining sodium carbonate to a 25 ml graduated cylinder using a paper funnel (https://youtu.be/wh0nygy8s8y)
7. Calculate the molarity*
8. Calculate the percent yield (https://youtu.be/7lzgaoyez4u)
9. Propagation of errors (https://youtu.be/ecfnsdtvzlc)
10. Analysis of systematic (procedural) errors (https://youtu.be/cok_wxaqm8o)

Introduction

In this experiment you will:

1. Observe the reaction:

   $$2\ NaHCO_{3(s)} + \text{heat} \rightarrow Na_2CO_{3(s)} + H_2O_{(g)} + CO_{2(g)}$$

   This reaction will occur at a high temperature so the H_2O will be a gas and evaporate. Carbon dioxide gas is also created, an important part of why baking soda is used in baking.

2. Calculate the % yield of Na_2CO_3 obtained as a product.

3. Perform an error analysis on the *random* instrumental errors associated with use of the analytical balance. For each use of the analytical balance, there is a random error of ±0.04 g.

4. Perform an analysis on the *systematic* procedural or human errors associated with this experiment.

Error analysis of random instrumental errors is completed using a technique called "Propagation of Errors". The calculations involved in Propagation of Errors are summarized below in Table 1. For example, a number “a” has an error or standard deviation s_a and “b” has an error or standard deviation s_b. If a is subtracted from b, the result is “c” with error s_c.

Given two numbers: $a \pm s_a$, $b \pm s_b$

Subtract these two numbers: b – a = c

Use Propagation of Errors to calculate error in c: $s_c = \sqrt{\sigma_a^2 + \sigma_b^2}$

Result: $c \pm s_c$,

Table I - Arithmetic Calculations of Error Propagation

Type[1]	Example	Standard Deviation (σ_x)
Addition or Subtraction	x = a + b - c	$\sigma_x = \sqrt{\sigma_a{}^2 + \sigma_b{}^2 + \sigma_c{}^2}$ (10)
Multiplication or Division	x = a x b/c	$\frac{\sigma_x}{x} = \sqrt{\left(\frac{\sigma_a}{a}\right)^2 + \left(\frac{\sigma_b}{b}\right)^2 + \left(\frac{\sigma_c}{c}\right)^2}$ (11)
Exponential	x = a^y	$\frac{\sigma_x}{x} = y(\frac{\sigma_a}{a})$ (12)
Logarithmic	x = log(a)	$\sigma_x = 0.434(\frac{\sigma_a}{a})$ (13)
Anti-logarithmic	x = antilog(a)	$\frac{\sigma_x}{x} = 2.303(\sigma_a)$ (14)

Where a, b, and c are measured variables from an experiment; and σ_a, σ_b, and σ_c are the standard deviations (or errors) of those variables. Note that addition, subtraction, and logarithmic equations leads to an absolute standard deviation, while multiplication, division, exponential, and anti-logarithmic equations lead to relative standard deviations.

Here is an example of the application of Propagation of Errors to a portion of this experiment if ≈ 15 g of $NaHCO_3$ were used:

Data:		Given Error
Mass dish	124.05 g	Instrumental: ± 0.04 g
Mass dish + $NaHCO_3$ (before heating)	139.20 g	Instrumental: ± 0.04 g
Mass dish + Na_2CO_3 (after heating)	133.65 g	Instrumental: ± 0.04 g
Molar mass $NaHCO_3$	84.007 g	Instrumental: ± 0.002 g
Molar mass Na_2CO_3	105.988 g	Instrumental: ± 0.001 g

1. Calculation of mass of $NaHCO_3$ (before heating) and its error:

   a. Mass of $NaHCO_3$ $_{\text{(before heating)}}$ = Mass dish + $NaHCO_{3\text{(before heating)}}$ – Mass dish

   = 139.20 g – 124.05 g = 15.15 g

   b. Error in mass of $NaHCO_3$ (before heating) $s_{15.15} = \sqrt{0.04^2 + 0.04^2} = 0.0\underline{5}66$ g

   Final result: Mass of $NaHCO_3$ (before heating) = 15.15 ± $0.0\underline{5}66$ g

2. Calculation of theoretical mass of Na_2CO_3 based on initial mass of $NaHCO_3$ (before heating) and its error:

   a. Theoretical mass of Na_2CO_3 based on initial mass of $NaHCO_3$ (before heating):

15.15 g $NaHCO_3$	1 mol $NaHCO_3$	1 mol Na_2CO_3	105.988 g Na_2CO_3	= $9.55\underline{7}05$ g Na_2CO_3
	84.007 g $NaHCO_3$	2 mol $NaHCO_3$	1 mol Na_2CO_3	

   b. Error in theoretical mass of Na_2CO_3 based on initial mass of $NaHCO_3$ (before heating):

   There is no error in the whole numbers "1" or "2", the coefficients in the balanced reaction.

$$\frac{\sigma_{9.55705}}{9.55705} = \sqrt{\left(\frac{0.0566}{15.15}\right)^2 + \left(\frac{0.002}{84.007}\right)^2 + \left(\frac{0.001}{105.988}\right)^2} = 0.00\underline{3}7361$$

   $s_{9.55705} = 0.0\underline{3}5706$

   Final result: $9.55\underline{7}05 \pm 0.0\underline{3}5706$ g

For evaluating systematic errors, we will use a different approach. Our hypothesis will be that there IS a systematic error in the procedure for the experiment that makes the percent yields tend to be greater than 100%. We will attempt to discover if our hypothesis is true or false.

We will look at the class set of data to see if there is a trend in the percent yields. To do this, we will take the average and standard deviation of the percent yields for all of the students in the class. Based on these values, you will be asked if you think there is a significant systematic error in the experiment.

Most small glass and ceramic dishes are oven-safe if they don't have any decoration on them – the dish is plain. This is especially true if you put the dish into the oven before the oven preheats and take it out after the oven has cooled down. Slow temperature changes generally disfavor cracks in the dish. Rapid temperature changes tend to favor cracks in the dish. Please don't take your (or your mother's or your significant other's) fancy dish for this experiment! If you don't have a dish that meets the needs of this experiment, please let your instructor know. That goes the same for not having an oven or any of the supplies for this lab.

The product of this experiment, Na_2CO_3, will be dissolved in distilled water to make a solution. This solution will be saved for the next experiment.

PROCEDURE – YOU WILL WORK ON THIS LAB INDEPENDENTLY (NO LAB PARTNERS).

A. Decompose Sodium Bicarbonate, $NaHCO_3$ (video 1 procedure/skills 1 above)

1. Record the mass of a clean, dry oven-safe dish. Make sure that the mass is less than 165 g.

2. Add ≈30 g of baking soda ($NaHCO_3$) to the dish. Record the mass.

3. Set your oven to 400°F. Allow the oven to preheat to 400°F. Once preheated, place the dish into your oven. It may help to place the dish onto a baking sheet while in the oven. Heat for 20 minutes while at 400°F.

4. Turn off the oven. Allow the oven and the dish to cool. If you have oven mitts, hot pads, and/or a trivet, you may remove the dish from the oven and allow it to cool on a trivet.

5. Once the dish is cooled, Record the mass of the dish.

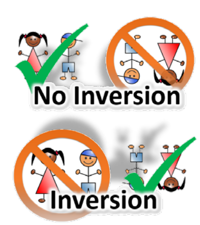
   Note: The dish should only contain sodium carbonate, Na_2CO_3.

B. Preparing A Solution Of Known Concentration

1. Record the mass of a 100.0 mL graduated cylinder. It need not be dry, but if it is not dry, condition it with distilled water.

2. Take the graduated cylinder off of the scale. Add approximately 10 grams of the sodium carbonate, Na_2CO_3, from part A of this lab from the dish into the graduated cylinder. The remaining sodium carbonate will be stored for a future experiment. Record the mass of the graduated cylinder with the Na_2CO_3.

3. Add approximately 50 mL of distilled water to the graduated cylinder. Mix well without spilling (no inversion): Swirl the graduated cylinder until the salt dissolves without spilling the solution.



4. Add distilled water until the graduated cylinder is filled exactly to the 100.0 mL line. Use a pipette conditioned with distilled water to add the last few mLs and/or drops. Do not go over the line because you cannot take solution out of the graduated cylinder.

5. Mix well without spilling (with inversion): cover the top of the graduated cylinder with either (i) a piece of plastic wrap and your hand or (ii) a gloved hand. With the top covered, invert the graduated cylinder to mix. If you do this, be careful that none of the solution leaks out or spills until the solution is well mixed. If a little bit spills out once it is well mixed, that is okay.

6. Keep the solution covered with plastic. Store the covered solution for the next lab.

C. Transfer the remaining sodium carbonate to a 25 ml graduated cylinder using a paper funnel. (video 2 procedure/skill 6 above**)**

1. Making the paper funnel out of scratch paper: Gather scratch paper, scissors and tape.

2. Cut the paper into a square **(Figure 1)**.

3. Cut and fold paper square **(Figure 2)**: Fold the square diagonally in half. Fold it in half again (so it's in quarters). Cut the edges of the folded paper into a curve.

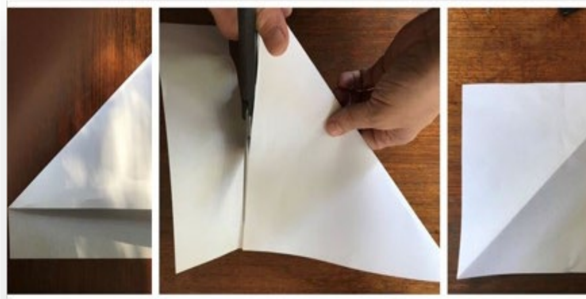


Figure 1 - Making a square

4. Cut out part of circle and tape into a cone shape **(Figure 3)**. Unfold your paper circle and cut away one quarter. Overlap the sections of the paper to form a cone and tape edge in place.

Figure 2 - Cut and fold the paper square

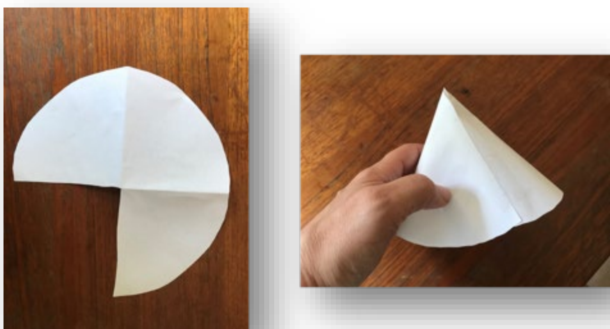


Figure 3 - Cut out part of circle and tape into a cone shape

5. Cut out opening at end of funnel: Flatten the cone and cut an inverted V shape at the end of the cone to form a hole. The hole size should be large enough to allow the sodium carbonate to flow freely, but small enough to fit easily in the graduated cylinder. You can make the hole larger if isn't big enough. Transfer the remaining sodium carbonate into 25 mL graduated cylinder. Cover securely with plastic wrap and store for future use. **(Figure 4)**.

Figure 4 - Cut opening at the end of funnel

CALCULATIONS

A. Calculations for the decomposition of $NaHCO_3$

1. Calculate the initial mass of $NaHCO_3$ (before heating).

2. Calculate the mass of Na_2CO_3.

3. Based on the mass of $NaHCO_3$ (before heating) in step 2 and using stoichiometry, calculate the theoretical mass of Na_2CO_3.

4. Using the result of step 3 as your theoretical or correct result and the result of step 2 as your experimental result, calculate the percent yield in the mass of Na_2CO_3. **(Video 3 Procedure/Skill 8 above)**

B. Calculate the Molarity of the Na_2CO_3 solution:

1. Convert grams of Na_2CO_3 to moles of Na_2CO_3.

2. Convert mL of solution in your graduated cylinder to L of solution.

3. Molarity is:

$$M = \frac{\text{mol of solute}}{\text{L of solution}}$$

C. Propagation of errors: Based on the video and the examples shown in the introduction, complete an error analysis of random instrumental errors for this experiment. Your final result will be an error (or standard deviation) in the value of your percent error. **(Video 4 Procedure/Skill 9 above)**

D. Analysis of systematic (procedural) errors: Ask your classmates or your instructor for each student's percent error. Once you have them all, take the average and standard deviation of these values. Write a paragraph of 3-5 sentences about whether or not there is a systematic error that tends to make the percent errors positive for this lab. **(Video 5 Procedure/Skill 10 above)**

POST-LAB QUESTIONS:

1. Why is baking soda, $NaHCO_3$, included in recipes for cakes and muffins? (What purpose does it fulfill? *Qualitative question*)

2. How much baking soda will you need to start with in order to produce 10.25g Na_2CO_3? (You need to calculate this, do not forget your units and significant digits. *Quantative question*)

3. If there was a loss of 5.63 g after heating the sodium bicarbonate, how many grams of sodium bicarbonate was present before heating? (You need to calculate this, do not forget your units and significant digits. *Quantative question*)

4. Assume that ten students achieved the percent yield as show to the right. Describe how you would either prove or disprove that there is a systemic bias in this experiment that makes it higher than 100% yield. (*Quantative question*)

Student Values
99.68%
102.32%
102.39%
101.49%
101.54%
100.46%
99.23%
99.03%
99.72%
99.85%

RESULTS

Table 1: Data

Data		Given Error
Mass dish		Instrumental: ± 0.04 g
Mass dish + initial mass $NaHCO_3$ (before heating)		Instrumental: ± 0.04 g
Mass dish + Na_2CO_3 (after heating)		Instrumental: ± 0.04 g
Molar mass $NaHCO_3$	84.007 g	Instrumental: ± 0.002 g
Molar mass Na_2CO_3	105.988 g	Instrumental: ± 0.001 g
Mass 100 mL grad cylinder		
Mass 100 mL grad cylinder + Na_2CO_3		
Molarity of Na_2CO_3		

Table 2: Calculations

Calculations		Calculated Error
Mass of $NaHCO_3$ (before heating)		
Mass of Na_2CO_3 (after heating)		
Theoretical mass of Na_2CO_3		
% Yield Na_2CO_3		