# Determination of % by Mass of $NaHCO_3$ in Alka-Seltzer Tablets

## Learning Objectives:

- To study and apply the concept of stoichiometry to measure the amount of a substance consumed, by measuring the amounts of products formed in a chemical reaction
- To apply the concept of limiting reactants

## Experimental Objectives:

- To determine the amount of sodium hydrogen carbonate ($NaHCO_3$, familiarly known as sodium bicarbonate) in Alka-Seltzer® tablets by measuring the amount of $CO_2$ produced from the acid-base reaction of bicarbonate ($HCO_3^-$) with acetic acid (vinegar)
- To determine the limiting reactant in the reaction between vinegar (acetic acid) and sodium bicarbonate by observing the effect of incremental increases in the volume of the vinegar used in the reaction

## Introduction:

### Stoichiometry

Stoichiometry refers to the quantitative relationships between the amounts (moles) of reactants and products in a chemical reaction. Analysis of stoichiometry involves other fundamental chemical topics such as balancing chemical reactions, which involves the correct stoichiometric coefficients for the reactants and products; understanding molar ratios; theoretical and percent (%) yields, and limiting reactants.

Stoichiometric coefficients that balance a chemical reaction describe the number of "particles" (individual atoms, molecules, ions, or number of moles) involved in a chemical reaction. In the general chemistry laboratory, it is not possible to measure directly the number of molecules reacted or formed during a chemical reaction, so typically, masses and volumes are the quantities measured. Thus, it is necessary to convert quantitatively the measured masses or volumes into the corresponding number of particles (e.g. moles) using the molar ratios of the substances from the balanced chemical equation.

### Alka-Seltzer®

Alka-Seltzer® is a common over-the-counter drug that is used for fast relief of heartburn, upset stomach, and indigestion, and also utilized as a pain reliever. Alka-Seltzer is available in several variants that are aimed at treating different symptoms. This lab uses the Alka-Seltzer® Original tablets that contain aspirin (acetylsalicylic acid, $C_9H_8O_4$), citric acid ($C_6H_8O_7$), and sodium bicarbonate ($NaHCO_3$).

When an Alka Seltzer tablet is dropped into water, an acid-base reaction between the citric acid / acetylsalicylic acid (generalized as $H^+$) and the sodium bicarbonate (acting as the base) occurs, producing carbon dioxide gas ($CO_2$), which is observed as a "bubbling" or effervescence (**eqn. 1**):

$$HCO_3^-{}_{(aq)} + H^+{}_{(aq)} \rightarrow CO_{2(g)} + H_2O_{(l)} \qquad \textbf{eqn. 1}$$

The carbon dioxide gas that is produced escapes from the solution into the atmosphere, resulting in a loss of mass of the tablet/solution after the acid-base reaction is complete. In the presence of vinegar (acetic acid, also generalized as $H^+$), the same acid-base reaction occurs. According to **eqn 1**, one mole of $HCO_3^-$ reacts with one mole of $H^+$ to give 1 mole of $CO_2$ and one mole of water ($H_2O$). Hence, the molar ratios can be written as:

$$1 \text{ mol } HCO_3^- : 1 \text{ mol } H^+ : 1 \text{ mol } CO_2 : 1 \text{ mol } H_2O$$

If the numbers of moles of the two reactants are in different proportions from those shown above, for example, if we mix 3 moles of $HCO_3^-$ with 2 moles of $H^+$, then one mol of $HCO_3^-$ will remain unreacted at the end of the reaction, and all the $H^+$ will be consumed. In this case, the acid, $H^+$, is the limiting reactant, and the amount of $H^+$ available will determine how much of the two products will be formed. In this case, two moles each of $CO_2$ and $H_2O$ will be generated. Conversely, if we mix two moles of $HCO_3^-$ with 3 moles of $H^+$, then all the $HCO_3^-$ will be consumed, and one mole of $H^+$ will remain unreacted. In this example, $HCO_3^-$ is the limiting reactant.

**Experiment Proper**

In this experiment, Alka-Seltzer® Original tablets will be dissolved in various volumes of vinegar (acetic acid) and the amount of gaseous $CO_2$ produced in the reaction (**eqn 1**) can be indirectly measured from the mass lost. One mole of $CO_2$ is produced per one mole of $NaHCO_3$ consumed. From the mass of $CO_2$ product obtained, the mass of $NaHCO_3$ reacted can be obtained, and finally its % by weight in the tablet can be calculated (**eqns 2, 3**).

$$\text{mass of NaHCO}_3 = \frac{\text{mass of CO}_2\text{ produced}}{\text{MM of CO}_2} \times \frac{1\text{ mol NaHCO}_3}{1\text{ mol CO}_2} \times \text{ MM of NaHCO}_3 \qquad \textbf{eqn. 2}$$

where *MM = molar mass

$$\%\text{ by mass of NaHCO}_3 = \frac{\text{mass of NaHCO}_3\text{ in tablet}}{\text{mass of tablet}} \text{x } 100\% \qquad \textbf{eqn. 3}$$

## Materials:

- 250 mL beaker
- 50 mL graduated cylinder
- 10 mL graduated cylinder
- Top-loading balance

### Chemicals:

- 8 Alka-Seltzer® original tablets
- Vinegar (~4.5% acetic acid)

## Safety

At all times, handle all chemicals carefully. If you come into contact with any chemical, flush any exposed area of your body with large amounts of water (15 minutes) and alert your TA. The solutions used today can be disposed of in the sink. If any solids or liquids are spilled on or around the balances, **clean it up**!

## Experimental Procedure:

**The total volume of vinegar-water solution for each run should be 35 mL.*

1. Measure 35 mL of distilled water into a clean 250 mL beaker. Weigh and record the total mass of the beaker plus water (sample data table below). Also, record the actual measured volume of the water (e.g. Write 33.5 mL if that is what you measured, not 35).
2. Weigh and record the mass of one Alka-Seltzer® tablet.
3. Drop the tablet into the beaker and swirl carefully. Keep swirling until the acid-base reaction is complete, which is apparent when bubbling ceases. Give the beaker one last good stir. Weigh the beaker again with the dissolved solution. Record this mass.
4. Rinse the beaker with distilled water. Then repeat steps 1-3 using 5 mL of vinegar + 30 mL water, then with 10 mL vinegar + 25 mL water, and so on, increasing the volume of vinegar by 5 mL each time while keeping the total volume of the solution at 35 mL (see **Table 1**).
5. Record your data in the sample table below (**Table 2**).
6. Calculate the mass of $CO_{2(g)}$ generated for each run. Record the amount in the table below.
7. All solutions can be diluted with water and disposed of down the sink.

**Table 1.** Volumes of vinegar and water for each run.

| Run | Volume of vinegar (mL) | Volume of Water (mL) |
|---|---|---|
| 1 | 0 | 35 |
| 2 | 5 | 30 |
| 3 | 10 | 25 |
| 4 | 15 | 20 |
| 5 | 20 | 15 |
| 6 | 25 | 10 |
| 7 | 30 | 5 |
| 8 | 35 | 0 |

## Data and Analysis:

**Table 2.** Data and Results

| Run | Volume (mL) | | Mass (g) | | | | | Mass of $NaHCO_3$ in tablet | % $NaHCO_3$ in tablet |
|---|---|---|---|---|---|---|---|---|---|
| | Vinegar | Water | Beaker + vinegar/water | Tablet | Total mass before reaction | Total mass after reaction | $CO_2$ Formed | | |
| **1** | | | | | | | | | |
| **2** | | | | | | | | | |
| **3** | | | | | | | | | |
| **4** | | | | | | | | | |
| **5** | | | | | | | | | |
| **6** | | | | | | | | | |
| **7** | | | | | | | | | |
| **8** | | | | | | | | | |

**Post Lab Exercises:**

- Write the balanced equation for the reaction between the $NaHCO_3$ and acetic acid.
- Calculate the mass of carbon dioxide gas generated in each of the runs.
- Calculate the mass of $NaHCO_3$ reacted for each run. Show a sample calculation.
- Calculate the percent by mass of $NaHCO_3$ in each of the tablets.
- Calculate the average percent of $NaHCO_3$ in the tablets.
- Prepare a graph of Percent by Mass of $NaHCO_3$ in each tablet as a function of the volume of vinegar used.

**Post Lab Questions**

1. This reaction requires uses only 35 mL of liquid. Why is the reaction run in a 250 mL beaker?

2. The effervescent tablet contains citric acid which causes it to react in pure water. Why is acetic acid added to the reaction?

3. Why must the mixture be stirred after the reaction is completed?

4. Using the graph (% by mass $NaHCO_3$ vs. vinegar volume) determine the limiting reactant for <u>each</u> of the runs. Explain your answer.

5. Does the percent of $NaHCO_3$ vary among the different tablets? Based on your data and your plot, what is the average percent by mass of $NaHCO_3$ in an Alka-Seltzer® tablet? Show any calculations used to determine your answers.

6. Carbon dioxide dissolves in water and water evaporates into the atmosphere during the experiment. How do these two factors affect the results of your analysis?

7. Compare your calculated mass of $NaHCO_3$ to the mass printed on the tablet label. Describe possible sources of error. Be specific.

8. Would it be possible to do a similar experiment by measuring the volume of $CO_2$ generated? Explain.