Mole Ratios and Reaction Stoichiometry

Objectives and Background

The objectives of this laboratory are to experimentally determine the mole-to-mole ratios between the underlined reactants and products in the following two double displacement "gas forming" reactions:

(A) <u>sodium bicarbonate</u> + hydrochloric acid $\rightarrow$ <u>sodium chloride</u> + carbon dioxide + water

(B) <u>sodium carbonate</u> + hydrochloric acid $\rightarrow$ <u>sodium chloride</u> + carbon dioxide + water

The easiest way to obtain the mole-to-mole ratios would be to simply balance the chemical equations for these reactions. This would be considered a theoretical approach to the problem. The balanced equations for reactions A and B are:

(A) $\underline{\mathbf{1}}\ NaHCO_3\ (s) + 1\ HCl\ (aq) \rightarrow \underline{\mathbf{1}}\ NaCl\ (aq) + 1\ CO_2\ (g) + 1\ H_2O\ (l)$

(B) $\underline{\mathbf{1}}\ Na_2CO_3\ (s) + 2\ HCl\ (aq) \rightarrow \underline{\mathbf{2}}\ NaCl\ (aq) + 1\ CO_2\ (g) + 1\ H_2O\ (l)$

In reaction A, the balancing coefficients indicate that there is a 1:1 mole ratio between reactant $NaHCO_3$ and product NaCl. This means that for every 1 mole of sodium bicarbonate that reacts, 1 mole of sodium chloride should be produced. However in reaction B, the balancing coefficients indicate that there is a 1:2 mole ratio between reactant Na_2CO_3 and product NaCl. In this case, for every 1 mole of sodium carbonate that reacts, 2 moles of sodium chloride should be produced.

To determine these mole-to-mole ratios experimentally, a quantitative analysis of both reactions is required. Specifically, a pre-weighed mass of sodium bicarbonate/carbonate will be allowed to react with a slight excess of hydrochloric acid. The sodium chloride product will then be carefully retrieved, dried and weighed at the end of the reaction. This mass of collected sodium chloride is called an *experimental yield*. Both the mass of sodium bicarbonate/carbonate reactant used and the mass of sodium chloride product can be converted to mole quantities via their respective molar masses. Finally, dividing both the reactant and product moles by the lower of the two values should yield the simplest whole number mole-to-mole ratio of reactant and product.

While an experimental product yield is obtained by actually performing a reaction in lab, a *theoretical yield* is the maximum mass of product that could be obtained from a reaction provided that no errors occur. Theoretical product yields can only be determined by performing a series of stoichiometric calculations. Thus, using this method, theoretical yields of sodium chloride will be calculated for reactions A and B. Once obtained, the *percent yield* of sodium chloride can be determined for both reactions, where

$$\textit{Percent Yield} = \frac{\textit{Experimental Yield}}{\textit{Theoretical Yield}} \times 100$$

Good experimental practices in the lab (with minimum error) generally result in a high percent yield, where the experimental yield closely approaches the theoretical yield.

Procedure

Safety

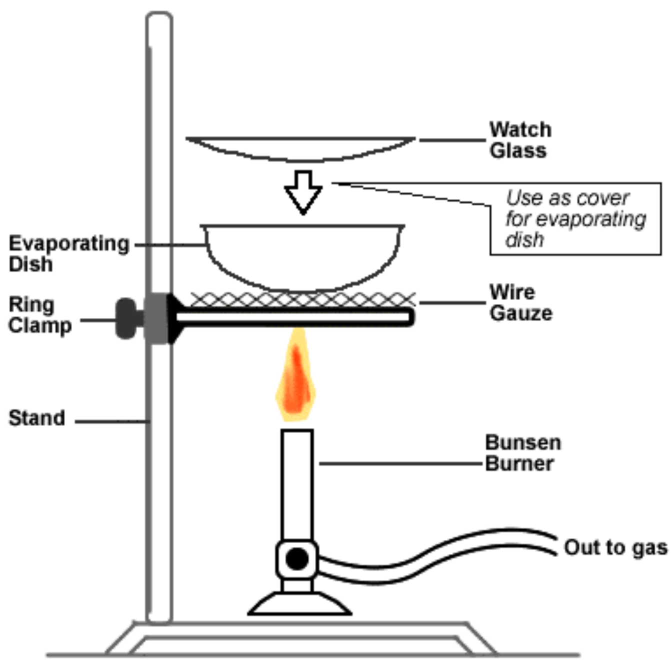
Be especially careful when handling the 6M HCl (*aq*), as it can cause chemical burns to the skin. If any acid spills on you, rinse immediately under running water for up to 15 minutes and report the accident to your instructor. Acid spills may also be neutralized using the sodium bicarbonate solution by the sinks. Also, be sure to exercise appropriate caution when using the Bunsen burner and handling hot equipment.

Materials and Equipment

Solid sodium bicarbonate ($NaHCO_3$), solid sodium carbonate (Na_2CO_3), 6M hydrochloric acid (HCl), electronic balance, evaporating dish, watch glass (to fit as a cover for the evaporating dish), stand and ring clamp, wire gauze, dropper pipette, small beaker, and Bunsen burner.

Experimental Procedure

1. Measure and record the mass of your clean dry evaporating dish + watch glass (assembled together with the watch glass acting as a cover on top of the evaporating dish).
2. Carefully add 0.3 – 0.4 g of solid sodium bicarbonate ($NaHCO_3$) to the evaporating dish. ***Do not do this over the balance!*** Then measure and record the mass of the evaporating dish + watch glass + $NaHCO_3$.
3. Obtain about a 5-mL quantity of hydrochloric acid (HCl) in your small beaker. Then using your dropper pipette, add the HCl ***drop by drop*** to the sodium bicarbonate in the evaporating dish. The reaction will be evident by the bubbling that takes place. Gently mix the reactants after every 4-5 drops of HCl. Continue adding HCl until the bubbling stops and all of the $NaHCO_3$ is dissolved – this indicates that the reaction is complete.
4. Assemble the stand, ring clamp and wire gauze apparatus for heating as shown in the figure below. Cover the evaporating dish with the watch glass and place it on the wire gauze.



5. ***Gently heat*** the solution in the covered evaporating dish with a Bunsen burner flame in order to remove the water generated in the reaction (as well as any excess HCl present). The flame should be adjusted to a lower temperature and wafted under the evaporating dish constantly. Continue heating until the contents are ***completely dry***. Note that the watch glass cover should also be dry!
6. After allowing the evaporating dish to cool to room temperature, measure and record the mass of the evaporating dish + watch glass + residue (NaCl).
7. Repeat steps 1 to 6 with a 0.3 – 0.4 g sample of sodium carbonate (Na_2CO_3).
8. The waste from this experiment may be disposed of in the sink.
9. Analysis: Experimental Mole-to-Mole Ratios – Convert the initial mass of sodium bicarbonate (or carbonate) reactant to moles (via its molar mass). In a similar manner, convert the final mass of collected sodium chloride product to moles (via its molar mass). Finally, obtain the simplest whole number mole-to-mole ratio by dividing both the reactant and product moles by the lower of the two values.
10. Analysis: Percent Yields – Calculate the theoretical yield of NaCl for both reactions A and B via standard mass-to-mass stoichiometry. Use your masses of sodium bicarbonate/carbonate reactants weighed out in lab as the starting point and the mole ratios from the balanced equations for these calculations. Then determine your percent yield for each reaction using the calculated theoretical yields along with your experimental yields of NaCl, obtained in lab. See the Theory Section for the equation, if necessary.