Solution Stoichiometry

INTRODUCTION

Stoichiometry is the calculation of the quantities of substances involved in chemical reactions. In solution stoichiometry, volumes of solutions are measured and quantities calculated using the molarities of the solutions.

Chemical analysis often uses the accurately known molarity of a solution to determine the quantity of a substance present in a sample. The ***solute*** in the solution reacts with the substance in the sample, and as the solution is added to the sample, the reaction is observed. The process of adding one reactant to another while monitoring the completeness of the reaction is called ***titration***. At the ***equivalence point*** of the titration, the amount of solute added precisely matches the amount of substance present. To know when the equivalence point is reached, some observable phenomenon must occur. This is called the ***endpoint*** of the titration.

The acid-base titration will use a standardized solution of NaOH to find the percentage of acetic acid in a sample of vinegar. In analytical work, molarities are usually measured to 3 or 4 significant digits. A solution with an accurately measured molarity is called a ***standardized*** solution. The reaction is:

$$NaOH\ (aq) + CH_3COOH\ (aq) \rightarrow CH_3COO^- Na^+\ (aq) + H_2O\ (l)$$

After enough NaOH is added to react with all of the acetic acid present in the vinegar, addition of more NaOH will cause the solution to turn basic. To be able to observe when this has happened, a small amount of the dye phenolphthalein is added at the beginning of the titration. Phenolphthalein is colorless in acid solutions, vivid pink in basic solutions. It is one of many dyes (called acid-base indicators) that change color depending on the acid-base level of the solution. As soon as the color of the vinegar solution begins to turn pink, addition of NaOH is stopped. Knowing the volume and the strength of the NaOH solution will enable you to find the moles, and hence the mass, of the acetic acid present.

In this experiment, you will use pre-standardized solutions and simple techniques to get an introduction to solution stoichiometry.

Titration is one of the methods used to determine the concentration of an unknown sample. The procedure involves a chemical reaction between two substances, usually an acid and a base. One of the substances is a standard solution, that is, the concentration of the standard solution is known with a high degree of precision. To the mixture is added a substance that changes color when the chemical reaction is complete. This substance is called an **indicator**. The indicator used in this experiment is phenolphthalein. This indicator is colorless in acid solutions and pink in basic solutions. When the indicator changes color, the end point of the titration has been reached.

Titration is defined as the measurement of a volume of standard solution that is needed to completely react with a known volume (or mass) of unknown sample. The unknown sample is often referred to as the **analyte**. Sodium hydroxide is the **standard solution** in this experiment. Vinegar, the analyte, is an aqueous solution of acetic acid whose concentration is unknown. The goal in this experiment is to determine the concentration of vinegar. Let us begin with a balanced chemical equation for the reaction:

$$CH_3COOH(aq) + NaOH\ (aq) \rightarrow CH_3COO^- Na^+\ (aq) + H_2O(l)$$

Chemical formulas are often abbreviated; acetic acid (also written as $HC_2H_3O_2$) is abbreviated as AcOH (or HOAc) and acetate ion ($C_2H_3O_2^{-1}$ or CH_3COO^{-1}) is written as AcO^{-1} (or OAc^{-1}). Thus we can write the acid base reaction as:

$$AcOH(aq) + NaOH(aq) \rightarrow NaOAc(aq) + H_2O(l)$$

This reaction represents a **neutralization reaction** since an acid and base will react (will neutralize each other) to produce water and a salt. Notice in the reaction of acetic acid and NaOH that the stoichiometry between acid and base is 1:1. *The reaction stoichiometry is always part of the calculation in a titration.*

We start the titration by carefully measuring the volume of our analyte (vinegar). The sample of vinegar is added to a clean Erlenmeyer flask and D.I. water is added to dilute the sample. Phenolphthalein is added to this solution and now we are ready to titrate the vinegar (acid) with base.

The base is added using a buret. The buret allows us to carefully measure the amount of base needed to reach the end point. The end point means that the neutralization reaction is complete; in other words, at the end point, the number of moles of acid and the number of moles of base (in the reaction) flask is equal. The end point is obvious since the solution turns pink. Once the **end point** is reached, we must perform some calculations to determine the concentration of our vinegar solution (the analyte).
The concentration of vinegar is obtained using the familiar equation for molarity:

$$\text{Molarity} = \text{mole} / \text{liter}$$

In order to calculate the concentration of vinegar, we need the volume and the number of moles in the 25.00 mL sample that we measured at the beginning of the experiment. Of course we have the volume of vinegar since we used the volumetric pipet to transfer the analyte. The number of moles of vinegar is calculated from the standard solution (base). Remember that since the stoichiometry is 1:1, the number of moles of vinegar (acid) is equal to the number of moles of base at the end point.

We obtain the number of moles of base by rearranging the molarity equation:

$$\text{mole base} = (\text{Molarity base}) \times (\text{liter base})$$

Since moles of base equal moles of acid at the end point:

$$\text{mole base} = \text{mole acid}$$

the concentration of acid can be calculated:

$$\text{Molarity acid} = \text{mole acid} / \text{liter acid}$$

Name _____________________________________ Date _______ Grade ____

Pre-lab Assignment: A Series of Chemical Reactions
MUST be completed before an experiment is started. The COPY pages will be collected as you enter the lab.

Q1. Calculate the mass of sodium hydroxide needed to prepare 100 mL of a 0.100 *M* solution.

Q2. Calculate the mass of acetic acid (CH_3COOH, mm = 60 g/mole) needed to react completely with 25 mL of a 0.100 *M* NaOH solution.

Q3. Calculate the molarity of a solution of sodium hydroxide if 23.64 mL of this solution is needed to neutralize 0.5632 g of acetic acid.

Q4. It is found that 24.68 mL of 0.1165 *M* NaOH is needed to titrate 0.2931 g of an unknown monoprotic acid to the equivalence point. Calculate the molar mass of the acid.

EXPERIMENTAL PROCEDURE

Safety: Be especially careful with acids and bases. Wear your goggles at all time.
To avoid contaminating standardized solutions, ***NEVER stick the pipets and/or pour the excess solutions back into the stock containers.***

Procedure:
You will measure the volume of standardized NaOH 1.0 M solution by adding it from a graduated cylinder into a flask containing tested sample using a transfer pipet. To avoid contaminating standardized solutions, the following procedures are applied.

1) Place about 20 mL of standardized NaOH solution in a 50-mL plastic beaker and bring it to your work place
2) Rinse the transfer pipet with deionized water.
3) Draw up a small amount of standardized solution into the transfer pipet, rotate to rinse all of the inner surface, then discard the solution into the disposal beaker. Repeat.
4) Rinse the graduated cylinder with deionized water and allow it to drain.
5) Add 2 mL of the standardized solution, and while rotating the cylinder, allow the solution to rinse the walls of the cylinder as you pour the solution out into the disposal beaker. Repeat.
6) Fill the cylinder with the standardized NaOH solution. This cylinder does NOT need to read 10.00 mL, since we measure volumes by difference. Read the initial volume to the nearest 0.01 mL and record it on the data sheet.
7) Record the molarity of the standardized NaOH solution in the data table.
8) Weigh about 0.8 grams of vinegar into the 50-mL flask. (Zero out the flask weight, then add vinegar until about 0.8 gram is on the display.) Record the mass of the vinegar.
9) Add about 20 mL of deionized water, using the mark on the flask to monitor the volume. Then add 2 drops of phenolphthalein solution.
10) Use the transfer pipet to add the NaOH solution dropwise from the graduated cylinder into the flask containing vinegar until the permanent faint pink caused by the excess unreacted OH^- ions interacting with the phenolphthalein.
11) Squirt any unused solution from the transfer pipet back into the graduated cylinder. 12) Read the volume of solution in the cylinder, and record to the nearest 0.01 mL as the final volume in the data table.
13) ***Dispose of these solutions in the "Waste Bottle".***
14) Repeat steps 6 -13 until you get 2 consistent data sets.
15) Clean up the equipment and the work space. Then proceed with the calculations.

Solution Stoichiometry

Name ______________________________ Date ________

Partner's Name __________________________

DATA

1) Molarity of NaOH solution: ____________ M

	Run 1	**Run 2**	**Run 3 (if needed)**
2) Mass of vinegar	________ g	________ g	________ g
3) Initial volume of NaOH	________ mL	________ mL	________ mL
4) Final volume of NaOH	________ mL	________ mL	________ mL

CALCULATIONS (Show your work)

5) Volume of NaOH used	________ mL	________ mL	________ mL
6) Moles of NaOH used	________ mol	________ mol	________ mol
7) Moles of CH_3COOH in vinegar sample	________ mol	________ mol	________ mol
8) Mass of CH_3COOH in vinegar sample	________ g	________ g	________ g
9) % of CH_3COOH in vinegar sample	________ %	________ %	________ %

10) Average % of CH_3COOH in vinegar sample: ________ %

Name ________________________________ **Date ________** **Grade ____**

Post-Laboratory Questions and Exercises
(Due after completing lab. Answer in space provided)

Q1. Consider the following and briefly explain what would be the effect on the calculated analyte concentration; i.e., why would the calculated analyte concentration be higher or lower (or unchanged) than the actual value if:

a. the last drop of base was not rinsed from the buret into the reaction flask?

b. the reaction flask contained traces of water in it before the acid was added with the volumetric pipet?

c. The volumetric pipet used to transfer the acid solution contained traces of water?

Q2. Look on the vinegar bottle label to find the % acetic acid listed. Find the % deviation of your result from the label. Notice how many significant digits there are in the numerator after the subtraction. This will limit the digits in the % value.

$$\%deviation = \frac{|\,Experimental\% - Labeled\%\,|}{Labeled\%} x100$$

Q3. The 20 mL of water added to the flask serves as the medium in which the reaction takes place. If 50 mL were added instead of 20, your results would be the same. Explain why varying this volume does not change the result.

Q4. What would you do to improve the accuracy of the analysis you performed today? To answer, look at the calculations. Which numbers used in the calculations have the fewest number of significant digits? What would you do to get more significant digits for these numbers? (It is a constant assumption that if you were more careful, your results would be better, so please do NOT use the "more careful" cliché in your answer.)

Q5. Predict the effect each of the following situations would have on the reported % acetic acid in vinegar. Would the value be higher, lower, or unaffected as compared to the true value? Explain.

a) You overshoot the endpoint.

b) You spill some of the vinegar solution in the flask while swirling the flask during the titration.

c) You did not dry the flask in which you placed the standardized NaOH solution.

Q6. The following data was collected for the titration of 0.145 g of a weak monoprotic acid with 0.100 *M* NaOH as the titrant:

Volume of NaOH added, mL	0.00	5.00	10.00	12.50	15.00	20.00	24.00	24.90	25.00	26.00	30.00
pH	2.88	4.15	5.58	4.76	4.93	5.36	6.14	7.15	8.73	11.29	11.96

(a) Use computer graphing software to graph pH vs. volume of NaOH.

(b) Analyze your graph. What is volume of NaOH required to reach the equivalence point?

(c) What is the pH at the equivalence point?

(d) Calculate the molar mass of the weak monoprotic acid?

(e) Give the K_a and pK_a value of the acid. Justify your answer.