Unknown Acid Molecular Weight Determination by Equivalent Weight Method

Introduction

For most reactions, there is no certain method in which to attain the stoichiometric relationships between reactants and products except to write out a balanced reaction. On the other hand, acid-base reactions are such that they allow chemists to bypass the balanced equation in most cases.

In acid-base neutralization reactions, acids provide protons (H^+) and bases provide hydroxide ions (OH^-). Regardless of the acid-base combination, however, the NET ionic equation for the neutralization reaction is ALWAYS exactly the same:

$$H^+ + OH^- \rightarrow H_2O$$

Let's suppose that 36 grams of an acid, e.g., HCl, was able to furnish specifically one mole of protons, and a base, e.g., NaOH, one mole of hydroxide ions. Since one mole of acid reacts with one mole of base, as presented in the neutralization reaction, above, we now know that 36 grams of acid is exactly enough to react with 40 grams of the base (how do we know 40 grams?). It is possible to do this without knowing what the particular acid or base is. All we absolutely have to know is how much of the acid donates 1 mole of protons and how much base it requires to give one mole of hydroxide ions.

The type of reasoning we have just developed constitutes the basis of defining a chemical quantity called the equivalent, which is abbreviated Eq. The specific definition depends on whether the reaction is an acid-base reaction or a reduction-oxidation reaction. For the purposes of this laboratory experiment, we shall limit ourselves to the acid-base type of reactions. The definition of an equivalent in either reaction, however, is such that equivalents always react in/on a one-to-one ratio. This key concept is summarized in the table, below:

1 Eq of reactant A reacts with exactly 1 Eq of reactant B

The next question is how shall we define equivalents for acids and bases? The definitions are in the box, below:

One equivalent of an acid is the amount of acid that is able to furnish one mole of protons.
One equivalent of base is the amount of base that is able to furnish one mole of hydroxide ions.

Now let's examine applications of our definitions to some real acids and bases. Let's use as examples for acids, HCl and H_2SO_4. One mole of HCl is enough to provide one mole of H^+, therefore, one MOLE of HCl must be EQUIVALENT to one equivalent of HCl. Conversely, ONE mole of H_2SO_4 is enough acid to provide TWO moles of H^+, IF the sulfuric acid is completely neutralized. In other words, ONE mole of sulfuric acid must be equal to TWO equivalents of H^+ (See table, below).

1 mole HCl = 1 Eq H^+
1 mole H_2SO_4 = 2 Eq H^+

There is, therefore, a relationship between moles and equivalents for acids: the number of equivalents in one mole of any acid is equivalent to the number of protons that are neutralized when one molecule of the acid reacts.

The number of equivalents in any base may be determined in a likewise manner, although the focus is now on the hydroxide groups. Let's look at NaOH and $Ba(OH)_2$, as examples. NaOH provides one mole of OH^-, so an equivalent of sodium hydroxide is the same as one mole of NaOH. One mole of barium hydroxide is able to provide two equivalents of base (See table, below).

1 mole NaOH = 1 Eq OH^-
1 mole $Ba(OH)_2$ = 2 Eq OH^-

Thus, we may now define what an equivalent for bases is: the number of equivalents in one mole of the base is equal to the number of hydroxides in one formula unit of the base.

In using equivalents, it is most helpful to know the mass of an equivalent of each of the reactants. Earlier we discussed a scenario where we used 36 grams of an acid to provide 1 mol (abbreviation for mole) of H^+ and 40 grams of a base provided 1 mol of OH^-. The given quantities each corresponded to one equivalent of acid and base. Knowing this likeness establishes a mass relationship between the two reactants, which may be utilized in stoichiometric relationships.

The weight in grams of one equivalent is called the equivalent weight. Determining the value for a specific chemical is done most simply using the molecular weight and having prior knowledge of the number of equivalents per mol.

Example:

PROBLEM: calculate the equivalent weight of aluminum hydroxide ($Al(OH)_3$), assuming it will be completely neutralized when it reacts.

SOLUTION: The formula weight (molecular weight) of aluminum hydroxide is 88 g/mol. Therefore, 1 mol of $Al(OH)_3$ has a mass of 88 grams. For complete neutralization,

1 mol $Al(OH)_3$ = 3 Eq OH^-

therefore,

1 Eq $Al(OH)_3$ = 0.33 mol $Al(OH)_3$

Since 0.33 mol $Al(OH)_3$ has a mass of 29.33 grams,

1 Eq $Al(OH)_3$ = 29.33 grams $Al(OH)_3$

We could also work this problem with the factor label method and start thusly:

1 Eq $Al(OH)_3$ = ? grams

To solve this, we multiply conversion factors to manipulate the equation to grams:

$$\frac{1eq\ Al(OH)_3\ (1mol\ Al(OH)_3)(88\,grams\ Al(OH)_3)}{(3\,Eq\ Al(OH)_3)(1mol\ Al(OH)_3)} = 29.33\,g\ Al(OH)_3$$

The short version to remember is:

$$Eq.Wt. = \frac{Molecular\ weight}{number\ of\ equivalents\ per\ mol}$$

In previous experiments and problem sets, the term MOLARITY has been used to express the concentration of a solution. If you recall, since MOLARITY is equal to the number of moles of the solute per liter of solution, the number of moles of the solute may be determined by simply multiplying MOLARITY by VOLUME in liters. This concept allows us to provide the number of moles in some container or reaction to a given volume. We have now learned of another unit which allows us to express MASS AMOUNTS in a new unit which is similar to moles: EQUIVALENTS. If moles are similar to equivalents, then MOLARITY must have a likewise similar unit. This unit is called NORMALITY (N), and is expressed as the number of equivalents per liter of solution, table, below:

$Molarity = \dfrac{moles\ of\ solute}{L\ of\ solution}$
$Normality = \dfrac{Equivalents\ of\ solute}{L\ of\ solution}$

If there is a solution which is expressed as 1 N (**1 NORMAL**), this would mean that there is 1 equivalent of the solute per liter of solution. One would suspect that since normality and molarity are similar that there is a relationship between the two concentration units. This is the case, indeed, table, below:

$N = Mx$
N = Normality
M = Molarity
X = the number of either H+ OR OH-

The relationship between the two units relies upon the number of protons or hydroxide ions present in the acid or the base.

Let us take, for example, HCl and H_2SO_4. Using the above equation, if each acid is 0.5 M, the respective normalities are 0.5 and 1 N. This is because there is only one H^+ in HCl and 2 H^+ in H_2SO_4. Likewise, if we were to look at 1 M solutions of NaOH and $Ca(OH)_2$, their normalities would be 1 and 2 N, respectively. This is due to the numbers of OH^- groups.

Now that we have this information, what do we do with our new concepts of equivalents, equivalent weights and normality? For this lab, we will utilize these concepts to determine the equivalent weight of an organic acid, and then identify the organic acid.

The application of this information is by using titration endpoint data. The overlying concept is that the amount of titrant added to a solid or solution is EQUAL in amount to what is being analyzed. Therefore, the product of the titrant's normality and volume is equal to the product of the analyte's normality and volume:

$$N_1V_1 = N_2V_2$$

For this laboratory experiment, then, knowing the mass of the organic acid and the equivalents of the titrant added to reach neutrality, the equivalent weight is easily calculated:

$$Eq.Wt. = \frac{Mass\ of\ acid\ in\ grams}{Eq\ of\ base\ added}$$

Experimental

Obtain enough 0.1 N NaOH to mostly fill your buret. Mass out about 0.05 grams of oxalic acid dihydrate and place it in an Erlenmeyer flask -- do this step 3 time with three different flasks. Record your data in the data table, below. Once all three flasks have the solid acid in them, add about 25 mL distilled water to each flask and allow the acid to dissolve. After solvation, add a couple of drops (gtts) of phenolphthalein to the solution and begin titrating the acid to its endpoint as in the antacid neutralization lab experiment. This means that you have to get the NaOH, find the buret, and clamp and ring stand and review last week's experiment to see how to get set up).

Be certain to record the mass of your acid on the data sheet!!!! Be certain to record your starting volume and final volumes in your buret on your data table before and after each titration (you'll have 3).

Perform this experiment in triplicate to determine the average molecular weight of the acid. Once you have determined the equivalent weight of your organic acid, multiply your value times the number of protons that are on the formula on the label on the bottle from which you obtained your acid. Enter this new value on your data table. In order to determine how close your experimental data is to the value on the bottle, calculate the per cent error.

Data Handling

DATA					
		TRIAL 1	TRIAL 2	TRIAL 3	Sample Calculation -- you show me
Row 1	Mass of oxalic acid dihydrate (g)				None
Row 2	Corrected mass of oxalic acid dihydrate (mg)				
Row 3	Final volume of NaOH (mL)				
Row 4	Initial volume of NaOH (mL)				
Row 5	Volume of NaOH used (mL)				
Row 6	Normality of NaOH				
Row 7	Eq of OH-				
Row 8	Eq of H+				
Row 9	Eq Wt of oxalic acid				
Row 10	Molecular weight of oxalic acid				
Row 11	Average molecular weight of oxalic acid				
Row 12	Molecular weight of oxalic acid on bottle				
Row 13	Per cent error		$\frac{(Exp\,MW)-(Bottle\,MW)}{Bottle\,MW}$*100		

Laboratory Exercises

Complete the questions on separate paper and attach them to this experiment for turn-in.

1. If you used 60 mL of a 0.5 N NaOH solution to neutralize 45 mL of an acid, what is the normality of the acid?
2. 0.5 grams of an unknown acid were titrated to neutrality with 25 mL of 0.25 N KOH. What is the equivalent weight of the unknown acid?
3. If a solution of phosphoric acid (H_3PO_4) is 0.5 M, what is its normality?
4. The molecular weight of sulfuric acid (H_2SO_4) is 98.0 g/mol.

- What is its equivalent weight?
- How much solid NaOH would be required to neutralize 25 mL of 18 M H_2SO_4? The MW of NaOH is 40 g/mol.

Source: Carman, F.S. III: GenChem II: Inorganic Chemistry -- An Inorganic Lab/Data Book and Qualititative Analysis Primer. (W.C. Brown: Dubuque) © 1994, p. 24.

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