Neutralization reaction*

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Neutralization reaction refers to acid and base reaction producing salt and water. The equivalent amounts of acid react with base to form equivalent amounts of salt and water. When the reaction is complete, acid and base are said to neutralize each other. Since water is produced, neutralization reaction is also referred as "water forming reaction".

$$\text{acid} + \text{base} \rightarrow \text{salt} + \text{water}$$

Consider reaction like :

$$NaOH + HCl \rightarrow NaCl + H_2O$$

We can rewrite the reaction in ionic form as :

$$Na^+\,(aq) + OH^{-1}\,(aq) + H^+\,(aq) + Cl^-\,(aq) \rightarrow Na^+\,(aq) + Cl^-\,(aq) + H_2O$$

Essentially, neutralization reaction is double displacement reaction. Some definitions used in the study of neutralization reaction are :

Equivalence point : The state of acid base reaction when acid and base react in exact equivalent amounts as determined theoretically.

End point : The state of acid base reaction when acid and base react in exact equivalent amounts as determined practically (during titration). Clearly, end point volume measurement is slightly greater than that corresponding to equivalence point.

Neutral point : The state of acid-base reaction when product solution is neutral (pH=7).

The ionic salt formed from the reaction of strong acid $[H_2SO_{4,}HCl, HNO_{3,}H_3PO_4]$ and strong base $\left[NaOH, KOH, Mg(OH)_{2,}Ca(OH)_2\right]$ are pH neutral. Also, water is pH neutral. As such, strong acid and strong base reaction yields neutral products or product solution. In this case, equivalence and neutral points are same.

However, salts formed with other combinations like "strong acid - weak base" and "weak acid - strong base" are not neutral. They produce salts, which are either acidic or basic in nature. As such, pH of the product solution is not 7. Here, equivalence point is not same as neutral point.

$$H_2SO_4\,(\text{strong acid}) + 2NH_4OH\,(\text{weak base}) \rightarrow (NH_4)_2SO_4\,(\text{acidic salt}) + 2H_2O$$

$$CH_3COOH\,(\text{weak acid}) + NaOH\,(\text{strong base}) \rightarrow CH_3COONa\,(\text{basic salt}) + H_2O$$

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We refer acid-base reaction as neutralization reaction even though products are not neutral (pH=7). As a matter of fact, product solution is acidic (pH<3) for strong acid –weak base reaction. We need to add more of base solution beyond equivalence volume to make the product solution neutral. Similarly, product solution is basic (pH>7) for weak acid-strong base reaction. Here, we need to add more acid beyond equivalence volume to make the product solution neutral.

1 Titration

The acid-base reaction involves completion of reaction in equivalent proportion of solutes in the solutions. The experimental process to study proportion of reacting volumes and calculation of mass/ concentration of solution is known as "titration". Completion of reaction is known by chemical indicator or by other means depending on the type of reaction involved. We shall study details of titration process separately.

2 Analyzing neutralization reaction

We treat neutralization reaction on similar footing as other reactions. Generally, it involves reaction between two solutions of certain concentrations. Clearly, it is helpful to describe analysis in terms of molarity or normality. For a generic consideration :

$$mA_1 + nA_2 \rightarrow pA_3 + qA_4$$

In terms of moles, we have :

$$\text{m moles of} \quad A_1 \equiv \text{n moles of} \quad A_2 \equiv \text{p moles of} \quad A_3 \equiv \text{q moles of} \quad A_4$$

$$mM_1V_1 \equiv nM_2V_2 \equiv pM_3V_3 \equiv qM_4V_4$$

Consideration in molarity gives a relation that needs to be analyzed using unitary method. It is important to realize that this is not a relation which are not connected with "equal to (=)" sign. In terms of gram equivalents (geq), we have :

$$\text{geq of} \quad A_1 = \text{geq of} \quad A_2 = \text{geq of} \quad A_3 = \text{geq of} \quad A_4$$

$$N_1V_1 = N_2V_2 = N_3V_3 = N_4V_4$$

Consideration in normality gives a relation that are connected with "equal to (=)" sign. It is so because constituents react in the proportion of equivalent weights. As such, gram equivalents are equal. Clearly, analysis involving normality is relatively easier to handle.

Example 1

Problem : A 25 ml of nitric acid taken from a stock volume of 1 litre neutralizes 50 ml of 0 .1N NaOH solution. Determine the mass of nitric acid in the stock volume.

Solution : Let us denote nitric acid and sodium hydroxide by subscripts "1" and "2" respectively. Applying neutralization equation,

$$N_1V_1 = N_2V_2$$

$$\Rightarrow N_1X25 = 0.1X50$$

$$\Rightarrow N_1 = \frac{5}{25} = 0.2$$

The normality of sample and the stock volume is same. Hence, normality of 1 litre stock volume is 0.2N. Using formula,

$$\Rightarrow \text{geq} = NV = 0.2X1 = 0.2 = \frac{g_B}{E} = \frac{xg_B}{M_O}$$

Valence factor of nitric acid is 1 as it has one furnishable hydrogen. Therefore,

$$\Rightarrow g_B = \frac{0.2M_O}{x} = \frac{0.2X\left(1+14+3X16\right)}{1} = 12.6 \quad gm$$

2.1 Successive neutralization

In this case, data of two or more neutralization reactions is analyzed to determine unknown concentration of solution.

Example 2

Problem : 18 ml of 0.1N H_2SO_4 is neutralized by 20 ml of a NaOH solution. On the other hand, 10 ml of oxalic acid is required to neutralize the same volume of NaOH solution. Determine the mass of oxalic acid crystals $\{(COOH)_2.2H_2O\}$ used.

Solution : A solution of known concentration of sulphuric acid neutralizes sodium hydroxide solution of unknown concentration. Applying neutralization equation, we determine normality of sodium hydroxide solution :

$$N_1V_1 = N_2V_2$$

$$\Rightarrow 0.1X18 = N_2X20$$

$$\Rightarrow N_2 = \frac{1.8}{20} = 0.09N$$

Now, a solution of known concentration of sodium hydroxide neutralizes oxalic acid solution of unknown concentration. Again applying neutralization equation, we determine normality of oxalic acid solution :

$$N_1V_1 = N_2V_2$$

$$\Rightarrow 0.09X20 = N_2X10$$

$$\Rightarrow N_2 = \frac{1.8}{10} = 0.18N$$

Using formula,

$$\Rightarrow \text{geq} = NV = \frac{0.19X10}{1000} = \frac{1.9}{1000} = 0.0019 = \frac{g_B}{E} = \frac{xg_B}{M_O}$$

Valence factor of oxalic acid is 2 as it has two furnishable hydrogens. Therefore,

$$\Rightarrow g_B = \frac{0.0019M_O}{x} = \frac{0.0019X\{2X\left(12+2X16+1\right)+2X18\}}{2} = 0.1197 \quad gm$$

2.2 Dilution and neutralization

The resulting solution of two or more solutions or diluted solution is neutralized by other solution.

Example 3

Problem : 5 ml each of 2N hydrochloric and 3N nitric acids volumes are mixed with a certain volume of 5N sulphuric and the resulting solution is made up to 1 litre. A volume of 25 ml of this solution neutralizes 50 ml of sodium carbonate solution containing 1 gm of $Na_2CO_3.10H_2O$ in water. Determine the volume of sulphuric acid in the mixture.

Solution : A combination of different acids are used here. The mixture is then diluted up to 1 litre. Let the volume of sulphuric acid used is x ml. Here, milli-gram equivalents of the mixture is :

$$\Rightarrow \text{meq} = 5X2 + 5X3 + 5x = 25 + 5x$$

Applying equation of dilution,

$$N_1V_1 = N_2V_2$$

$$\Rightarrow 25 + 5x = N_2X1000$$

$$\Rightarrow N_2 = \frac{25 + 5x}{1000}$$

We see here that normality of acid solution has one unknown. 25 ml of diluted acid neutralizes 50 ml of sodium carbonate solution. Clearly, we need to calculate normality of sodium carbonate used. We see here that strength of sodium carbonate solution is given (1 gm/50 ml = 20 gm/l). Using relation,

$$S = NE$$

The valence factor of sodium carbonate is 2 as its cation or anion has 2 electronic charge.

$$\Rightarrow N = \frac{S}{E} = \frac{xS}{M_O} = \frac{2X20}{(2X23 + 12 + 3X16 + 10X18)} = \frac{40}{286} = 0.14N$$

Now, using neutralization equation :

$$N_1V_1 = N_2V_2$$

$$\Rightarrow \frac{25 + 5x}{1000}X25 = 0.14X50$$

$$\Rightarrow 25 + 5x = 0.28X1000 = 280$$

$$\Rightarrow 5x = 280 - 25 = 255$$

$$\Rightarrow x = \frac{255}{5} = 51 \quad ml$$

2.3 Neutralization of oleum

Oleum is concentrated sulphuric acid and free suplhur trioxide (SO_3). When SO_3 reacts with water, it produces sulphuric acid.

$$SO_3 + H_2O \rightarrow H_2SO_4$$

It means that SO_3 molecule is equivalent to sulphuric acid in the presence of water. Thus, neutralization of base with oleum acid will follow the equivalence as :

$$\text{geq of} \quad H_2SO_4 + \text{geq of} \quad SO_3 = \text{geq of} \quad base$$

Example 4

Problem : 1 gm of oleum is diluted in water. The resulting solution requires 45 ml of 0.5N sodium hydroxide solution for neutralization. Determine the mass of free SO_3 in the oleum.

Solution : Let mass of SO_3 in oleum is x. Then, mass of sulphuric acid in the oleum is 1-x. We can find gram-equivalents of the sulphuric acid and oleum provided we know valence factors. The valence factor of each of them is 2. Hence, equivalent weights of sulphuric acid and Sulphur trioxide are 98/2=49 and 80/2=40 respectively. Applying neutralization equation,

$$\text{geq of} \quad H_2SO_4 + \text{geq of} \quad SO_3 = \text{geq of} \quad base$$

$$\frac{1-x}{49} + \frac{x}{40} = NV = \frac{0.5X45}{1000} = \frac{22.5}{1000}$$

$$\Rightarrow 40 - 40x + 49x = 49X40X\frac{22.5}{1000} = 44.100$$

$$\Rightarrow 9x = 4.41$$

$$\Rightarrow x = \frac{4.41}{9} = 0.5 \quad gm$$