CALCULATIONS AND SOLUTIONS

Water is a polar molecule having properties of cohesion and adhesion with high specific heat. It has maximum density at 4°C important for water life. It is a Universal solvent of life because it can dissolve almost everything in it due to strong hydrogen bonding and highly polar characteristics.

Solution:

A solution is a homogenous mixture of two or more than two chemical substances having uniform composition throughout. For example, a solution of orange juice.

A solution usually has two parts

Solvent: The substance which has the capacity to dissolve other chemical substances (solutes)

Solutes: A solute is a substance which has the property to dissolve in solvent and usually in smaller quantity. For examples a solution of sugar containing water as a solvent and sugar is a solute.

Binary solution:

The solution which contains one solute and one solvent is called binary solution. For example sucrose dissolves in water.

Multi solute Solution:

The solution which contains more than one solutes and one solvent is called multi solution. For example Pepsi and 7 up drinks.

Concentrated solution:

The solution in which solvent is in small quantity as compared to the solute. For example rectified spirit which contains 95% ethanol in which solute (ethanol) is in larger amount as compared to distilled water acts as a solvent.

Dilute solution:

The solution in which solute is in small quantity as compared to the solvent. For example 5% $CuSO_4$ solution which contains 5g of $CuSO_4$ solute which is in smaller amount as compared to distilled water which acts as a solvent.

Concentration of the Solution

The concentration of the solution is defined as the amount of solute present in known quantity of the solution.

Mostly the concentration of the solutions is expressed in following ways.

1. Percentage solutions
2. Normal solutions
3. Molar solutions
4. Molal solutions

PERCENTAGE SOLUTIONS

The amount of solute present in 100 parts of solution is called percentage solution.

There are three major types of percentage solutions

Weight by weight percentage (W/W %):

The weight of solute in grams present in 100 parts of weight of solution is called weight by weight percentage solution. A 50% solution of weight by weight percentage means 50 g solute dissolves in 50 g of solvent, final weight of solution becomes 100g means 50 %.

$$\text{Weight/Mass percentage} = \frac{\text{Mass of solute (g)}}{\text{Mass of solution (g)}} \times 100$$

Mass or Weight by Volume percentage (W/V %):

The weight of solute in grams present in 100 parts of volume (mL) of solution is called Weight by Volume percentage solution. A 50% solution of weight by volume percentage means 50 g by weight of solute dissolve in volume of solvent and makes the final volume up to 100 mL of solution.

$$\text{Weight/Volume percentage} = \frac{\text{Mass of solute (g)}}{\text{Volume of solution (mL)}} \times 100$$

Volume by Volume percentage (V/V %):

The volume of solute in millimeter present in 100 parts of volume (mL) of solution is called Volume by Volume percentage solution. A 50% solution of volume by volume percentage means 50 mL by volume of solute dissolve in solvent and makes the final volume up to 100 of solution.

$$\text{Volume /Volume percentage} = \frac{\text{Volume of solute (mL)}}{\text{Volume of solution (mL)}} \times 100$$

Note: In all percentage solutions; percentage is checked in solution not in solvents.

Solubility is the amount of solute that can be dissolved in a given amount of solvent.

Non-quantitative terms: this means it does not contain any numbers but is based on relative strengths.

- Unsaturated solution: the solution can dissolve more solute.
- Saturated solution: the solution contains the maximum amount of solute than solvent or solution has incapable to dissolve more solute.
- Supersaturated solution: the solution contains more solute than a saturated solution. This is very unstable condition and slight disturbance causes the excess solute to settle out.

Note: All of these are temperature dependent. A solution that is saturated at 25^{o}C may be unsaturated at 45^{o}C.

NORMAL SOLUTIONS (N)

Normality:

It is the numbers of equivalents dissolve in 1 dm^3 or liter of solution. It is represented by capital N.

Normality = n x Molarity

n = number of replaceable H ions and OH ions in case of acids and bases and number of cations in case of ionic compound.

$$\text{Normality} = \frac{\text{No. of equivalents}}{\text{1 Litre of solution}}$$

$$\text{Normality} = \frac{\text{Mass of solute}}{\text{Equivalent mass of solute}} \times \frac{1}{\text{1 Litre of solution}}$$

$$\text{Equivalent mass of solute} = \frac{\text{Formula mass of solute}}{\text{No. replaceable H or OH or cations}}$$

If the Molarity of sulfuric acid is 2 M, then what is its normality?

$$H_2SO_4 \longleftrightarrow 2H^+ + SO^{-2}_4$$

Normality = n x Molarity

Whereas n responds to

- The number of moles of H^+ or OH^- ions replaced in a chemical reaction.
- The number of replaceable H^+ or OH^- ions in a compound.
- The number of moles of electrons transferred in a chemical reaction (red-ox).

Normality = 2 x Molarity

Normality = 2 x 2 = 4 N

MOLAR SOLUTIONS (M)

Molarity: It is the numbers of moles of solute dissolve in 1 dm^3 or 1 Litre of solution. It is represented by capital M. One molar solution means 1 mole of solute dissolve in one Litre of solution.

Note:

1 dm^3 = 1000mL or 1000 cm^3

1 Litre = 1000mL or 1000 cm^3

$$\text{Molarity} = \frac{\text{moles of solute}}{\text{Liters of solution}}$$

$$\text{No. of Moles} = \frac{\text{Mass of solute}}{\text{Formula mass}}$$

$$\text{Molarity} = \frac{\text{Mass of solute}}{\text{Formula mass}} \times \frac{1}{\text{1 Litre of solution}}$$

MOLALITY

It is the numbers of moles of solute dissolve in 1 Kg of solvent. It is represented by small m. One molar solution means 1 mole of solute dissolve in one Kilogram of solvent.

Stock Solution:

A solution which has maximum known concentration is called stock solution.

Dilution Formula:

The dilution formula is used to dilute a concentrated stock solution (these stock solutions are concentrated so as to save room during storage and costs in shipping) to a desired concentration.

$$C_1V_1 = C_2V_2$$

C_1 = the initial concentration C_2 = the final concentration

V_1 = the initial volume V_2 = the final volume

OSPE QUESTIONS:

1. What is the Molarity of sodium hydroxide when 20 g of NaOH dissolve in 500 mL of solution?
2. What is the Normality of sulfuric acid when 49 g of H_2SO_4 dissolve in 200 mL of solution?
3. The stock solution of hydrochloric acid has molarity 12M. Then make 2 M solution of HCl for 100 mL of solution.
4. Define the following terms
   a) Molar solution
   b) Normality

1. Make 1 M Sodium hydroxide (NaOH) solution for 100 mL?
Calculations

1. What is the percentage of 0.1M of sodium chloride (NaCl) when prepare in 20 mL of solution?
Calculations:

Buffers:

A solution which resists any change of pH when a small amount of a strong acid or a strong base is added to it is called a buffer solution or simply as a buffer. Alternatively, a buffer solution may be defined as a solution whose pH value does not change appreciably upon the addition of small amounts of a strong acid, base and/or water from outside. Thus, buffers have reserve acidity and reserve alkalinity.

Buffer solutions usually consist of a mixture of a weak acid and its salt with a strong base e.g., CH_3COOH and CH_3COONa, or that of a weak base and its salt with a strong acid e.g., NH_4OH and NH_4Cl. The solution of any salt of a weak acid and a weak base **e.g.,** ammonium acetate, also shows buffering property.

Types of Buffers

There are two types of buffers, **acid buffer and basic buffer**.

Acid buffer: A buffer solution containing a weak acid, and its salt with a strong base, is termed as an acid buffer. Such buffer solutions have pH on the acidic side i.e., pH is less than 7 at 298 K. The pH of an acid buffer is given by the equation.

$$pH = pKa + \log \frac{[salt]}{[acid]}$$

Whereas Ka is the acid dissociation constant of the weak acid

Basic buffer: A buffer solution containing relatively large amounts of a weak base and its salt of a strong acid is termed as a basic buffer. Such buffers have pH on the alkaline side i.e., pH is higher than 7 at 298 K.
The pOH of a basic buffer is given by the equation:

$$pH = pKb + \log \frac{[salt]}{[base]}$$

Where K_b is dissociation constant of the weak base
These equations are called **Henderson equation.**

Buffer-capacity and Buffer-range

The effectiveness of any buffer is described in terms of its buffer capacity. It is defined as, 'the number of equivalents of a strong acid (or a strong base) required to change the pH of one Litre of a buffer solution by one unit, keeping the total amount of the acid and the salt in the buffer constant'.
The body's chemical buffer system consists of three individual buffers: the carbonate/carbonic acid buffer, the phosphate buffer and the buffering of plasma proteins. While the third buffer is the most plentiful, the first is usually considered the most important since it is coupled to the respiratory system.

Carbonic acid (H_2CO_3) is a weak acid and is therefore in equilibrium with bicarbonate (HCO_3^-) in solution. When significant amounts of both carbonic acid and bicarbonate are present, a buffer is formed. This buffer system can be written as:

$$H_2CO_3 + H_2O \longleftrightarrow H_3O^+ + HCO_3^-$$

Under normal circumstances there is much more bicarbonate present than carbonic acid (the ratio is approximately 20:1). As normal metabolism produces more acids than bases, this is consistent with the body's needs. The blood, with its high base concentration, is able to neutralize the metabolic acids produced. Since relatively small amounts of metabolic bases are produced, the carbonic acid concentration in the blood can be lower. Since carbonic acid is not stable in aqueous solutions some of it decomposes to form carbon dioxide and water. The respiratory system is responsible for removing the carbon dioxide.

$$H_2CO_3 \longleftrightarrow H_2O + CO_2$$

By combining the two reactions of carbonic acid we can write:

$$2\, H_2O + CO_2 \longleftrightarrow H_2CO_3 + H_2O \longleftrightarrow H_3O^+ + HCO_3^-$$

It is the production of carbon dioxide from this reaction that couples the carbonic acid/bicarbonate buffer to the respiratory system.

Derivation of Henderson Hassel Bach Equation

Acid dissociation in solution

$$HA \longleftrightarrow H^+ + A^-$$

According to the law of mass action

$$Ka = \frac{[H^+] \times [A]}{[HA^-]}$$

Rearranging the equation

$$Ka \times [HA] \ [A^-] = [H^+]$$

Multiplying the both sides by Log

$$\text{Log } Ka + \text{Log } [HA] - \text{Log } [A^-] = \text{Log } [H^+]$$

According to the logarithms rule

$$\text{Log } Ka + \text{Log } [HA] / [A^-] = \text{Log}[H^+]$$

By taking negative sign on both sides

$$-\text{Log } Ka - \text{Log } [HA] / [A^-] = -\text{Log}[H^+]$$

We know from the knowledge of acid and bases

$$pKa - \text{Log } [HA] / [A^-] = pH$$

Rearranging the equation

$$pH = pKa - \text{Log } [HA] / [A^-]$$

According to rule of the Mathematics

$$pH = pKa + \text{Log } [A^-] / [HA]$$

So $[A^-]$= salt concentration [HA] = acid concentration

$$pH = pKa + \text{Log } [salt] / [acid]$$

This is called Henderson Hassel Bach Equation

This equation is to determine the

- pH of solution
- pKa of solution
- salt and acid concentration

Practical; Make a 1M phosphate buffer solution whose pH= 7.4 and pKa value is 7.2 for 500 mL of solution.

Suppose salt = x

Buffer = acid + salt

1 = acid + x

Acid = 1 – x

Acid $NaH_2PO_4.2H_2O$ Molecular weight = 156

Salt $Na_2HPO_4.2H_2O$ Molecular weight = 178

Putting the values in Henderson Hassel Bach Equation

$$pH = pKa + \text{Log } [salt] / [acid]$$

$$7.4 = 7.2 + \text{Log } x / 1-x$$

$$7.4 - 7.2 = \text{Log } x / 1-x$$

$0.2 = \text{Log } x / 1-x$

Anti Log 0.2 = $x / 1-x$

$1.58 = x / 1-x$

Cross multiplying

$1.58 \text{ X } 1-x = x$

$1.58 - 1.58x = x$

$1.58 = x + 1.58x$

$1.58 = x(1 + 1.58)$

$1.58 = x(2.58)$

$1.58 / 2.58 = x$ (salt)

Salt = 0.612 M

Acid = 1 - x

Acid = 1 – 0.612 = 0.388 M

Molarity of acid = mass of acid/formula mass of acid x 1 Litre of solution

0.388 = mass of an acid / 156 x 0.5

Mass of an acid = 0.388 x 156 x 0.5 = 30.25 g

Molarity of salt = mass of salt/formula mass of salt x 1 Litre of solution

0.612 = mass of an salt / 178 x 0.5

Mass of an salt = 0.612 x 156 x 0.5 = 54.45 g

We take 30.25 g of $NaHPO_4.2H_2O$ (acid) and 54.45 g (salt) dissolved in distilled water and make final volume up to 500 mL with distilled water then phosphate buffer of 7.4 pH is ready for use to maintain the pH.

Teacher Signature: ________________ ***Date:*** _______________