Chapter 6

# SOLUTIONS

## CONCEPTUAL LINKAGE

Before reading this chapter, the student must know the,

- Type of mixtures
- Matter and its states
- Moles and its determination

## TIME ALLOCATION

Teaching periods = 16

Assessment periods = 02

Weightage = 13%



## LEARNING OUTCOMES

After reading this chapter, the Student will be able to:

- Define the terms solution, solute and solvent with examples. (Remembering)
- Explain the differences between saturated, unsaturated and super saturated solutions. (Analyzing)
- Explain the formation of solutions (mixing gases into gases, gases into liquids, gases into solids) and give an example of each. (Understanding)
- Explain the formation of solutions (mixing liquids into gases, liquids into liquids, liquids into solids) and give an example of each. (Understanding)
- Explain the formation of solutions (mixing solids into gases, solids into liquids, solids into solids) and give an example of each. (Understanding)
- Explain what is meant by the concentration of a solution. (Understanding)
- Define Molarity. (Remembering)
- Define percentage solution. (Remembering)
- Solve problems involving the Molarity of a solution. (Applying)
- Describe how to prepare a solution of a given Molarity. (Applying)
- Describe how to prepare dilute solutions from concentrated solutions of known Molarity. (Applying)
- Convert between the Molarity of a solution and its concentration in $g/dm^3$. (Applying)
- Use the rule that "like is dissolved by like" to predict the solubility of one substance in another. (Understanding)

## 6.1 Solutions

In our daily life we often deal with a variety of mixtures where the components are mixed for different uses, such combinations are called solutions.

In this chapter we will study such solution mixtures in a little detail.

A solution is defined as the homogenous mixture of two or more substances.

A solution consists of two parts, the solute, and the solvent. The solute is that part which is lesser in quantity, while the solvent is that which is larger in quantity. For example, in the aqueous solution of sugar syrup in water, the sugar is the solute and the water is solvent, similarly when 10g of wax is dissolved in 100ml of benzene, the wax is solute and the benzene is solvent.

Generally in our daily routine we deal with many solutions, mostly prepared in the water solvent, such water solutions are called aqueous solutions. In a solution the components show their own properties, this makes the solution different from compound in which the components lost their properties.

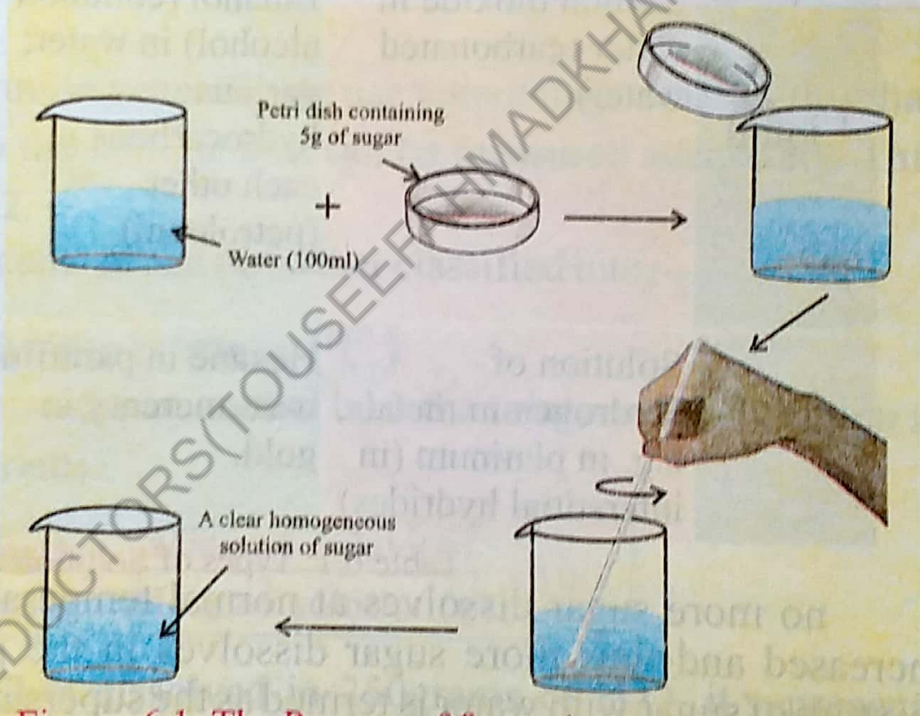


Figure: 6.1: The Process of formation of sugar solution

## 6.2 Saturated, Unsaturated and Supersaturated Solutions

A solution could be unsaturated, saturated or supersaturated. The unsaturated solution, as the name indicates is that solution which can dissolve further solute on addition at room temperature, e.g. when you put a spoon of sugar in a glass of water and still there is possibility of dissolving more sugar in normal conditions, this solution is the unsaturated solution of sugar. The saturated solution is that in which no further addition of the solute is possible at normal conditions of temperature, pressure, e.g. in the above example of sugar solution when you mix more sugar and a stage come when no more sugar dissolves further, this is the saturated solution. While the supersaturated solution is the solution in which more of the solute have been dissolved by increase in temperature (or pressure sometimes), e.g. in above

| Solvent | Solution | | |
|---|---|---|---|
| | Gas | Liquid | Solid |
| Gas | Oxygen and other gases in nitrogen (air) | Water vapor in air (humidity) | Smoke |
| Liquid | Carbon dioxide in water (carbonated water) | Ethanol (common alcohol) in water; various hydrocarbons in each other (petroleum) | Sucrose (table sugar) in water; sodium chloride (table salt) in water; gold in mercury, forming an amalgam |
| Solid | Solution of Hydrogen in metals, e.g. in platinum (in interstitial hydrides) | Hexane in paraffin wax, mercury in gold. | Steel, duralumin, other metal alloys |

Table 6.1: Types of Solutions

no more sugar dissolves at normal temperature then temperature is increased and thus more sugar dissolves in the given water, this heated mixture of sugar with water is termed as the supersaturated

## 6.3 Types of Solutions

In a solution, the parts may be in the same phase or in different phases. The table 6.1 shows the 9 different types of phases present in a solution, with examples.

## 6.4 Concentration Units

Concentration of a solution is the amount of the solute in the given quantity of

***Practical Activity***

Using the help of your teacher in the laboratory prepare unsaturated, saturated and super saturated solutions of table salt (NaCl) in 100ml of water and observe the difference between each.

solvent/solution. It gives us the exact strength of a solution. For representing the concentration of solution following units are used frequently,

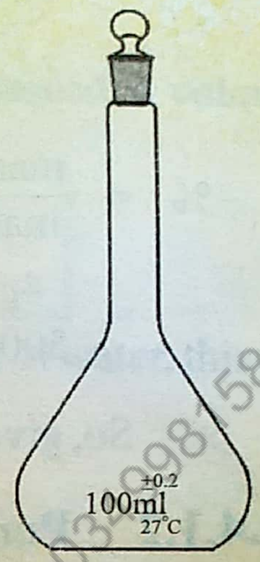

Figure: 6.2
Volumetric flask

### 6.4.1 Percentage (composition)(%)

The percentage means parts out of hundred. The idea of percentage is very useful in calculating and understanding the constitution of a solution, for example, a 20% solution of sucrose means that the solution contains 20:80 constitution of the solution where the solute is 20 parts and the solvent is 80 parts. (or simply as the 20g sucrose in a solution whose final volume is 100ml).

For preparing a solution generally we use volumetric flasks, this has a long narrow neck so the volume in it can be measured accurately. This flask is shown in figure 6.2.

The concept of percentage can be further classified into:--

#### 6.4.1.1 Percentage by mass/mass $\left(\frac{m}{m}\right)$

In this type of solution the amount of both the solute and the solution is expressed in the units of grams.

$$\%\text{by}\ \frac{\text{mass}}{\text{mass}} = \frac{\text{Mass of solute(g)}}{\text{Mass of solution(g)}} \times 100$$

e.g., if 10 grams of NaCl is dissolved in 250grams of $H_2O$, it represents $\frac{\text{mass}}{\text{mass}}$ relation between the solute and the solvent.

**Example 6.1**

Find out the % of a solution that has 4g of glucose dissolved in 500g of water:

**Solution:** Here 4g of glucose has been dissolved in 500mg of water, so $\frac{\text{mass}}{\text{mass}}$ relationship exists;

The % of solution can be determined by applying formula:

$$\% = \frac{\text{mass of glucose}}{\text{mass of solution}} \times 100$$

$$= \frac{4g}{500g} \times 100 = 0.8\%$$

So, given solution has 0.8%

### 6.4.1.2 Percentage by mass/volume $\left(\frac{m}{v}\right)$

This involves the measurement of solute in mass units (grams) and of solution in volume units ($cm^3$ or ml).

$$\% \text{by } \frac{\text{mass}}{\text{volume}} = \frac{\text{Mass of solute(g)}}{\text{Volume of solution}(cm^3)} \times 100$$

For example, if 10g of Glucose is dissolved in 1 litre of water, this relation is $\frac{\text{mass}}{\text{volume}}$.

**Example 6.2**

Calculate percentage of NaCl in a solution which has been prepared by dissolving 8g of NaCl in 250ml of water.

Solution: In this example the mass/volume relation exists and the percentage of this solution can be determined by applying the formula:

$$\% = \frac{\text{mass of solute}}{\text{volume of solution}} \times 100$$

by putting up the values in the above formula and solving the problem we will get the required result.

$$\% = \frac{\text{mass of solute}}{\text{volume of solution}} \times 100$$

$$= \frac{8\ g}{250ml} \times 100 = 3.2\%$$

So, given solution has 3.2% of NaCl

### 6.4.1.3 Percentage by volume/mass ($^{v}/_{m}$)

In such type of solutions the amount of solute is expressed in volume unit and of solution in mass units.

$$\%\text{ by }\frac{\text{volume}}{\text{mass}} = \frac{\text{Volume of solute}(cm^3)}{\text{Mass of solution}(g)} \times 100$$

For example, if 10ml of alcohol is dissolved in 100gms of water, this is the $\frac{\text{volume}}{\text{mass}}$ relation.

**Example 6.3**

In a face cream recipe 6ml of almond oil has been mixed in petroleum jelly to get 50g of total mixture solution. Find out the percentage of almond oil in this cream.

Solution: In this example the solute has been measured in volume unit and solution is in a grams. So the relation here is volume/mass.

the solved this example we will use the following formula:

$$\text{Percentage} = \frac{\text{Volume of solute}}{\text{Mass of solution}} \times 100$$

$$\text{Percentage} = \frac{6\text{ml}}{50\text{g}} \times 100 = 12\%$$

So, given solution mixture has 12% of almond oil.

### 6.4.1.4 Percentage by volume/volume ($^{v}/_{v}$)

In such type of solutions the amount of both the solute and the solution are expressed in volume units.

$$\%\text{ by }\frac{\text{volume}}{\text{volume}} = \frac{\text{Volume of solute}(cm^3)}{\text{Volume of solution}(cm^3)} \times 100$$

***Activity 6.1***

For the preparation of vinegar 30ml of acetic acid has been dissolved in water to make the total volume of mixture one litre. Calculate the percentage of $CH_3COOH$ (acetic acid) in this vinegar mixture.

For example, this relation is observable in case when 10ml of alcohol is dissolved in 100ml of water.

### 6.4.2 Molarity (M)

This is the unit which is used frequently for well description of a solution's components. Molarity is the number of moles of a solute dissolved per litre of a solution, e.g. 0.1M NaCl solution means that 0.1 moles of NaCl (5.85g) dissolved in 1 litre of aqueous solution.

$$\text{Molarity (M)} = \frac{\text{number of moles of solute}}{\text{Volume of solution in Litre}}$$

### 6.4.3 Problems involving the Molarity of a Solution

In order to calculate the molarity of a solution or the amount of solute in molar quantity above formula is used:

$$\text{Molarity} = \frac{\text{Moles}}{\text{Amount of solution in litre}}$$

Or more simplified form of this formula is:

$$\text{Molarity} = \frac{\text{Mass of solute}}{\text{Molecular mass of solute} \times \text{Amount of solution in litre}}$$

This is further explained by the help of following example:

**Example: 6.4:** Calculate amount of NaOH required to prepare its 0.1M solution in 500ml of water.

**Solution:** As we know that the molarity calculations involve the use of formula:

$$\text{Molarity} = \frac{\text{Mass of solute}}{\text{Molecular mass of solute} \times \text{Amount of solution in litre}}$$

Or

$$\text{Mass of Solute} = \text{Molarity} \times \text{Molecular mass of solute} \times \text{Amount of solution in litre}$$

By inserting values in this formula

$$\text{Mass of Solute} = 0.1 \times 40 \times 0.5 \text{ (lit)}$$

$$\text{Mass of Solute} = 2\text{gms}$$

So, if 2 grams of NaOH is dissolved in 500ml of water it will give 0.1M solution of NaOH.

**Activity: 6.2**

How will you prepare a 250 ml of a solution of 0.5M $NaHCO_3$?

## 6.5 Dilution of Solutions

Although we often make solution for any purpose, but many times we are provided with some prepared solutions and we just have to fix its molarity or percentage as per our requirements, for this purpose we have to dilute the solutions up to the desired level, this process is called dilution of solution.

The dilution of a solution is brought about by using a simple relationship that is present among the required and the given solutions, this relation is given by the expression,

$$M_1V_1 = M_2V_2$$

Where $M_1$ and $V_1$ are molarity and volume of dilute solutions while $M_2$ and $V_2$ are molarity and volume of concentrated solutions.

$V$ = Volume

1 and 2 represents the provided and required solutions.

**Example 6.5:** What is the volume of HCl required to prepare 500ml of 0.1M solution from the commercially provided 36M HCl acid?

**Solution:** This process requires the dilution process. The formula that will work is:

$$M_1V_1 = M_2V_2$$

Here $M_1$ = Molarity of commercial HCl = 36M

$V_1$ = Volume of commercial HCl = ?

$M_2$ = Molarity of required HCl = 0.1M

$V_2$ = Volume of required HCl = 500 ml

So, by inserting values in the given formula, we get

$$M_1V_1 = M_2V_2$$

$$36 \times V_1 = 0.1 \times 500$$

$$V_1 = 1.39 \text{ ml}$$

**Activity: 6.3**

Prepare a solution of 0.5M $H_2SO_4$ from the commercially provided 12M solution in 400 ml quantity.

**Activity: 6.4**

Prepare a solution of 200ml of 2% glucose from 10%.

It means that when we take 1.39ml of commercially provided HCl, and then make its volume upto 500ml, it will be solution of desired strength and quantity, i.e. 0.1M in 500ml.

Same relation is used for the preparation of solutions from the percentage values.

## 6.6 Solubility

Solubility is defined as the amount of a substance which is able to dissolve in the given quantity of a solvent at a particular temperature.

Normally in the solubility, the amounts of both the solute and the solvent are taken in the units of grams, thus it can also be defined as the number of grams of a solute which are soluble in 100gm of solvent.

Solubility is related with many factors, of which the nature of solute and solvent are very important, a general phenomenon which is observed during solubility is that like is dissolved by the like, this means that polar solute are soluble in polar solvent and non polar solutes are soluble in non polar solvents, thus NaCl is soluble in water (both are polar) and petroleum jelly is dissolvable in benzene (both are non polar).

Further more temperature also plays an important role in determining solubility; this will be discussed in detail later in this chapter.

### 6.6.1 Solute-solvent interaction during Solubility

As described earlier that a general phenomenon works in formation of solutions, i.e. like is dissolved by like. This is due to development of attractive forces among the solute and the solvent particles, and the resultant product of the process has lower stabilizing energy, so the solution is formed.

The process of solubility involves ionization of solute (in the polar solvents), in a manner that each cation is captured by negative poles of solvent and anions by positive poles of solvent. The process is known as salvation or solvolysis. This process of solvolysis between NaCl and $H_2O$ is shown in figure 6.3.

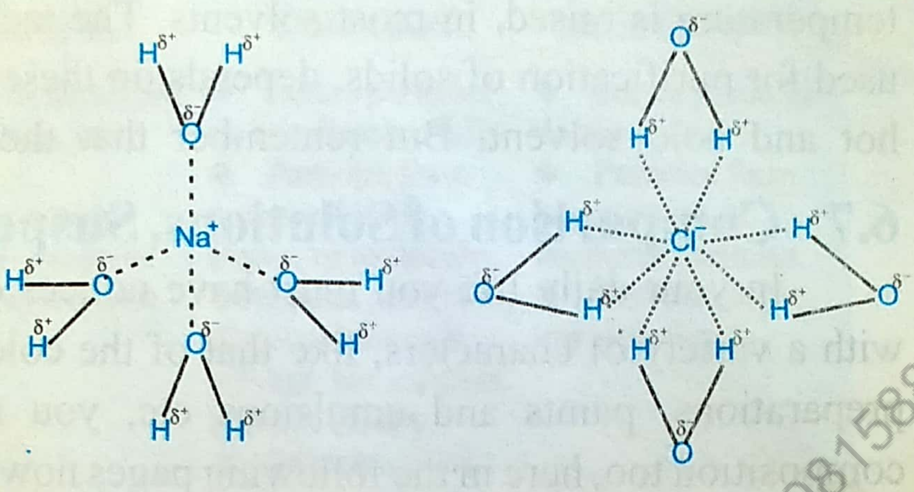


Figure 6.3: Solute – solvent interaction forces in sodium chloride solvolysis

## 6.6.2 Solubility and the Temperature

The solubility of a given solute in a given solvent generally depends upon the temperature. For around 95% of solid solutes, the solubility increases with temperature, but the gaseous solutes, the temperature increase usually decreases solubility in water, and solubility increases in the organic solvents mostly.

The given graph in figure 6.4 shows solubility curves for some typical inorganic salts (all solids).

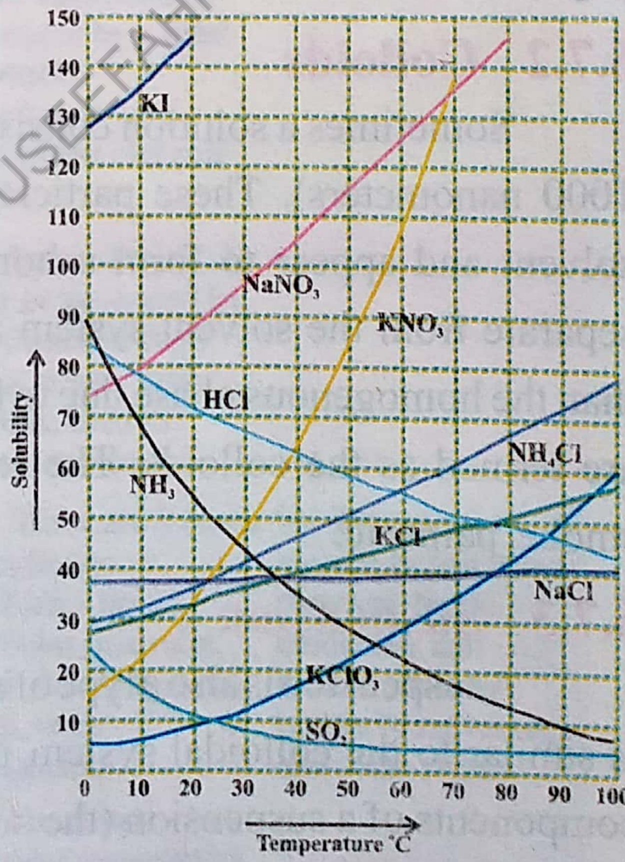


Figure 6.4: Relation between Solubility and Temperature

It can be seen here that many salts like sodium nitrate and potassium nitrate show a large increase in solubility with temperature. Some solutes (e.g. NaCl in water) are fairly independent of temperature. A few, such as HCl, $NH_3$ become less soluble in hot water. Organic compounds nearly always become soluble as the temperature is raised, in most solvents. The technique of recrystallization, used for purification of solids, depends on these differences in solubility in hot and cold solvent. But remember that there are always exceptions.

## 6.7 Comparison of Solutions, Suspension and Colloids

In your daily life you must have notices different types of solutions with a variety of characters, like that of the cold drinks, sugar syrup, drug preparations, paints and emulsions etc, you must have observed their composition too, here in the following pages now we will make you aware of the interesting features and differences among these in the scientific view,

### 6.7.1 Solution

Solution or a typical completely miscible form of solution is actually the best regarded true form of solution that we have described in the previous pages.

### 6.7.2 Colloids

Sometimes a solution consists of bigger solute particles, (between 2 to 1000 nanometers). These particles although are evenly distributed in the solvent and appear to form a homogenous mixture, but over a time they separate from the solvent system and form a heterogeneous mixture rather than the homogenous phase due to having a bigger solute size. Such solutions are termed as the colloids. The examples of such colloids are blood, fog, smoke, paint etc.

### 6.7.3 Suspension

A suspension is also a type of solution which is in heterogeneous phase. It is similar to the colloidal system in many ways, but unlike the colloids the components of a suspension (the solute) seems always separated through the solvent system, whereas in the colloids, the solute get separated over a time period. The particle size of suspension is greater than 1000nm.

The solution of flour in water (sattu) and mud in water are the common examples of suspensions. Many of the medicinal solutions are marketed as a

| | SOLUTIONS | COLLOIDS | SUSPENSIONS |
|---|---|---|---|
| COMPOSITION | ♦ solute particles have dissolved to the point of ions, atoms, or molecules<br>♦ solute particles are evenly dispersed throughout the solvent Particles do not settle down with time. | ♦ Solute particles do not dissolve fully<br>♦ Particles form groups of ions, atoms, or molecules.<br>♦ Particles are evenly dispersed through solvent, but solution appears cloudy<br>♦ Particles do not settle out with time | ♦ Solute particles do not dissolve<br>♦ Particles form large groups of insoluble particles.<br>♦ Particles settle out with time |
| SIZE | ♦ Particles are too small to see with naked eye (less than 1 nanometer = 0.000000001 m) | ♦ Particles are usually not seen by naked eye (1 - 1000 nanometers) | ♦ Particles can be seen with naked eye (larger than 1000 nm) |
| SEPARTION | ♦ Solute particles will pass through a paper filter and a semi permeable membrane; cannot be separated except through distillation | ♦ Solute particles will pass through a paper filter; can be separated by a semi permeable membrane, i.e., cellophane and cell walls | ♦ can be easily separated by filtering |
| OTHER | ♦ May be dilute or concentrated; May be unsaturated, saturated, or supersaturated.<br>Degree of saturation is dependent on temperature; ex, more sugar will dissolve when tea is hot) | ♦ Parts of a colloid may be separated by an ultracentrifuge (spin at very high speeds; used to separate blood) | |
| TYPES | ♦ There are 9 types of solutions, based on the solute (1st) and the solvent (these are also discussed in table 6.1)<br>solute — solvent — example<br>gas — gas — air<br>gas — liquid — soda water<br>gas — solid — hydrogen in Pt<br>liquid — gas — water vapor in air<br>liquid — liquid — alcohol in water<br>liquid — liquid — silver amalgam<br>solid — gas — sulfur vapor in air<br>solid — liquid — sugar in water<br>solid — solid — brass | ♦ There are 3 types of colloids:<br>(a) Gels - liquid particles in a solid, flow slowly (gelatin, jelly, stick deodorant)<br>(b) Emulsions - two liquids (mayonnaise, hand cream, milk)<br>(c) Aerosols - solid or liquid in a gas (fog, smoke, paint-spray can) | ♦ Examples include Italian salad dressing, liquid medicines that require shaking before being taken; and some paints. |

suspension, which are also labeled as "suspension" and instructed to be well shaken before use. Ice cream is also a suspension of ice crystals in cream.

The following table 6.2 brings the summary of differences between these three types.

## SUMMARY OF THE CHAPTER

- Solution is a homogeneous mixture of two or more substances.
- Solution is not a pure substance, and its composition varies in different types.
- The component of solution which is lesser in quantity is called solute.
- The component of solution which is greater in quantity is called solvent.
- Solution may be unsaturated, saturated and super saturated, depending upon the amount of solute and temperature.
- If more solute can be added in a solution then the solution is called unsaturated solution.
- If no more solute can be dissolved further in making of a solution, then the solution is called saturated solution.
- When more solute is added to in a solution by increasing the temperature, then the solution is said to be super saturated solution.
- Solution can be formed in all states of matter, thus there are 9 different types of solutions which are formed.
- The strength of a solution is represented by various means, like in percentage, molarity etc.
- The percentage composition of a solution describes the parts of solute per hundred parts of solution.
- Molarity of a solution gives the number of moles of solute dissolved per liter of solvent; it is symbolized as "M".
- Generally increase in temperature increases the solubility of a solute,

but the solutions of gases do not follow this rule.

- The solution mixture in which size of particles ranges from 1-1000nm is called the **colloid** or **colloidal solution**.
- The solution mixture in which size of particles is greater than 1000nm is called the **suspension**. Some times the particles in suspension can even be seen w.th naked eye.

## EXERCISE

**Q1. Fill in the blanks with appropriate words.**

i) A solution is the ............ type of mixture.

ii) Strength of a solution in mole/litre is called .............

iii) The solute-solvent interaction in dissolution process is termed as .............

iv) Generally heating ............ the solution formation.

v) Milk of magnesia is the example of ............

vi) The solute is that part of solution which is ............ in quantity.

vii) In ............ solution no more quantity of solute can be dissolved at normal temperature.

viii) In dissolution process, a general rule of solubility is that ............ dissolves like.

ix) ppm stands for .............

x) The solubility of gases ............ with increase in temperature.

**Q2. Choose the correct answer.**

i) The solvent is the part of solution which is:
(a) more in quantity (b) less in quantity
(c) equal in quantity (d) does not depend on quantity

ii) The heterogeneous mixtures where the particle size of solute is larger than 1200nm is called:
(a) solution (b) colloids

(c) buffers (d) emulsion

iii) In dissolving table salt, heating accelerates the solvolysis.

(a) true (b) false

(c) both statements are false (d) both statements are true

iv) The air is a solution:

(a) true (b) false

(c) both statements are false (d) both statements are true

v) Steel is the type of solution having:

(a) liquid-solid composition (b) liquid-liquid composition

(c) solid-solid composition (d) solid-gas composition

## Q3. Answer the following questions in short.

i) What is the difference between unsaturated, saturated and super saturated solutions?

ii) Draw a picture to show that what happens when an ionic substance is added to water to dissolve?

iii) Why NaCl is dissolved easily in cold water but not in heated cooking oil?

iv) What types of solutions can form? Example of each type.

v) What is meant by molarity?

vi) Explain dilution of solutions with an example.

vii) Explain the term suspension?

viii) What are colloids?

ix) Compare advantages and disadvantages of percentage and molarity over each other.

x) What would happen if solubility of oxygen in water increased one thousand times?

## Q4. Answer the following questions with reasoning.

i) Which of the following expected to dissolve in $H_2O$ and why?

(a) Alcohol, (b) Hydrocarbon, (c) NaCl, (d) Iron

ii) Explain why some liquids are miscible in one another which other liquids are immiscible.

iii) Why it is necessary to bubble air through an aquarium?

iv) Why solubility of gases decreases with an increase in temperature?

v) Explain how can you obtain pure solute from a solution by adding more solute to the solution.

Q5. Define the term solution? How the solutions form.

Q6. Discuss various concentration units?

Q7. Calculate the molarity of a solution of $NaHCO_3$ that contains 50gm of $NaHCO_3$ in 250ml of water.

Q8. Find out the amount of glucose required to prepare its 0.5M solution in 500ml of water.

Q9. How the temperature effects the solubility process?, give examples to prove your statements.

Q10. How would you differentiate between the solution, suspension and colloids?