SLO 7: Solutions

7.1 Introduction to Solutions

7.1.1 Exemplify The Following Terms:

1. **Solvent**: The component of a solution which is present in larger quantity is called solvent.
2. **Solute**: The component of solution which is present in smaller quantity is called solute.
3. **Solution**: A solution is a homogeneous mixture of two or more substances.
4. **Aqueous solution**: The solution which is formed by dissolving a substance in water.
5. **Non-aqueous solution**: A solution in which the solvent is a liquid other than water.
6. **Residue**: The solid material that remains on the filter paper after a filtration process, separating an undissolved solid from a liquid.
7. **Filtrate**: The liquid (or sometimes gas) that passes through the filter paper during the filtration process.

7.2 Types of Solution According to Phases

7.2.1 Classify Different Types Of Solutions According To The Following Phases:

Solute	Solvent	Example	Solute	Solvent	Example
Gas	Gas	Air	Liquid	Solid	Dental fillings, butter
Gas	Liquid	Carbonated water	Solid	Gas	Dust particles in air
Gas	Solid	Hydrogen in palladium	Solid	Liquid	Saltwater
Liquid	Gas	Mist, fog	Solid	Solid	Alloys like steel
Liquid	Liquid	Alcohol in water			

7.3 Types of Solution According to Concentration

7.3.1 Differentiate Among Saturated, Unsaturated, Supersaturated Solutions

Feature	Unsaturated Solution	Saturated Solution	Supersaturated Solution
Solute Amount	Less than solubility limit	Exactly at solubility limit	More than solubility limit
Stability	Stable	Stable	Unstable
Adding More Solute	Additional solute will dissolve	Additional solute will fall to the bottom	Will make crystals of excess solute
Appearance	Clear	Undissolved solute	Crystals when disturbed
Preparation	Dissolving a small amount of solute in a solvent.	Dissolving solute until no more will dissolve, usually with heating and cooling.	Heating a saturated solution, dissolving more solute, and cooling slowly

7.3.2 Differentiate Between Dilute And Concentrated Solutions

The solutions are classified as dilute or concentrated on the basis of relative amount of solute present in them. Dilute solutions are those which contain relatively small amount of dissolved solute in the solution. Concentrated solutions are those which contain relatively large amount of dissolved solute in the solution. For example, brine is a concentrated solution of common salt in water. These terms describe the concentration of the solution. Addition of more solvent will dilute the solution and its concentration decreases.

7.4 Comparison of Solution, Suspension and Colloid

7.4.1 Compare The Characteristics Of Solutions, Suspensions And Colloids

Property	Solution	Colloid	Suspension
Homogeneity	Homogeneous	heterogeneous micro level	Heterogeneous
Particle Size	less than 1nm in diameter	between 1nm and 1000nm	greater than 1000nm
Visibility	Particles not visible to the naked eye or microscope	Particles visible with microscope	Particles visible to naked eye
Stability	Particles do not settle	Particles do not settle	Particles settle out
Filtration	Cannot be separated	Cannot be separated	Can be separated

7.5 Concentration Units and Dilution of Solutions

7.5.1 Define The Term Molarity

It is a concentration unit defined as number of moles of solute dissolved in one dm^3 of the solution. It is represented by M. Molarity is the unit mostly used in chemistry. It is also known as molar concentration.

$$\text{Molarity (M)} = \frac{\frac{Mass\ of\ solute\ (g)}{Molar\ mass\ of\ solute\ (gmol^{-1})}}{\text{Volume of solution } (dm^3)} = \frac{Number\ of\ moles\ of\ solute}{Volume\ of\ Solution}$$

7.5.2 Solve Problems Based On Molarity Of A Solution

1. A solution is prepared by dissolving 5.844 grams of sodium chloride NaCl in enough water to make a final volume of $500cm^3$. Calculate the molarity of the resulting solution.
2. How many grams of glucose $C_6H_{12}O_6$ are required to prepare $400cm^3$ of a 0.25 M glucose solution?
3. What is the molarity of a solution that contains 0.15 moles of sulfuric acid H_2SO_4 in $250dm^3$ of solution?

7.5.3 Define The Term 'Percentage' As A Unit Of Concentration

Percentage concentration is a unit that expresses the amount of a solute relative to the total amount of the solution, as a fraction of 100. It is a practical, quantitative way to describe a solution's composition.

$$\text{Percentage Concentration} = \frac{\text{Amount of Solute}}{\text{Total Amount of Solution}} \times 100\%$$

7.5.4 Calculate The Percentage Composition Of Different Solutions

% Mass/Mass

This measures the grams of solute per 100 grams of solution.

$$\text{Mass Percentage} = \frac{\text{Mass of Solute (g)}}{\text{Total Mass of Solution (g)}} \times 100\%$$

% Mass/Volume

This measures the grams of solute per 100 milliliters of solution.

$$\text{Mass/Volume Percentage} = \frac{\text{Mass of Solute (g)}}{\text{Total Volume of Solution (mL)}} \times 100\%$$

% Volume/Volume

This measures the milliliters of solute per 100 milliliters of solution.

$$\text{Volume Percentage} = \frac{\text{Volume of Solute (mL)}}{\text{Total Volume of Solution (mL)}} \times 100\%$$

% Volume/Mass

This measures the milliliters of solute per 100 grams of solution.

$$\text{Volume/Mass Percentage} = \frac{\text{Volume of Solute (mL)}}{\text{Total Mass of Solution (g)}} \times 100\%$$

7.5.5 Solve Problems Based On Dilution Of Solutions From Concentrated Solutions Of Known Molarity

Practice work. Do it yourself.

7.6 Factors Affecting Solubility

7.6.1 Define The Term 'Solubility'

Solubility is a physical property of a substance that quantifies the maximum amount of a solute that can dissolve in a specific amount of a solvent at a given temperature and pressure to form a saturated solution.

7.6.2 Explain The Factors That Affect Solubility

The Nature Of The Solute And Solvent ("Like Dissolves Like")

The fundamental principle governing solubility is that substances with similar chemical properties (specifically their polarity) tend to dissolve in one another. This is often summarized by the phrase "like dissolves like."

1. Polar Solvents: Solvents like water and alcohol can dissolve polar or ionic solutes (e.g., table salt, sugar, ethanol) because the strong attraction between the polar molecules of both the solute and the solvent can overcome the forces holding the solute together.
2. Nonpolar Solvents: Solvents like oil, benzene, or paint thinners can dissolve nonpolar solutes (e.g., fats, waxes, grease).
3. Immiscible Substances: Substances with dissimilar properties will not mix to form a solution. For example, oil (nonpolar) does not dissolve in water (polar), leading to separation into two distinct layers.

Temperature

Temperature has a significant and varied effect on solubility, depending on the phase of the solute:

1. Solids in Liquids: For most solid solutes, increasing the temperature of the solvent increases their solubility. The increased thermal energy helps break the bonds in the solid solute more easily. This is why more sugar can dissolve in hot tea than in iced tea. (There are a few exceptions, like cerium sulphate, which becomes less soluble as temperature increases).
2. Gases in Liquids: For all gaseous solutes, increasing the temperature of the solvent decreases their solubility. The gas molecules have more kinetic energy at higher temperatures and are more likely to escape the liquid phase. This is why a warm soda goes flat faster than a cold soda.

Pressure

Pressure primarily affects the solubility of gaseous solutes in liquid solvents:

1. Gases in Liquids: Increasing the partial pressure of a gas above a liquid increases the amount of gas that dissolves in the liquid. This relationship is described by Henry's Law. For example, carbonated

beverages are bottled under high pressure of carbon dioxide. When you open the cap, the pressure is released, the solubility of CO_2 decreases, and the gas rapidly escapes as bubbles.
2. Solids and Liquids in Liquids: Changes in pressure have virtually no effect on the solubility of solid or liquid solutes in a liquid solvent.

7.6.3 Predict The Solubility Of One Substance Into Another Using Like Dissolves Like

The rule of "like dissolves like" is a general guideline used to predict whether one substance (solute) will dissolve significantly into another substance (solvent) based on their molecular polarities. Substances with similar polarities will mix to form a solution, while substances with different polarities generally will not.

Example 1: Water and Ethanol
- Water: Highly polar solvent.
- Ethanol: Polar solute (due to the -OH group).
- Prediction: High Solubility. The polar water molecules can form strong hydrogen bonds and electrostatic attractions with the polar ethanol molecules. This is why alcohol is miscible (mixes completely) with water in any proportion.

Example 2: Water and Oil
- Water: Highly polar solvent.
- Oil (e.g., vegetable oil): Nonpolar substance (composed of long hydrocarbon chains).
- Prediction: Low Solubility. The strong polar attractions between water molecules are much greater than any weak attractions they might have for the nonpolar oil molecules. The substances will repel each other and separate into two distinct layers.

Example 3: Iodine in Water vs. Iodine in Hexane
- Iodine: Nonpolar solute.
- Water: Polar solvent.
- Hexane: Nonpolar solvent.
- Prediction:
  - Iodine in Water: Low Solubility. Nonpolar iodine does not dissolve well in polar water.
  - Iodine in Hexane: High Solubility. Nonpolar iodine readily dissolves in nonpolar hexane.

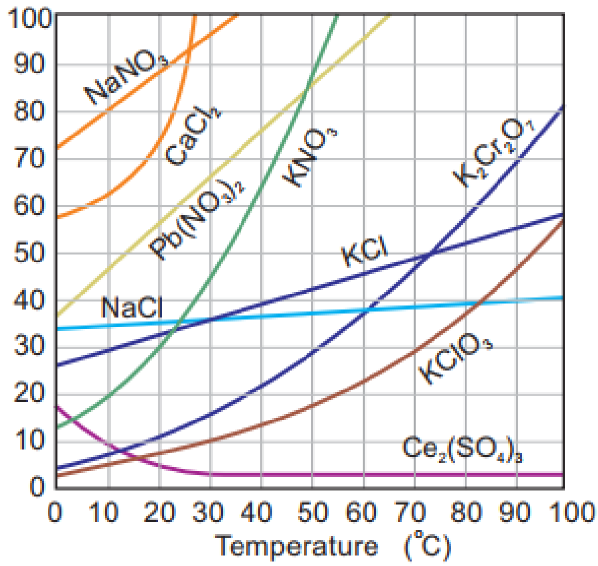
Example 4: Salt in Water
- Table Salt: Ionic (a very polar type of substance).
- Water: Highly polar solvent.
- Prediction: High Solubility. The positively and negatively charged ions of the salt are strongly attracted to the polar ends of the water molecules. Water molecules surround the ions, pulling them into the solution.

7.6.4 Interpret The Effect Of Temperature On The Solubility Of Different Salts

Temperature has major effect on the solubility of most of the substances. Generally, it seems that solubility increases with the increase of temperature, but it is not always true. When a solution is formed by adding a salt in solvent, there are different possibilities with reference to effect of temperature.

Heat Is Absorbed

When salts like KNO_3 , $NaNO_3$ and KCl are added in water, the test tube becomes cold. It means during dissolution of these salts heat is absorbed. Such dissolving process is called 'endothermic'. Solubility usually increases with the increase in temperature for such solutes. It means that heat is required to break the attractive forces between the ions of solute. This requirement is fulfilled by the surrounding molecules. As a result, their temperature falls down and test tube becomes cold.



Heat Is Given Out

When salts like Li_2SO_4 and $Ce_2(SO_4)_3$ are dissolved in water, the test tube becomes warm. i.e. heat is released during this dissolution. In such cases, the solubility of salt decreases with the increase of temperature. In such cases, attractive forces among the solute particles are weaker and solute-solvent interactions are stronger. As a result, there is release of energy.

No Change In Heat

In some cases, during a dissolution process neither the heat is absorbed nor released. When salt like NaCl is added in water, the solution temperature remains almost the same. In such case temperature has a minimum effect on solubility.

7.7 Methods for Separating Mixtures and Purification Techniques

7.7.1 Explain The Following Methods Of Separation And Purification:

Evaporation

This method separates a soluble solid (solute) from a liquid (solvent) by heating the solution until the liquid turns into gas. The liquid is lost to the atmosphere, leaving the solid residue behind.

Filtration

Used to separate an insoluble solid from a liquid. The mixture is passed through a filter medium (like filter paper) that traps the solid particles (residue) while allowing the liquid (filtrate) to pass through.

Crystallization

A purification technique used to obtain pure solid crystals from a solution. The solution is heated to become saturated and then cooled slowly; as solubility decreases, the pure substance forms organized crystals, leaving impurities in the remaining liquid.

Distillation

This process separates a liquid from a solution or from other liquids with significantly different boiling points. The mixture is heated to vaporize the liquid, which is then cooled in a condenser to turn it back into a pure liquid (distillate).

Decantation

A quick but less precise method for separating immiscible liquids or a liquid from a settled solid. The mixture is allowed to settle until layers form, and the top layer is carefully poured off into another container.

Fractional Distillation

Used to separate a mixture of miscible liquids with closer boiling points (typically less than 25°C difference). It uses a fractionating column to allow repeated evaporation and condensation, effectively separating the mixture into different "fractions" (e.g., refining crude oil).

7.7.2 Define The Following Terms:

Chromatography
The technique of using a solvent to separate a mixture into its components is called chromatography. The technique that you have just used is called paper chromatography.

Stationary Phase
This is the substance that does not move during the chromatography process. It acts as a "track" or surface for the mixture to travel over. Example: In paper chromatography, the stationary phase is the paper.

Mobile Phase
This is the solvent (liquid or gas) that moves through or over the stationary phase. It carries the mixture's components along with it. Example: In paper chromatography, the mobile phase is the solvent (like water or ethanol) that travels up the paper.

Chromatogram
The visible result or pattern produced on the stationary phase after the separation is complete. It usually appears as a series of colored spots or peaks that allow you to analyze the different components present in the original mixture.

Locating Agent
A chemical substance (usually a spray) used to make colorless spots visible on a chromatogram. Some substances, like amino acids or sugars, are invisible to the naked eye; spraying them with a locating agent reacts with the spots to produce a color so they can be identified.

Retention Factor (R_f)
the ratio between distance travelled by the substance and the distance travelled by the solvent is a constant. This ratio is called the R_f value of the substance.

$$R, = \frac{distance\ travelled\ by\ the\ substance}{distance\ travelled\ by\ solvent}$$

The R_f value of a substance does not change as long as chromatography is carried out under the same conditions (i.e. same solvent and same temperature).

7.7.3 Apply Paper Chromatography For Separating Mixtures And Isolating Compounds

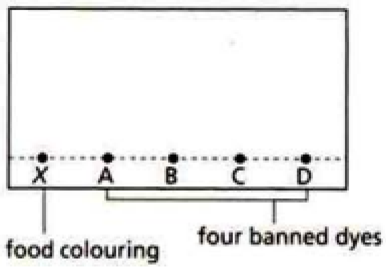
Ink is a mixture of different dyes. A small drop of ink is placed in the center of a piece of filter paper. When the drop has dried up, another drop is added at exactly the same spot and is allowed to dry. Ethanol, which is a solvent, is slowly added drop by drop onto the spot.

- A dye that is not very soluble in ethanol will not be carried far along the paper.
- A dye that is very soluble in ethanol will be carried far along the paper.

The addition of ethanol causes the spot of ink to slowly spread out into different colored rings. Each ring represents a different dye that made up the ink. This is paper chromatography. Paper chromatography can be used to separate dyes in ink, pigments in plants, amino acids obtained from proteins, to identify poisons (e.g. pesticides) or drugs, and to detect traces of banned substances in food.

If the compounds are colorless (like amino acids), spray the dried chromatogram with a locating agent (e.g., ninhydrin) to reveal their positions. To isolate a specific compound, cut out the segment of paper containing the desired spot and dissolve it in a fresh solvent. This pure extract can then be analyzed using tools.

7.7.4 Interpret Chromatograms Using The R_f Equation And Spotting (Locating) Agents To Recognize Components In A Mixture



Paper chromatography is used to separate the dyes in the sample. Each dye can then be identified by comparing its position in the chromatogram with that of a known dye. Each dye can also be identified by comparing its R_f, value with the R_f value of a known dye. Chemists can then check whether the dyes are permitted for use in food.

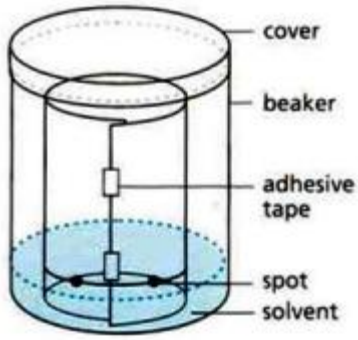
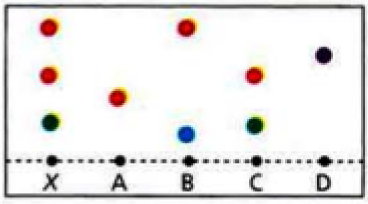


Figure shows a sample of food coloring (labelled 'X) as well as four dyes (labelled 'A', 'B', 'C' and 'D') on a large sheet of chromatography paper. The four dyes are banned because they are not safe to be consumed. We need to determine whether the food coloring contains any of these banned substances. If it does, it is not safe to be consumed.

The sheet of chromatography paper is coiled into a cylinder and secured with adhesive tape. It is put in a beaker containing a suitable solvent. The chromatogram is obtained.



Dyes A and D are pure. Both dye B and dye C are mixtures of two different dyes. Sample X is a mixture of three dyes. Identical dyes produce spots at the same height and in the same colour on the paper when the same solvent is used (as in this case). Figure shows that sample X does not contain the banned dyes A, B and D. However, X contains the banned dye C. Therefore, it must not be consumed.

7.7.5 Predict Techniques For Separating And Purifying Everyday Mixtures.

Everyday Mixture	Technique
Mud from water	Filtration
Salt from water (keep salt)	Evaporation
Salt from water (keep water)	Simple Distillation
Oil from water	Decantation
Alcohol from water	Fractional Distillation
Different colors in ink	Chromatography