Nasima Akter Mukta, PhD
Assistant Professor
Department of MPS, EWU

Solutions & Expressing Concentrations

Objectives

At the end of this, we will be able to

- Know the solutions of different types.
- Explain the several terms that are used to express concentrations of solutions.
- Know how to convert solution concentrations from one way to another.

Contents

- Solutions
- Types of Solutions
- Expressing Concentration of Solutions
- Problems on solution concentrations

Solutions

A mixture of a substances which is uniform in composition and properties throughout is said homogeneous mixture or solution.

- A given solution of sucrose (cane sugar) in water is uniformly sweet throughout the solution, but the sweetness of another sucrose solution

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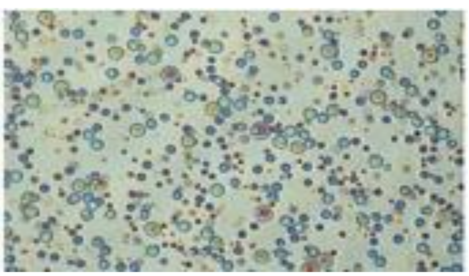
may be rather different if the sugar and water are present in different proportions.

- Air is a homogeneous mixture of several gases, principally the elements nitrogen and oxygen.
- Seawater is a solution of the compounds water, sodium chloride (salt), and a host of others.
- Gasoline is a homogeneous mixture of dozens of components.

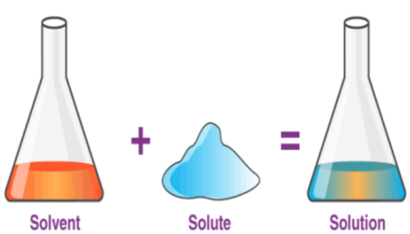
In heterogeneous mixtures sand and water, for example the components separate into distinct regions. Thus, the composition and physical properties vary from one part of the mixture to another.



Homogenized milk is a heterogeneous mixture

- Salad dressing
- A slab of concrete
- Leaf of a plant.

A solution is a homogenous mixture which mainly comprises two components namely solute and solvent.



A solution can be categorized into several components.

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- In solid solutions, solute and solvent are in the solid-state. Ceramics and polymer blends.
- In liquid solutions, solid, gas or liquid is mixed in a liquid state.
- Gaseous solutions are usually homogenous mixtures of gases like air.

The solvent is the component that is present in the greatest quantity or that determines the state of matter in which a solution exists. Other solution components, called solutes, are said to be dissolved in the solvent.

Some common solutions-

Solution	Components
Gaseous solutions	
Air	N_2, O_2, and several others
Natural gas	CH_4, C_2H_6, and several others
Liquid solutions	
Seawater	H_2O, NaCl, and many others
Vinegar	H_2O, CH_3COOH (acetic acid)
Soda pop	H_2O, CO_2, $C_{12}H_{22}O_{11}$ (sucrose), and several others
Solid solutions	
Yellow brass	Cu, Zn
Palladium–Hydrogen	Pd, H_2

Types of Solutions

Depending upon the dissolution of the solute in the solvent, solutions can be categorized into **supersaturated solutions, unsaturated and saturated solutions.**

A supersaturated solution comprises a large amount of solute at a temperature wherein it will be reduced, as a result, the extra solute will crystallize quickly.

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An unsaturated solution is a solution in which a solvent is capable of dissolving any more solute at a given temperature.

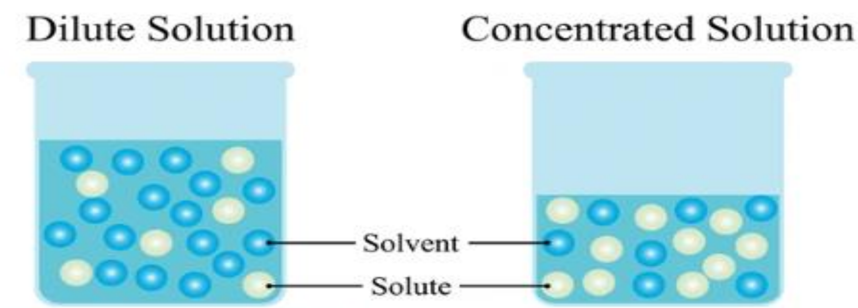
A saturated solution can be defined as a solution in which a solvent is not capable of dissolving any more solute at a given temperature.

The solutions are of two forms, depending on whether the solvent is water or not.

Aqueous solution – When a solute is dissolved in water the solution is called an aqueous solution. E.g. Salt in water, sugar in water, and copper sulfate in water.

Non-aqueous solution – When a solute is dissolved in a solvent other than water, it is called a non-aqueous solution. E.g. Iodine in carbon tetrachloride, sulfur in carbon disulfide, phosphorus in ethyl alcohol.

Solutions are spoken of as having two components, the solvent and the solute. Another classification of the solution depends on the amount of solute added to the solvent.



A dilute solution contains a small amount of solute in a large amount of solvent.

A concentrated solution contains a relatively large amount of solute dissolved in a small amount of solvent.

Consider solutions containing sucrose (cane sugar) as one of the solutes in the solvent water: Pancake syrup is a concentrated solution, whereas a sweetened cup of coffee is much more dilute.

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Concentration of a solution is a measure of the quantity of solute in a given quantity of solvent (or solution).
Several methods of expressing concentration, each of which serves a different purpose-

Mass Percentage (w/w)

When the concentration is expressed as the percent of one component in the solution by mass, it is called mass percentage (w/w).
Suppose we have a solution containing component A as the solute and B as the solvent, then its mass percentage is expressed as
Mass % of A = (Mass of component A in the solution/ Total mass of the solution) ×100
If we dissolve 5.00 g NaCl in 95.0 g, we get 100.0 g of a solution that is 5.00% NaCl, by mass. Mass percent is widely used in industrial chemistry.

Volume Percentage (V/V)

The concentration as a percent of one component in the solution by volume is then called volume percentage. Suppose we have a solution containing component A as the solute and B as the solvent, then its volume percentage is given as
Volume % of A = (Volume of component A in the solution/Total volume of the solution) ×100
For example, 25 % methyl alcohol-water antifreeze solution (freezing point -15.6 °C, by volume) is prepared by dissolving 25 mL CH_3OH (l) in water up to 100 mL in total.

Mass by Volume Percentage (w/V)

It is defined as the mass of a solute dissolved per 100 mL of the solution. Suppose we have a solution containing component A as the solute and B as the solvent, then its mass by volume percentage is given as
% w/V = (Mass of component A in the solution/ Total Volume of the Solution) x 100
An aqueous solution with 0.9 g NaCl in 100.0 mL of solution is said to be 0.9% NaCl (mass/volume). Mass/volume percent is extensively used in the medical and pharmaceutical fields.

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Parts per Million (ppm), Parts per Billion (ppb), and Parts per Trillion (ppt)

- In solutions where the mass or volume percent of a component is very low, we often switch to other units to describe solution concentration.
- For example, 1 mg solute/ L solution amounts to only 0.001 g/ L. A solution that is this dilute will have the same density as water, approximately 1g/ mL therefore, the solution concentration is 0.001 g solute/ 1000 g solution, which is the same as 1g solute/ 1000000 g solution. We can describe the solute concentration more succinctly as 1 part per million (ppm).
- For a solution with only 1µg solute/ L solution, the situation is $1X10^{-6}$ g solute/ 1000 g solution, or 1g solute/ $1X10^{9}$ g solution. Here, the solute concentration is 1 part per billion (ppb).
- If the solute concentration is only 1µg solute/ 1000 L solution or 1g solute/ $1X10^{12}$ g solution, the concentration is 1 part per trillion (ppt).

KEEP IN MIND

that 1 ppm = 1 mg/L,
1 ppb = 1 µg/L, and
1 ppt = 1 ng/L.

These terms are widely used in environmental reporting, they may be more familiar than other units that chemists use.
For example, the maximum contaminant level of water allowed for nitrate ion is 45 ppm, and for carbon tetrachloride is 0.5 ppb reported in a state of USA.

Mole Fraction and Mole Percent

To relate certain physical properties (such as vapor pressure) to solution concentration, we need a unit in which all solution components are expressed on a mole basis. We can do this with the mole fraction.

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The mole fraction of component i, designated x_i is the fraction of all the molecules in a solution that are of type i. The mole fraction of component j is x_j and so on.

The mole fraction of a solution component is defined as

$$x_i = \frac{\text{amount of component } i \text{ (in moles)}}{\text{total amount of all solution components (in moles)}}$$

The sum of the mole fractions of all the solution components is 1.

$$x_i + x_j + x_k + \cdots = 1$$

The mole percent of a solution component is the percent of all the molecules in the solution that are of a given type. Mole percents are mole fractions multiplied by 100 %.

Note: Molarity depends on temperature while mole fraction and molality are independent of temperature.

Molarity (M)

One of the commonly used methods for expressing the concentrations is molarity. It is the number of moles of solute dissolved in one liter of a solution. Suppose a solution of ethanol is marked 0.25 M, this means that in one liter of the given solution, 0.25 moles of ethanol is dissolved.

Molarity (M) = Amount of solute (in moles)/Volume of solution (in liters)

Suppose we prepare a solution at 20 ^{o}C by using a volumetric flask calibrated at 20 ^{o}C. Then suppose we warm this solution to 25 ^{o}C. As the temperature increases from 20 ^{o}C to 25 ^{o}C the amount of solute remains constant, but the solution volume increases slightly (by about 0.1%). The number of moles of solute per liter the molarity decreases slightly (by about 0.1%). This temperature dependence of molarity can be a problem in experiments demanding a high precision. That is, the solution might be used at a temperature different from the one at which it was prepared, and so its molarity is not exactly the one written on the label.

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A concentration unit that is independent of temperature, and also proportional to mole fraction in dilute solutions, is molality (m).

Molality (m)

Molality represents the concentration of moles of solute and the mass of solvent. It is given by moles of solute dissolved per kg of the solvent. The molality formula is-

Molality (m) = Amount of solute (in moles)/ Mass of solvent (in kg)

A solution in which 1.00 mol of urea $CO(NH_2)_2$, is dissolved in 1.00 kg of water is described as a 1.00 molal solution and designated as 1.00 m $CO(NH_2)_2$ solution.

Normality

It is the number of gram equivalents of solute present in one liter of the solution and it is denoted by N.

N = Weight of solute in grams / Equivalent mass ×Volume in liter

The relation between normality and molarity.

- **N x Eq. Wt = Molarity x Molar mass**
- **N = Molarity x Valency**
- **N = Molarity x Number of H^+ or OH^- ion**

Formality

It is the number of gram formula units present in one liter of solution. It is denoted by F.

F= Weight of solute in gram / Formula wt × Volume in liter

It is generally applied to a substance that does not consist of individual molecules, such as the ionic compound sodium chloride.

Check List

1. An ethanol-water solution is prepared by dissolving 10.00 mL of ethanol (CH_3CH_2OH, d= 0.789 g/ mL), in a sufficient volume of water to produce 100.0 mL of a solution with a density of 0.982 g/ mL. What is the concentration of ethanol in this solution expressed as (a)volume

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percent; (b)mass percent; (c)mass/volume percent; (d)mole fraction; (e)mole percent; (f)molarity; (g)molality?

2. A solution that is 20.0% ethanol, by volume, is found to have a density of 0.977 g/ mL. Use this fact, together with data from Example 1, to determine the mass percent of ethanol in the solution.

3. An 11.3 mL sample of CH_3OH (d = 0.793 g/ mL) is dissolved in enough water to produce 75.0 mL of a solution with a density of 0.977 g/ mL. What is the solution concentration expressed as (a) mole fraction of H_2O; (b) molarity of CH_3OH (c) molality of CH_3OH?

4. Laboratory ammonia is 14.8 M NH_3 (aq.) with a density of 0.8980 g/ mL. What is xNH_3 in this solution?

5. A16.00% aqueous solution of glycerol, $HOCH_2CH(OH)CH_2OH$, by mass, has a density of 1.037 g/mL. What is the mole fraction of glycerol in this solution?

6. A 10.00% aqueous solution of sucrose, $C_{12}H_{22}O_{11}$ by mass, has a density of 1.040 g/mL. What is (a) the molarity; (b) the molality; and (c) the mole fraction of $C_{12}H_{22}O_{11}$, in this solution?

7. Which of the several concentration units are temperature-dependent and which are not? Explain.