The Islamic University of Gaza- Environmental Engineering Department
Environmental Chemistry I (EENV 2301)

CHAPTER 3: SOLUTIONS

The Solution Process, Solubility and Concentration
Standard Solutions and Titrations
Solution Equilibria
Colloidal Suspensions

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Definitions

A solution is a homogeneous mixture of two or more substances, consisting of ions or molecules.

A colloid, although it also appears to be homogeneous, consists of comparatively large particles of a substance dispersed throughout another substance.

The solute is the dissolved substance. In the case of a solution of a gas or solid in a liquid, it is the gas or solid.

The solvent is the dissolving medium. Generally it is the component of greater amount.

dissolving the mixing of a solid with a liquid to make a solution.

mixture Two or more substances that are mixed together but are not chemically joined.

saturated A solution containing the maximum amount of solute that it can hold.

soluble A substance that can dissolve in a solvent.

solubility A measure of how much solute can dissolve in a solvent at a given temperature.

Types of solutions: Solutions may exist as **gases, liquids,** or **solids**

a. Gaseous solutions: Fluids that dissolve in each other in all proportions are said to be **miscible fluids**.

If two fluids do not mix, they are said to be **immiscible.**

For example, air is a solution of oxygen, nitrogen, and smaller amounts of other gases.

The solubility of a gas in a liquid is directly proportional to its pressure (**Henrys Law $S_g = kP_g$**).

Henry's Law Constants (k) for Some Gases in Water at 25°C

Gas	K, $mol \times L^{-1} \times atm^{-1}$
O_2	1.28×10^{-3}
CO_2	3.38×10^{-2}
H_2	7.90×10^{-4}
CH_4	1.34×10^{-3}
N_2	6.48×10^{-4}
NO	2.0×10^{-4}

b. Liquid solutions are the most common types of solutions found in the chemistry lab.

Many inorganic compounds are soluble in water or other suitable solvents.

Rates of chemical reactions increase when the likelihood of molecular collisions increases.

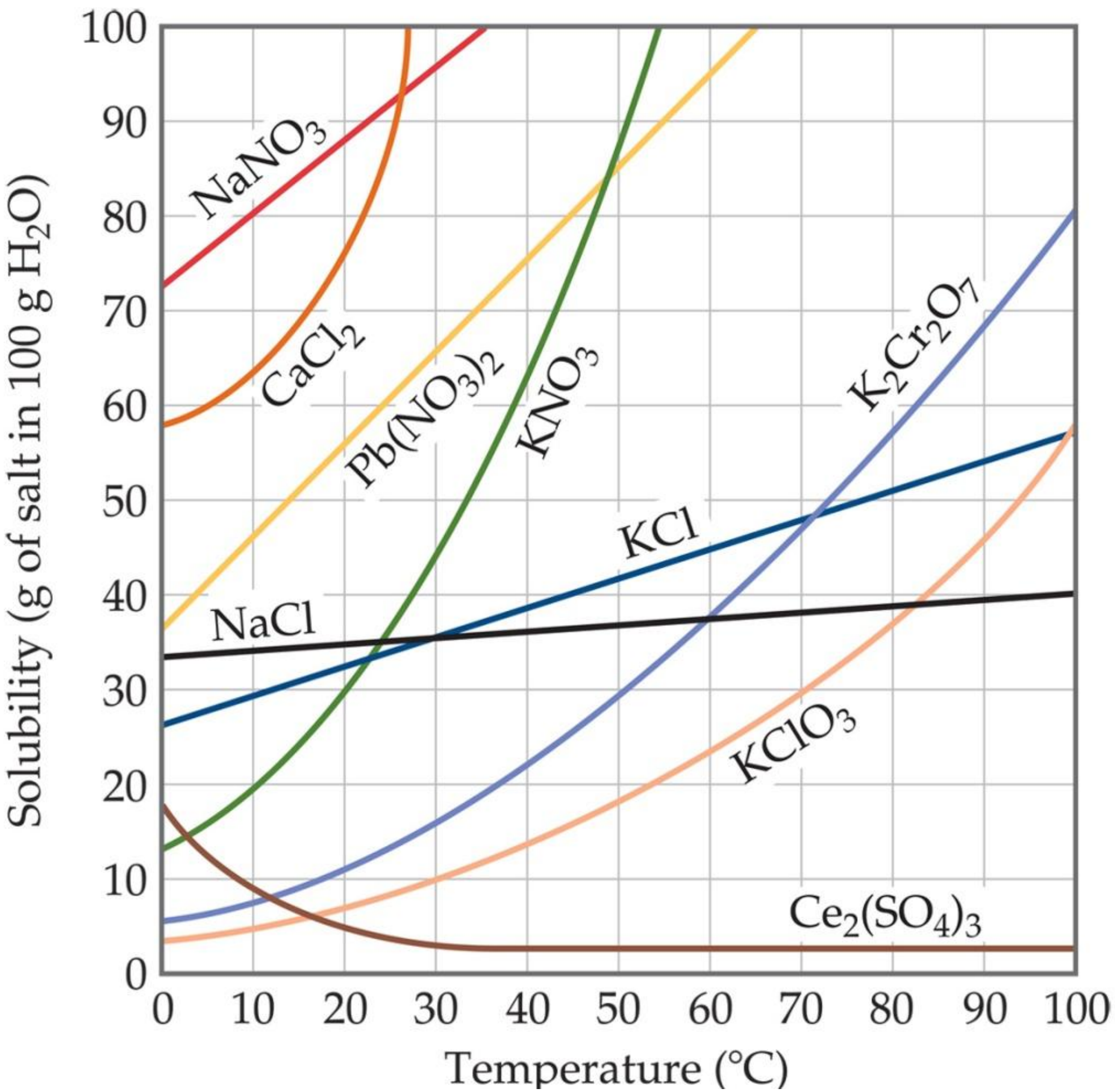
This increase in molecular collisions is enhanced when molecules move freely in solution.

Many factors affect solubility, such as **temperature** and, in some cases, **pressure**

There is a limit as to how much of a given solute will dissolve at a given temperature.

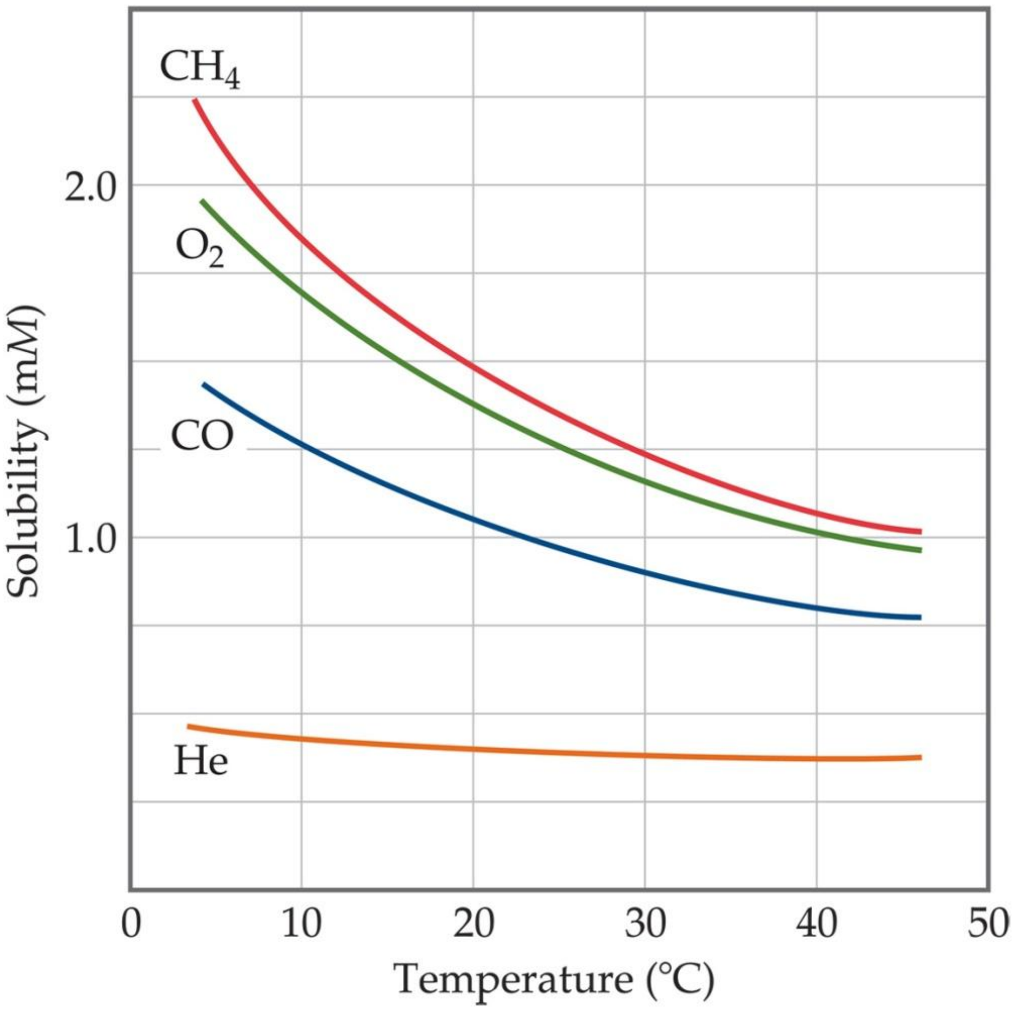
A **saturated solution** is one holding as much solute as is allowed at a stated temperature

The solubility of solid solutes in liquid solvents increases with increasing temperature.

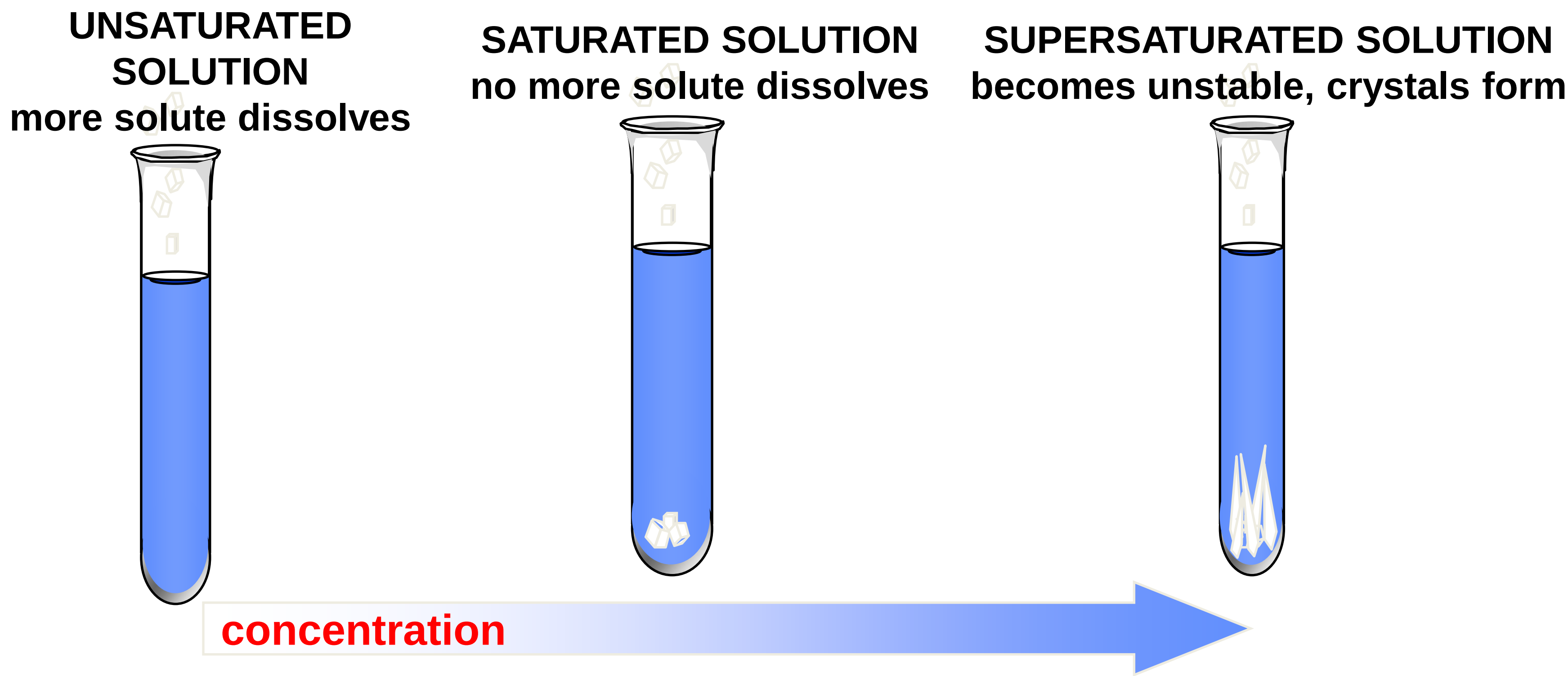


The solubility of gazes solutes in liquid solvents decrease with increasing temperature

Warm lakes have less O_2 dissolved in them than cool lakes



Solubility



Unsaturated: Less than the maximum amount of solute for that temperature is dissolved in the solvent.

Saturated: Solvent holds as much solute as is possible at that temperature.

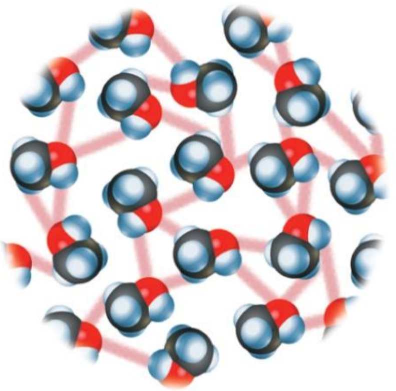
Supersaturated: Solvent holds more solute than is normally possible at that temperature. These solutions are unstable; crystallization can usually be stimulated by adding a “seed crystal” or scratching the side of the flask.

Factors affecting the solubility

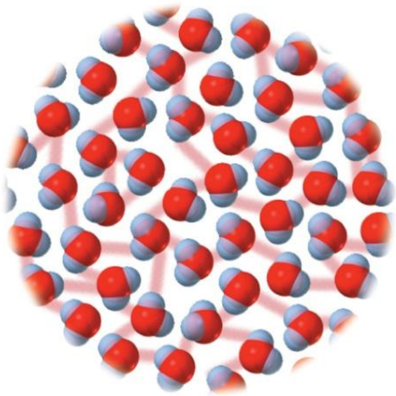
Like Dissolves Like

Two substances form a solution

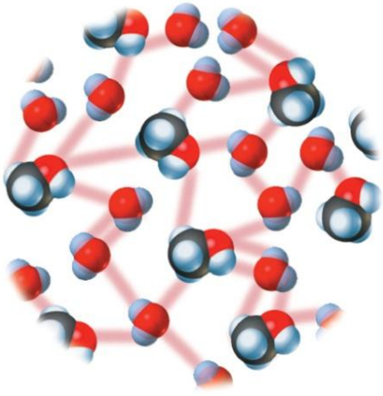
- when there is an attraction between the particles of the solute and solvent
- when a polar solvent (such as water) dissolves polar solutes (such as sugar) and/or ionic solutes (such as NaCl)
- when a nonpolar solvent such as hexane (C_6H_{14}) dissolves nonpolar solutes such as oil or grease



Methanol (CH_3OH) solute



Water solvent



Methanol-water solution with hydrogen bonding

Important Organic Solvents

Solvent	Solvent Use (may have many other nonsolvent uses)	Approximate Annual U.S. Production, millions of kilograms
Acetone	Solvent for spinning cellulose acetate fibers and for spreading paints and other protective coatings.	1,000
Benzene	Dissolves grease and other organic compounds.	6,500
Perchloroethylene	Best solvent for dry cleaning, also used for degreasing metals and extraction of fats.	125
Stoddard solvent	Mixture of alkanes and aromatic hydrocarbons containing from 7 to 12 C atoms per molecule used as a solvent for organic materials	17
Toluene	Dissolves grease and other organic materials; substitute for benzene, but not so toxic	2,700
Trichloroethylene	Vapor degreasing of metal parts; solvent for greases, oils, fats, waxes, and tars; fabric cleaner; waterless dying; ingredient of formulations of adhesives, lubricants, paints, varnishes, paint strippers	90

c. Solid solutions of metals are referred to as alloys (سبائك).

Brass is an alloy composed of copper and zinc.

Bronze is an alloy of copper and tin.

Pewter is an alloy of zinc and tin (قصدير.)

Ways of Expressing Concentration

a. Molarity

The **molarity** of a solution is the moles of solute in a liter of solution.

$$Molarity\,(M) = \frac{moles\ of\ solute}{liters\ \text{of solution}}$$

Example, 0.20 mol of ethylene glycol dissolved in enough water to give 2.0 L of solution has a molarity of

$$\frac{0.20\,mol\ \text{ethyleneglycol}}{2.0\,L\ \text{solution}} = 0.10\ \text{M}$$

b. Mass percentage of solute

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

Example, a 3.5% sodium chloride solution contains 3.5 grams NaCl in 100.0 grams of solution.

c. Molality

The **molality** of a solution is the moles of solute per kilogram of solvent.

$$molality(\boldsymbol{m}) = \frac{moles\ of\ solute}{\text{kilograms of solvent}}$$

Example 0.20 mol of ethylene glycol dissolved in 2.0 x 10^3 g (= 2.0 kg) of water has a molality of

$$\frac{0.20\, mol\ \text{ethylene glycol}}{2.0\ kg\ \text{solvent}} = 0.10\, \boldsymbol{m}$$

d. Formality moles per kilogram of solution (mol/ kg Solution)

$$Formality = \frac{\text{Moles of solute}}{\text{Kilogram of Solution}}$$

Example: What is the molality of a solution containing 5.67 g of glucose, $C_6H_{12}O_6$, dissolved in 25.2 g of water?

First, convert the mass of glucose to moles

$$5.67\ \text{g}\ C_6H_{12}O_6 \times \frac{1\ \text{mol}\ C_6H_{12}O_6}{180.2\ \text{g}\ C_6H_{12}O_6} = 0.0315\ \text{mol}\ C_6H_{12}O_6$$

divide it by the kilograms of solvent (water).

$$\text{Molality} = \frac{0.0315\ \text{mol}\ C_6H_{12}O_6}{25.2 \times 10^{-3}\ \text{kg solvent}} = 1.25\ m\ C_6H_{12}O_6$$

f. Mole Fraction

The **mole fraction** of a component "A" (χ_A) in a solution is defined as the moles of the component substance divided by the total moles of solution (that is, moles of solute and solvent).

$$\chi_A = \frac{\text{moles of substance A}}{\text{total moles of solution}}$$

For example, 1 mol ethylene glycol in 9 mol water gives a mole fraction for the ethylene glycol of 1/10 = 0.10.

Example: An aqueous solution is 0.120 m glucose. What are the mole fractions of each of the components?

A 0.120 *m* solution contains 0.120 mol of glucose in 1.00 kg of water. After converting the 1.00 kg H_2O into moles, we can calculate the mole fractions.

$$1.00 \times 10^3 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.0 \text{ g}} = 55.6 \text{ mol } H_2O$$

$$\chi_{\text{glucose}} = \frac{0.120 \text{ mol}}{(0.120 + 55.6) \text{ mol}} = 0.00215$$

$$\chi_{\text{water}} = \frac{55.6 \text{ mol}}{(0.120 + 55.6) \text{ mol}} = 0.998$$

j. Parts per Million and Parts per Billion

Parts per Million (ppm)

$$\textbf{ppm} = \frac{\text{mass of A in solution}}{\text{total mass of solution}} \times 10^6 \quad = \text{mg/l}$$

Parts per Billion (ppb)

$$\textbf{ppb} = \frac{\text{mass of A in solution}}{\text{total mass of solution}} \times 10^9 \quad = \mu\text{g/l}$$

Physical Properties of Solutions

The physical properties of solutions are those properties that depend on solute concentration.

1. vapor pressure reduction: Chemists have observed that the vapor pressure of a volatile solvent can be reduced by the addition of a nonvolatile solute.

Raoult's law states that the vapor pressure of a solution containing a nonelectrolyte nonvolatile solute is proportional to the mole fraction of the solvent.

$$P_{solution} = (P^{o}_{solvent})(\chi_{solvent})$$

where

$P_{solution}$ is the vapor pressure of the solution,
$X_{solvent}$ is the mole fraction of the solvent,
$P^{o}_{solvent}$ is the pure vapor pressure of the solvent.

If a solution contains a **volatile solute**, then each component contributes to the vapor pressure of the solution.

$$P_{solution} = (P^{o}_{solvent})(\chi_{solvent}) + (P^{o}_{solute})(\chi_{solute})$$

- The vapor pressure of the solution is the sum of the partial vapor pressures of the solvent and the solute.

- Volatile compounds can be separated using fractional distillation.

2. Boiling Point Elevation: The **normal boiling point** of a liquid is the temperature at which its vapor pressure equals 1 atm.

- Because vapor pressure is reduced in the presence of a nonvolatile solute, a greater temperature must be reached to achieve boiling

- The **boiling-point elevation**, **DT*b***, is found to be proportional to the molal concentration, **c*m***, of the solution.

$$\Delta T_b = (K_b)(c_m)$$

The constant of proportionality, **K*b*** (called the **boiling-point-elevation constant**), depends only on the solvent.

3. Freezing Point Depression

- The **freezing-point depression**, **DT*f***, is a colligative property equal to the freezing point of the pure solvent minus the freezing point of a solution.

  - Freezing-point depression is also proportional to the molal concentration, **c*m* ,** of the solute.

$$\Delta T_f = (K_f)(c_m)$$

  - where **K*f*** ,the **freezing-point-depression constant,** depends only on the solvent.

Molal Boiling Point Elevation/Freezing Point Depression Constants for Various Solvents

Solvents

Solvent	Normal BP (°C)	K_b (°C/*m*)	Normal FP (°C)	K_f (°C/*m*)
H_2O	100.0	0.52	0.0	1.86
Benzene, C_6H_6	80.1	2.53	5.5	5.12
Ethanol, C_2H_5OH	78.4	1.22	-114.6	1.99
CCl_4	76.8	5.02	-22.3	29.8
Chloroform, $CHCl_3$	61.2	3.63	-63.5	4.68

Example: An aqueous solution is 0.0222 m in glucose. What are the boiling point and freezing point for this solution?

From the Table $\boldsymbol{K_b}$ and $\boldsymbol{K_f}$ for water as 0.512 $^oC/m$ and 1.86 $^oC/m$, respectively. Therefore,

$$\Delta T_b = (K_b)(c_m) = 0.512^o C/m \times 0.0222\, m = \ 0.0114^o C$$

$$\Delta T_f = (K_f)(c_m) = 1.86^o C/m \times 0.0222\, m \ = \ 0.0413^o C$$

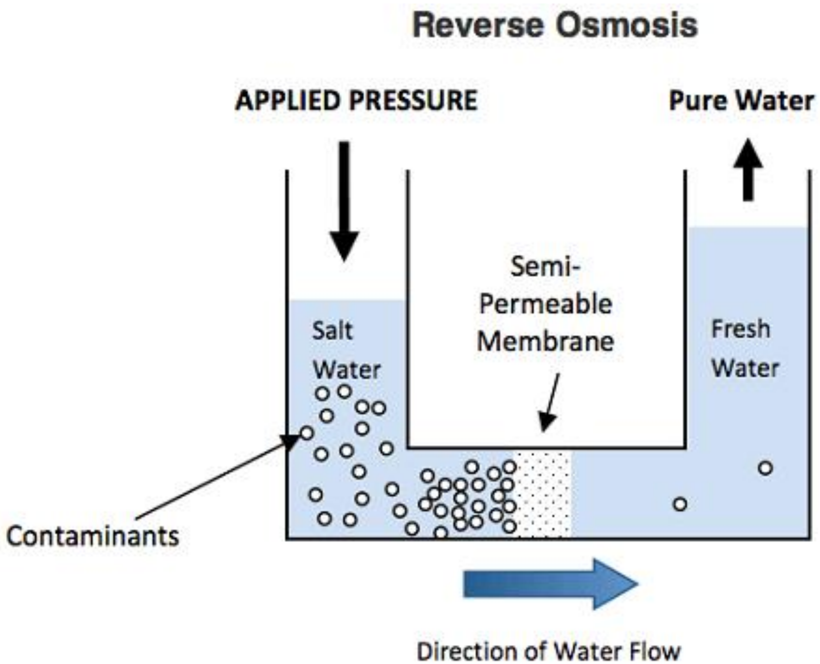
The boiling point of the solution is 100.011^{o}C and the freezing point is –0.041^{o}C.

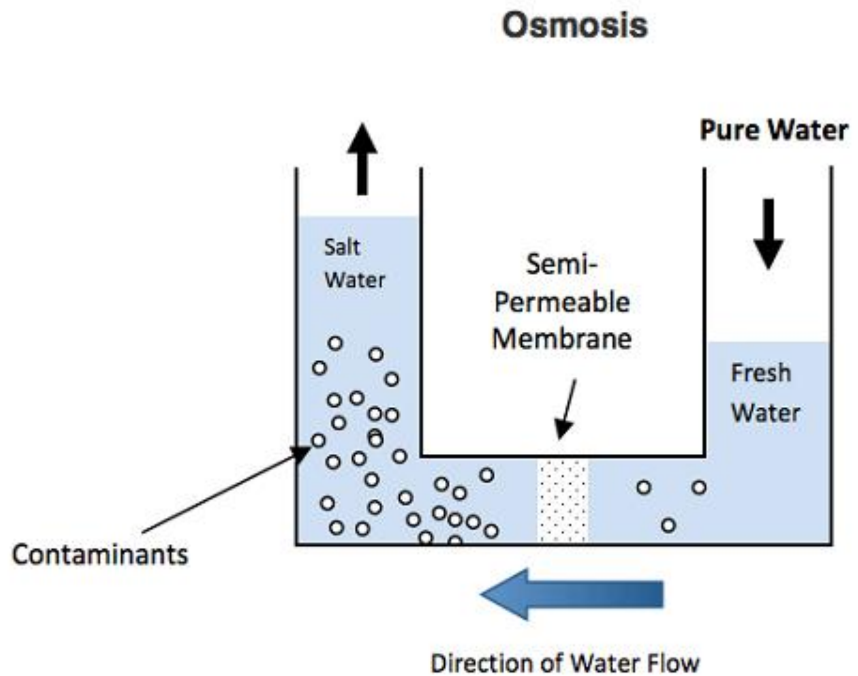
4. Osmotic pressure is a colligative property of a solution equal to the pressure that, when applied to the solution, just stops osmosis.

osmotic pressure, π, of a solution is related to the molar concentration of the solute.

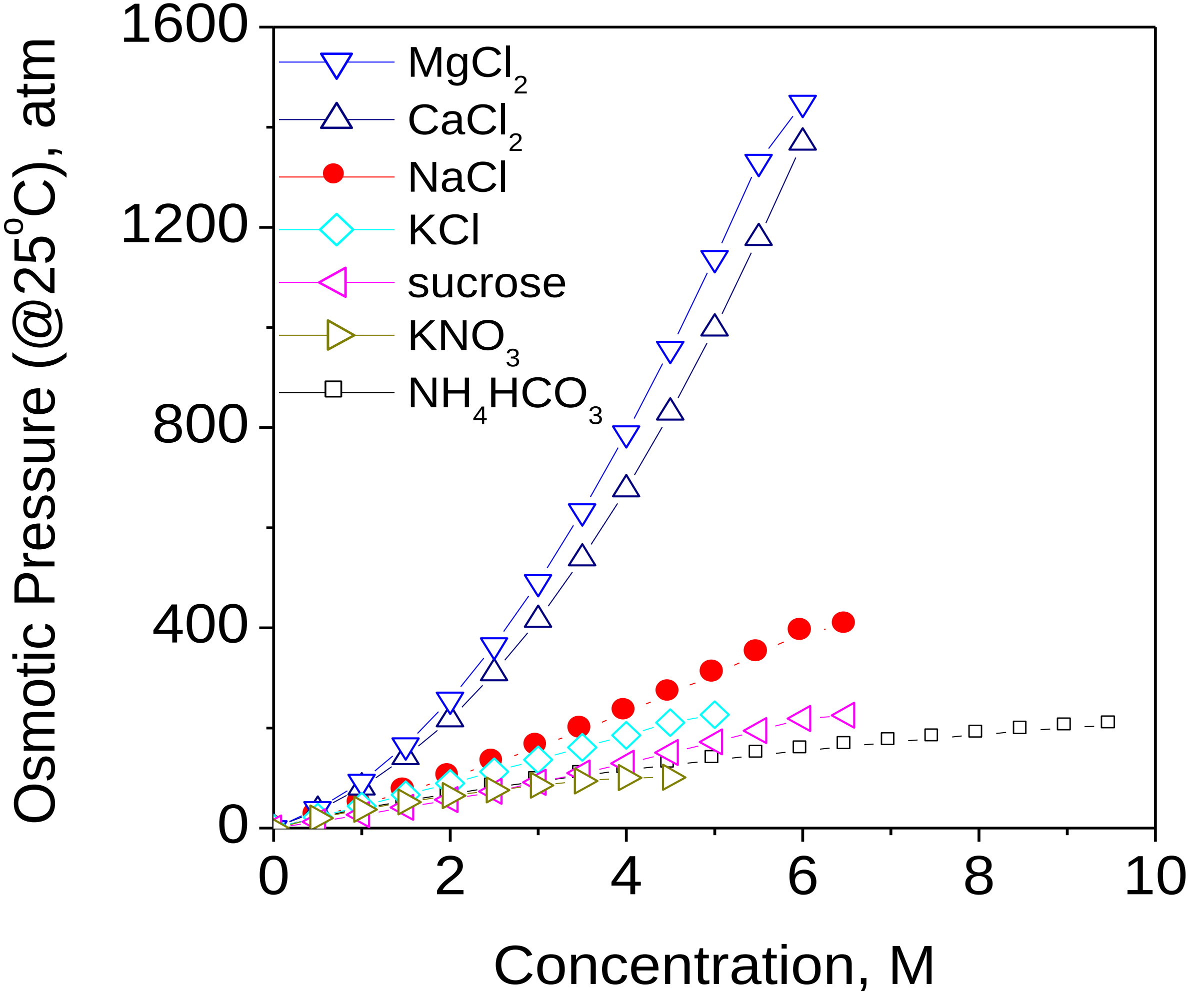
$$\pi = iRMT$$

I = The van't Hoff factor, symbol *i*, expresses how may ions and particles are formed (on an average) in a solution from one formula unit of solute,
M is the concentration in mole.
R is the ideal gas constant (0.0821 L atm K^{-1} mol^{-1})
T is the absolute temperature (Kelvin).





Osmotic Pressure for different solutions



STANDARD SOLUTIONS AND TITRATIONS

Titration: is a method for determining the concentration of a solution by reacting a known volume of that solution with a solution of known concentration.

If you wish to find the concentration of an acid solution, you would titrate the acid solution with a solution of a base of known concentration.

You could also titrate a base of unknown concentration with an acid of known concentration.

Analyte: the solution of unknown concentration but known volume.

Titrant: the solution of known concentration.

$$\text{Analyte} + \text{Titrant} \rightarrow \text{Products}$$

Equivalence Point: the point at which exactly the right volume of titrant has been added to complete the reaction.

End point: Related to the physical sign that associate with the condition of chemical equivalence. Ideally, the end point and equivalent one coincide. (variation may be to color change of indicator)

Indicator: substance that changes color when an excess of titrant has been added (phenolphthalein, bromocresol green).

Types of Titrimetry

1- Precipitation:

$Ag^+ + Cl^- \longrightarrow AgCl\ (s)$

2- Acid Base titration:

$OH^- + HA \longrightarrow A^- + H_2O$

3- Complex formation

$EDTA^{2-} + Ca^{2+} \longrightarrow EDTA\ Ca.xH_2O$

4- Oxidation Reduction

$MnO_4^- + 5Fe^{2+} + 8H^+ \longrightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$

Calculating the results of Titration

Needs: the volume and molarity of the titrant

aA + bB → Products

(Titrant) (substance titrated)

No. of m.moles of A = Volume of A titrated (ml) . Molarity of A (M) Or $mmoles_A = ml_A \cdot (M_A)$

No. of m.moles of B is obtained by multiplying the No. of mmoles of A by the combining ratio (b/a)

$$mmoles_B = mmoles_A \times (b/a) = ml_A \times (M_A) \times (b/a)$$

$$M_B = \frac{ml_A \times M_A}{ml_B} \times \frac{b}{a}$$

Example 1: Calculate the molar concentration of the HCl if 50.0 mL (0.0500 L) of HCl solution were titrated with 0.0100 M standard NaOH, requiring 40.0 (0.0400 L) mL of the titrant solution.

$$M = \frac{\text{Moles solute}}{\text{Volume solution}}$$

In this case, as shown by Reaction $HCl_{(aq)} + NaOH_{(aq)} \longrightarrow NaCl_{(aq)} + H_2O$

the number of moles of HCl in the sample exactly equals the number of moles of NaOH at the end point, which leads to the relationship

M HCl x Volume HCl = M NaOH x Volume NaOH

where the subscript formulas denote HCl and NaOH solutions. This equation can be rearranged and values substituted into it to give the following:

$$M_{HCl} = \frac{M_{NaOH} \times \text{Volume NaOH}}{\text{Volume HCl}}$$

$$M_{HCl} = \frac{0.0100 \text{ mol/L} \times 0.0400 \text{ L}}{0.0500 \text{ L}} = 0.00800 \text{ mol/L}$$

Example 2: How many ml of 0.25 M NaOH will react with 10.0 ml of 0.10 M H_2SO_4

$H_2SO_4 + 2\ NaOH \rightarrow Na_2SO_4 + 2\ H_2O$

mmol NaOH = 2 mmol H_2SO_4

$(½) \times M_{NaOH} \times V_{mL(NaOH)} = M_{(H2SO4)} \times V_{mL(H2SO4)}$

$0.25 \times V_{mL} = 2 \times 0.10 \times 10$

$V_{mL} = 8$ ml

Example 3: 0.4671 g sample containing $NaHCO_3$ (FW = 84.01 mg/mmol) was dissolved and titrated with 0.1067 M HCl requiring 40.72 mL. Find the percentage of sodium bicarbonate in the sample.

write the equation in order to identify the stoichiometry

$NaHCO_3 + HCl$ g $NaCl + H_2CO_3$

Now it is clear that the number of mmol of sodium bicarbonate is equal to the number of mmol HCl from the equation:

$M_1.V_1$ (HCl) = $M_2.V_2$ ($NaHCO_3$)

mmol $NaHCO_3$ = mmol HCl

mmol = M x VmL

mmol $NaHCO_3$ = (0.1067 mmol/ml) x 40.72 mL = 4.345 mmol

mg $NaHCO_3$ = 4.345 mmol x (84.01 mg/mmol) = 365.01

% $NaHCO_3$ = (365.01 x 10^{-3} g/0.4671 g) x 100 = 78.14%

Example 4: A 0.1876 g of pure sodium carbonate (FW = 106 mg/mmol) was titrated with approximately 0.1 M HCl requiring 35.86 ml. Find the molarity of HCl.

The first thing writing the equation of the reaction.

$Na_2CO_3 + 2\ HCl \rightarrow 2\ NaCl + H_2CO_3$

from the equation

2 mmol HCl react with 1 mmol carbonate

mmol HCl = 2 mmol Na_2CO_3 **or**

M_{HCl} X V_{ml} 1/2 = mmol Na_2CO_3

substitute for mmol carbonate by mg carbonate/FW carbonate. This gives

M_{HCl} x 35.86 = 2 x 187.6 mg/ (106 mg/mmol)

M_{HCl} = 0.09872 M

Colloids

A **colloid:** is a dispersion of particles of one substance (the dispersed phase) throughout another substance or solution (the continuous phase).

A colloid differs from a true solution in that the dispersed particles are larger than normal molecules.

Tyndall effect: The scattering of light by colloidal-size particles.

Types of Colloids

A **sol** consists of solid particles dispersed throughout a liquid.

An **aerosol** consists of liquid droplets or solid particles dispersed throughout a gas.

An **emulsion** consists of liquid droplets dispersed throughout another liquid

Hydrophilic and Hydrophobic Colloids

A **hydrophilic colloid (Water love)** is a colloid in which there is a strong attraction between the dispersed phase and the continuous phase (water).

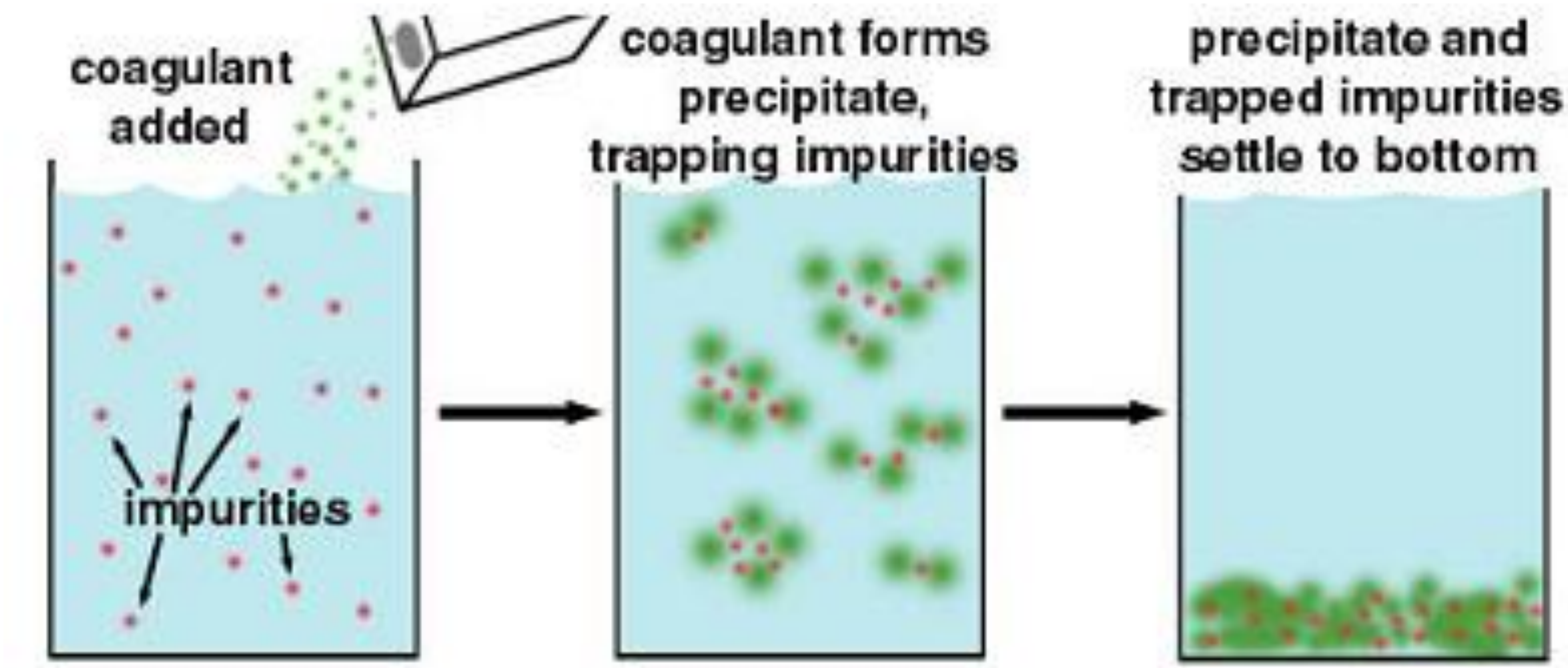
A **hydrophobic colloid (Water hate)** is a colloid in which there is a lack of attraction of the dispersed phase for the continuous phase (water).

Comparison of Solutions, Colloids, and Suspensions

solutions	colloids	suspensions
< 1 nm		> 100 nm
- single atoms -small molecules - ions - polyatomic ion -Transparent (clear) - molecular motion - never settle	- aggregates of atoms, molecules or ions - macromolecules (proteins) - transparent with Tyndall effect - Brownian motion- colloidal particles moved by solvent - coagulation – can settle	- clumps of particles, - mineral grains such as sand -Translucent (cloudy) - movement by gravity

Coagulation

Coagulation is the process by which the dispersed phase of a colloid is made to aggregate and thereby separate from the continuous phase.



Homework No. 3

1.Determine the vapor pressure of a solution of 92.1 g of glycerin, $C_3H_5(OH)_3$, in 184.4 g of ethanol at 40 °C. The vapor pressure of pure ethanol is 0.178 atm at 40 °C, and glycerin is essentially nonvolatile.

2.Find the boiling point of a solution of 92.1 g of iodine in 800.0 g of chloroform.

3.Calculate the freezing point of a solution of 0.724 g of calcium chloride in 175 g of water, assuming complete dissociation by the solute.

4.Determine the osmotic pressure of a solution with a volume of 0.750 L that contains 5.0 g of methanol (i=1) in water at 37 °C.

5.List the following aqueous solutions in order of their expected freezing points: 0.050 m $CaCl_2$, 0.15 m NaCl, 0.10 m HCl, 0.050 m $HC_2H_3O_2$, and 0.10 m $C_{12}H_{22}O_{11}$.

6.A solution of 4.00 g of a nonelectrolyte dissolved in 55.0 g of benzene is found to freeze at 2.32 °C. What is the molar mass of this compound?

7. A solution of 35.7 g of a nonelectrolyte in 220.0 g of chloroform has a boiling point of 64.5 °C. What is the molar mass of this compound?