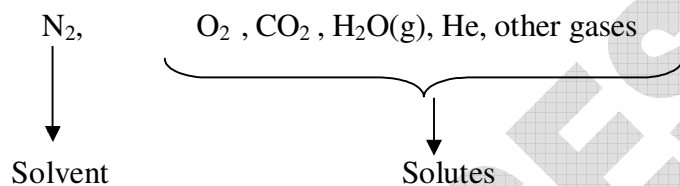


GASEOUS SOLUTIONS:

- are the solutions where both SOLUTE and SOLVENT are GASES

Ex: AIR

homogeneous mixture of



NOTE: All gases mix with each other in all proportions. Gases are MISCIBLE FLUIDS.

LIQUID SOLUTIONS

SOLUTE: Gas, Liquid, or Solid

Solvent: Liquid

Examples:

Gas in Liquid
Soda water

Liquid in Liquid
Vinegar

Solid in Liquid
Salt water

TERMINOLOGY:

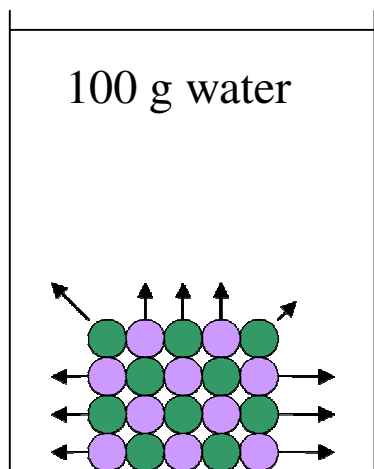
- **Miscible liquids:** two liquids that dissolve in each other.
Ex: Acetic acid and water
Cooking oil and kerosene
- **Immiscible liquids:** two liquids that do not dissolve in each other
Ex: Cooking oil and water
kerosene and water

THE SOLUTION PROCESS

- Consider that 40 grams of NaCl are dropped in 100 g of water whose temperature is 20°C

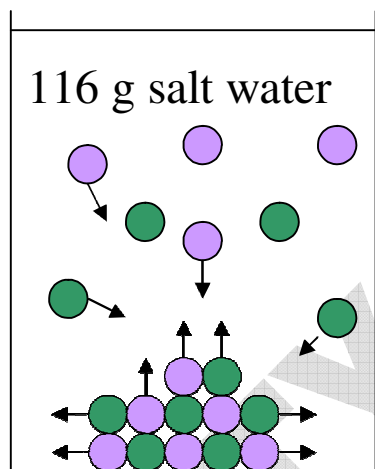
● = Na⁺ ions

● = Cl⁻ ions



100 g water

40 g undissolved NaCl

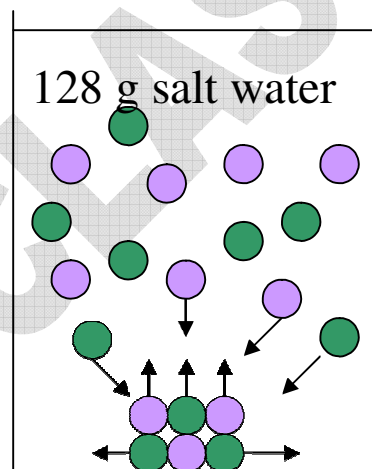


116 g salt water

24 g undissolved NaCl

Na⁺ and Cl⁻ ions:
- leave the crystal
- dissolve in water

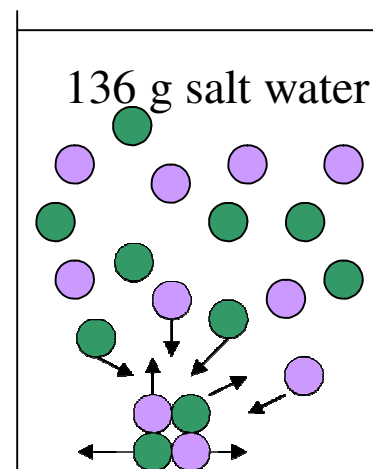
Nr. of ions dissolving \rightleftharpoons Nr. of ions returning



128 g salt water

12 g undissolved NaCl

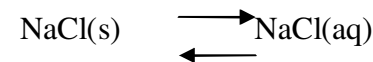
Nr. of ions dissolving \rightleftharpoons Nr. of ions returning

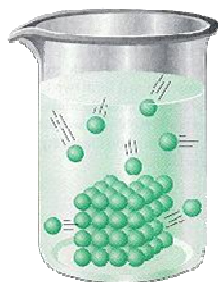


136 g salt water

4 g undissolved NaCl

Nr. of ions dissolving = Nr. of ions returning
Dynamic equilibrium has been established



ATEOUILIBRIUM

Rate at which ions
leave the crystal

=

Rate at which ions
return to the crystal

Rate of dissolving

=

Rate of crystallization

NaCl(s)



NaCl(aq)

- The composition of the solution no longer changes
- A saturated solution has been obtained

CONCLUSIONS:

- At 20°C no more than 36 g of NaCl can dissolve in 100 g of water.

Solubility of a substance:

- is the amount of substance that can be dissolved in 100 g of solvent at a given temperature.
Ex: The solubility of NaCl at 20°C is 36 g NaCl/100 g water

Saturated Solution:

- A solution containing the maximum amount of solute that can be dissolved in a given amount of solvent at a given temperature
Ex: At 20°C, a solution containing 36 g of NaCl dissolved in 100 g of water

Unsaturated Solution:

- A solution containing less than the maximum amount of solute that can be dissolved in a given amount of solvent at a given temperature
Ex: At 20°C, a solution containing 28 g of NaCl dissolved in 100 g of water
(8 g more of NaCl can be dissolved)

Supersaturated Solution:

- A solution containing more dissolved solute than a saturated solution

FACTORS AFFECTING SOLUBILITY

- Why do some substances mix and others do not?
- There are 2 main factors that determine the solubility of a substance in a given solvent.

I. TENDENCY TOWARD DISORDER (Tendency toward a state of lower energy)

Substances have a natural tendency to mix.

Ex: all gases are miscible in each other

This factor favors the dissolving process

NOTE: If this were the only factor, all substances would have unlimited solubility in each other.

II. RELATIVE FORCES OF ATTRACTION BETWEEN SOLUTE AND SOLVENT SPECIES

There are 3 types of forces of attraction:

1. Between

solute → ⇌ solvent

particles

Favor the dissolving process

2. Between

solute → ⇌ solute

particles

Works against the dissolving process

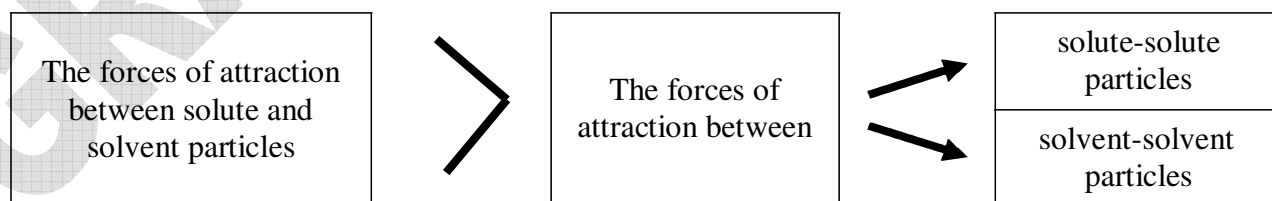
3. Between

solvent → ⇌ solvent

particles

Works against the dissolving process

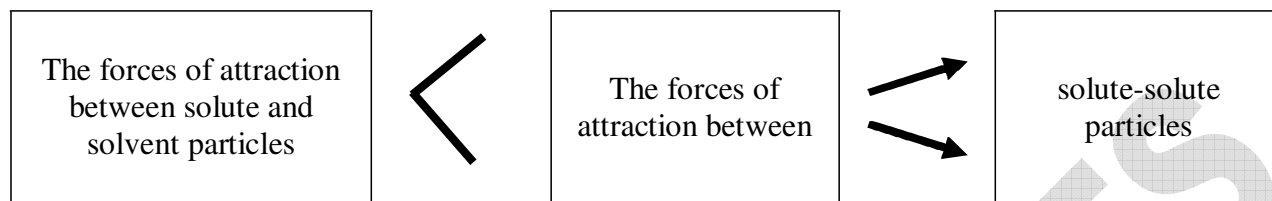
CASE 1:



This happens when the solute and solvent:

- are similar substances
- have similar intermolecular forces of attractions
- will dissolve in each other

Ex: Ethyl alcohol dissolves in water (Both are polar and both form H bonds)

CASE2:

This happens when the solute and solvent

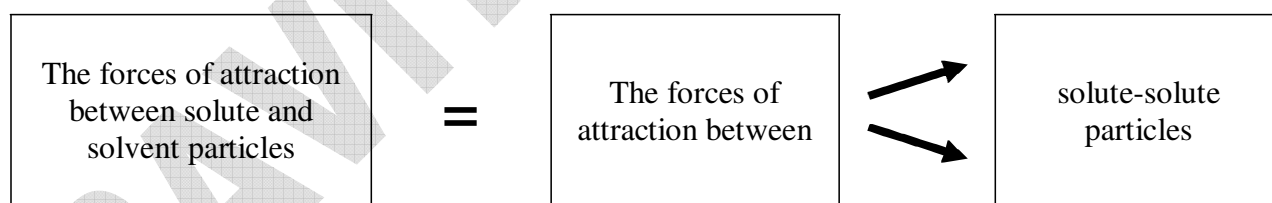
- are different in their chemical nature
- have different type of intermolecular forces of attractions
- will not dissolve in each other

Ex: CCl_4 does not dissolve in H_2O

Nonpolar molecule Associated through London forces		Polar molecule Associated through H bonds
--	--	---

CONCLUSIONS:

1. **“LIKE DISSOLVES LIKE”** (Similar substances dissolve one another)
2. The more similar substances are in their chemical nature, the better they dissolve in each other.

CASE3:

NOTE: There are no favored attractions

- The natural tendency of substances to mix (natural tendency toward disorder) will cause the solute to dissolve in the solvent.

Ex: Heptane (C_7H_{16}) dissolves in Octane (C_8H_{18})

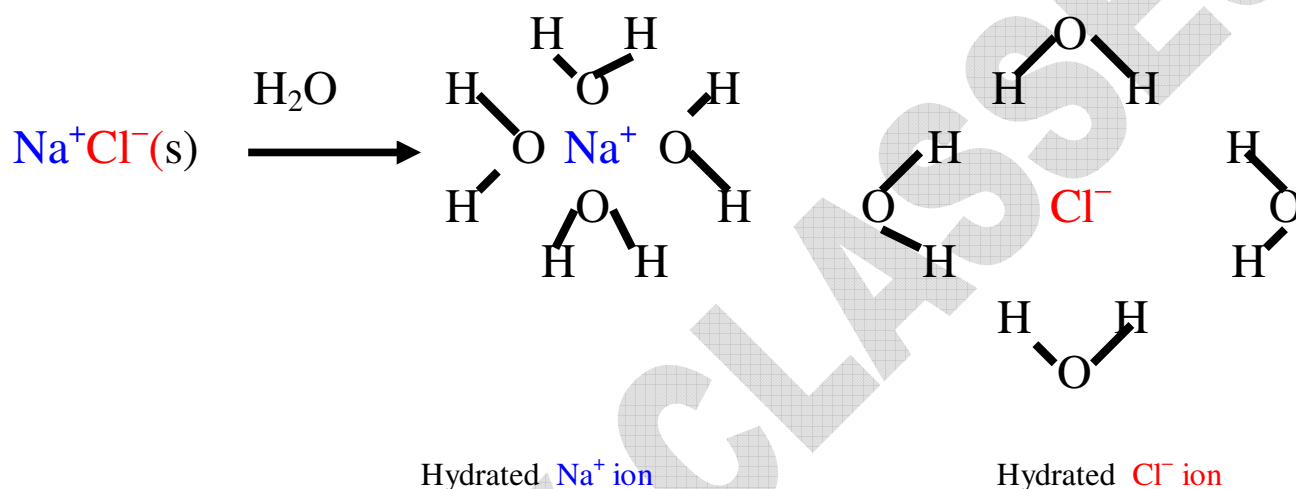
Hydrocarbon Nonpolar molecule London Forces		Hydrocarbon Nonpolar molecule London Forces
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SOLUBILITY OF IONIC SUBSTANCES IN WATER

- Solubility of ionic substances in water is determined by the relative strength of the:

I. ION-DIPOLE FORCES OF ATTRACTION

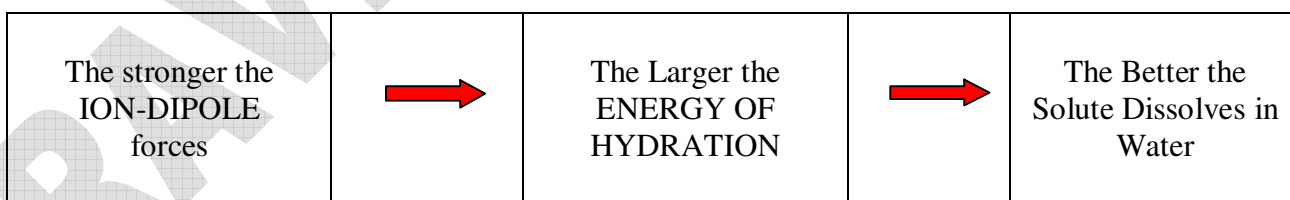
- These are attractions between solute ions and polar water molecules.



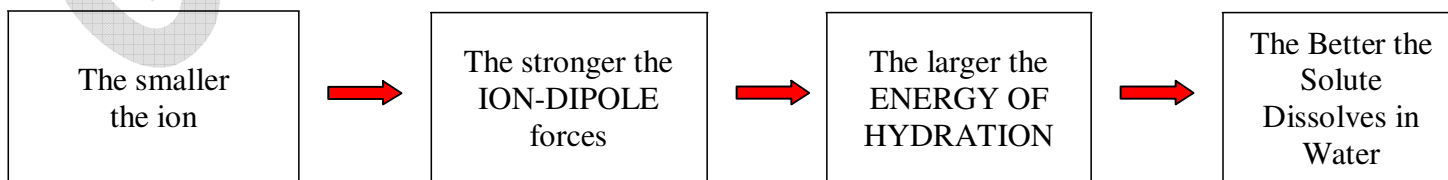
- HYDRATION is the linking of the ions to the polar water molecules (an exothermic process)
- ENERGY OF HYDRATION is the energy given off when ions are hydrated.

NOTE:

- ION-DIPOLE FORCES favor the solution process.**



- ION-DIPOLE FORCES are inversely proportional to the size of the ion.**

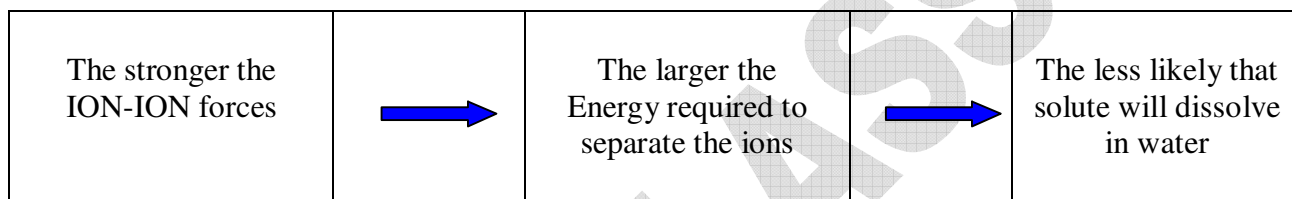


II. ION-ION FORCES OF ATTRACTION

- These are attractions between cations (+) and anions (-) in the crystal lattice.
- Separation of Ions from crystal lattice requires energy and is an endothermic process
- LATTICE ENERGY is the energy required to separate the ions from the crystal lattice.

NOTE:

1. ION-ION FORCES work against the solution process.



2. ION-ION FORCES :

- are inversely proportional to the size of the ions.
- are directly proportional to the charges of the ions

CONCLUSIONS:

1. A solute is likely to dissolve in water if:



2. A solute is not likely to dissolve in water if:



3. The solution process is favored by:

- any decrease in LATTICE ENERGY
- any increase in HYDRATION ENERGY

4. Two main factors affect the LATTICE ENERGY and the HYDRATION ENERGY

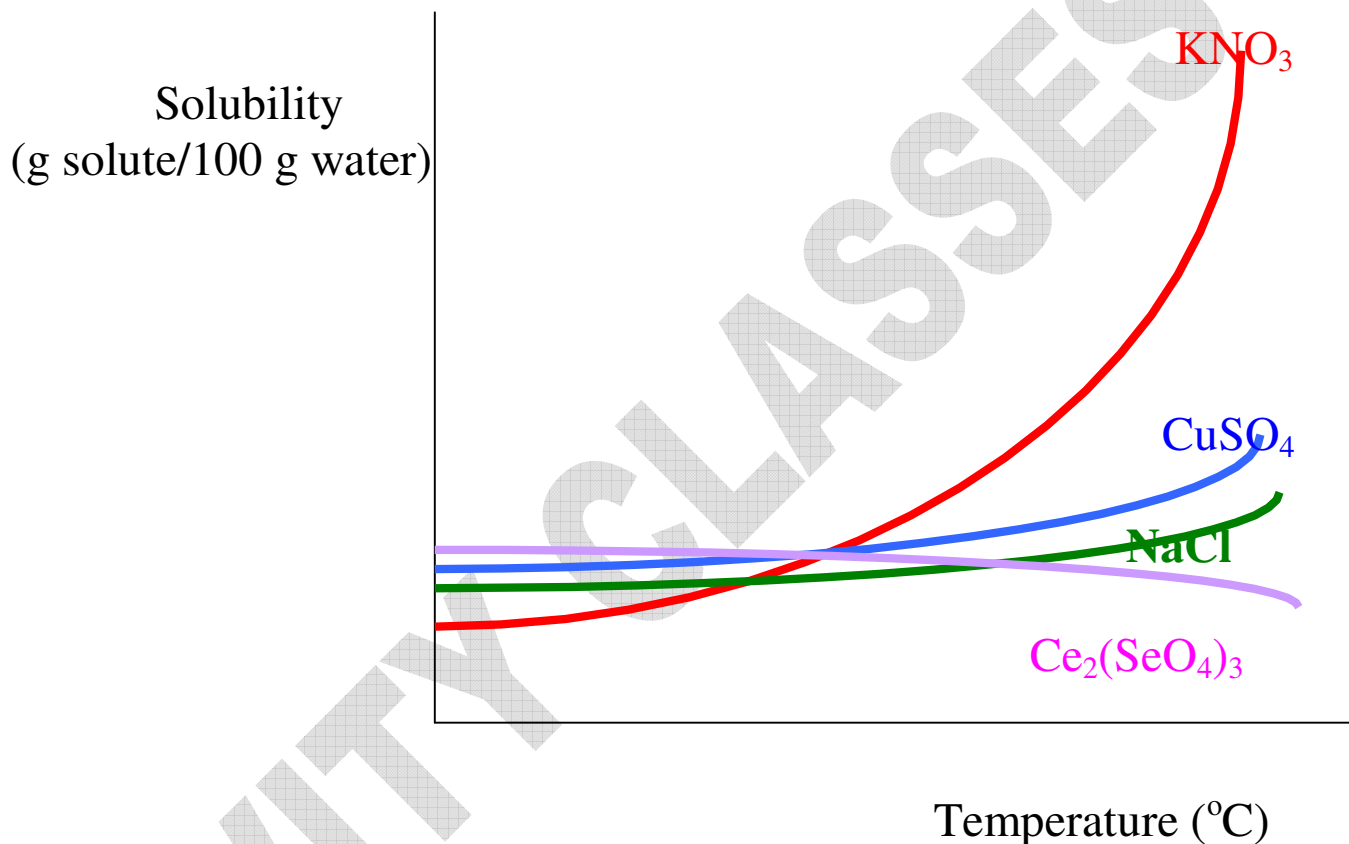
A) Size of the Ions: inversely proportional to both

B) Charge of the ions: directly proportional to the LATTICE ENERGY

FACTORS AFFECTING SOLUBILITY

I. TEMPERATURE

1. Solubility of Ionic Substances in Water



- For the majority of Ionic Salts, the Solubility increases with temperature (the warmer the water, the better they dissolve).

Exceptions: $\text{Ce}_2(\text{SeO}_4)_3$, $\text{Ca}(\text{OH})_2$, CaSO_4

2. Solubility of Gases in Water

- The Solubility of gases decreases with increasing temperature (the colder the water, the better the gases dissolve). Examples are:
 - soda water keeps its carbonation (CO_2 gas) better at low temperatures (at room temperature they go “flat” faster)
 - cold oceans have a higher concentration of dissolved O_2 than warm oceans; this affects marine life.

II. PRESSURE

- Solubility of Ionic Substances in Water is not affected by pressure changes
 - Solubility of Gases in Water
 - is very dependent on pressure changes
 - can be predicted from **Henry's Law**
- "The Solubility of a gas in water is directly proportional to the Partial Pressure of the gas above the aqueous solution"

$$S = K_H P$$

where S = solubility of the gas
 P = partial pressure of the gas
 K_H = Henry's Law Constant
 = Constant for:
 - a particular solvent
 - at a given temperature

$S \propto P$

$\frac{S_1}{S_2} = \frac{P_1}{P_2}$

← Formula used to calculate the solubility of a gas if the partial pressure changes

SUMMARY

	IONIC SUBSTANCES	GASES
Effect of Temperature	solubility generally increases	Solubility decreases
Effect of Pressure	No effect	Solubility increases

Example:

The solubility of carbon dioxide in water is 0.161 g of carbon dioxide in 100 mL of water at 20°C and 1.00 atm. A soft drink is carbonated with carbon dioxide gas at 5.50 atm. of pressure. What is the solubility of carbon dioxide in water at this pressure ?

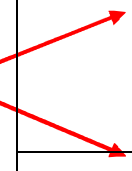
$$\begin{array}{l} S_1 = 0.161 \text{ g/100 mL} \\ P_1 = 1.00 \text{ atm} \end{array}$$

$$\begin{array}{l} S_2 = ? \\ P_2 = 5.50 \text{ atm} \end{array}$$

$$S_2 = 0.161 \text{ g/100 mL} \times \frac{5.50 \text{ atm}}{1.00 \text{ atm}} = 0.886 \text{ g/100 mL}$$

CONCENTRATION UNITS

- The various methods of expressing concentration of a solution are listed below:

A given amount of Solute dissolved in a given amount of			CONCENTRATION	UNITS	SYMBOL
	SOLUTION 		Molarity	moles solute/L sol'n	M
			Mole Fraction	moles solute/moles sol'n	unitless
			Mass Percent	g solute / g sol'n) x 100	% w/w
	SOLVENT	Molality	mole solute / Kg solvent	m	

- The interconversion of units is an important skill in studying the chemistry of solutions.

Molarity → **% by mass**

The molarity of a particular brand of vinegar (solution of acetic acid, $\text{HC}_2\text{H}_3\text{O}_2$, in water) is 0.8527 M. The density of vinegar is 1.0052 g/mL. Calculate the mass percent of $\text{HC}_2\text{H}_3\text{O}_2$ in vinegar.

$$? \frac{\text{g HC}_2\text{H}_3\text{O}_2}{\text{g vinegar}} \times 100 = \frac{0.8527 \text{ moles HC}_2\text{H}_3\text{O}_2}{1 \text{ L vinegar}} \times \frac{60.06 \text{ g HC}_2\text{H}_3\text{O}_2}{1 \text{ mole HC}_2\text{H}_3\text{O}_2} \times \frac{1 \text{ L vinegar}}{1000 \text{ mL vinegar}} \times \frac{1 \text{ mL vinegar}}{1.0052 \text{ g vinegar}} = 5.975\%$$

% by mass → **Molarity**

A sugar syrup solution contains 15.0 % sugar, $\text{C}_{12}\text{H}_{22}\text{O}_{11}$, by mass and has a density of 1.06 g/mL. What is the molarity of this solution?

$$? \frac{\text{moles C}_{12}\text{H}_{22}\text{O}_{11}}{\text{L syrup}} = \frac{15.0 \text{ g C}_{12}\text{H}_{22}\text{O}_{11}}{100. \text{ g syrup}} \times \frac{1 \text{ mole C}_{12}\text{H}_{22}\text{O}_{11}}{342.3 \text{ g C}_{12}\text{H}_{22}\text{O}_{11}} \times \frac{1.06 \text{ g syrup}}{1 \text{ mL syrup}} \times \frac{1000 \text{ mL syrup}}{1 \text{ L syrup}} = 0.465 \text{ M}$$

MOLALITY & MOLE FRACTION
Molality

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?

$$\text{Recall: Molality} = \frac{\text{moles solute}}{\text{kg solvent}} = \frac{\text{moles } C_6H_{12}O_6}{\text{kg water}}$$

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

$$? \text{ kg water} = 25.2 \text{ g} \times \frac{1 \text{ kg}}{1000 \text{ g}} = 0.0252 \text{ kg water}$$

$$\text{Molality} = \frac{0.0315 \text{ mol } C_6H_{12}O_6}{0.0252 \text{ kg water}} = 1.25 \text{ molal} = 1.25 \text{ m}$$

Mole Fraction

An automobile antifreeze solution contains 2.25 kg of ethylene glycol ($C_2H_6O_2$) and 2.00 kg of water.

A) Find the mole fraction of ethylene glycol in this solution.

$$? \text{ moles ethylene glycol} = 2250 \text{ g} \times \frac{1 \text{ mole ethylene glycol}}{62.07 \text{ g ethylene glycol}} = 36.25 \text{ moles}$$

$$? \text{ moles water} = 2000 \text{ g} \times \frac{1 \text{ mol water}}{18.02 \text{ g}} = 110.98 \text{ moles}$$

$$\text{Total no. of moles in solution} = 36.25 \text{ moles} + 110.98 \text{ moles} = 147.2 \text{ moles solution}$$

$$\text{Mole Fraction of ethylene glycol} = \frac{36.25 \text{ moles ethylene glycol}}{147.2 \text{ moles solution}} = 0.246$$

B) Find the Mole Fraction of water in this solution.

VAPOR PRESSURE OF A SOLUTION

- Vapor Pressure is the pressure of the vapor over a liquid, measured at equilibrium, at a given temperature.
- Vapor Pressure depends on:
 - temperature (increases with temperature)
 - nature of the liquid
- Volatile Liquids have relatively high vapor pressure.
- Non volatile Liquids have relatively low vapor pressure

Ex: Water is much more volatile than EthyleneGlycol ($\text{CH}_2\text{OH CH}_2\text{OH}$)
 (higher P_v) (lower P_v)

It follows: EthyleneGlycol can be considered to be nonvolatile compared to Water

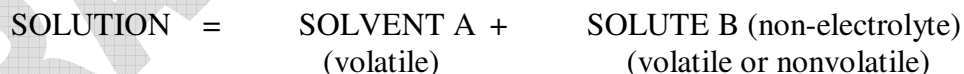
- **The Vapor pressure of a volatile solvent is lowered by addition of a non-volatile solute.**

	Pure Solvent	Solution
	(water)	(0.100 mole fraction ethylene glycol in water)
P_v at 20°C	17.54 mmHg	17.36 mmHg

$$\Delta P = \text{Vapor Pressure Lowering} = 17.54 \text{ mm Hg} - 17.36 \text{ mm Hg} \\ = 0.18 \text{ mm Hg}$$

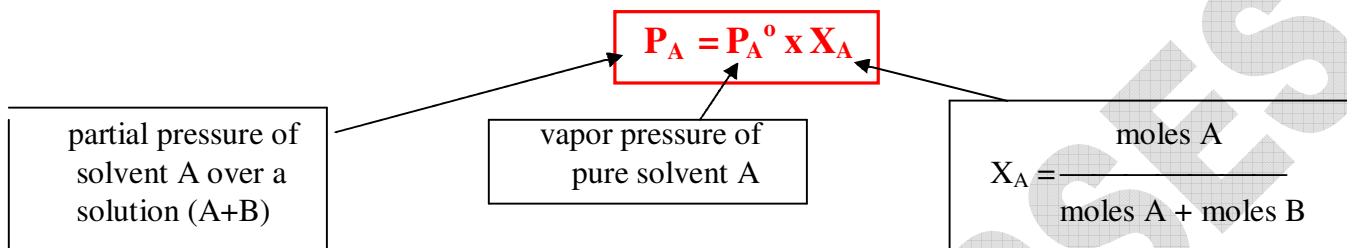
Raoult's Observation;

- The Vapor Pressure of a solvent (A) over the solution of a non-electrolyte solute (B) depends on the Mole Fraction (X_A) of solvent in the solution.



RAOULT'S LAW

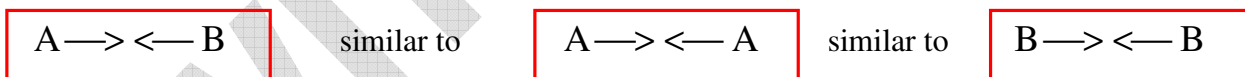
- The partial pressure of solvent (P_A) over a solution equals the vapor pressure of the pure solvent (P_A^0) times the mole fraction of solvent A in the solution (X_A)

**NOTE:**

- (1) $X_A < 1$ therefore: $P_A < P_A^0$; Vapor Pressure is lowered
- (2) If solute B is nonvolatile: $P_A = P_T$ (Total vapor pressure of solution)

IDEALSOLUTIONS:

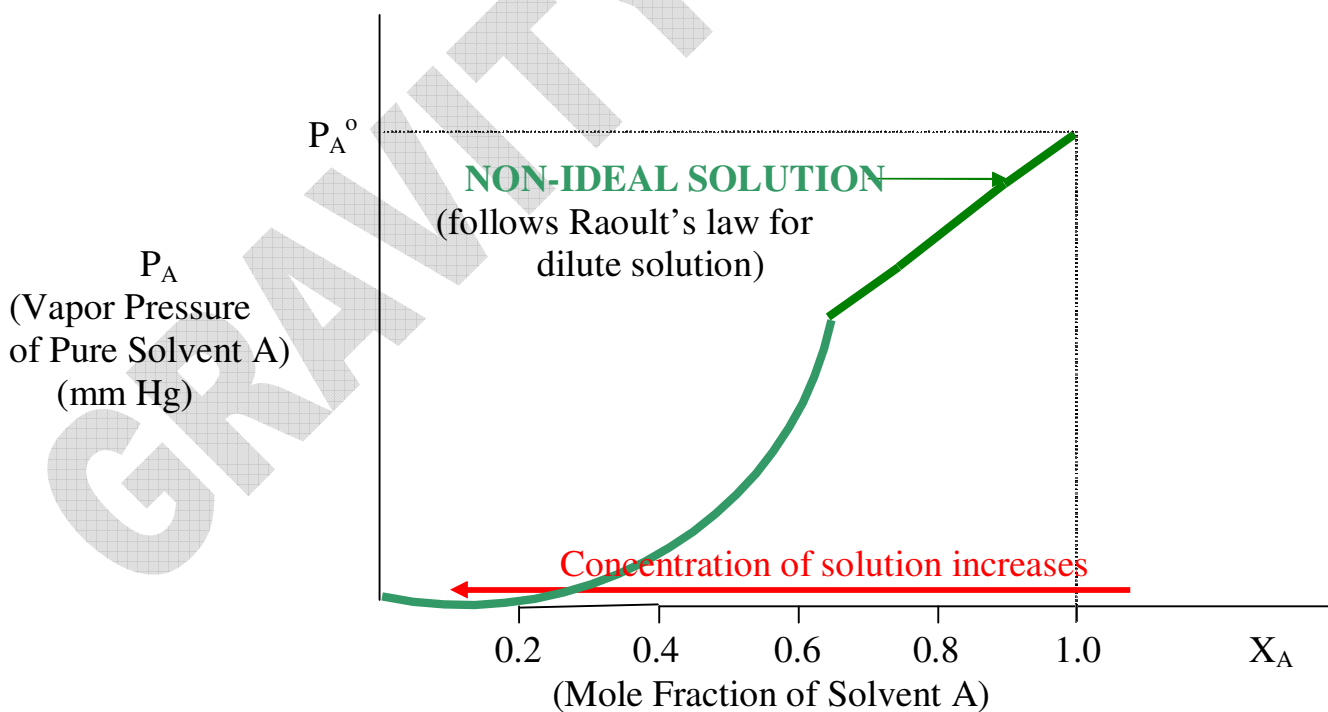
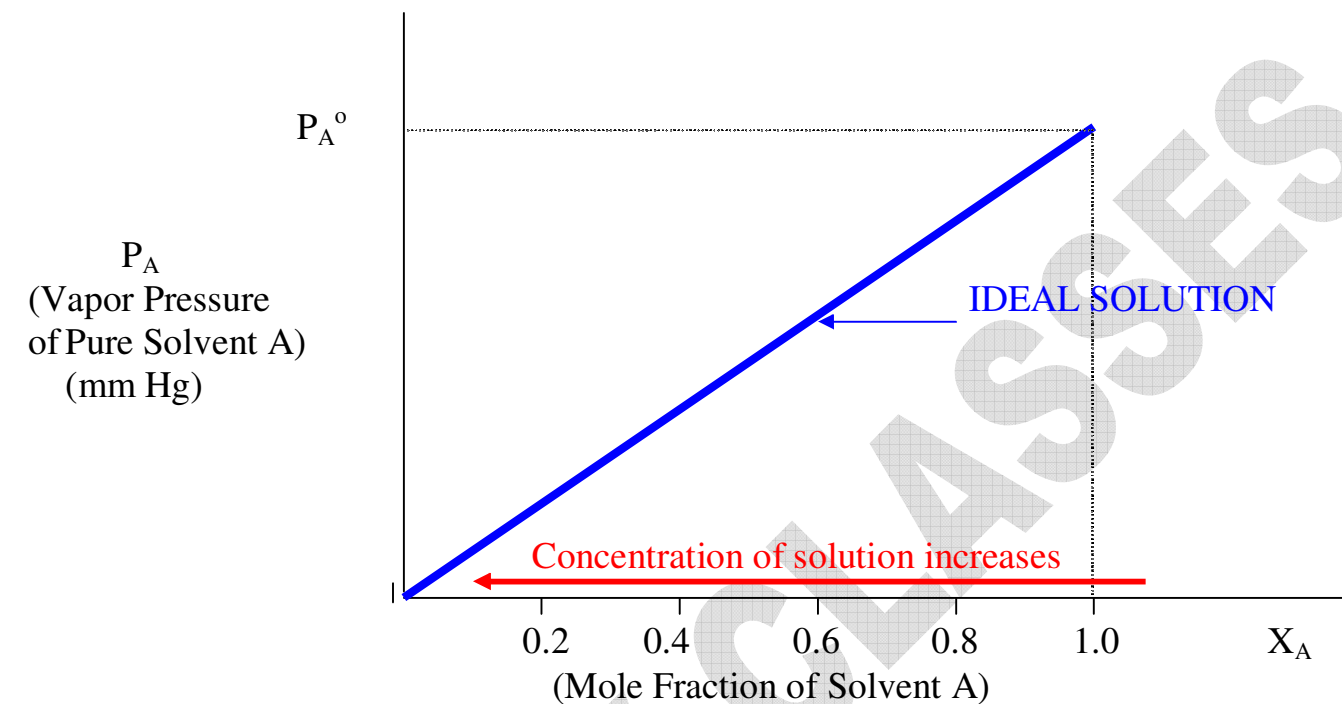
- These are solutions for which Raoult's Law holds true for **ALL VALUES OF MOLE FRACTIONS**.
- In these solutions:
 - Solvent A and Solute B are chemically similar
 - Intermolecular Forces of Attraction between:



- Solvent A is volatile
- Solute B is a non-electrolyte and may be volatile or nonvolatile

NON-IDEALSOLUTIONS:

- These are solutions for which Raoult's Law holds true only if :
 - Solute B is a nonvolatile electrolyte and
 - Solution is dilute ($X_A \gg \gg \gg X_B$)

IDEAL & NON-IDEAL SOLUTIONS

For an Ideal Solution:

$\Delta P = \text{Vapor Pressure Lowering}$

$$\Delta P = P_A^\circ - P_A = P_A^\circ - P_A^\circ X_A = P_A^\circ (1 - X_A)$$

Recall:

Mole Fraction of Component 1 + Mole Fraction of Component 2 = 1

Mole Fraction of Solvent A + Mole Fraction of Solute B = 1

$$X_A + X_B = 1$$

It follows: $X_B = 1 - X_A$

Therefore:

$$\Delta P = P_A^\circ X_B$$

- Vapor Pressure Lowering (ΔP) is a **COLLIGATIVE PROPERTY**.
- This means: ΔP :
 - depends on the concentration of solute
 - does not depend on the nature of the solute
- Consider the following solutions at 20°C

	X_B	P_A°	P_A	ΔP
	Mole Fraction of Solute B	Vapor Pressure of Pure Solvent A	Vapor Pressure of Solvent A in Sol'n	Vapor Pressure Lowering
Ethylene Glycol in Water	0.0100	17.54 mmHg	17.36 mmHg	0.18 mmHg
	0.0200	17.54 mmHg	17.18 mmHg	0.36 mmHg
Urea In Water	0.0100	17.54 mmHg	17.36 mmHg	0.18 mmHg
	0.0200	17.54 mmHg	17.18 mmHg	0.36 mmHg

Examples:

1. What is the vapor pressure at 23°C of a solution of 1.20 g naphthalene (C₁₀H₈) in 25.6 g of benzene (C₆H₆)? The vapor pressure of pure benzene at 23°C is 86.0 mm Hg; the vapor pressure of naphthalene can be neglected.

(HINT: First calculate the vapor pressure lowering of the solution).

	Formula	Mass	Molar Mass	# of Moles	Mole Fraction (X)
Solute B	C ₁₀ H ₈	1.20 g	128.2 g/mol	9.36x10 ⁻³	0.0278
Solvent A	C ₆ H ₆	25.6 g	78.1 g/mol	327.8x10 ⁻³	0.973
Total Number of Moles				337x10 ⁻³	1.000

$$\Delta P = P_A^{\circ} X_B = (86.0 \text{ mm Hg}) (0.0278) = 2.39 \text{ mm Hg}$$

$$P_A = P_A^{\circ} - \Delta P = 86.0 \text{ mm Hg} - 2.39 \text{ mm Hg} = \mathbf{83.6 \text{ mm Hg}}$$

- When both Solvent A and Solute B have significant vapor pressures, it follows that:

$$P_T = \text{Total Vapor Pressure over Solution} = P_A + P_B = P_A X_A + P_B X_B$$

- Consider a solution containing toluene (C₇H₈, less volatile) in benzene (C₆H₆, more volatile) (Note: Toluene and Benzene are chemically similar substances)

	V.P. of Pure Liquid	Mole Fraction in Solution	Partial V.P. over Solution	Mole Fraction of Vapor
Toluene (C ₇ H ₈)	P _B [°] = 22 mmHg	X _B = 0.30	P _B = 6.6 mmHg	X _B (v) = 0.11
Benzene (C ₆ H ₆)	P _A [°] = 75 mmHg	X _A = 0.70	P _A = 52.5 mmHg	X _A (v) = 0.89
		1.00	P _T = 59 mmHg	1.00

- Liquid is 0.30 mole fraction toluene and 0.70 mole fraction benzene.
- Vapor is 0.11 mole fraction toluene and 0.89 mole fraction benzene.

CONCLUSION:

THE VAPOR PRESSURE OVER A SOLUTION IS RICHER IN THE MORE VOLATILE COMPONENT