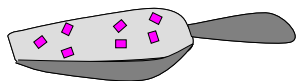
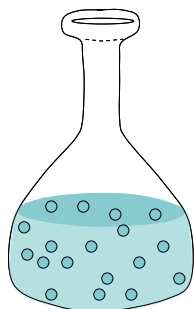


## Colligative Properties

*Properties that depend on the number of solute particles dissolved in solution (amount), and not on the identity of the solute particle*



The FOUR Colligative properties are...



- 1.
- 2.
- 3.
- 4.

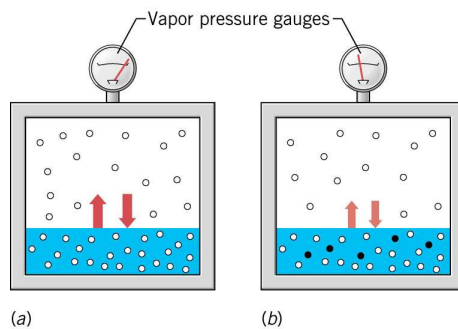
**Note: Number of dissolved solute particles in solution, depend on whether the solute is a strong, weak, or non-electrolyte!!!**

## Vapor Pressure Lowering

**CASE #1: Nonvolatile solute dissolved in solvent.**

Vapor Pressure:

$$\text{VP (pure solvent)} > \text{VP (solution)}$$



## Raoult's Law

*Vapor pressure of a solution is dependent on how much (i.e. conc.) SOLVENT is present!!*

$$P_{\text{soln}} = X_{\text{solvent}} P_{\text{solvent}}^{\circ}$$

$P_{\text{soln}}$  = vapor pressure of the solution

$X_{\text{solvent}}$  = mole fraction of the solvent

$P_{\text{solvent}}^{\circ}$  = vapor pressure of pure solvent

Raoult's Law works best for ideal solutions:

- 1.
- 2.

Derive the expression for the change in Vapor Pressure.

1. Calculate the vapor pressure of a solution made by dissolving 20.0 g glucose,  $\text{C}_6\text{H}_{12}\text{O}_6$ , in 500.0 g of water. The vapor pressure of pure water is 47.1 torr at 37°C.
2. What is the vapor pressure (in mm Hg) of a solution made by dissolving 5.0 g of  $\text{CaCl}_2$  in 50.0 g of  $\text{H}_2\text{O}$  at 70 °C. The vapor pressure of pure water at 70 °C is 233.7 mm Hg.
3. How many grams of sucrose must be added to 320. g of water to lower the vapor pressure by 1.5 mm Hg at 25 °C? The vapor pressure of water at 25 °C is 23.8 mm Hg, and the molar mass of sucrose is 342.3 g/mol. (4.1 x10<sup>2</sup> g)

## Vapor Pressure Lowering

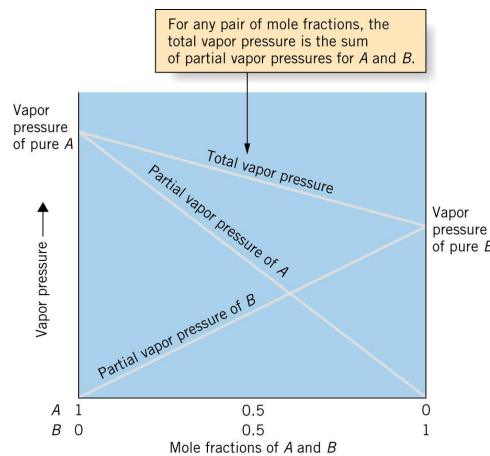
### CASE #2: Two (or more) volatile substances mixed.

Both substances contribute to VP of solution....

$$P_{\text{soln}} = P_1 + P_2$$

..but, from Raoult's Law

... Hence



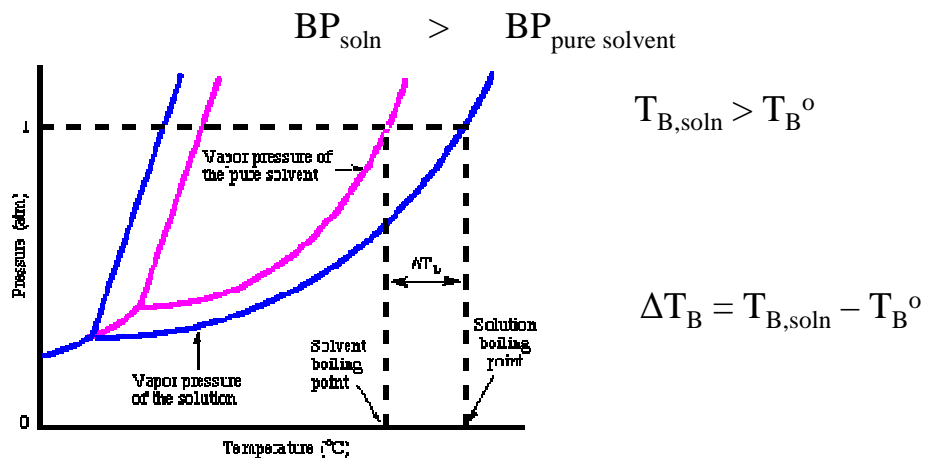
## Sample Questions

1. In a solution of water in ethanol, the mole fraction of water is 0.25. If the vapor pressures of pure water and ethanol are 23.8 mm Hg and 61.2 mm Hg at 25°C, respectively, what is the vapor pressure of this solution?
2. Acetone,  $\text{C}_3\text{H}_6\text{O}$ , and ethyl acetate,  $\text{C}_4\text{H}_8\text{O}_2$ , are organic liquids often used as solvents. At 30°C, the vapor pressure of pure acetone is 285 torr. What is the vapor pressure of pure ethyl acetate at 30°C, if the vapor pressure of a solution of 25.0 g acetone in 25.0 g ethyl acetate is 219 torr?

## Boiling Point Elevation

Normal BP:

The boiling point (BP) of a *solution* of a solvent with a *nonvolatile* solute is always **HIGHER** than the boiling point of the *pure* solvent.



## Boiling Point Elevation

What is the increase in the boiling point of the solution?

this gives the **CHANGE**,  
not the new BP

boiling point elevation

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

molality of solute particles

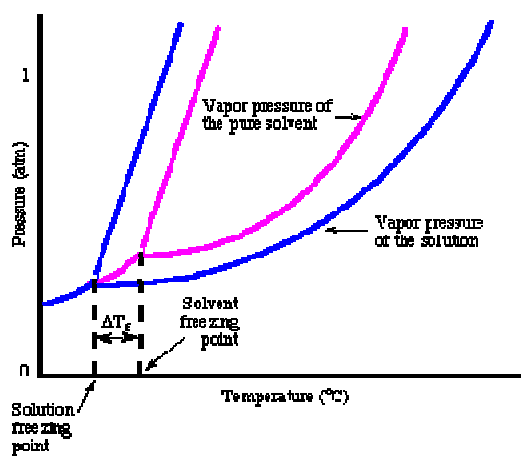
molal BP elevation constant that is  
**DIFFERENT**  
for different solvents  
(units are °C.kg/mol)

## Freezing Point Depression

Freezing point The temperature at which both the solid and liquid of the substance **COEXIST**

The freezing point (FP) of a solution of a solvent with a *nonvolatile* solute is always **LOWER** than the freezing point of the pure solvent

$$FP_{\text{soln}} < FP_{\text{pure solvent}}$$



$$T_{F,\text{soln}} < T_{F,\text{solvent}}^{\circ}$$

$$\Delta T_F = T_{F,\text{solvent}}^{\circ} - T_{F,\text{soln}}$$

## Freezing Point Depression

How much lower is the freezing point of the solution?

this gives the **CHANGE**,  
not the new FP

$$\Delta T_f = K_f m$$

← molality of solute particles

$$molality = \frac{\# \text{ mols solute}}{\text{kg solvent}}$$

← molal FP Depression constant that is

**DIFFERENT**  
for different solvents  
(units are °C.kg/mol)

← freezing point depression

**And different from  $K_b$ !!**

## Sample Questions

- What are the boiling points of the following aqueous solutions?  
(for water:  $K_b = 0.51\text{ }^\circ\text{C kg/mol}$ )  
  
0.90 m sugar solution                      0.90 m  $\text{Sr}(\text{ClO}_3)_2$
- What is the normal boiling point (in  $^\circ\text{C}$ ) of a solution prepared by dissolving 1.50 g of aspirin (acetylsalicylic acid,  $\text{C}_9\text{H}_8\text{O}_4$ ) in 75.00 g of chloroform ( $\text{CHCl}_3$ )? The normal boiling point of chloroform is  $61.7\text{ }^\circ\text{C}$ , and  $K_b$  for chloroform is  $3.63\text{ }^\circ\text{C.kg/mol}$ .
- What mass of NaCl is dissolved in 200. g of water if the freezing point of the solution is  $-2.14\text{ }^\circ\text{C}$ ?  $K_f(\text{water}) = 1.86\text{ }^\circ\text{C.kg/mol}$

- A 0.100 g sample of PCB (a carcinogenic polychlorinated biphenyl) is dissolved in 10.0 g camphor. The freezing point of the resulting solution is  $178.35\text{ }^\circ\text{C}$ . Calculate the molecular weight of the PCB.  
For camphor:  $K_f = 37.7\text{ }^\circ\text{C.kg/mol}$  and  $T_f = 179.50\text{ }^\circ\text{C}$
- $\beta$ -carotene is a dietary source of vitamin A. Dissolving 0.0250 g of  $\beta$ -carotene in 1.50 g of camphor gives a freezing-point depression of  $1.17\text{ }^\circ\text{C}$ . What is the molar mass of  $\beta$ -carotene?  $K_f$  for camphor is  $37.7\text{ }^\circ\text{C.kg/mol}$ . (537 g/mol)
- Which one of the following solutions has the highest boiling point? lowest boiling point?  
 $K_b(\text{water}) = 0.51\text{ }^\circ\text{C kg/mol}$ .  
  
0.50 m sugar              0.50 m  $\text{CaCl}_2$               0.50 m NaCl              0.50 m HF              0.50 m  $\text{AlCl}_3$
- Which one of the following solutions has the highest freezing point? lowest freezing point?  
  
0.40 m  $\text{Na}_2\text{SO}_4$               0.50 m  $\text{KNO}_3$               0.60 m  $\text{C}_6\text{H}_{12}\text{O}_6$   
0.20 m  $\text{Al}(\text{C}_2\text{H}_3\text{O}_2)_3$               0.60 m  $\text{HC}_2\text{H}_3\text{O}_2$

## Osmotic Pressure ( $\pi$ )

### semipermeable membrane:

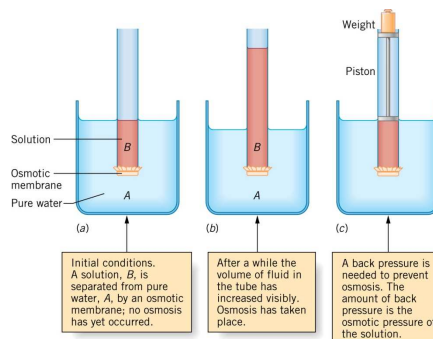
solvent molecules **can** pass through  
solute molecules **cannot** pass through

### Osmosis:

Net movement of SOLVENT particles through a semipermeable membrane from a region of low concentration (dilute solution/pure solvent) to a region of high concentration.

### Osmotic pressure:

The extra pressure required to stop osmosis of the solvent through the semipermeable membrane.



## Osmotic Pressure

Experiments by van't Holf in 1887 showed that the osmotic pressure is related to the *molarity* of the solution according to the equation

$$\pi = M R T$$

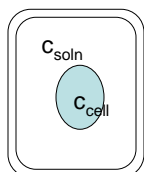
$\pi$  ← osmotic pressure (atm)  
 $M$  ← **molarity** of the solution (mol/L)  
 $R$  ← **Ideal GAS CONSTANT** (0.08206 L.atm/mol.k)  
 $T$  ← Kelvin temperature

This equation can also be re-written as...  
(a form similar to the Ideal gas equation)

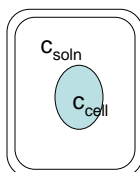
## Osmotic Pressure Effects

A red blood cell is placed in each of the following solutions. What will happen to the red blood cell in each solution?

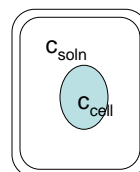
Which solution is isotonic? hypotonic? hypertonic?



$$C_{soln} > C_{cell}$$



$$C_{soln} < C_{cell}$$



$$C_{soln} = C_{cell}$$

## Sample Questions

1. What osmotic pressure (in atm) would you expect for each of the following solutions?
  - a. 5.00 g of NaCl in 350.0 ml of at 50 °C.
  - b. 6.33 g of sodium acetate, CH<sub>3</sub>CO<sub>2</sub>Na, in 55.0 ml of aqueous solution at 10 °C. (65.2 atm)
2. A 2.00 g sample of a protein dissolved in 0.100 L of solution exhibited an osmotic pressure of 16 mm Hg at 25°C. What is the molar mass of the protein?
3. What is the molar mass of sucrose (table sugar) if a solution prepared by dissolving 0.822 g of sucrose in 300.0 ml of water has an osmotic pressure of 149 mm Hg at 298 K?

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Colligative Properties

4. A 0.0500 M  $\text{FeCl}_3$  solution exerts an osmotic pressure of 4.16 atm at  $25^\circ\text{C}$ . Calculate the van't Hoff factor. Why is the experimental van't Hoff factor less than the theoretical van't Hoff factor?
5. A solution of 4.94 g  $\text{K}_3\text{Fe}(\text{CN})_6$  dissolved in 100. g of water has a freezing point of  $-1.1^\circ\text{C}$ . How many ions result from the dissolution of the  $\text{K}_3\text{Fe}(\text{CN})_6$  in water?
6. When stranded at sea without fresh water, why is it NOT a good idea to drink seawater?
7. Use your knowledge of osmotic pressure to explain how fresh water can be obtained from seawater.