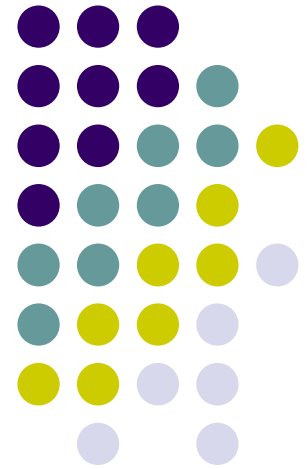# Colligative Properties of Solutions

Yanovska Anna Olexandrivna

PhD physical chemistry

Lecturer of General chemistry department

● In our life we can see decreasing of freezing point by adding salt on the road. Due to this road is free of snow and ice.
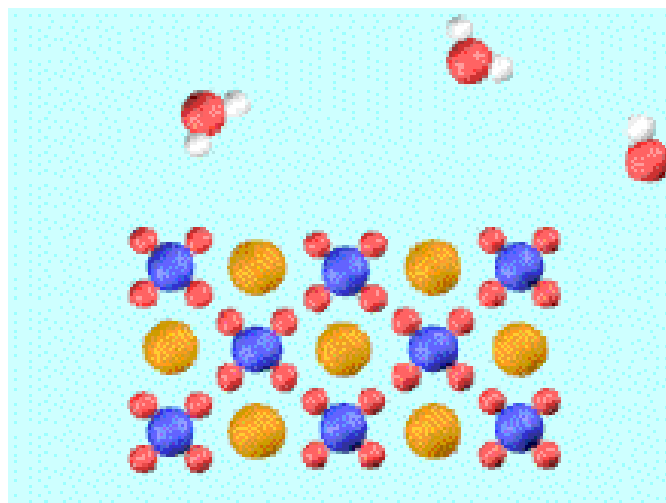
IONIC COMPOUNDS
Compounds in Aqueous Solution

Many reactions involve ionic compounds, especially reactions in water — aqueous solutions.

KMnO$_4$ in water

K$^+$(aq) + MnO$_4^-$(aq)

H_2O

MnO_4^-

K^+

Aqueous Solutions

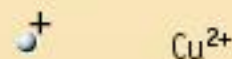If compounds completely dissociates on ions they are called ELECTROLYTES

HCl, MgCl$_2$, and NaCl are strong electrolytes.

Degree of dissociation α for such electrolytes is 1 or nearly 100%.

Strong Electrolyte

$CuCl_2$

+ Cu^{2+}

− Cl^-

A strong electrolyte conducts electricity. $CuCl_2$ is completely dissociated into Cu^{2+} and Cl^- ions.

Electrolytes in the Body

- Carry messages to and from the brain as electrical signals

- Maintain cellular function with the correct concentrations electrolytes

Make your own

**50-70 g sugar
One liter of warm water
Pinch of salt
200ml of sugar free fruit squash
Mix, cool and drink**

Aqueous Solutions

Some compounds dissolve in water but do not conduct electricity. They are called nonelectrolytes.
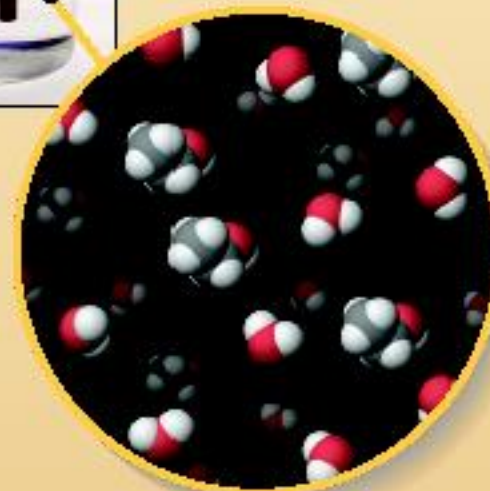
Examples include:
sugar
ethanol
ethylene glycol

Nonelectrolyte

Ethanol

A nonelectrolyte does not conduct electricity because no ions are present in solution.

Constant of dissociation for weak electrolytes

$$Kt_xAn_y \Leftrightarrow xKt^{y+} + yAn^{x-}.$$
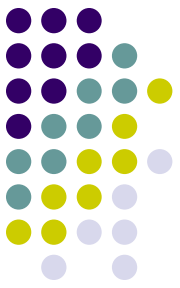
$$K = \frac{[Kt^{y+}]^x \cdot [An^{x-}]^y}{[Kt_xAn_y]};$$

$$[Kt^+] = [An^-] = \alpha C,$$

$$[KtAn] = C - \alpha C = C(1 - \alpha).$$

$$Kd = \frac{[Kt^+][An^-]}{[KtAn]} = \frac{\alpha C \cdot \alpha C}{C(1-\alpha)} = \frac{\alpha^2 C}{1-\alpha}.$$

$$K = \alpha^2 C,$$

$$\alpha = \sqrt{K/C}.$$

Colligative properties

- Properties of ideal solutions don't depend on nature of the solute they only depend on its concentration.

- So properties that depend only on the number of solute particles and not on their identity named – ***colligative properties:***

- Vapor pressure lowering

- Boiling point elevation

- Freezing Point depression

Colligative Properties

On adding a solute to a solvent, the properties of the solvent are modified.

- Vapor pressure   decreases
- Melting point   decreases
- Boiling point   increases
- Osmosis is possible (osmotic pressure)

These changes are called COLLIGATIVE PROPERTIES.

They depend only on the NUMBER of solute particles relative to solvent particles, not on the KIND of solute particles.
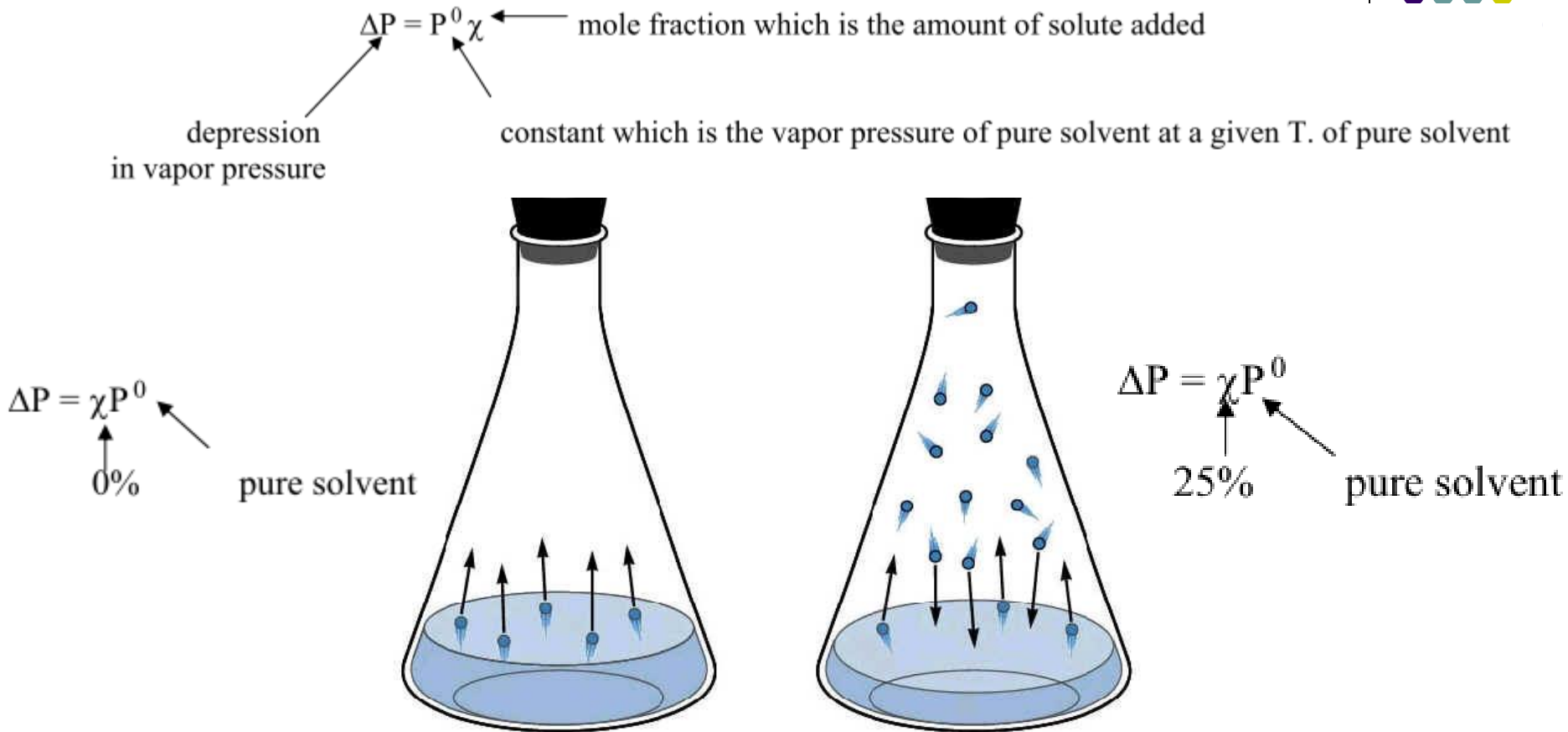
Vapour pressure depression

The Raoult's law: The relative depression of the saturated vapour pressure of a solvent over a solution equals the mole fraction of the solute.

The mathematical expression of the first Raoult's law is:

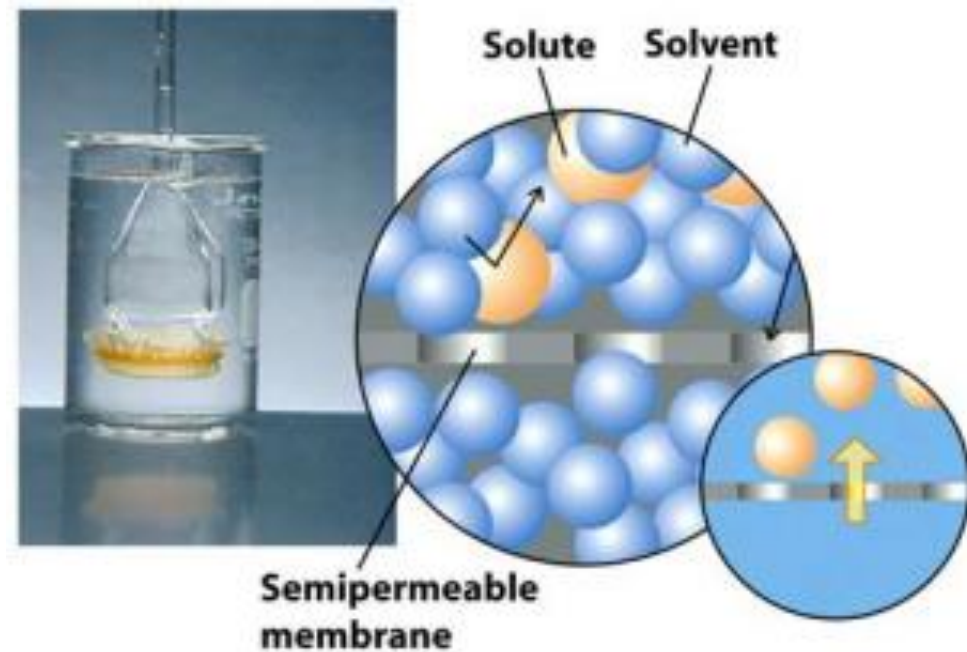$$\frac{P_o - P_s}{P^o} = \frac{n_2}{n_1 + n_2},$$

where p^o – vapour pressure of the solvent,

P_s – vapour pressure of the solution,

n_2 – number of moles of the solute,

n_1 – number of moles of the solvent,

Vapour pressure depression

$\Delta P = P^0 \chi$ ← mole fraction which is the amount of solute added

depression in vapor pressure

constant which is the vapor pressure of pure solvent at a given T. of pure solvent

$\Delta P = \chi P^0$

0%   pure solvent

$\Delta P = \chi P^0$

25%   pure solvent

- The particles of solute are surrounded by and attracted to particles of solvent.
- Now the solvent particles have less kinetic energy and tend less to escape into the space above the liquid.
- So the vapor pressure is less.

P osmotic= C_MRT

Solute   Solvent

Semipermeable
membrane

$\pi = MRT$ ← molarity which is the amount of solute added

Osmotic pressure   constant, RT, which seems to pop up everywhere
increase because of solute

The constants R and T are the ideal gas law constant and the system temperature

So the osmotic pressure change is $\pi = MRT = (1.17\ M)(0.082)(298\ K) = $ **28.6 atm**

Isotonic, hypotonic and hypertonic solutions
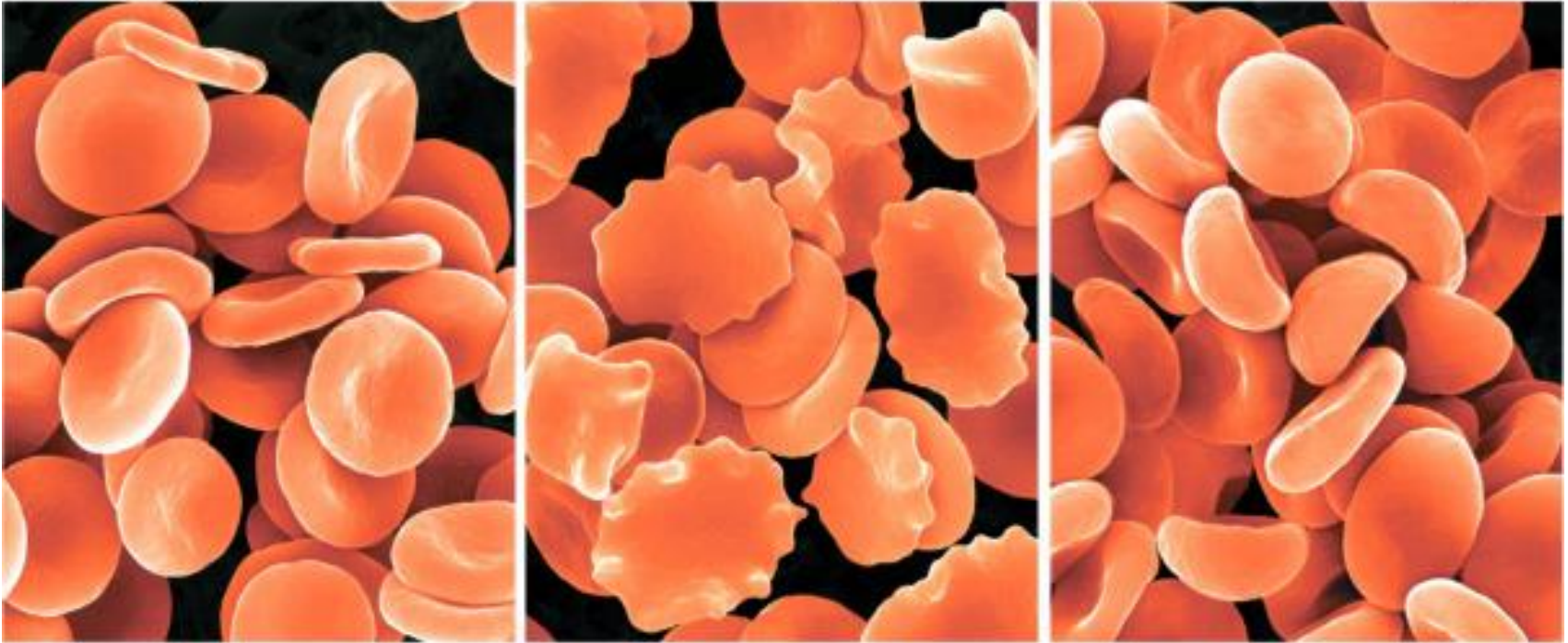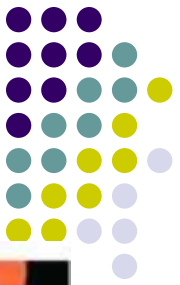
The solution around the cells has <u>the same</u> concentrations like inside of them (first picture), <u>too high concentration</u> in which case the water flows out of the cell
and they shrivel up (second picture), or <u>too low</u> concentration in which case water flows into the cells and they lyse or rupture (third picture.)

- **Example** 1.2 L of solution contains 20.5 mg of sucrose ($C_{12}H_{22}O_{11}$). Calculate the osmotic pressure of the solution at 22ºC.

- **Solution**

$$M(C_{12}H_{22}O_{11}) = 342 \, g/mol$$

$$C_M = \frac{n(C_{12}H_{22}O_{11})}{V(solution)} = \frac{m(C_{12}H_{22}O_{11})}{M(C_{12}H_{22}O_{11}) \cdot V(solution)} = \frac{20.5 \cdot 10^{-2} \, g}{342 g/mol \cdot 1.2 \, L} = 5.0 \cdot 10^{-5} mol/L$$

$$P_{osmotic} = C_M RT = 5.0 \cdot 10^{-5} \, mol/L \cdot 8.314 J/mol \cdot K \cdot 295 \, K = 0.123 \, kPa = 123 \, Pa.$$

Answer: $P_{osmotic}$=123 Pa.

Ionic vs Molecular Solutes Electrolytes vs Non electrolytes
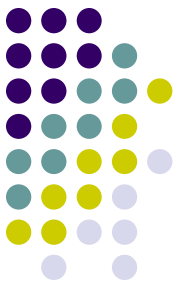
- Ionic solutes produce two or more ion particles in solution.

- They affect the colligative properties proportionately more than molecular solutes (that do not ionize).

- The effect is proportional to the **number of particles of the solute in the solution.**

$$Kt_xAn_y \Leftrightarrow xKt^{y+} + yAn^{x-}$$

$$nAl_2(SO_4)_3 \rightarrow 2nAl^{3+} + 3nSO_4^{2-}$$

Freezing Point Depression and Boiling Point Elevation
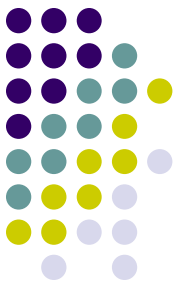
Boiling Point Elevation

- $\Delta T_b = k_b\ Cm$ (for water $k_b = 0.52\ ^oC/m$)

- Freezing Point Depression

- $\Delta T_f = k_f\ Cm$ (for water $k_f = 1.86\ ^oC/m$)

- **Note**: C**m is the molality of the particles**, so if the solute is ionic, multiply by the *i -Vant Hoff coefficient* of particles it dissociates to (ν).

- **i=1+α(ν-1)**

Boiling Point Elevation and Freezing Point Depression

$$\Delta T = K \cdot Cm \cdot i$$

i = van't Hoff factor = number of particles produced per molecule/formula unit. For covalent compounds, i = 1. For ionic compounds, i = the number of ions present (both + and -)

Compound	Theoretical Value of **i**
glycol	1
NaCl	2
$CaCl_2$	3
$Ca_3(PO_4)_2$	5

Boiling Point Elevation and Freezing Point Depression

$$\Delta T = K \cdot Cm \cdot i$$

Cm = molality

K = molal freezing
   point/boiling point constant

Substance	K_f
benzene	5.12
camphor	40.
carbon tetrachloride	30.
ethyl ether	1.79
water	1.86

Substance	K_b
benzene	2.53
camphor	5.95
carbon tetrachloride	5.03
ethyl ether	2.02
water	0.52

How many particles do each of the following give upon solvation?

- NaCl
- $CaCl_2$
- Glucose
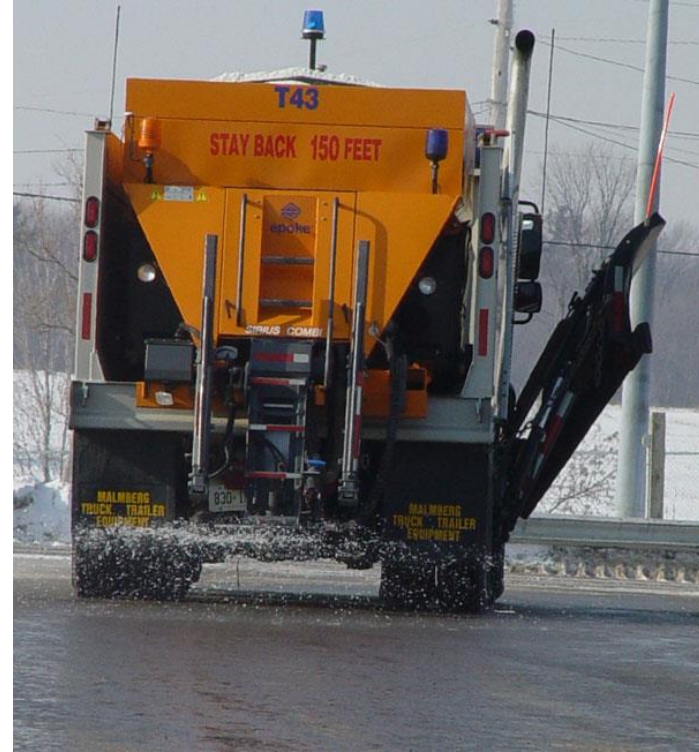
Which is more effective for lowering the freezing point of water? NaCl, $CaCl_2$ or Glucose

$$\Delta T_f = Kf \; K \cdot kg/mol \cdot \frac{m \, (solute)g \cdot 1000}{M(solute) \, g/mol \cdot m(H_2O)g}$$

$$\Delta T_b = K_b \; K \cdot kg/mol \cdot \frac{m \, (solute)g \cdot 1000}{M(solute) \, g/mol \cdot m(H_2O)g}$$

Freezing Point Depression

$$\Delta T_f = Kf \cdot Cm \qquad \Delta T_f = i \cdot Kf \cdot Cm$$
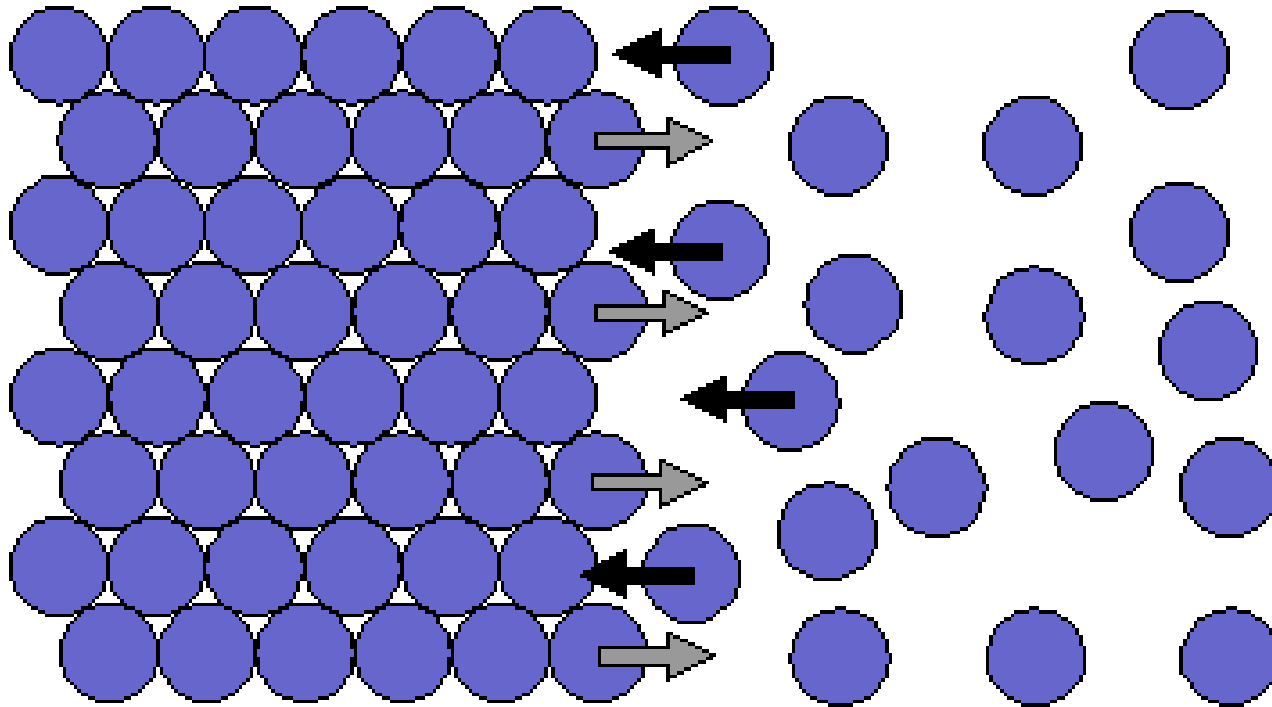
Change in Freezing Point

Pure water

Ethylene glycol/water solution
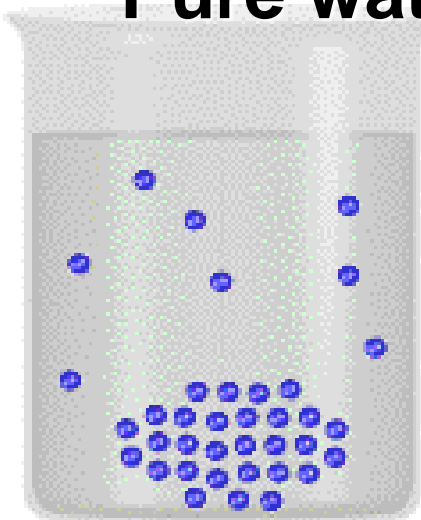
Pure water
(without solute)
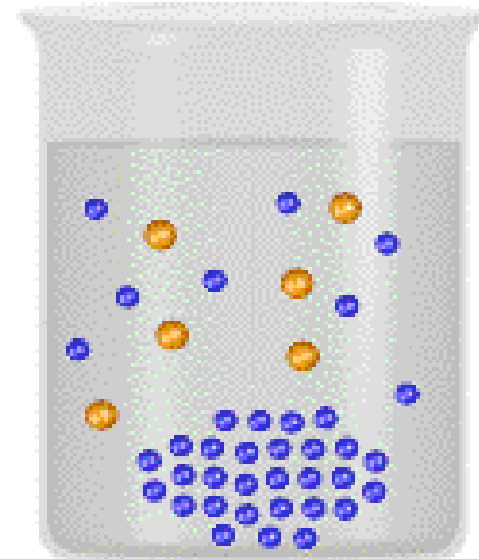
Ethylene glycol
solution

The freezing point of a solution is LOWER
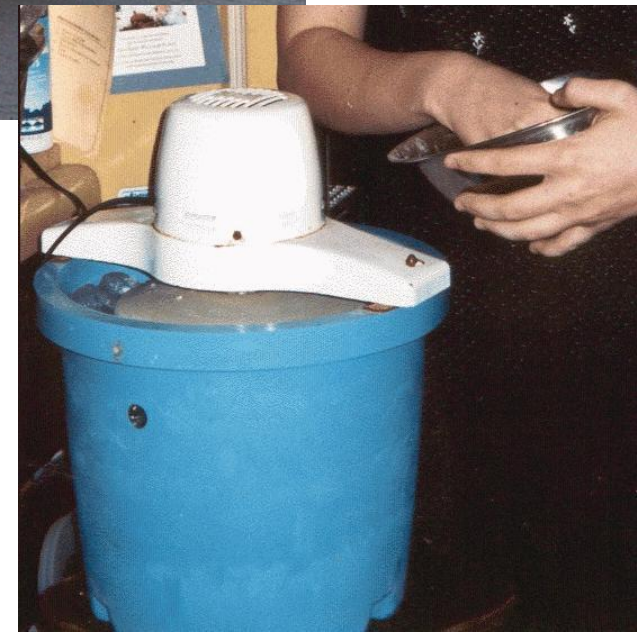than that of the pure solvent

Change in Freezing Point
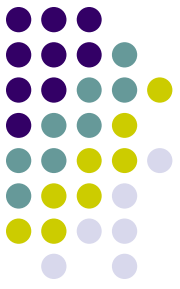
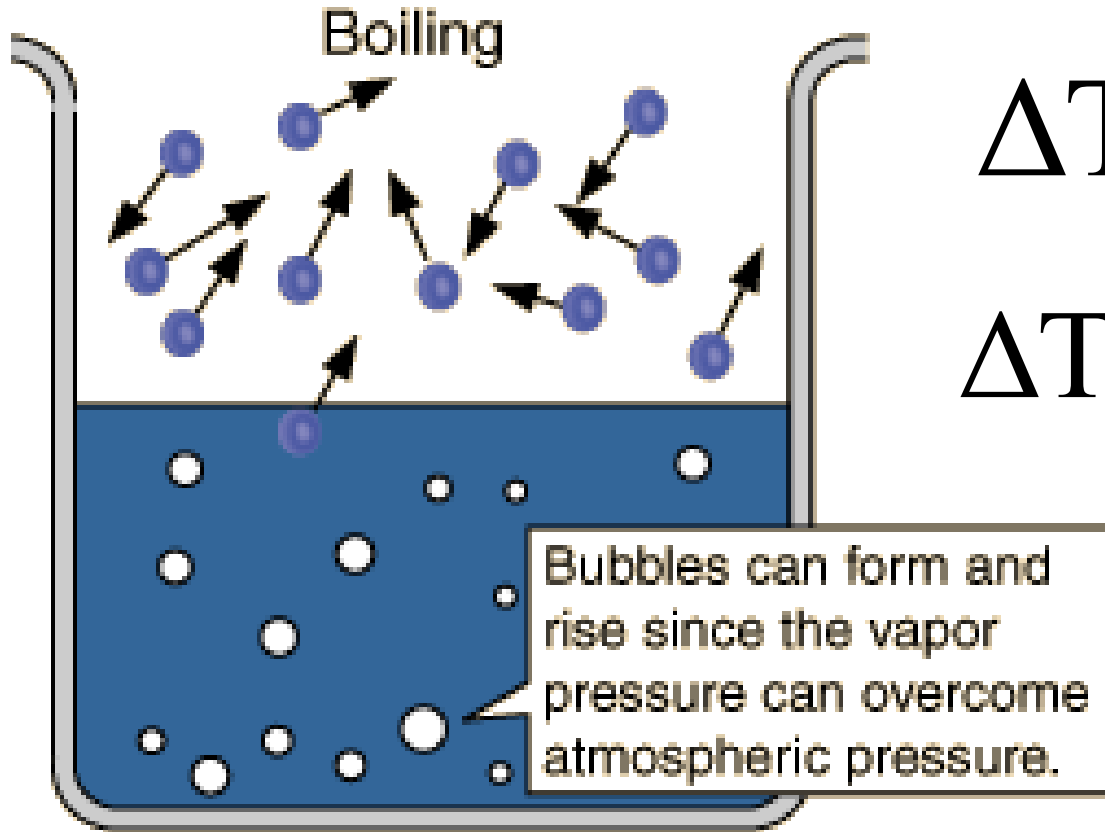Common Applications of Freezing Point Depression
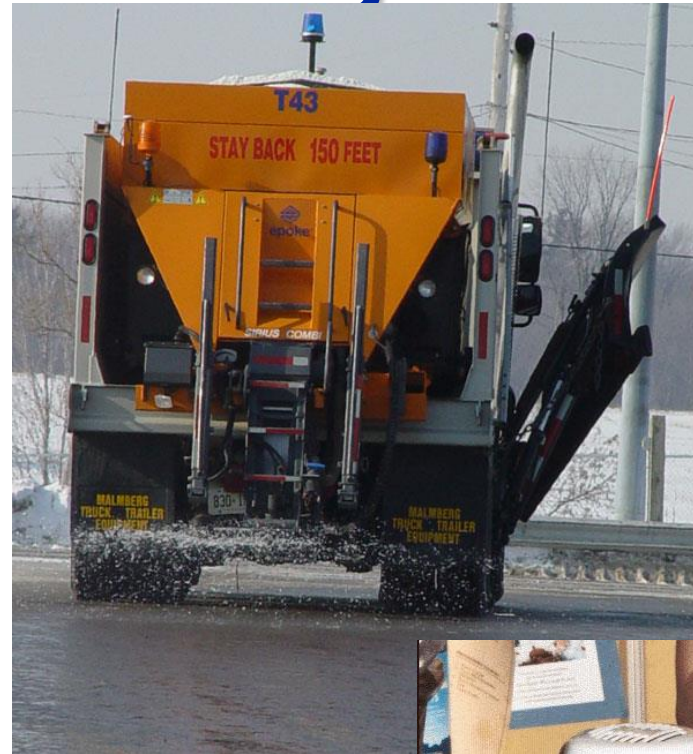
Propylene glycol

Ethylene glycol – deadly to small animals

Boiling Point Elevation

Boiling

$$\Delta T_f = Kf \cdot Cm$$

$$\Delta T_f = i \cdot Kf \cdot Cm$$

Bubbles can form and rise since the vapor pressure can overcome atmospheric pressure.

Change in Boiling Point

Common Applications of Boiling Point Elevation

Change in Boiling Point

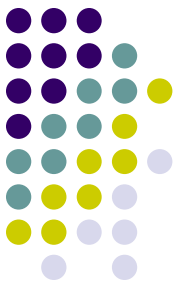Dissolve 62.1 g of glycol (1.00 mol) in 250. g of water. What is the boiling point of the solution?

K_b = 0.52 ^{o}C/molal for water (see K_b table).

Solution ΔT_{BP} = K_b • Cm • i

1.   Calculate solution molality = 4.00 m

2. ΔT_{BP} = K_b • Cm • i

       ΔT_{BP} = 0.52 ^{o}C/molal (4.00 molal) (1)

       ΔT_{BP} = 2.08 ^{o}C

       BP = 100 + 2.08 = 102.08 ^{o}C

   (water normally boils at 100)

Freezing Point Depression

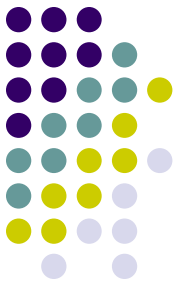At what temperature will a 5.4 molal solution of NaCl freeze?

Solution

$$\Delta T_{FP} \;=\; K_f \bullet Cm \bullet i$$

$$\Delta T_{FP} = (1.86\ ^oC/molal) \bullet 5.4\ mol/kg \bullet 2$$

$$\Delta T_{FP} = \; 20.1\ ^oC$$

FP = 0 – 20.1 = -20.1 ^oC

Thank you for your attention!