Your final exam is scheduled
Monday, December 15th
9:00 – 11:30 AM

You may make alternative arrangements to take the exam if:

1) You have a conflict.
2) You have 2 exams in a row.

Complete form on-line:
https://uwaterloo.ca/registrar/final-examinations/relief-information

and contact Bill Owen or Jonathan Histon in the 1st year Engineering Office.

By the end of today's class you will be able to identify an unknown solute using Raoult's law, calculate the elevation in boiling point and calculate the depression in freezing point that occurs when a substance is dissolved.

VAPOR PRESSURE DEPRESSION, BOILING AND FREEZING IN SOLUTION

Henry's Law & Raoult's Law Review

- Henry's Law: Increasing pressure increases solubility of gas in liquid.

$$P_i = k_i x_i$$

- Raoult's Law: Presence of solute lowers vapor pressure of solvent.

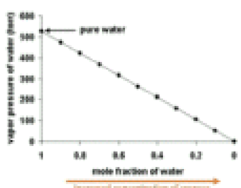
$$P_i = P^{o}_{vap} x_i$$

Colligative Properties

- A solution that obeys both Raoult's Law and Henry's Law is an ideal solution.
- For dilute solutions (x_{solv} > 0.98) the assumptions of ideality are valid.
- Consider a non-volatile solute in a volatile liquid solvent.
- Colligative properties depend on the ratio of solute particles to solvent molecules.
  1) Vapor pressure lowering
  2) Boiling point elevation
  3) Freezing point depression
  4) Osmotic pressure

1. Vapor Pressure Lowering

Vapor pressure is lowered when a solute is present.



Estimating Molar Mass Using ΔP

$$\Delta P_{solvent} = -x_{solid} P^{\circ}_{vap,liq}$$

From this equation we can use vapor pressure date to estimate the molar mass of an unknown solid dissolved in a known liquid.

Example 1

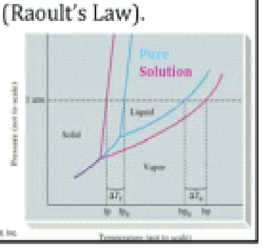
Twenty grams of a non-volatile solute are added to 100 g of water at 25 °C. The vapor pressure of pure water is 23.76 mmHg. The vapor pressure of the solution is 22.41 mmHg.

a) Calculate the molar mass of the solute.

b) What mass of this solute is required in 100 g of water to reduce the vapor pressure to ½ of the value of pure water?

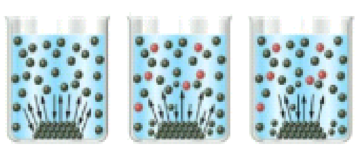
2. Boiling Point Elevation

- Recall: Normal boiling point is the temperature at which the vapor pressure equals 1 atm.
- Vapor pressure of solution is lower than vapor pressure of pure solvent (Raoult's Law).
- Therefore temperature must be **increased** to reach vapor pressure of 1 atm.



3. Freezing Point Depression

- Normal freezing point is the temperature at which a liquid crystallizes at 1 atm.

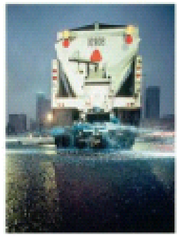


Equilibrium at freezing point of solvent — Equilibrium disrupted by solute added to solvent — Equilibrium restored at a lower temperature

- Freezing point is lowered due to presence of solute.

Freezing Point Depression

A 10% salt solution lowers the freezing point to -6 °C (20 °F) and a 20% salt solution lowers it to -16 °C (2 °F).



▲ Lowering the freezing point of water on roads.

Boiling Point Elevation & Freezing Point Depression

$\Delta T_b = K_b b$ $\Delta T_f = -K_f b$

b *is* the **molality of the solution** (mole solute/kg solvent).
K_b is the boiling point elevation constant.
K_f is the freezing point depression constant.

K_b and K_f depend only on solvent type.

TABLE 14.2 Freezing-Point Depression and Boiling-Point Elevation Constants

Solvent	K_f	K_b
Acetic acid	3.90	3.07
Benzene	5.12	2.53
Nitrobenzene	8.1	5.24
Phenol	7.27	3.56
Water	1.86	0.512

Values correspond to freezing-point depressions and boiling-point elevations, in degrees Celsius, due to 1 mol of solute particles dissolved in 1 kg of solvent in an ideal solution. Units: °C kg solvent (mol solute)$^{-1}$ or °C m^{-1}.

Example 2

When 39.8 g of a non-dissociating, non-volatile sugar is dissolved in 200 g of water, the boiling point of water is raised by 0.30 °C. Estimate the molar mass of the sugar.

Data: K_b = 0.512 K·kg/mol

Example 3

The freezing point depression constant for $HgCl_2$ is 34.3 K·kg/mol. For a solution containing 0.849 g of mercurous chloride (empirical formula HgCl) in 50 g of $HgCl_2$, the freezing point depression is 1.24 °C.

What is the molecular weight of mercurous chloride? What is its molecular formula?

Example 4

When 0.812 g of a hydrocarbon of the type C_nH_{2n+2} is dissolved in 203.0 g of ethylene bromide, the freezing point of the resulting solution is 9.50 °C. Calculate the value of n. The freezing point of pure ethylene bromide is 10.00 °C.

Data: K_f = 12.5 K·kg/mol

Suggested Readings

- 13.6 Vapor Pressures of Solutions
- 13.8 Freezing-Point Depression and Boiling Point Elevation of Nonelectrolyte Solutions