CHEM 1101B- Chemistry for Engineers

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HS (Health Sciences) 1301
Mondays & Wednesdays 8:35am - 9:55am

Lecture 14: Solutions

↳ finish phase changes!

Please feel free to introduce yourself to your neighbors– name, pronouns, a hobby, etc.

and/or

Answer first wooclap question

UJQBJM

Mental Health Resources

Health and Counselling- general counselling available or specialists in Indigenous, 2SLGBTQ+, sexual assault and trauma, racialized and international counselling.
CTTC (1125 University Drive), (613) 520-6674

CUSA Service Centers- peer support, various tailored resources for student communities. Disability, 2SLGBTQ+, Racialized & international, Indigenous, Women, general wellness

https://www.cusaonline.ca/service-centres/

Wellness Navigator- directory of wellness services at Carleton

https://wellness.carleton.ca/navigator/

Immediate emergency: Campus Safety at 444

Good2Talk: 1-866-925-5454
Suicide Crisis Helpline: 9-8-8
Trans Lifeline: (877) 330-6366
Native Youth Crisis Helpline: 1-877-209-1266
Naseeha Muslim Youth Helpline: 1-866-627-3342

NOVEMBER 8TH, 2024 FROM 3-4PM

CELEBRATING PRIDE IN SCIENCE

SNACK / MINGLE / CELEBRATE

3431 HERZBERG LABORATORIES (SSSC)

JOIN US FOR A SCIENCE SOCIAL AND FUN PRIDE THEMED ACTIVITIES

Learning outcome for Topic 14: Phases of Matter – Solutions

Learning Outcomes:

- Describe select colligative properties of solutions and relate them to intermolecular forces
- Describe ideal and non-ideal solutions of ionic solutes
- Calculate the boiling points and freezing points of ideal and non-ideal solutions

Solutions are crucial to the processes that sustain life and to many other processes involving chemical reactions.

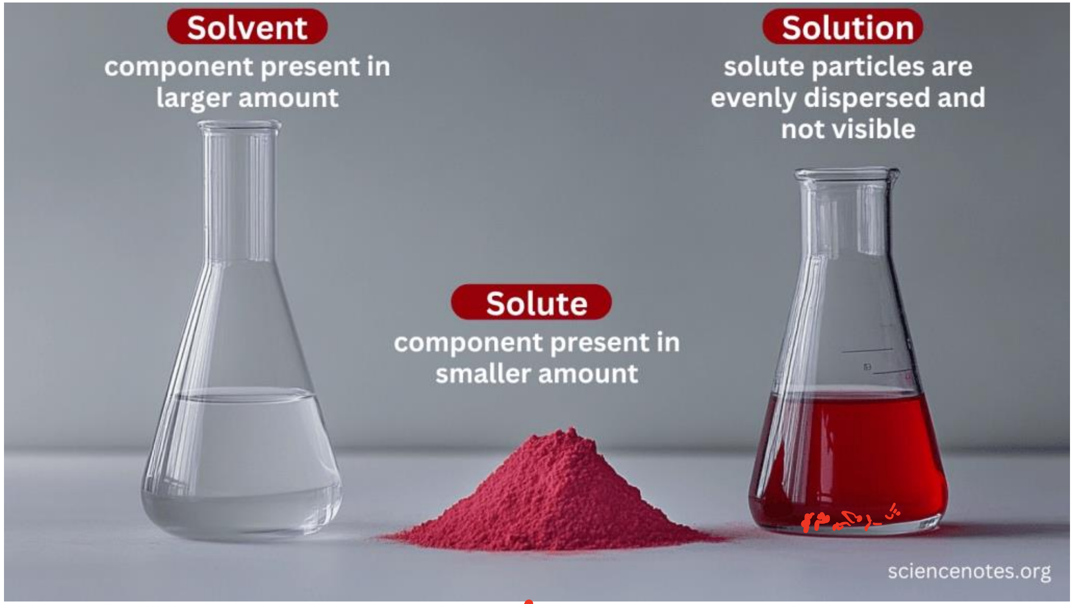
https://boisestate.pressbooks.pub/chemistry/chapter/intro-11/

Solutions: Solubilities and Intermolecular forces

Solubility: a chemical property that deals with the ability of a solute to become dissolved (miscible) in a solvent, forming a homogenous mixture known as a **solution**

Solution: a **homogenous mixture** of two or more substances

- A **solute** is a component of a solution present at a lower concentration than the **solvent**.
- A **heterogeneous mixture** is when a solute does not dissolve



[solute] = solution saturated sol'n

→ excess solute particles

Solutions: Solubilities and Intermolecular forces

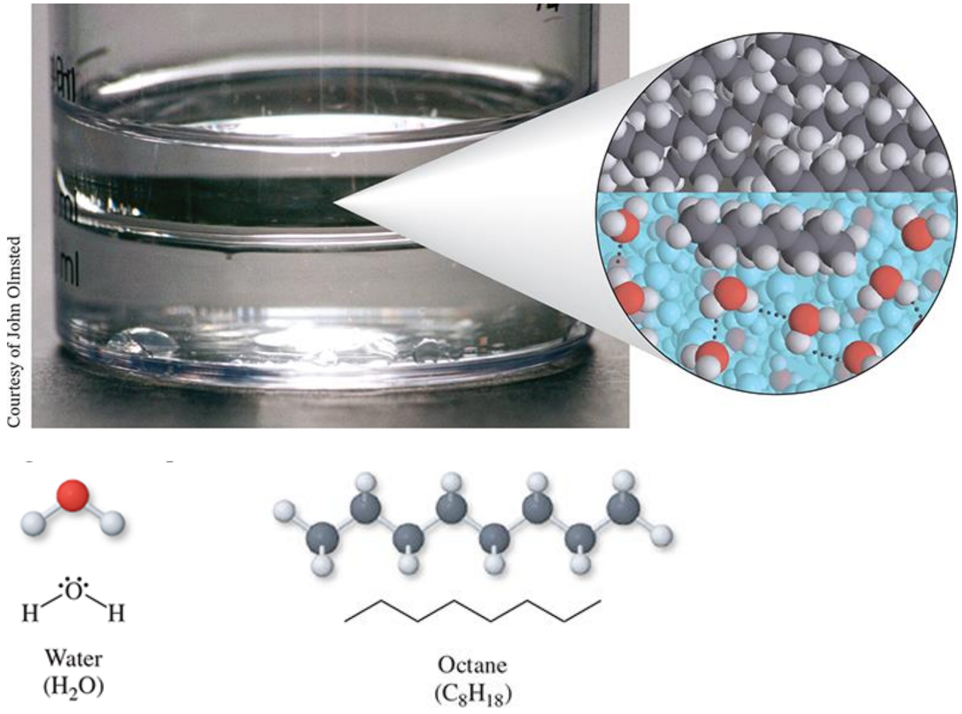
- Solubilities depend on **intermolecular forces**
- Substances that dissolve in each other usually have **similar types of intermolecular interactions and polarities** (“like dissolves like”)

Ion-dipole: **polar**, found in ionic compounds

Hydrogen bonding: **polar**, found in compounds directly bonded to F, O, or N

Dipole-dipole: **polar**, in polar covalent compounds

Dispersion forces: **non-polar**, all compounds but mainly nonpolar covalent



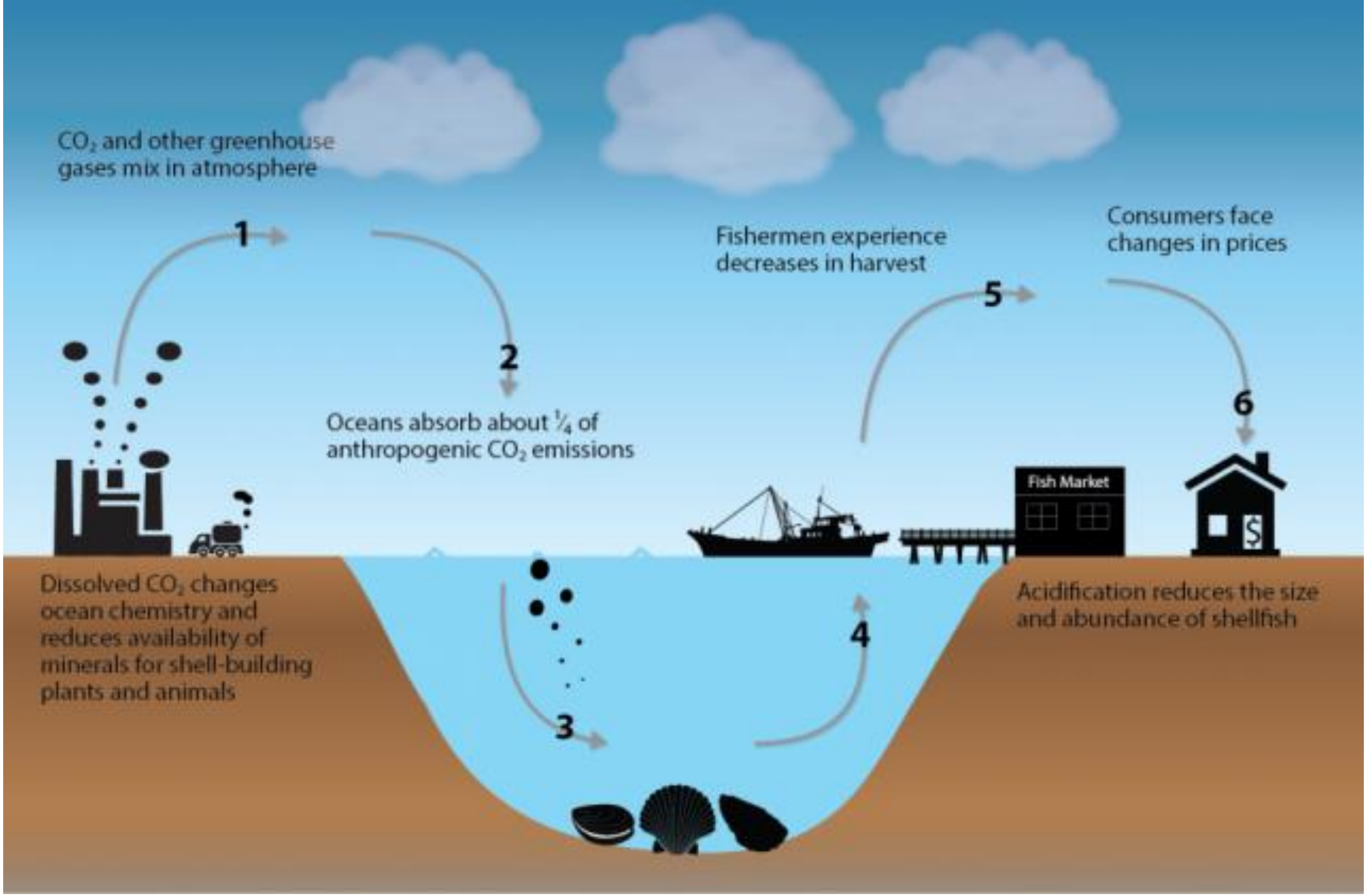
Types of binary solutions

→ solvent determines the phase of soln.

Types of binary solutions	Solute	Solvent	Examples
Solid solution	Solid	Solid	Copper dissolved in gold (alloys)
	Liquid	Solid	Mercury with sodium (amalgam)
Liquid solution	Solid	Liquid	Sodium chloride dissolved in water
	Liquid	Liquid	Ethyl alcohol dissolved in water
	Gas	Liquid	Carbon dioxide dissolved in water (soda water)
Gaseous solution	Liquid	Gas	Water vapour in air (cloud)
	Gas	Gas	Mixture of Helium-Oxygen gases

& oceans!!

https://www.yaclass.in/p/science-state-board/class-10/solutions-14119/solutions-components-types-properties-solubility-11481/re-91cbebfc-ece1-41b9-b3b1-d5e883437c7b



https://www.epa.gov/ocean-acidification/effects-ocean-and-coastal-acidification-ecosystems

Methods for expressing concentration of solutions

Concentrations are expressed as **amount of solute divided by the amount of solvent, or by the amount of solution.**

Two main categories of concentration unit:

1. Relate the amount of one component to the total amount of all other components including itself

   eg. molarity (M), mole fraction (x_i), mass percent (% m/m)

2. Relate the amount of one component to the amount of some other component(s)

   eg. molality (m)

Solution concentration example 1: Mass percent

In the laboratory, chemists often make solutions by weighing the solute. Thus, mass percent is a common measure of solution concentration:

$$\boxed{\text{Mass percent} = \frac{\text{Mass solute}}{\text{Total mass of solution}} \times 100\%} \quad \left(\frac{g}{g}\right)$$

%

100g

Solution concentration example 1: Mass percent

Example: Dissolving 12.5 g of NaCl in 100 g of water gives a solution that is 11.1 mass percent.

$$\text{Mass\%NaCl} = \frac{12.5\ \text{g}}{\underbrace{12.5\ \text{g} + 100.0\ \text{g}}_{\text{solution}}} \times 100\% = 11.1\ \text{mass\%}$$

Assume.

NaCl 5% m/m%   100g solution

$$\frac{5\text{g}}{\cancel{100\text{g}}} \times \cancel{100}$$

Solution concentration example 2: Molarity

Molarity: the number of moles of solute divided by the volume of solution.

Temperature dependent

$$\boxed{\text{Molarity} = \frac{\text{Moles of solute}}{\text{Total volume of solution}} \quad \text{or} \quad c = \frac{n_{\text{solute}}}{V_{\text{solution}}}} \quad \left(\frac{mol}{L}\right)$$

Solution concentration example 2: Molarity

Example: A 355-mL soft drink sample contains 0.133 mol of sucrose (table sugar). What is the molar concentration of sucrose in the beverage?

$$M = \left(\frac{mol_{solute}}{L_{solution}}\right) = \frac{0.133mol}{355mL\ x\ \left(\frac{1L}{1000mL}\right)} = 0.375\ \mathrm{M}$$

Practice: Calculating solution concentrations

Distilled white vinegar is a solution of acetic acid, CH_3CO_2H, in water. A 0.500-L vinegar solution contains 25.2 g of acetic acid. **What is the concentration of the acetic acid solution in units of molarity?**

Solution concentration example 3: Mole Fraction

The mole fraction, *X*, of a component is the ratio of its molar amount to the total number of moles of all solution components:

Independent of T, V

$$\boxed{\text{Mole fraction of } A = \frac{\text{Moles of } A}{\text{Total number of moles}} \quad \text{or} \quad X_A = \frac{n_A}{n_{\text{total}}}}$$

UNITLESS

$$\begin{aligned} 1\ \text{ppm} &= 1 \text{ molecule out of every } 10^6 \text{ molecules} \\ 1\ \text{ppb} &= 1 \text{ molecule out of every } 10^9 \text{ molecules} \end{aligned}$$

Solution concentration example 3: Mole Fraction

Example: Concentrated aqueous ammonia (also known as ammonium hydroxide) is 14.8 M and has a density of 0.898 g/mL. Determine the mole fraction of ammonia in this solution.

Step 1: Find mass of solution

$$\rho = \frac{m}{V} \text{ so } m = \rho V$$

$$m_{solution} = \left(0.898 \frac{g}{mL}\right)(1000 mL)$$
$$= 898\ g$$

Step 2: Find mass of solvent

$$m_{NH3} = nM = (14.8\ mol)\left(17\ \frac{g}{mol}\right)$$
$$= 252\ g\ NH_3$$

$$m_{solvent} = 898\ g - 252\ g = 646\ g$$

Step 3: Find moles of solvent

$$n_{solvent} = \frac{m}{M} = \frac{(646\ g)}{\left(18.0\ \frac{g}{mol}\right)}$$
$$= 35.9\ mol$$

Step 4: Find mole fraction

$$X = \frac{n_{solute}}{\mathrm{n_{solute}} + \mathrm{n_{solvent}}}$$

$$X = \frac{14.8\ mol}{14.8\ \mathrm{mol} + 35.9\ \mathrm{mol}} = 0.292\ \mathrm{mol}$$

Solution concentration example 4: Molality

Molality: the concentration unit defined as the ratio of the numbers of moles of solute to the mass of the solvent in kilograms.

Independent of T, V

$$\boxed{\text{Molality} = \frac{\text{Moles of solute}}{\text{Kilograms of solvent}} \quad \text{or} \quad b = \frac{n_{\text{solute}}}{m_{\text{solvent}}}} \quad \left(\frac{mol}{kg}\right)$$

Solution concentration example 4: Molality

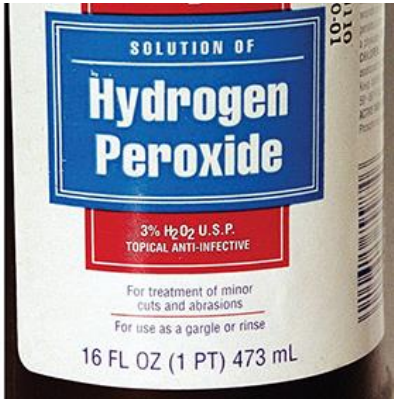
Example: Hydrogen peroxide disinfectant typically contains 3.0% H_2O_2 by mass. Assuming that the rest of the contents is water, what is the molality of this disinfectant?

$$M_{H_2O_2} = 2(16.00\ \text{g/mol}) + 2(1.008\ \text{g/mol}) = 34.02\ \text{g/mol}$$

$$n_{H_2O_2} = \frac{m}{M} = \frac{3.0\ \text{g}}{34.02\ \text{g/mol}} = 0.0882\ \text{mol}$$

$$m_{\text{water}} = (97\ \text{g})\left(\frac{1\ \text{kg}}{10^3\ \text{g}}\right) = 0.0970\ \text{kg}$$

$$b = \frac{n_{\text{solute}}}{m_{\text{solvent}}} = \frac{0.0882\ \text{mol}}{0.0970\ \text{kg}} = 0.91\ \text{mol/kg}$$



Courtesy of John Olmsted

Practice: Calculating solution concentrations

Example: The antifreeze in most automobile radiators is a mixture of equal volumes of ethylene glycol and water, with minor amounts of other additives that prevent corrosion. What is the **(a) mole fraction** and **(b) molality** of ethylene glycol, $C_2H_4(OH)_2$, in a solution prepared from 2.22×10^3 g of ethylene glycol and 2.00×10^3 g of water (approximately 2 L of glycol and 2 L of water)?

Molar mass $C_2H_4(OH)_2$: 62.07 g/mol

wooclap

Colligative properties

- The properties of a solution are different from those of either the pure solute(s) or solvent.
- Many solution properties are **dependent** upon the chemical **identity of the solute.**

Colligative property: property of a solution is proportional to the concentration of solute

Example 1: Salt in water causes solution to boil at a higher temp than pure water

Example 2: ethylene glycol to the water protects a solution against freezing

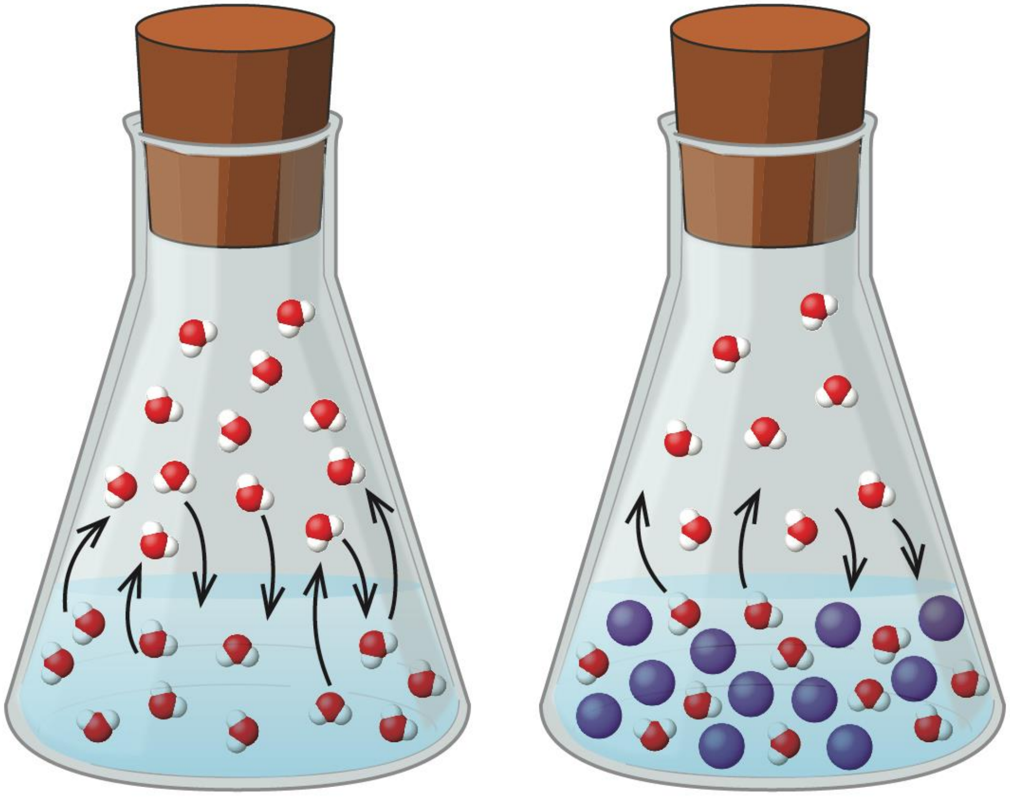
Presence of solute molecules can cause changes in **4 common properties**:

- **Vapour pressure**
- **Freezing point**
- **Boiling point**
- Osmotic pressure

https://www.thoughtco.com/adding-salt-increases-water-boiling-point-607447
https://www.crossroadshelpline.com/blog/key-ingredients-in-antifreeze/

Vapour Pressure Reduction

- Solute is non-volatile
- Addition of solute molecules reduces the rate of escape of solvent molecules compared with pure solvent
- Vapor pressure of solution is **lower** than vapour pressure of pure solvent



(a) Pure water

(b) Aqueous solution

Vapour Pressure Reduction

Molecular view suggests… extent of **vapour pressure lowering depends** on **fraction of solvent molecules** that have been **replaced**

Raoult's law: *The partial pressure exerted by any component of an ideal solution is equal to the vapor pressure of the pure component multiplied by its mole fraction in the solution.*

Relates **vapour pressure** of a solution to the **mole fractions** of the volatile solution components**.** If we represent the **solvent as "A"** and the **solute as "B"** then:

$$\boxed{p_{\text{vap, solution}} = X_{\text{A}} p_{\text{vap,A}}}$$

Example of Vapour Pressure Reduction

Calculate the vapour pressure of a 5% by mass benzoic acid ($C_7H_6O_2(aq)$) in ethanol solution at 35℃ . The vapour pressure of pure ethanol at this temperature is 13.40 kPa.

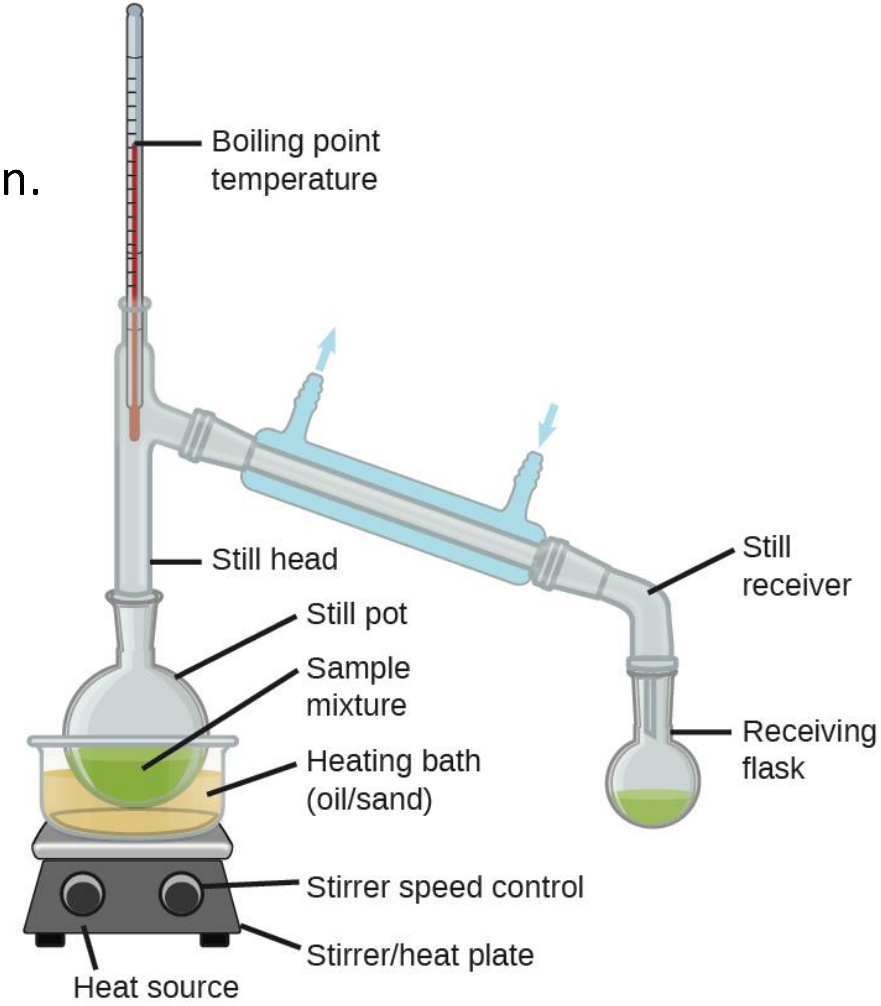
Assumption! Mass of solution is 100g

Fractional Distillation

Differences in vapour pressure can be used to separate liquid mixtures by fractional distillation.

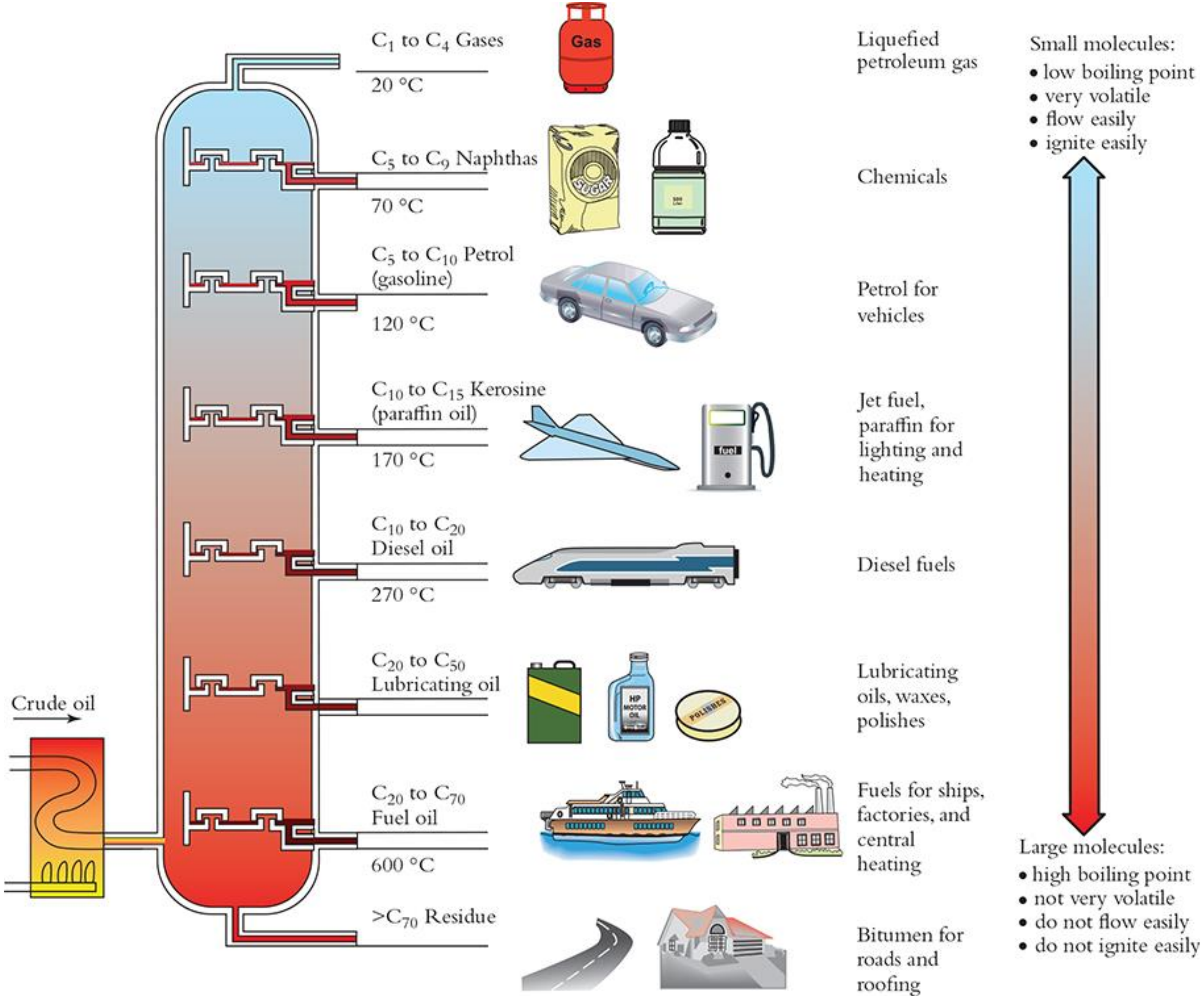
Fractional distillation: process of separating mixture of volatile components by performing repeated evaporation and condensation cycles

(a)



(b)

Oil refineries use large-scale fractional distillation



Boiling and freezing points

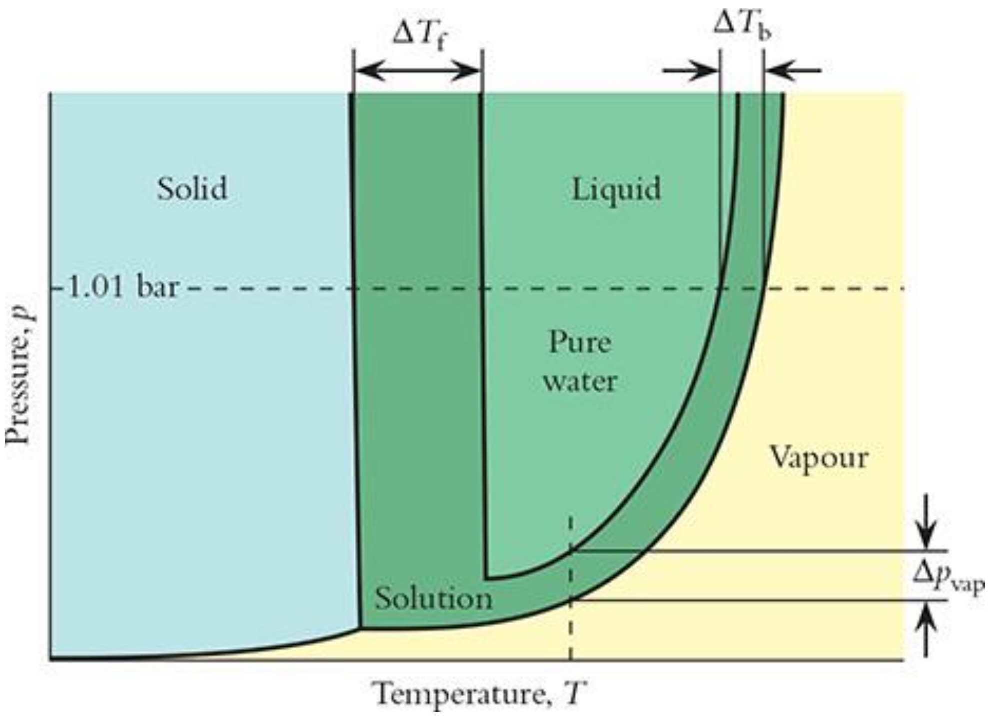
Lower vapour pressure of a solution compared with a pure solvent results in changes in the boiling point and freezing point of the solutions

Dissolved material "interferes" with the ability of solvent molecules to either:

- Leave the liquid and enter the gas phase
- Crystallize into a solid

"harder to boil" means that **boiling point goes up** **(ΔT_b= boiling point elevation)**

"harder to freeze" means that **freezing point goes down** **(ΔT_f= freezing point depression)**



Calculating ΔT_b and ΔT_f

Experiments show that at low solute concentration, the changes in the freezing point and boiling point of a solution, ΔT_b and ΔT_f , **depend on the molality (*b*) of the solute.**

We need to take account of any dissociation of the solute: **van't Hoff factor** (*i*)

Ex: 1 molal solution of NaCl (s) is 2 molal in ions: **1**NaCl (s) → **1**Na^+ (aq) + **1**Cl^- (aq)

$$i = \frac{\text{Moles of particles in solution}}{\text{Moles of solute dissolved}}$$

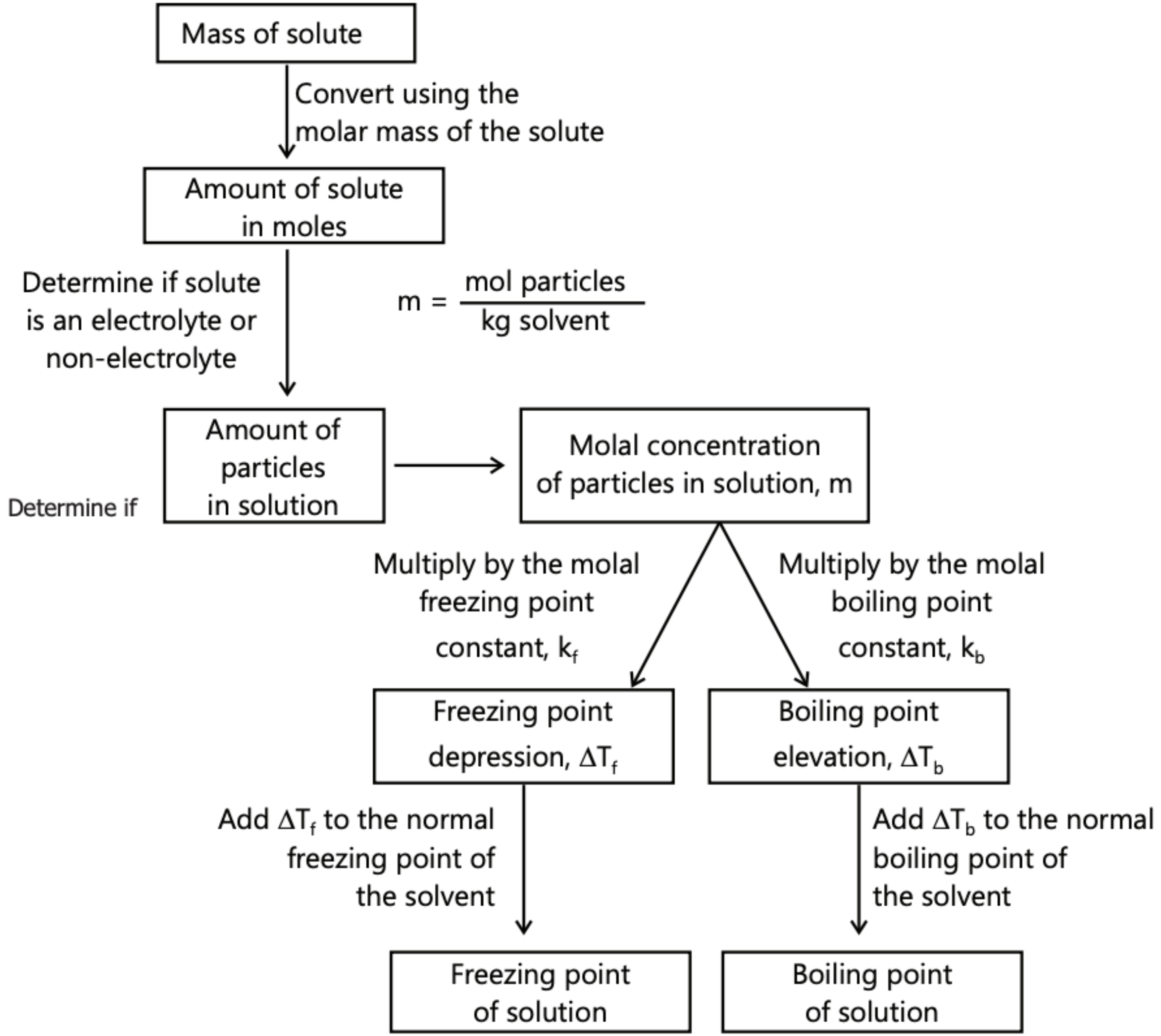
$$\boxed{\Delta T_\mathrm{f} = iK_\mathrm{f}b}$$

K_f = freezing point depression constant

$$\boxed{\Delta T_\mathrm{b} = iK_\mathrm{b}b}$$

K_b= boiling point elevation constant

General Plan for Solving Problems Involving Freezing Point Depression and Boiling Point Elevation



Example: Calculating ΔT_b and ΔT_f

Ethylene glycol (1,2-ethanediol) is added to automobile radiators to prevent cooling water from freezing. Estimate the freezing point of coolant that contains 2.00 kg of ethylene glycol in 5.00 L of water. **Is this a high enough concentration to protect a radiator in Montreal, where the temperature may be as low as – 40.0 ℃?**

Water
K_f =1.858 °C kg/mol
K_b = 0.512 °C kg/mol
ρ = 1.00 g/mL

Practice: Calculating ΔT_b and ΔT_f

Determine the **normal boiling point** and **normal freezing point** for a 20.% m/m sodium chloride solution (typical for road salt).

NaCl: 58.44 g/mol
H_2O: 18.015 g/mol

Water
K_f =1.858 °C kg/mol
K_b = 0.512 °C kg/mol
ρ = 1.00 g/mL

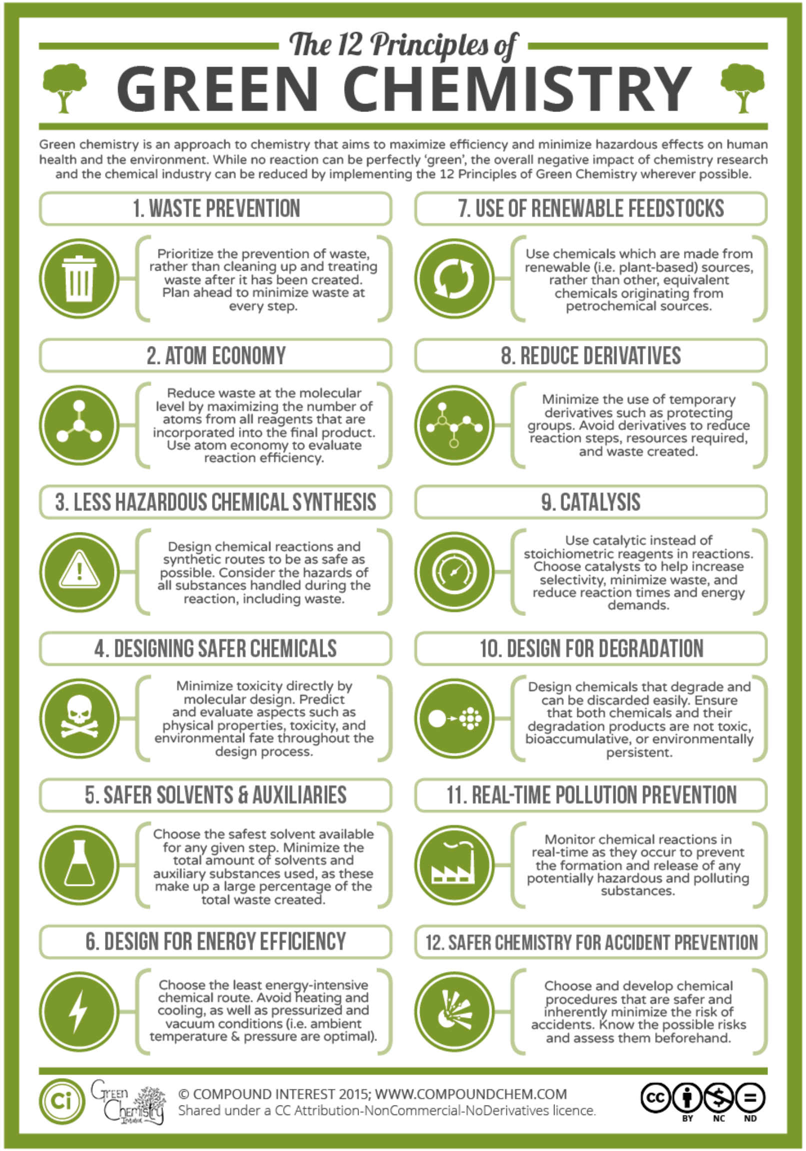
How many grams of water in a 20% m/m NaCl solution?

wooclap

Practical examples of colligative properties: De-icing

Ionic compounds (NaCl, $MgCl_2$) are often used to de-ice roadways and sidewalks, since they will have a freezing point lower than 0 °C, the freezing point of pure water.

Covalent compounds (ethylene and propylene glycol) used in antifreeze or to de-ice planes. Can lower freezing point and elevate boiling point!



Ethylene glycol vs **propylene glycol**

Which is "greener"?

- Propylene glycol
  - Readily **biodegradable** under aerobic conditions in freshwater, sea water, and soil so it is not persistent in the environment
  - **Low toxicity**

- Ethylene glycol
  - **High toxicity**
  - **Poisonous**, must be handled with caution to restrict any human or animal exposure