CHEMISTRY

Chapter 11

Solutions and Colloids

CHAPTER 11: SOLUTIONS AND COLLOIDS

11.1 THE DISSOLUTION PROCESS

Solutions

- Homogeneous mixtures or two or more substances are called solutions.
- The substance present in the *larger* amount is the *solvent*.
- The substance present in the *smaller* amount is the *solute*.

Copper(II) sulfate dissolved in water forms a homogeneous solution.

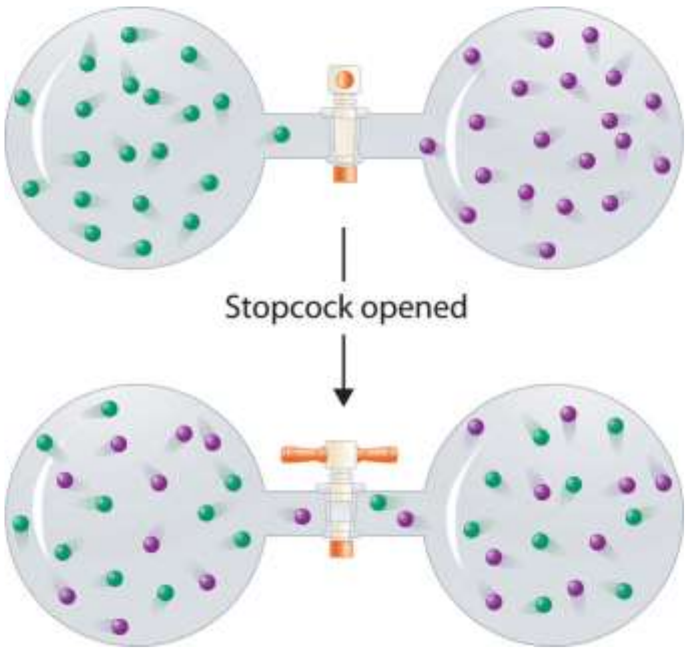
$CuSO_4(s) \rightarrow Cu^{2+}(aq) + SO_4^{2-}(aq)$

The *solute* is copper(II) sulfate.
The *solvent* is water.

11.1 THE DISSOLUTION PROCESS

Solutions

- The particles in a homogeneous solution are uniformly distributed.



Pure samples gas mix when the stopcock is opened. A homogeneous solution forms upon mixing.

11.1 THE DISSOLUTION PROCESS

Solutions

Different Types of Solutions

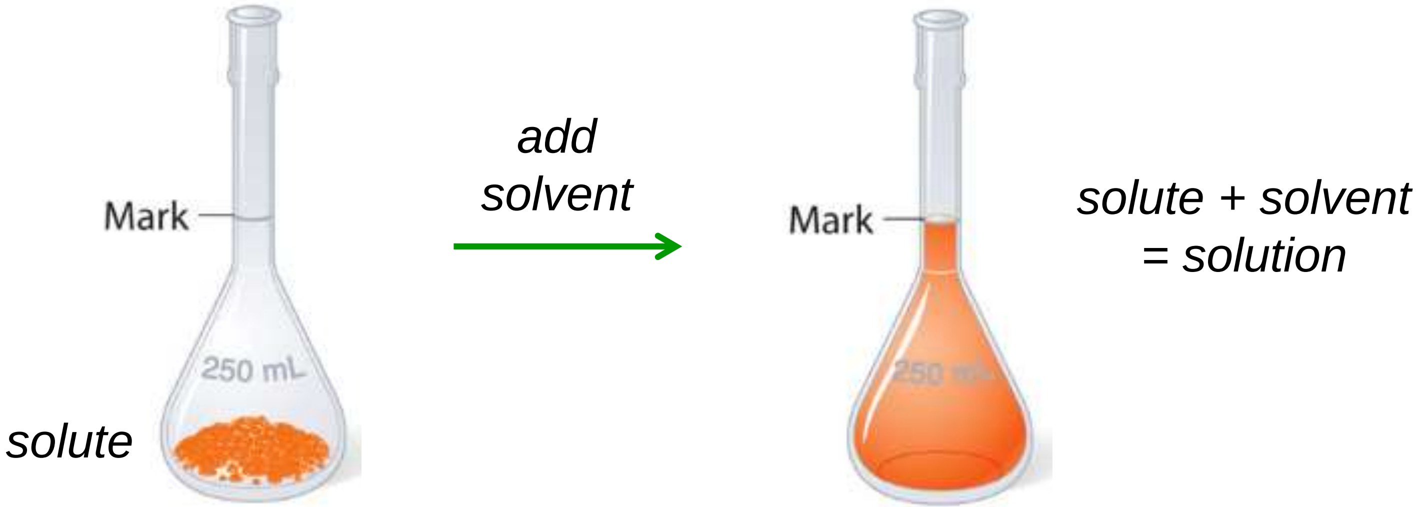
Solution	Solute	Solvent
air	$O_2(g)$	$N_2(g)$
soft drinks[1]	$CO_2(g)$	$H_2O(l)$
hydrogen in palladium	$H_2(g)$	$Pd(s)$
rubbing alcohol	$H_2O(l)$	$C_3H_8O(l)$ (2-propanol)
saltwater	$NaCl(s)$	$H_2O(l)$
brass	$Zn(s)$	$Cu(s)$

[1] *If bubbles of gas are observed, then the mixture is not homogeneous and therefore not a solution.*

11.1 THE DISSOLUTION PROCESS

Solutions: Defining Traits

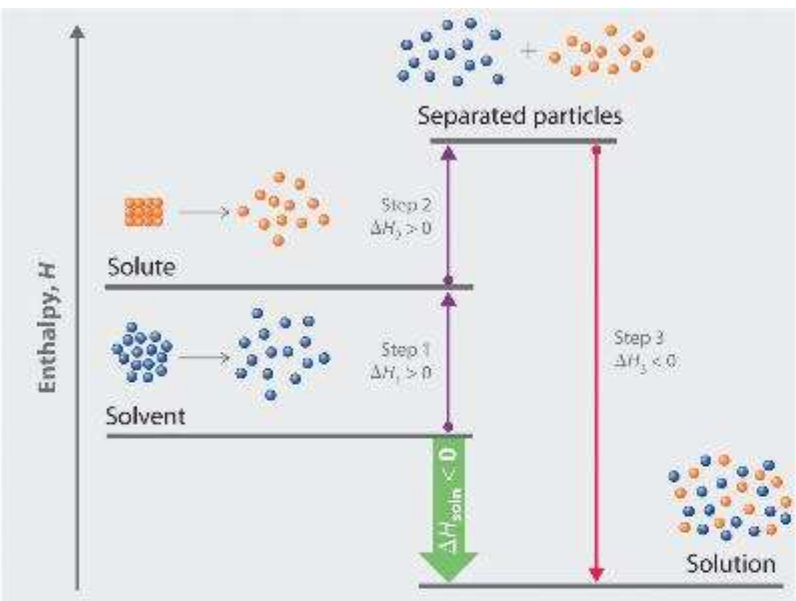
- A solution is homogeneous and has uniform composition.
- The physical state of a solution (s, ℓ, g) is typically the same as that of the solvent.
- The components of a solution are dispersed on a molecular scale.
- The dissolved solute in a solution will not separate from the solvent.
- Solutions may form in an exothermic or endothermic process.



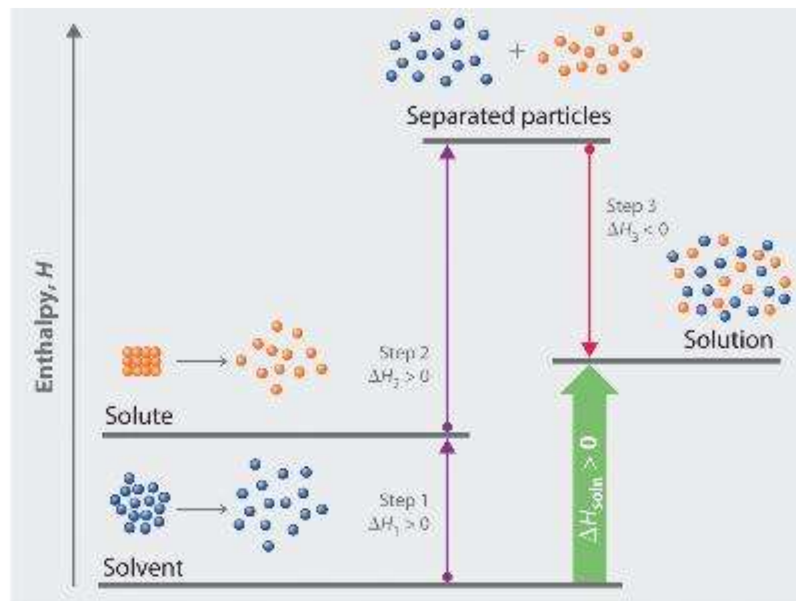
11.1 THE DISSOLUTION PROCESS

The Formation of Solutions

- The formation of a solution is a *spontaneous* process.
  - No energy input is required.
  - Stirring simply speeds up the process.
- Solution formation is favored if:
  - there is a decrease in internal energy of the system (exothermic).
  - there is an increase in dispersion of matter.



(a) Exothermic solution formation

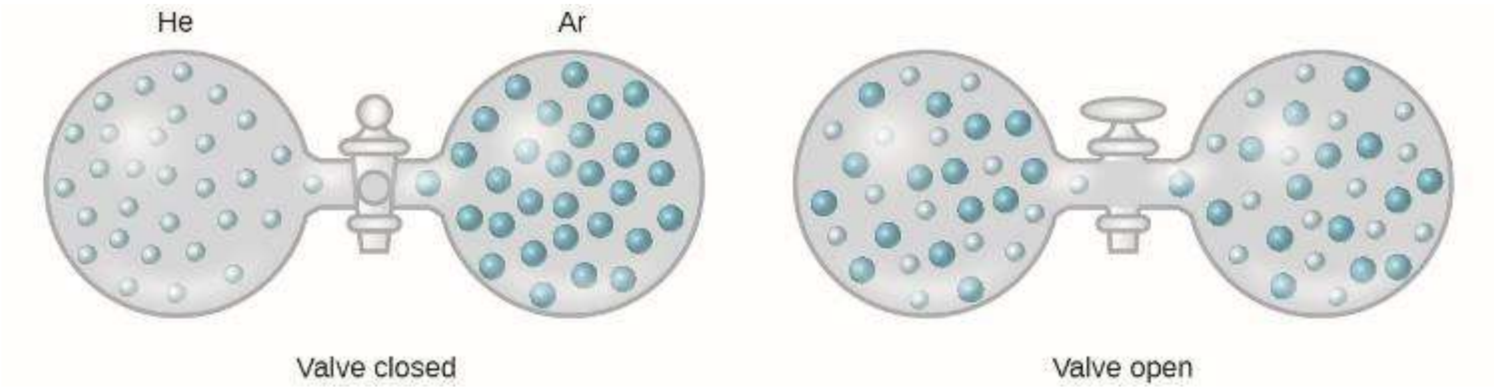


(b) Endothermic solution formation

11.1 THE DISSOLUTION PROCESS

Intermolecular Forces in Solutions

- An ideal solution has intermolecular forces that are similar to those present in the separated components.



- In the dissolution process:
  - solute-solute and solvent-solvent forces must be overcome
  - solute-solvent attractions are established during *solvation*.
  - the relative energies determine if dissolution occurs.

11.1 THE DISSOLUTION PROCESS

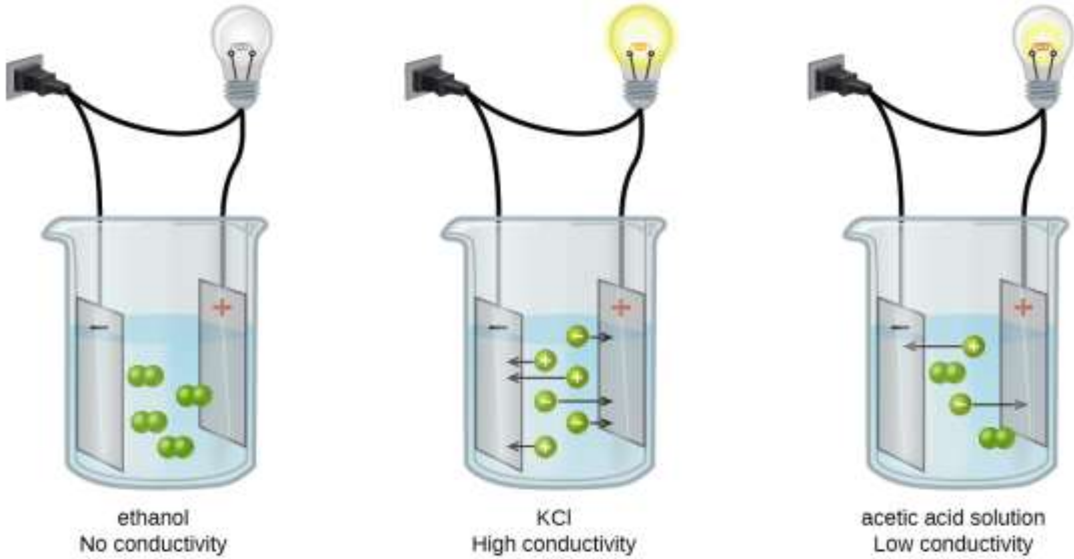
A mixture of cooking oil and water does not yield a solution.

Consider the intermolecular forces involved and explain.

11.2 ELECTROLYTES

Solutions Containing Electrolytes

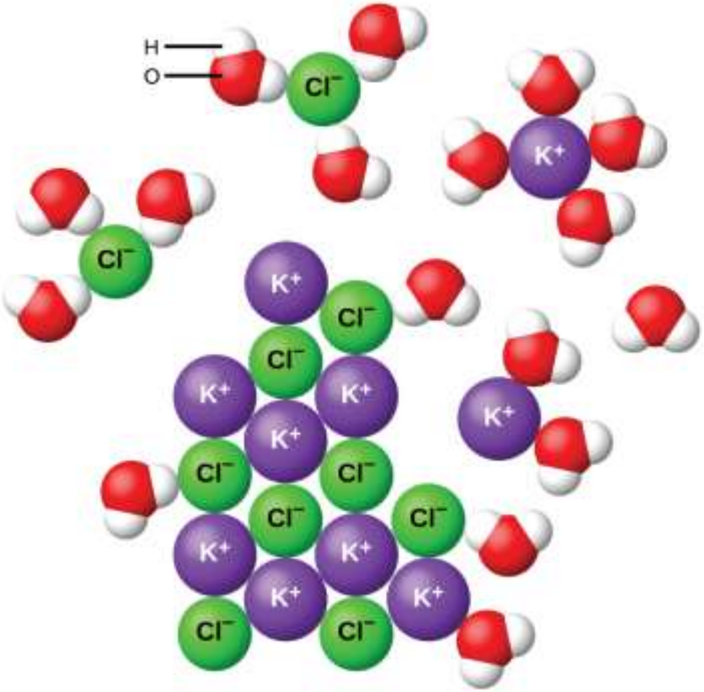
- If an ionic compound is able to dissolve in water, a solution containing ions is generated.
- These solutions are *electrolytes*.
    - a high percentage of ions yields a strong electrolyte.
    - few ions yields a weak electrolyte.
- Substances can be identified as strong or weak electrolytes by measuring conductivity.



11.2 ELECTROLYTES

Ionic Electrolytes

- The electrostatic attraction between polar water molecules and particles from an ionic compound such as KCl are ion-dipole interactions.
- The K^+ ions are attracted to the $\delta -$ part of water molecules.
- The Cl- ions are attracted to the $\delta +$ of water molecules.
- The water molecules form hydration shells around each dissolved cation or anion.
- Solutions of strong electrolytes conduct electricity easily.



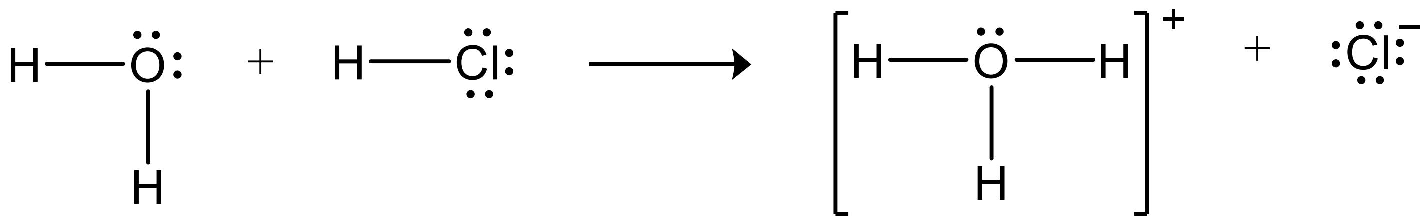
11.2 ELECTROLYTES

Covalent Electrolytes

- Pure water is a poor conductor because it only slightly ionizes to yield hydronium ions and hydroxide ions.

$$2H_2O(\ell) \rightarrow 2OH^-(aq) + H_3O^+(g)$$

- HCl is a covalently bonded compound in the gas phase.
- HCl in water, however, is a very good conductor.
  - HCl transfers H^+ to H_2O to form H_3O^+ and Cl^-.



hydronium ion

11.3 SOLUBILITY

Solutions

- The *solubility* of a compound in a particular solvent is the maximum concentration in solution that can be achieved.
  - solvent and temperature are important
  - *saturated*: [solute] = solubility
  - *unsaturated*: [solute] < solubility
  - *supersaturated*: [solute] > solubility

$$NaCl(s) \rightarrow Na^{+}(aq) + Cl^{-}(aq)$$

- At 25 °C, the solubility of NaCl in water is 359 kg/m^3.

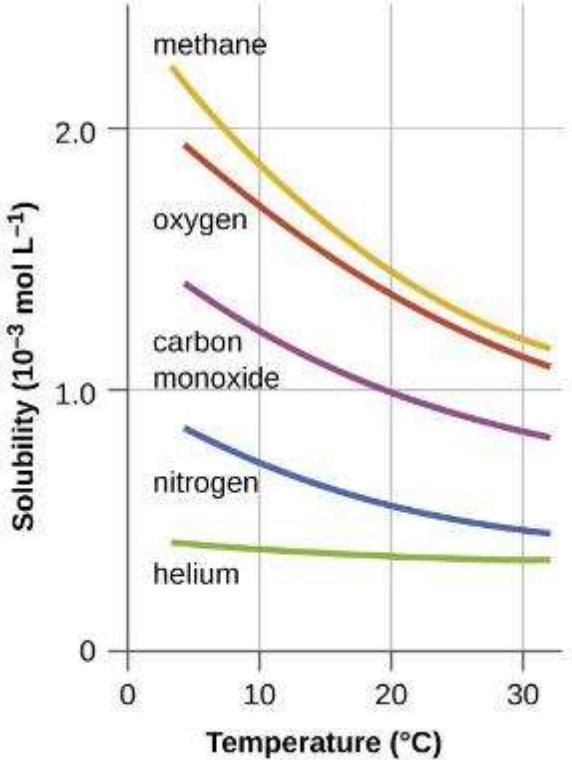
  What is the solubility in g/mL?

  What is the solubility in mol/L?

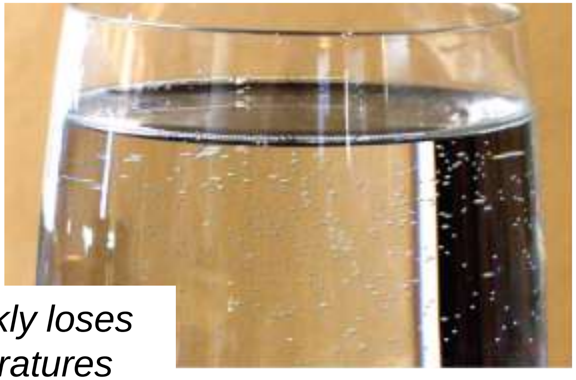
11.3 SOLUBILITY

Solutions: Gases in Liquids

- Temperature is one of major factors affecting solubility.
- At higher temperatures, the solubility of gases in water *decreases*.



All solubilities displayed were measured at a constant gas pressure of 1 atm.



Carbonated water quickly loses CO_2 at warmer temperatures

Decreased oxygen solubility in natural waters can lead to large-scale fish kills

DECOMPRESSION SICKNESS: THE BENDS

- Decompression sickness (DCS), or “the bends,” is an effect of the increased pressure of the air inhaled when swimming at considerable depths.
- Divers are subjected to atmospheric pressure as well as additional pressure due to the water The air inhaled by a diver while submerged contains gases at the corresponding higher ambient pressure, and the concentrations of the gases dissolved in the diver’s blood are proportionally high (see gas laws).
- As the diver ascends to the surface of the water, ambient pressure decreases and the dissolved gases becomes less soluble.
- Is ascent is rapid, gases escaping from the diver’s blood may form bubbles that can cause rashes, joint pain, paralysis, and death.
- To avoid DCS, divers must ascend from depths at relatively slow speeds (10 or 20 m/min) or otherwise make several decompression stops, pausing for several minutes at given depths during the ascent.
- When these preventive measures are unsuccessful, divers with DCS are often provided hyperbaric oxygen therapy in pressurized vessels.

(a)

(b)

a) US Navy divers undergo training in a recompression chamber.
b) Divers receive hyperbaric oxygen therapy.

11.3 SOLUBILITY

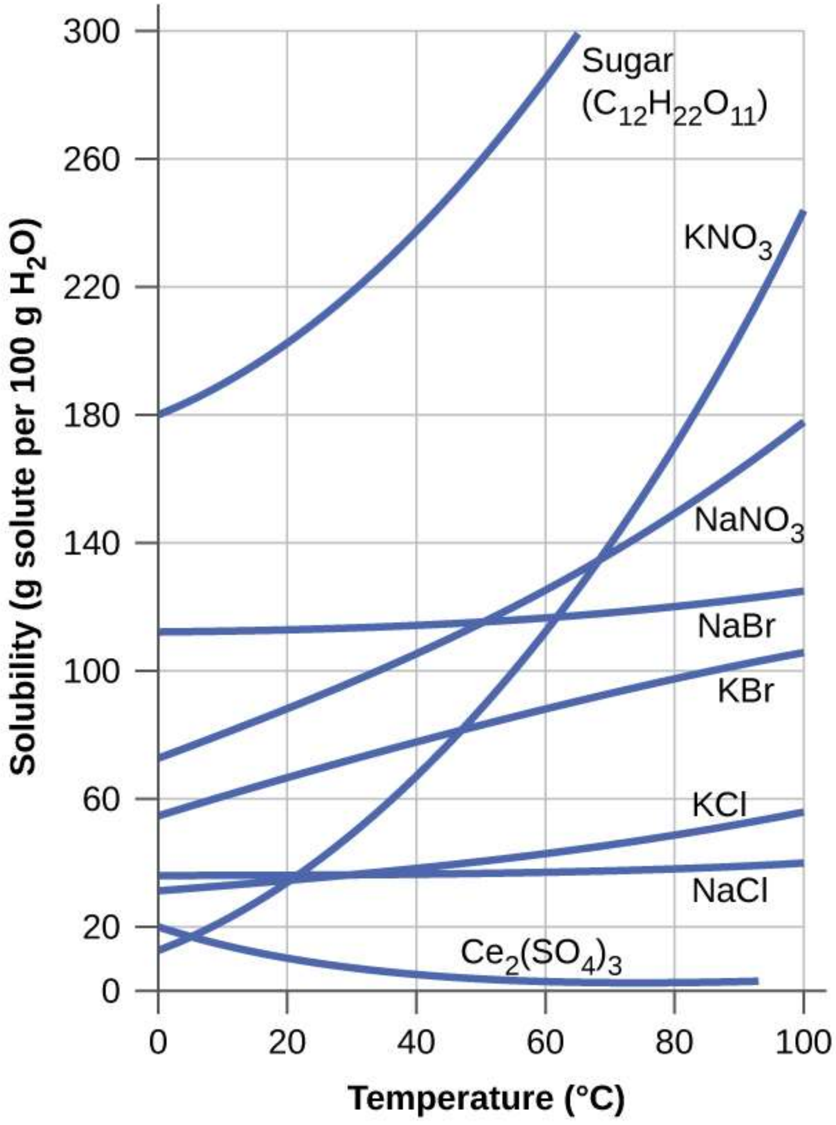
Solutions: Liquids in Liquids

- Some liquids mix with each other completely and have mutual solubility – these liquids are *miscible*.
    - Both components usually have the same polarity (i.e. polar/polar or nonpolar/nonpolar).
- Two liquids that have low mutual solubility and do not mix are called *immiscible*.
    - A polar and a nonpolar liquid (oil and water) do not mix to an appreciable extent.

11.3 SOLUBILITY

Solutions: Solids in Liquids

- Solubility usually increases with temperature.
- Examine the data. Which compound is an exception?



11.3 SOLUBILITY

Solutions: Solids in Liquids

- Solubility can be exploited to purify substances by crystallization.
    - A supersaturated solution can be made.
    - Crystallization can be initiated by adding a seed crystal or by agitating the solution.

Sodium acetate crystallized from a supersaturated solution (video).

11.3 SOLUBILITY

Sodium Acetate Hand Warmers

This hand warmer produces heat when the sodium acetate in a supersaturated solution precipitates. Precipitation of the solute is initiated by a mechanical shockwave generated when the flexible metal disk within the solution is “clicked.”

11.4 COLLIGATIVE PROPERTIES

Properties of Solutions

- The properties of solutions are different from those of pure solutes or pure solvents.
- *Colligative properties* depend solely upon the total concentration of solute particles and not the nature of those particles.

Vapor-Pressure Lowering	$P_1 = X_1 P_1^{\circ}$
Boiling-Point Elevation	$\Delta T_b = iK_b m$
Freezing-Point Depression	$\Delta T_f = iK_f m$
Osmotic Pressure (Π)	$\Pi = iMRT$

11.4 COLLIGATIVE PROPERTIES

Molality

- Thus far, concentration has been defined in terms of molarity.
- Solution volume varies with temperature and therefore molarity varies with temperature.

$$\boldsymbol{M} = \frac{mol\ solute}{L\ solution}$$

- Molality (m) is more appropriate for calculations where temperature is a factor because it *does not vary with temperature*.

$$\boldsymbol{m} = \frac{mol\ solute}{kg\ solvent}$$

11.4 COLLIGATIVE PROPERTIES

Mole Fraction

- The mole fraction is also a concentration unit that is not dependent upon temperature.

$$\boldsymbol{X_A} = \frac{mol\ A}{total\ moles\ in\ sample}$$

The van't Hoff Factor (i)

- Colligative properties depend upon the <u>*total number of particles*</u> in solution, the concentrations of electrolytes must be adjusted to account for the number of particles generated upon dissolution.
- The approximate value of the van't Hoff factor can be predicted:

NaCl	$MgCl_2$	$FeCl_3$	$C_6H_{12}O_6$ *glucose*
$i = 2$	$i = 3$	$i = 4$	$i = ?$

11.4 COLLIGATIVE PROPERTIES

Example: Molality, Molarity, and Mole Fraction

Commercial bleach is 5.25% sodium hypochlorite by mass: 100.00 g of bleach contains 5.25 g of NaClO. Calculate the molarity (M), the molality (m), and mole fraction (X_{NaClO}) of commercial bleach. Predict the van't Hoff factor (i) for commercial bleach.

The bleach solution has a density of 1.11 g/cm^3.
Water has a density of 1.00 g/cm^3.

$$M = \frac{mol\ solute}{L\ solution} \qquad \boldsymbol{m} = \frac{mol\ solute}{kg\ solvent} \qquad \boldsymbol{X_A} = \frac{mol\ A}{total\ moles}$$

11.4 COLLIGATIVE PROPERTIES

Example: Molality and Molarity

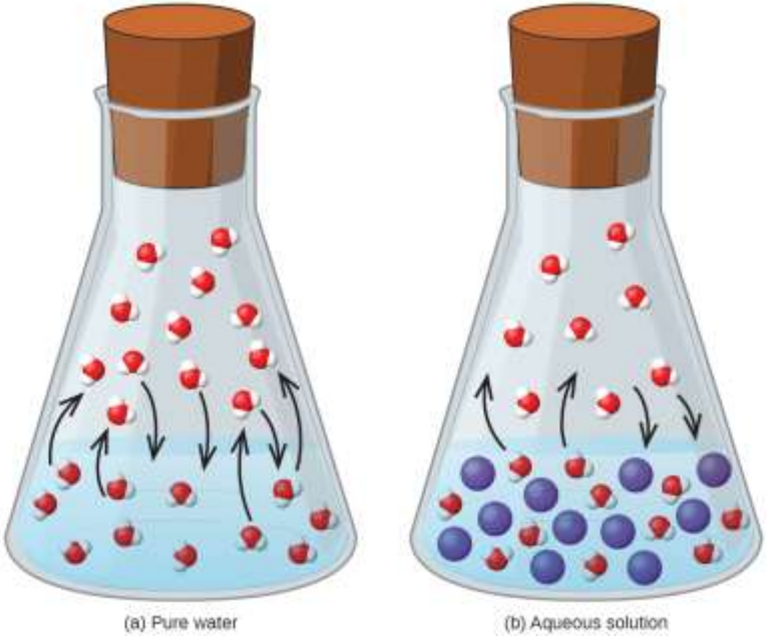
What is the molality of a 3.75 M aqueous ethanol (C_2H_5OH) solution? The density of the solution is 0.965 g/mL.

Hint: Assume that you have one liter to start.

11.4 COLLIGATIVE PROPERTIES

Vapor Pressure Lowering

- Dissolving a nonvolatile substance in a volatile liquid results in vapor pressure lowering.
- Solute molecules decrease the surface area of the liquid and hinder vaporization.
- This results in a lowering of the vapor pressure above the liquid.



11.4 COLLIGATIVE PROPERTIES

Vapor Pressure Lowering – Raoult's Law

- Vapor pressure and solute concentration are related.

$$P_A = X_A P_A^{\circ}$$

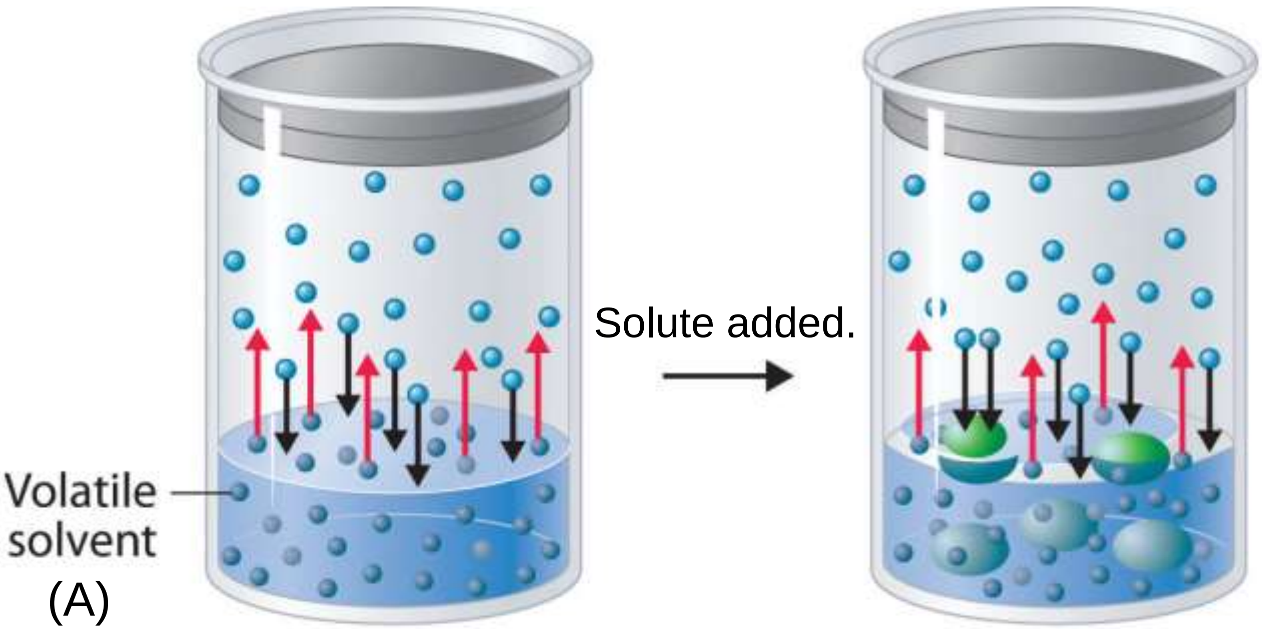
A is the volatile solvent.

P_A = partial pressure exerted by A in solution.

P_A° = vapor pressure of pure A.

X_A = mole fraction of A in the solution.

i = van't Hoff factor (apply to moles of solute)



- A vaporization blocked.
- The pressure above the solution is *lowered*.

11.4 COLLIGATIVE PROPERTIES

Example: Vapor Pressure Lowering – Antifreeze

Ethylene glycol ($HOCH_2CH_2OH$), the major ingredient in antifreeze, increases the boiling point of radiator fluid by lowering its vapor pressure. At 100°C, the vapor pressure of pure water is 760 mmHg. Calculate the vapor pressure of an aqueous solution containing 30.2% ethylene glycol by mass.

$$P_{solution} = X_{water}P^{\circ}_{water}$$

[Answer: 675 mmHg]

11.4 COLLIGATIVE PROPERTIES

Example: Vapor Pressure Lowering – Seawater

Seawater is a solution of 3.0% NaCl along with a small number of other salts. Calculate the *decrease* in vapor pressure of water at 25 °C caused by the NaCl. The vapor pressure of pure water at 25 °C is 23.80 mmHg.

Note that one mole of NaCl produces two moles of solute particles.

$$P_{seawater} = X_{water} P^{\circ}_{water}$$

[see next slide for answer]

11.4 COLLIGATIVE PROPERTIES

Answer:

$P_{seawater}$ = 23.35 mmHg and ΔP = 0.45 mmHg

The change is pressure is only 0.45 mmHg, but it constitutes a 2% decrease in the vapor pressure of water.

This is part of the reason that humidity tends to be higher in states around the Great Lakes, which are freshwater lakes.

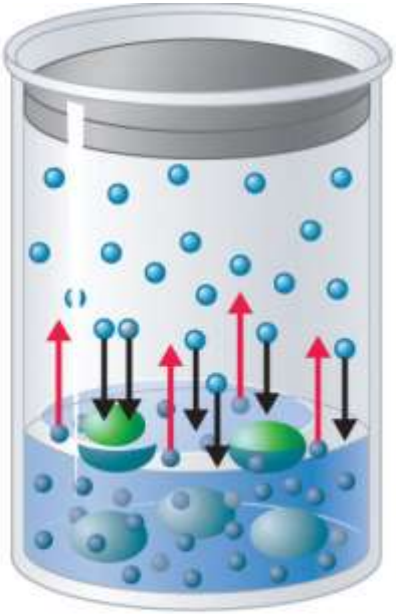
Scientists take such pressure changes into account when modeling climate change.

11.4 COLLIGATIVE PROPERTIES

Boiling Point Elevation

- The boiling point of a liquid is the temperature at which vapor pressure equals atmospheric pressure.
- Because vapor pressure is lowered when nonvolatile solutes are present, the boiling point increases.

$$\Delta T_b = i K_b m$$



ΔT_b = boiling point elevation

K_b = molal boiling point elevation constant

m = molal concentration of all solute species

i = van't Hoff factor

11.4 COLLIGATIVE PROPERTIES

Example 11.6

What is the boiling point of a solution containing 92.1 g of I_2 and 800.0 g of chloroform, $CHCl_3$. Assume that I_2 is non-volatile.

$$\Delta T_b = iK_b m$$

Solvent	Boiling Point	K_b (°C/m)	Freezing Point	K_f (°C/m)
H_2O	100.0 °C	0.512	0.0 °C	1.86
benzene	80.1 °C	2.53	5.5 °C	5.12
chloroform	61.26 °C	3.63	−63.5 °C	4.68

11.4 COLLIGATIVE PROPERTIES

Freezing Point Depression

- The boiling point of a liquid is the temperature at which vapor pressure equals atmospheric pressure.
- Because vapor pressure is lowered when nonvolatile solutes are present, the boiling point increases.

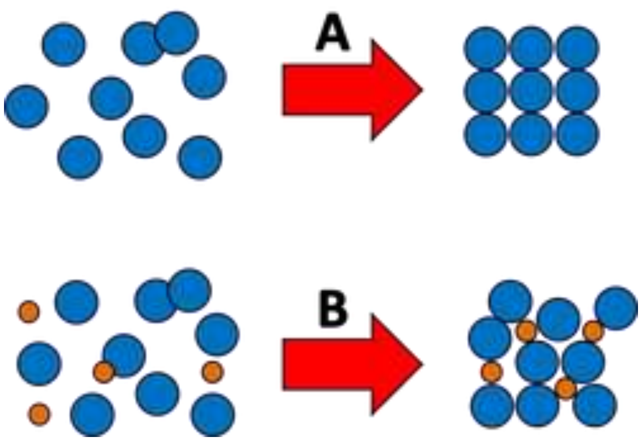
$$\Delta T_f = iK_b m$$

ΔT_f = freezing point depression

K_f = molal freezing point depression constant

m = molal concentration of all solute species

i = van't Hoff factor



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11.4 COLLIGATIVE PROPERTIES

Example – Sucrose in Water

What is the freezing point of a solution containing 115.0 g of sucrose dissolved in 350.0 g water?

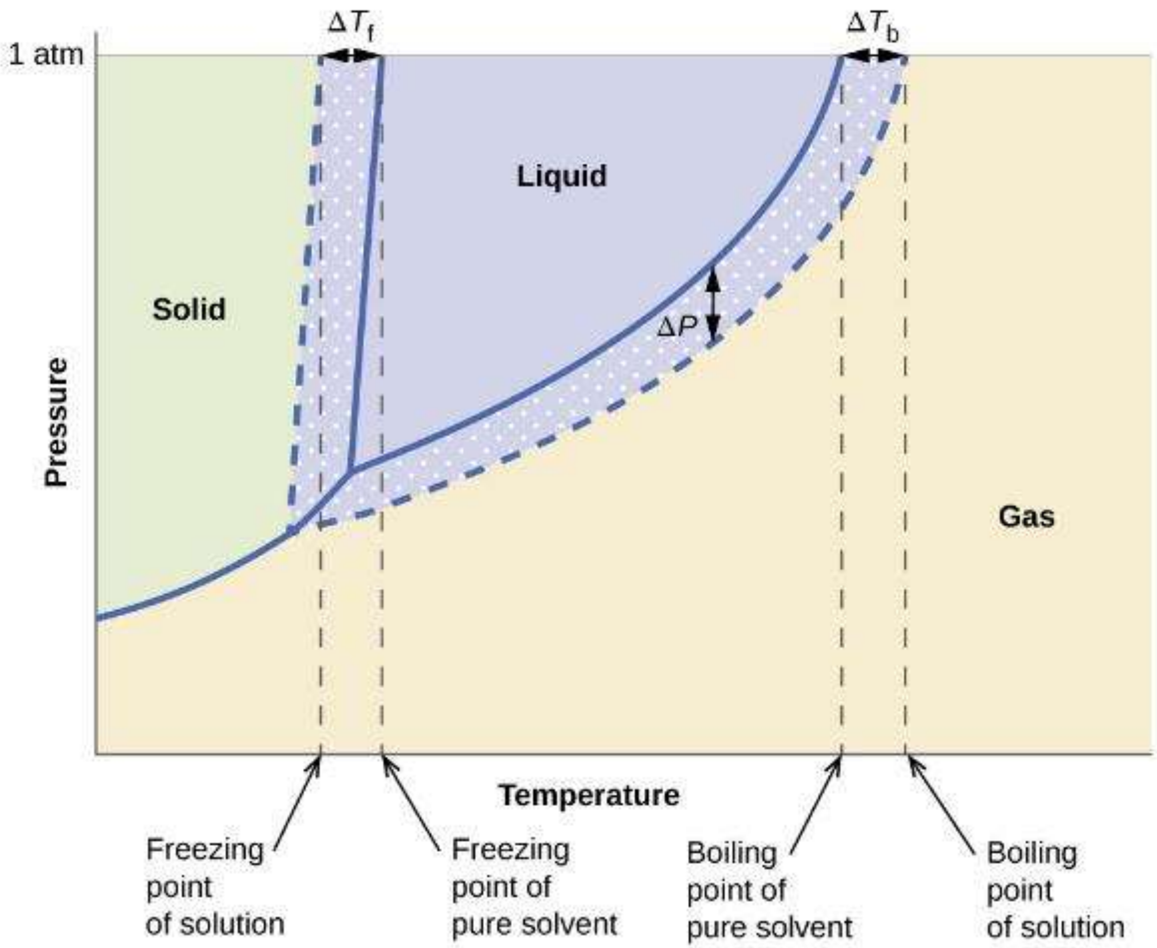
$$\Delta T_f = iK_f m$$

Solvent	Boiling Point	K_b (°C/m)	Freezing Point	K_f (°C/m)
H_2O	100.0 °C	0.512	0.0 °C	1.86
benzene	80.1 °C	2.53	5.5 °C	5.12
chloroform	61.26 °C	3.63	−63.5 °C	4.68

11.4 COLLIGATIVE PROPERTIES

Boiling Point and Freezing Point – Phase Diagram

- This phase diagram is for an aqueous solution of a nonelectrolyte (like sucrose) where i=1.0.

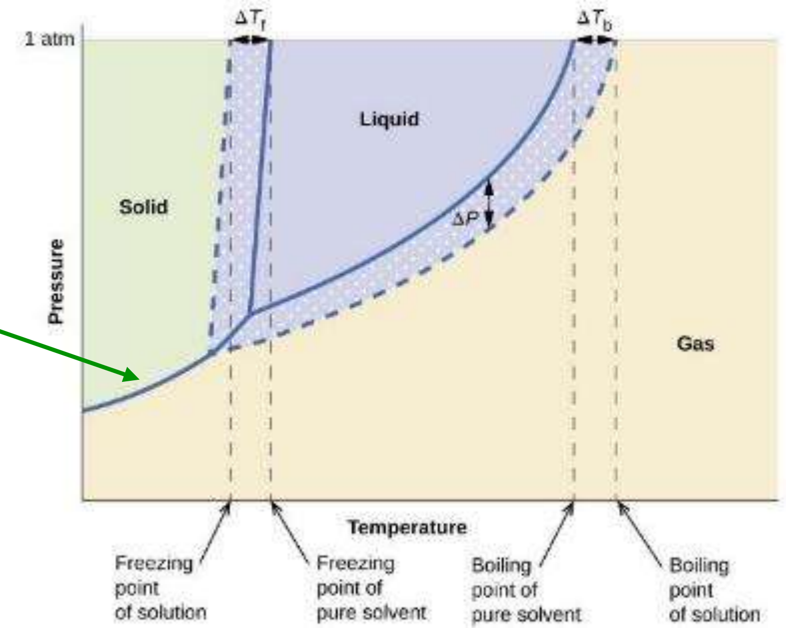


11.4 COLLIGATIVE PROPERTIES

Phase Diagram Interpretation

- The liquid-vapor curve is beneath the solvent curve.
  - *vapor pressure lowering*
- At any given pressure, the boiling point is higher.
  - *boiling point elevation*
- The solid-liquid curve for the solution is falls to the left of the pure solvent.
  - *freezing point depression*

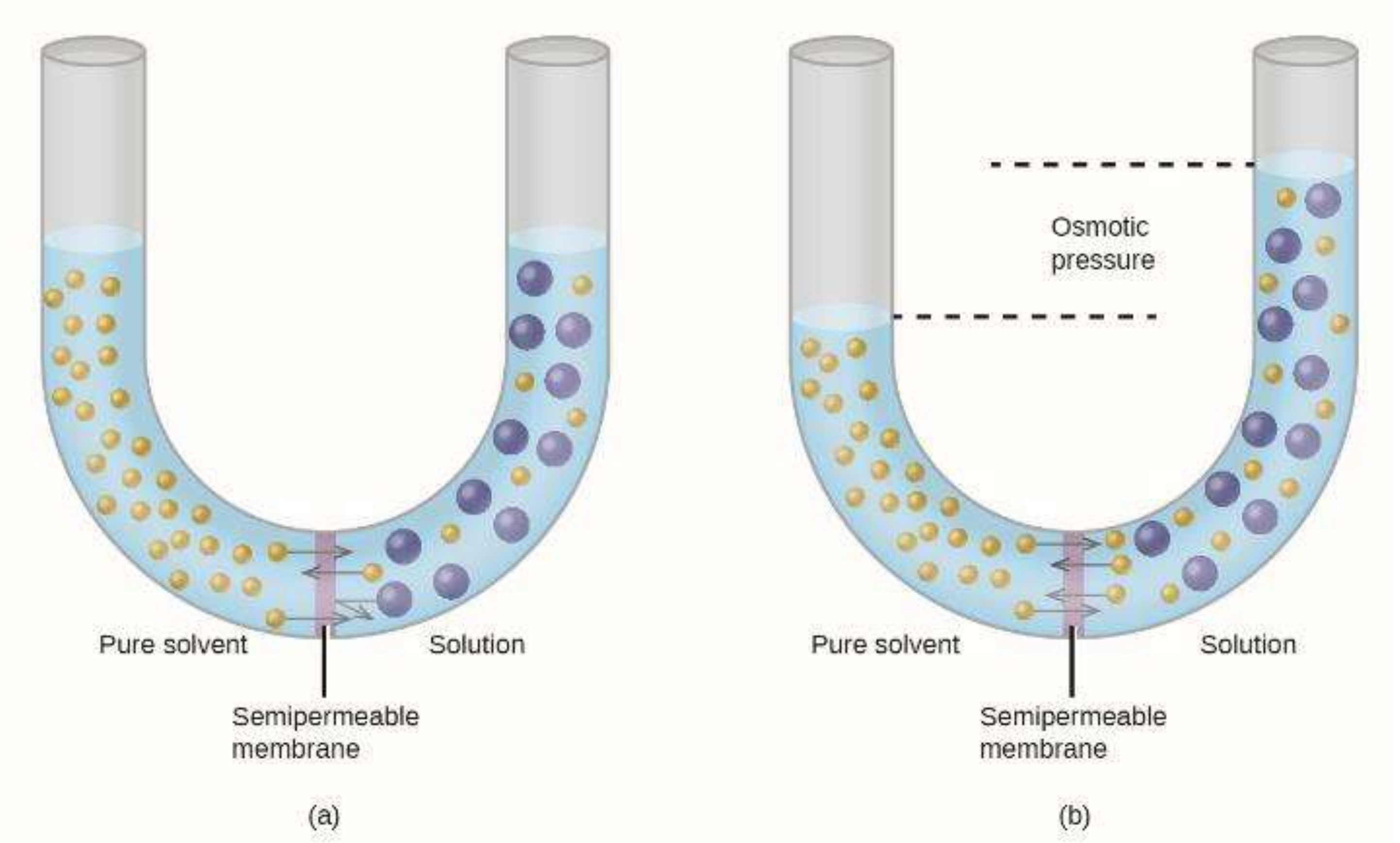
Why is the solid gas curve the same for both the pure solvent and the solution?



11.4 COLLIGATIVE PROPERTIES

Osmotic Pressure

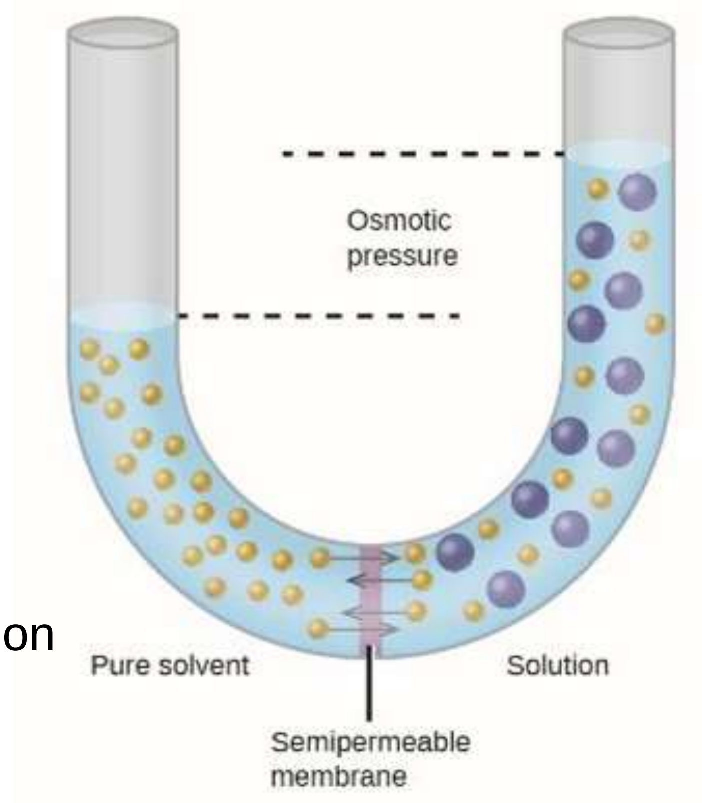
- *Osmosis* is diffusion-driven transfer of solvent molecules across a semipermeable membrane.



11.4 COLLIGATIVE PROPERTIES

Osmotic Pressure

- Osmosis in the apparatus shown, causes the volume/level of the solution to rise.
- This increases the hydrostatic pressure due to the weight of the column of solution in the tube.
- Solvent molecules are then pushed back into the pure solvent.
- The pressure at which solvent molecules move through the membrane at the same rate in both directions is the *osmotic pressure*.



$$\Pi = iMRT$$

Π = osmotic pressure

M = molarity of the solution

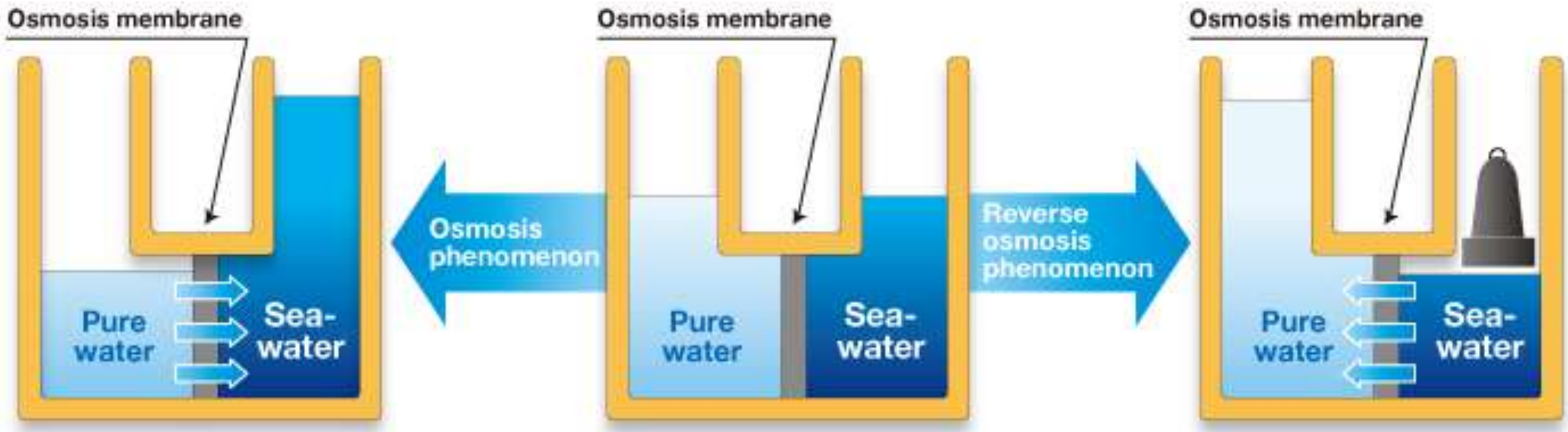
R = gas constant

i = van't Hoff factor

11.4 COLLIGATIVE PROPERTIES

Reverse Osmosis

- If pressure applied to the solution is greater than the osmotic pressure, reverse osmosis can occur.
- On a large scale, this process can be used to desalinate sea water.

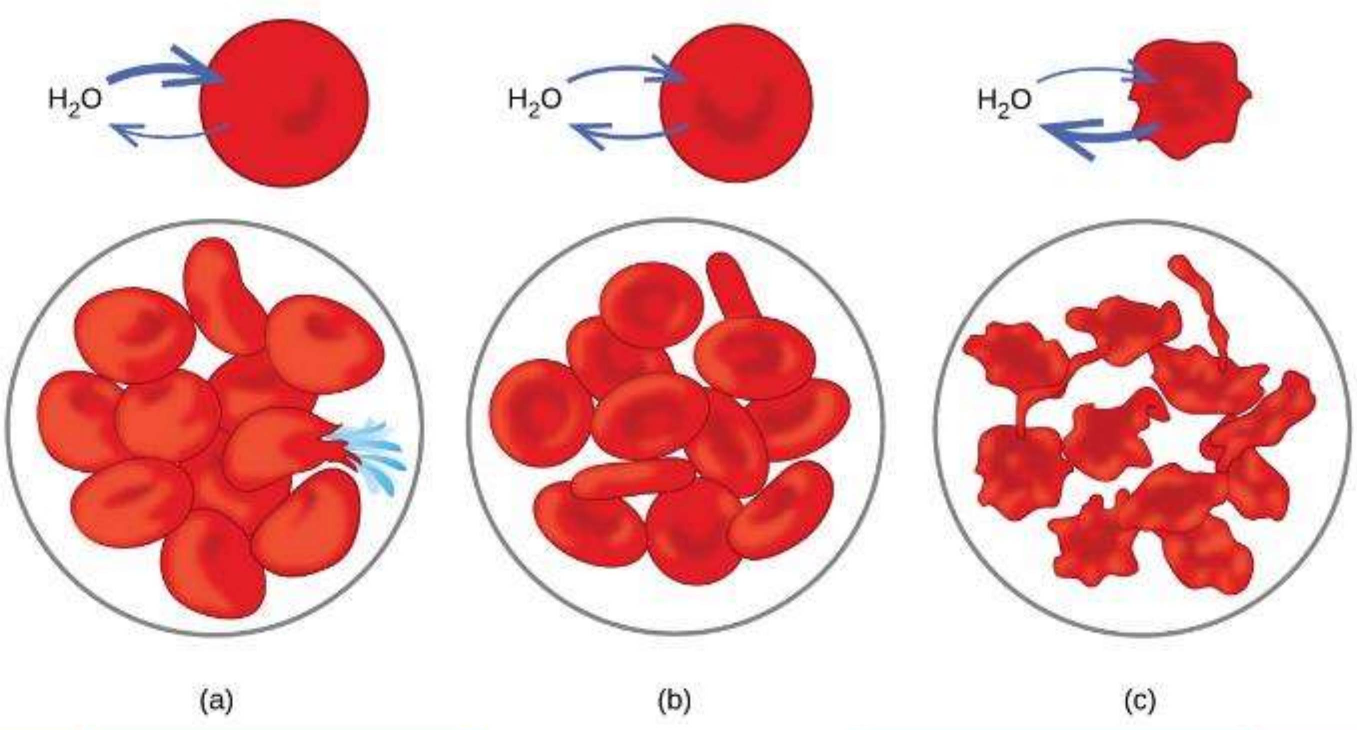


acewater.co.jp

11.4 COLLIGATIVE PROPERTIES

Osmosis in Biology

- Red blood cells have semipermeable membranes.
- Swell and burst in a *hypotonic* solution.
- Maintain their normal shape in an *isotonic* solution.
- Shrivel and become non-functional in a *hypertonic* solution.



END OF CHAPTER PROBLEMS – CHAPTER 11

Solutions: #1, 5, 9, 11, 15, 23

Colligative Properties: #33b, 38c, 43, 45,

For detailed solutions to these problems, go to the OpenStax Chemistry website and download the Student Solution Guide.

VIDEOS – CHAPTER 11

General Explanation of Solubility
http://screencast.com/t/e6UR0YisSor4

Predicting Solubility of Compounds
http://youtu.be/UPIQ72uX_-M

Raoult's Law (Calculating Vapor Pressure of Solution)
http://youtu.be/w8lbSyTci2Y
http://youtu.be/4e-NiMpOBQY

Freezing Point Depression Calculation
http://youtu.be/1sdAxF1eYig

Boiling Point Elevation Calculation
http://youtu.be/kIGya7eNXZo
(*note: The final answer for the calculation shown in the video should be 7.04 g, not 1.76 g)*

**All videos were created by MC Chemistry faculty unless otherwise indicated.*

SIMULATIONS – CHAPTER 11

Salts & Solubility (Solubility, Solutions)
https://phet.colorado.edu/en/simulation/legacy/soluble-salts

Concentration (Solutions, Concentration, Saturation)
https://phet.colorado.edu/en/simulation/concentration