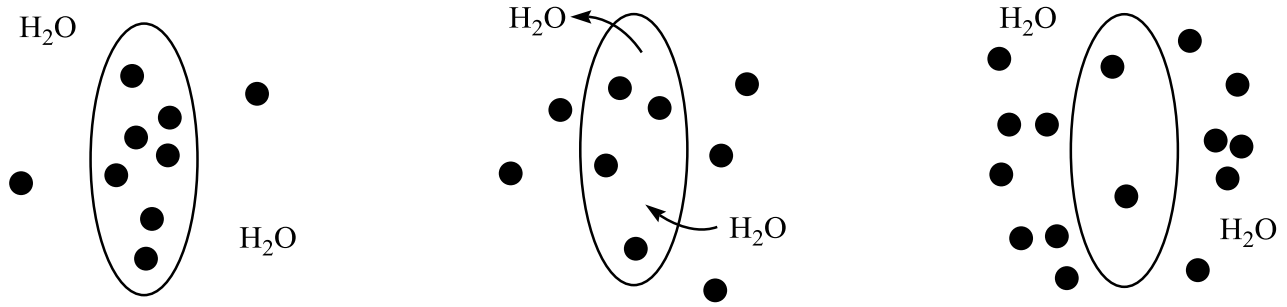
CHEM1612: Worksheet 8: Osmotic Pressure and Other Colligative Properties

Model 1: The origin of osmotic pressure

The cell membrane is a semi-permeable barrier to the passage of many (but not all) molecules and ions. Water can diffuse through it but many charged and large molecules cannot.

To maximise entropy, the concentration of the solutions on either side of a membrane tend to equalise. If the membrane is impermeable to the *solute*, only the *solvent* (water) can flow across the membrane to achieve this.

The schemes below show 3 cells with solute particles shown as black dots. The first picture represents a cell which has *higher* levels of solute relative to the medium it is in. The second represents a cell which has the *same* levels of solute as the medium. The third represents a cell which has *lower* levels of solute than the medium.



(i) Hypotonic medium (ii) Isotonic medium (iii) Hypertonic medium

Critical thinking questions

1. In an isotonic medium, water flows in and out at the same rate. Draw arrows on the other two pictures to indicate the direction in which water flows.

2. Describe what you think will happen to the size of the cell in each of the mediums.

   (i)

   (ii)

   (iii)

3. Animal cells do not have cell walls. Using your answer to Q2, describe what might occur if pure water is accidentally injected into a blood vessel.

4. (a) Animals continually expend energy by pumping Na^+ ions out of their cells. By considering the effect this has on the solute concentration in the cell, suggest why this action is vital for the health of the cell.

   (b) In some blood disorders, such as sphero- and elliptocytosis, the membrane of the red blood cells is so permeable to Na^+ ions that they diffuse back in more rapidly than the pump can cope with. What effect will this have on the flow of water and hence on the shape of the cell?
   (*Hint*: consider the names of these disorders.)

Model 2: Osmotic pressure

The pressure that must be applied to the solution to stop the processes described in Model 1 is called the *osmotic pressure*, π. For dilute solutions, it is given by:

$\pi = cRT$ where $R = 8.314$ J K^{-1} mol^{-1}

c is the concentration of *all* impermeable species in solution. As salts dissociate into ions in solution, the concentrations of all of the ions must be added together.

Critical thinking questions

1. If 0.35 mol of NaCl and 0.15 mol of KCl are added to 1.00 L of water, calculate:

   (i) $[Na^+(aq)]$

   (ii) $[K^+(aq)]$

   (iii) $[Cl^-(aq)]$

2. What is the overall concentration of ions in this solution? Convert this value into mol m^{-3}. (*Hint:* there are 1000 litres in a m^3).

3. Calculate the osmotic pressure for this solution at 298 K.

4. Explain why the osmotic pressure depends on the concentration of particles but not their identity. (*Hint*: re-read Model 1 on the origin of osmotic pressure).

5. Suppose a compartment separated from an extracellular medium by a semipermeable membrane. The membrane allows movement of water but not solute particles. For each of the initial compositions shown below, does the compartment (a) swell, (b) stay the same size or (c) shrink?

	compartment	**medium**			
(i)	0.1 M sucrose ($C_{12}H_{22}O_{11}$)	0.1 M glucose ($C_6H_{12}O_6$)	(a)	(b)	(c)
(ii)	0.1 M sucrose	0.05 M sucrose	(a)	(b)	(c)
(iii)	0.10 M sucrose	0.05 M NaCl	(a)	(b)	(c)
(iv)	0.10 M sucrose	0.050 M $MgCl_2$	(a)	(b)	(c)

Model 3: Other colligative properties

Osmotic pressure is an example of a colligative property: it depends on the concentration of the number of solute particles in a solution. Other colligative properties include:

- **Boiling point elevation**: the boiling point of a solution is higher than that of the pure solvent.
- **Freezing point depression**: the freezing point of a solution is lower than that of the pure solvent.

As with osmotic pressure, these properties depend on the concentration of *all* solute particles in solution:

- A 0.1 M solution of NaCl has $[Na^+(aq)] = 0.10$ M and $[Cl^-(aq) = 0.10$ M so the total concentration of ions is 0.2 M.
- A 0.1 M solution of $MgCl_2$ has $[Mg^{2+}(aq)] = 0.10$ M and $[Cl^-(aq) = 0.20$ M so the total concentration of ions is 0.3 M.

As a result, the boiling point elevation and the freezing point depression are both greater for the $MgCl_2$ solution: it will freeze at a lower temperature and boil at a higher temperature than the NaCl solution.

Critical thinking questions

1. What is the total concentration of particles in the following aqueous solutions:

   (a) 0.1 M sucrose

   (b) 0.1 M CH_3COOH[†]

   (c) 0.1 M HBr

   (d) 0.1 M $MgCl_2$

   (e) 0.1 M K_3PO_4

2. When these solutions are boiled, what evaporates?

3. Order these solutions according to their boiling point.

[†] Remember that CH_3COOH is a weak acid and HBr is a strong acid.