Objective 4 Quiz Practice Problems Solutions

1. You add enough sugar to water to make a 1 m solution.
a. The b.p. of the solution is 100.5°C.
What is the chemical formula of sugar? Is sugar a molecular compound or ionic compound? Why is i = 1 for sugar?
What is ΔT_b?
What is K_b of the solvent (water)?
Use the b.p. elevation equation to show how this b.p. is calculated.
b. The f.p. of this solution is -1.9°C. Use the f.p. elevation equation to show how this f.p. is calculated.
c. Is NaCl a molecular compound or ionic compound?
Why is i = 2 for NaCl?
Explain why a 1 m NaCl solution has a lower f.p. than the 1 m sugar solution.
Answers:
a. Table sugar formula = $C_{12}H_{22}O_{11}$
Sugar is a molecular compound.
i = 1 because sugar is a molecule. It does not break up into ions.
ΔT_b is boiling point elevation = boiling point of the solution - boiling point of the pure solvent
For water, K_b = 0.512 °C/m
$\Delta T_b = i\, K_b\, m$
ΔT_b = (1)(0.512 °C/m)(1 m)
ΔT_b = 0.512 °C
ΔT_b = 0.512 °C = boiling point of the solution - boiling point of the pure solvent
0.512 °C = boiling point of the solution – 100°C
boiling point of the solution = 100.5°C.
b. $\Delta T_f = i\, K_f\, m$
For water, K_f = 1.86 °C/m
ΔT_f = (1)(1.86 °C/m) = 1.86°C
ΔT_f = f.p. of pure solvent– f.p. of solution
1.86°C = 0°C - f.p. of solution
f.p. of solution = -1.86°C round to 1.9°C
c. NaCl is an ionic compound
i = 2 for NaCl because NaCl dissociates into two particles: Na^+ and Cl^- ions.
A 1 m NaCl solution has a lower f.p. than the 1 m sugar solution because NaCl solution has twice the number of particles in solution (i = 2) compared to sugar (i = 1) so $\Delta T_f = i\, K_f\, m$ is larger for NaCl and depresses (lowers) the f.p. more.

2. Freezing point depression application: salt is spread on icy roads to melt ice. You add 50 g salt (NaCl) to water to 2 cups (480 ml) of water.
a. Calculate the molality of this solution. (Answer: approximately 2 m)
b. Why is i = 2 for this solution?
c. Calculate the freezing point of this NaCl/water solution. (Answer: between -3 to -8°C)
d. Would adding 50 g of road salt ($CaCl_2$) to 2 cups of water depress the freezing point of water as much as 50 g of rock salt? Calculate the f.p. of each solution to support your answer.
Answers:
a. molality = moles solute/kg solvent
solute = NaCl
moles NaCl = 50 g/58.5 g/mole = 0.855 moles
kg solvent (water) = 480 ml (1 g/ml)(1 kg/1000 g) = 0.48 kg
molality = moles solute/kg solvent = 0.855 moles/0.48 kg = 1.8 m
b. NaCl dissociates into 2 ions (particles) so i = 2
c. $\Delta T_f = i\, K_f\, m$
For water, K_f = 1.86 °C/m
ΔT_f = (2)(1.86 °C/m) (1.8 m) = 6.7°C
ΔT_f = f.p. of pure solvent– f.p. of solution
6.7°C = 0°C - f.p. of solution
f.p. of solution = -6.7°C
d. $CaCl_2$ dissociates into 3 ions (1 Ca^{2+} + 2 Cl^-) so i = 3
molality = moles solute/kg solvent = (50 g/111 g/mole)/0.48 kg) = 0.94 m
ΔT_f = (3)(1.86 °C/m) (0.94 m) = 5.2°C
ΔT_f = f.p. of pure solvent– f.p. of solution
5.2°C = 0°C - f.p. of solution
f.p. of solution = -5.2°C

Adding 50 g of road salt ($CaCl_2$) to 2 cups of water does not depress the freezing point of water as much as 50 g of rock salt.

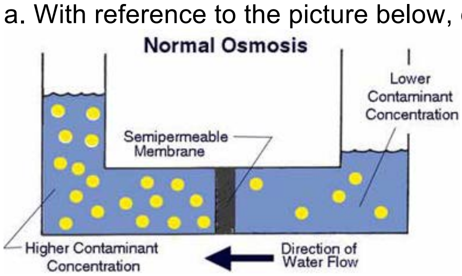
Osmosis applications:
3. Sugar is used to preserve home-made jam and jelly by killing bacteria that may cause botulism. The appropriate sugar concentration will allow water to pass out of the cell and collapse (crenation) the cell. Should the sugar concentration that is used to preserve the jam be ***higher*** or ***lower*** than the sugar concentration inside bacteria cells? Give reasons.
Answers:
Higher concentration. Want water concentration in cells to be higher (or sugar concentration to be lower) than water concentration in preserve solution.

4. Red blood cells (0.9% NaCl (m/V)) are placed in sea water (0.6 M NaCl).
a. Will water pass into the cells or out of the cells? Give reasons.
b. What happens to the concentration of NaCl in sea water as osmosis occurs?
c. Will you gain weight or lose weight if you drink sea water? Give reasons.
Answers:
a. Water will pass out of the cells due to osmosis. Water concentration in cells is higher than water concentration in sea water.
b. Concentration of NaCl in sea water decreases. Water passes out of cells and into sea water.
Concentration = moles/volume so increase in water will decrease concentration.
c. Lose weight due to water loss.

5. Red blood cells contain 0.9% NaCl (m/V).
a. Calculate the Molar concentration of red blood cells. (Answer: between 0.1 and 0.2 M)
b. Calculate the osmotic pressure of this solution at 37^{o}C. (Answer: between 6 and 9 atm.)
Answers:
a. 0.9% NaCl (m/V) = 0.9 g NaCl/100 ml solution.
Convert g NaCl to moles NaCl and ml to liters.
(0.9 g NaCl/100 ml solution) (1 mole NaCl/58.5 g NaCl)(1000 ml/1 liter) = 0.15 M
b. osmotic pressure = π = iMRT
i = 2 for NaCl, M = 0.15 M, R = 0.082 l atm/mole K, and T = 37^{o}C = 310 K.
π = (2) (0.15 M)(0.082 l atm/mole K)(310 K) = 7.6 atm

6. Hemoglobin is the oxygen carrying protein in our blood. 0.50 g of hemoglobin is dissolved in 100 ml of 25^{o}C water. The osmotic pressure of this solution is 0.00178 atm. Calculate the molar mass of hemoglobin.
Hint: Molarity is moles/liter of solution. Molar mass is mass/moles. What information about hemoglobin are you given? What information can you find?
(Answer: molar mass is between 60,000 and 70,000 g/mole.)
Answers:
osmotic pressure = π = iMRT
π = 0.00178 atm, i = 1, M = ?, R = 0.082 l atm/mole K, and T = 25^{o}C = 298 K.
Solve for M = π / iRT = 0.00178 atm/(1)(0.082 l atm/mole K)(298 K) = 7.28E-5 M
Calculate moles of hemoglobin in 100 ml of solution: 7.28E-5 M x 0.100 l = 7.28E-6 moles
molar mass of hemoglobin = mass of hemoglobin/moles of hemoglobin = 0.50 g/7.28E-6 moles = 68600 g/mole

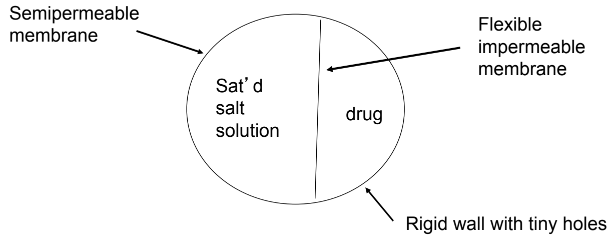
7. Desalination is a process by which salts are removed from seawater. Three major ways to accomplish desalination are distillation, freezing, and reverse osmosis. The freezing method is based on the fact that when an aqueous solution freezes, the solid that separates from the solution is almost pure water. Reverse osmosis uses water movement from a more concentrated solution to a less concentrated one through a semipermeable membrane.
a. With reference to the picture below, draw a diagram showing how reverse osmosis can be carried out.



b. What are the advantages and disadvantages of reverse osmosis compared to the freezing and boiling methods?
c. What minimum pressure (in atm) must be applied to seawater at 25^{o}C for reverse osmosis to occur? Treat seawater as a 0.60 M NaCl solution. (Answer: between 25-35 atm)

Answers:
a. apply pressure on the left side of the container (high contaminant concentration or low water concentration) greater than the osmotic pressure. This applied pressure will reverse the normal osmosis and water will flow into the right side of the container.
b. Reverse osmsosis needs membranes that can get clogged and need cleaning and pumps to apply pressure to reverse osmosis. Pumps require energy, which can be expensive.
Distillation requires heating the water to its boiling point. Water has a high boiling point and requires a lot of energy for heat.
c. $\pi = iMRT$
$i = 2$ for NaCl, $M = 0.6$ M, $R = 0.082$ l atm/mole K, and $T = 25^oC = 298$ K.
$\pi = (2)(0.6\text{ M})(0.082\text{ l atm/mole K})(298\text{ K}) = 29$ atm.

8. "Time-release" drugs have the advantage of releasing the drug to the body at a constant rate so that the drug concentration at any time is not so high to have harmful side effects or so low as to be ineffective. A schematic diagram of a pill that works on this basis is shown below. Explain how it works.



(See Chang, 6th ed., p. 463, Problem 13.85 for picture.)
Answers:
See osmosis. The concentration of NaCl in the saturated salt solution is very high. The concentration of NaCl in the body is lower. So water will pass into the drug through the semipermeable membrane.
As water enters the saturated salt solution, the water pushes on the flexible impermeable membrane.
As the flexible impermeable membrane pushes on the drug, the drug passes through the holes in the rigid wall into the body.

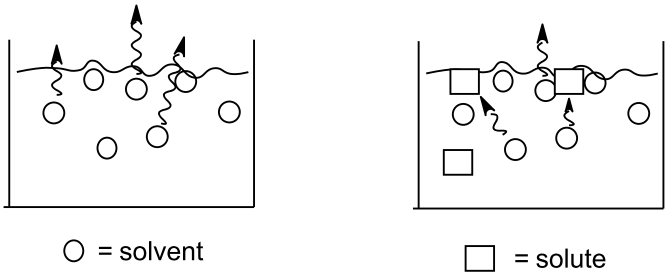
Vapor pressure lowering.
9. Which substance has the *highest* vapor pressure at 25^oC?
a. Water (vapor pressure of pure water = 23.8 mm Hg at 25^oC)
b. sea water (use $p = x\ p^o$). Sea water is 0.6 M NaCl. The mole fraction of NaCl in sea water is 0.01. Confirm the mole fraction of NaCl. The vapor pressure of sea water is 23.6 mm Hg. Confirm the vapor pressure of sea water.
c. 0.9% NaCl (m/V). Calculate the vapor pressure of 0.9% NaCl.
Which substance evaporates the fastest?
Which substance has the highest boiling point?
Answers:
adding a solute lowers the vapor pressure of the resulting solution. In other words, a pure solvent has a higher vapor pressure than a solution. So water has the highest vapor pressure.
The substance that evaporates the fastest is the substance with the highest vapor pressure = water.
The substance with the highest boiling point is the liquid with the lowest vapor pressure = sea water (highest solute concentration).
b. Sea water: 0.6 M NaCl
mole fraction of NaCl in sea water = 0.01
mole fraction of NaCl + mole fraction of water = 1
so mole fraction of water = 1 – mole fraction of NaCl = 1 – 0.01 = 0.99
$p = x\ p^o = 0.99 \times 23.8$ mm Hg = 23.6 mm Hg
c. 0.9% NaCl = 0.9 g NaCl/100 ml solution (1 mole NaCl/58.5 g NaCl) (1000 ml/1 l) = 0.15 M NaCl
0.15 M NaCl = 0.15 moles NaCl/liter of solution
Since 0.15 M is low concentration, assume 1 liter of solution = 1 liter of H_2O.
So 0.15 moles NaCl/liter of solution ≈ 0.15 moles NaCl/liter of H_2O.
1 liter of H_2O = 1000 ml of H_2O x 1 g/ml = 1000 g H_2O (1 mole H_2O/18 g H_2O) = 55.6 moles H_2O
mole fraction of H_2O = moles of H_2O/(moles of H_2O + moles of NaCl) = 55.6/(55.6 + 0.15) = 0.997
$p = x\ p^o = 0.997 \times 23.8$ mm Hg = 23.7 mm Hg

10. On a "molecular basis", DRAW A PICTURE that explains why:
- the boiling point of a solution is higher than the pure solvent. Hint: solvent molecules have to escape into the gas phase to boil.

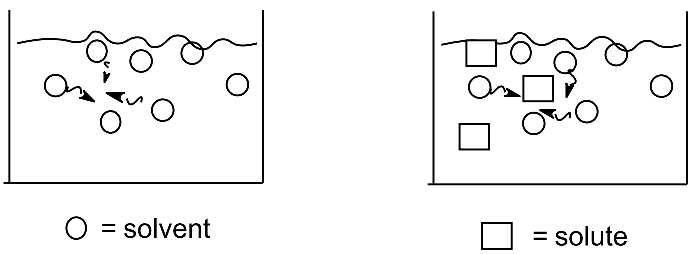
- The freezing point of a solution is lower than the pure solvent. Hint: solvent molecules have to move close together and form IM forces to turn from a liqud to a solid.
- Osmosis occurs.
- The vapor pressure of a solution is lower than the vapor pressure of a pure liquid.

Answers:

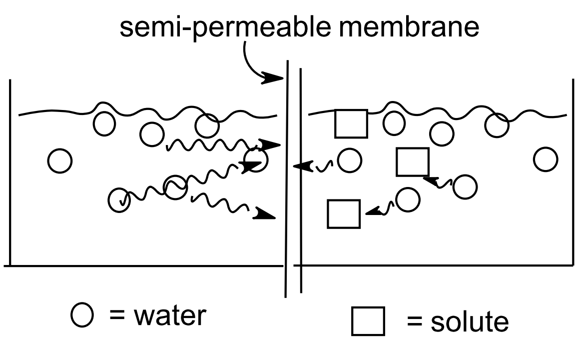
Boiling point elevation: When heated, pure solvent molecules move fast enough to escape from liquid to the gas phase. With solute present, solute blocks path of solvent molecules to escape from liquid to the gas phase so more energy (higher temperature) is needed to boil solution.



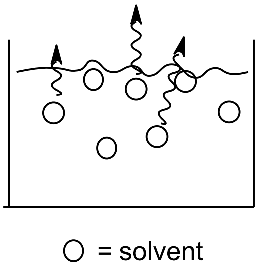
Freezing point depression: When cooled, pure solvent molecules move slow enough and closer together so attractive forces are strong enough to form a solid.
With solute present, solute blocks path of solvent molecules to get close together so attractive forces are strong enough to form a solid so lower temperature is needed to slow down solvent molecules enough to form a solid.

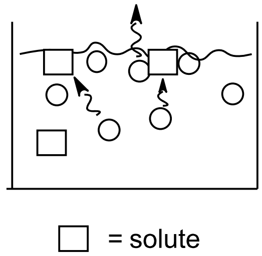


Osmosis: is the passage of water through a semi-permeable membrane due to a difference in concentration. Water passes from high water concentration (low solute concentration) to low water concentration (high solute concentration).
In picture, left side shows pure water – many water molecule pass through semi-permeable membrane to right side.
Right side shows water with solute – solute blocks water molecules from getting to membrane and passing through so fewer water molecules pass to left side.
Net movement of water is from left side to right side.



Vapor pressure lowering: similar to boiling point elevation. Pure solvent molecules move fast enough to escape from liquid to the gas phase. Some of the solvent vapor molecules return to the liquid. The pressure the solvent vapor molecules exert on the surface of the liquid is vapor pressure.
With solute present, solute blocks path of solvent molecules to escape from liquid to the gas phase so fewer solvent molecules escape and fewer solvent vapor molecules exert pressure on surface of liquid so lower vapor pressure.
Boiling point elevation is a special case of vapor pressure lowering. At the boiling point of a liquid, the vapor pressure = the atmospheric pressure.
E.g., water boils at $100^{\circ}C$ so the vapor pressure of water at $100^{\circ}C$ = 1 atm.
Add a solute, e.g., salt, to water. At $100^{\circ}C$, fewer water molecules escape to gas phase so fewer water vapor molecules exert pressure on surface of liquid so vapor pressure at $100^{\circ}C < 1$ atm.


○ = solvent


□ = solute