

Colligative Properties

1. What is a colligative property?

This is a property that is affected by the addition of a solute. These properties, in particular, depend on the number, not identity, of solute particles in an ideal solution.

2. What are three examples of colligative properties?

- a. Boiling Point Elevation
- b. Freezing Point Depression
- c. Osmotic Pressure

3. How does adding a solute affect the boiling point of a solvent?

It increases the boiling point. Remember that in order to boil the vapor pressure of the liquid must equal the vapor pressure of the atmosphere. Because adding in a solute drops the vapor pressure down, it takes more heat energy to reach the same final vapor pressure – and a higher temperature is required to reach the boiling point.

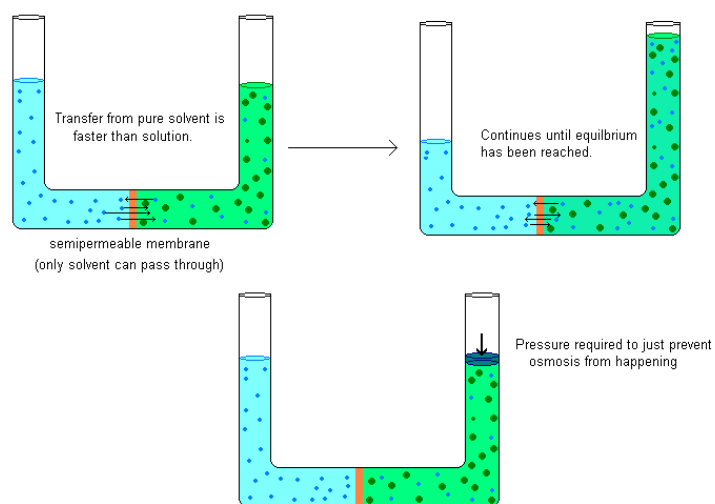
4. How does adding a solute affect the freezing point of a substance?

It lowers the freezing point. Remember that freezing depends on the IMFs between particles. Once a solute has been put into the solvent, it disrupts the typical IMFs experienced within the pure solvent and thus, makes it harder for the substance to solidify – necessitating lower temperatures to freeze.

5. What is osmotic pressure?

The pressure that just stops osmosis. As a reminder, osmosis is the spontaneous migration of a solvent from a less concentrated solution to a more concentrated solution.

6.



a. What does isotonic mean?

This occurs when two substances have identical osmotic pressures.

7. What is the Van't Hoff Factor?

Our colligative properties are affected by the *total* number of particles present in the solution. The Van't Hoff factor takes into account the number of particles present in solution if the compound dissolved breaks into ions.

Technically

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

Generally, i = number of ions in a formula

If the compound does not break into ions (like ethanol $\text{CH}_3\text{CH}_2\text{OH}$) it has an i value equal to one.

8. What is the equation for determining the

a. Boiling Point Elevation

$$\Delta T = i k_b m_{\text{solute}}$$

↑ How much the boiling point changed
 substance specific constant
 ↓
 ↑ molality of solute

b. Freezing Point Depression

$$\Delta T = i k_f m_{\text{solute}}$$

↑ How much the freezing point changed
 substance specific constant
 ↓
 ↑ molality of solute

c. Osmotic Pressure

$$\pi = i MRT$$

↑ Osmotic Pressure (atm)
 Molarity of solute
 ↓
 ↑ 0.08206 Latm molK
 Temp in K

9. A solution is prepared by dissolving 27.0 g of urea $[(\text{NH}_2)_2\text{CO}]$, in 150.0 g of water. Calculate the boiling point of the solution. Urea is a non-electrolyte. $k_b=0.51$ ($^{\circ}\text{C kg}/\text{mol}$).

As this is a situation where a solute has been added to a solvent, we are going to see a boiling point elevation and will need to calculate the change in the temperature using

$$\Delta T = i k_b m_{\text{solute}}$$

Because urea is a non electrolyte we know that $i = 1$. The only thing we need to calculate, before plugging in, is the molality.

$$\text{Molality (m)} = \frac{\text{moles of solute}}{\text{kg of solvent}}$$

$$27.0 \text{ g urea} \frac{1 \text{ mol urea}}{60.07 \text{ g}} = 0.449 \text{ mol}$$

$$150.0 \text{ g water} \frac{1 \text{ kg}}{1000 \text{ g}} = 0.150 \text{ kg}$$

$$m = \frac{0.449 \text{ mol urea}}{0.150 \text{ kg}} = \boxed{2.99 \text{ m}}$$

Plugging in all the data:

$$\Delta T = i k_b m_{\text{solute}} = (1) \left(0.51 \frac{^{\circ}\text{C kg}}{\text{mol}} \right) (2.99 \frac{\text{mol}}{\text{kg}}) = 1.53^{\circ}\text{C}$$

Thus the new boiling point would be:

$$100^{\circ}\text{C} + 1.53^{\circ}\text{C} = 101.53^{\circ}\text{C}$$

normal
boiling point
of water

10. What mass of glycerin ($\text{C}_3\text{H}_8\text{O}_3$), a nonelectrolyte, must be dissolved in 200.0 g of water to give a solution with a freezing point of -1.50°C ?

Once again we are looking at how a colligative property, freezing point depression. This means that we will be using:

$$\Delta T = i k_f m_{\text{solute}}$$

In this case we have the change in temperature, i , and we can use the molality to solve for the mass of glycerin.

$$\Delta T = i k_f m_{\text{solute}} = 1.5^{\circ}\text{C} = (1) \left(1.86 \frac{^{\circ}\text{C kg}}{\text{mol}} \right) \left(\frac{\text{mol glycerin}}{0.200 \text{ kg}} \right)$$

$$\text{mol glycerin} = 0.161 \text{ mol C}_3\text{H}_8\text{O}_3$$

Now converting to mass:

$$0.161 \text{ mol C}_3\text{H}_8\text{O}_3 \frac{\text{mol}}{92.11 \text{ g}} = \boxed{14.8 \text{ g}}$$

11. Consider the following

0.010 *m* Na₃PO₄ in water

$$i = 4 \rightarrow \text{ion molality} = 4 (0.010\text{m}) = 0.040 \text{ m}$$

0.020 *m* CaBr₂ in water

$$i = 3 \rightarrow \text{ion molality} = 3 (0.020\text{m}) = 0.060 \text{ m}$$

0.020 *m* KCl in water

$$i = 2 \rightarrow \text{ion molality} = 2 (0.020\text{m}) = 0.040 \text{ m}$$

0.020 *m* HF in water (HF is a weak acid)

$$i = 1 \rightarrow \text{ion molality} = 0.020 \text{ m}$$

- a. Assuming complete dissociation of soluble salts, which solution(s) would have the same boiling point as 0.040 *m* C₆H₁₂O₆ in water? (non-polar electrolyte).

We are basically looking for which substances have the same molality as 0.040 *m* C₆H₁₂O₆.

Na_3PO_4 and KCl both have a total molality (in terms of ions) equal to 0.040 m

Thus these two compounds would have the same boiling points.

b. Which solution would have the largest freezing point depression?

The greater the concentration of solute particles the greater the freezing point depression. This means that the CaBr_2 solution would have the lowest overall freezing point as it has the greatest concentration of ions in solution.

12. From the following :

pure water

solution of $\text{C}_6\text{H}_{12}\text{O}_6$ ($\chi = 0.01$) in water

$i = 1$

solution of NaCl ($\chi = 0.01$) in water

$i = 2$

solution of CaCl_2 ($\chi = 0.01$) in water

$i = 3$

Choose the one with the following:

a. Highest freezing point

Pure water. Any added solute would drop the freezing point.

b. Lowest freezing point

The CaCl_2 solution would have the lowest freezing point as this solution would contain the greatest number of particles. The greater the concentration of particles the lower the freezing point.

c. Highest Boiling Point

Once again, the CaCl_2 solution would have the highest boiling point as this solution would contain the greatest number of particles. The greater the concentration of particles the higher the boiling point elevation.

d. Lowest Boiling Point

Pure water. Any added solute would raise the boiling point.

e. Highest Osmotic Pressure

Again, the CaCl_2 solution would have the highest osmotic pressure as it has the greatest number of particles in solution. The osmotic pressure would be higher because more solvent would want to shift in order to compensate for the difference in concentration.

13. Determine the boiling point for a solution of 20.0 g of NaCl and 40.0 g CaF_2 in 1.00 L of H_2O . The K_b for water is $0.51^\circ\text{C kg/mol}$ and the density equals 1.00 g/cm^3 .

For this problem we are dealing with a boiling point elevation. Thus we will be using the formula:

$$\Delta T = i k_b m_{\text{solute}}$$

The trick here is that there is not a clear i value because we have two solutes. Remember that the whole point of the Van't Hoff factor is to change the molality of the overall solute into the molality of the ions.

$$20.0 \text{ g NaCl} \frac{1 \text{ mol}}{58.44 \text{ g}} = 0.342 \text{ mol NaCl} \frac{2 \text{ mol ions}}{1 \text{ mol NaCl}} = 0.684 \text{ mol ions}$$

$$40.0 \text{ g CaF}_2 \frac{1 \text{ mol CaF}_2}{78.08 \text{ g}} = 0.512 \text{ mol CaF}_2 \frac{3 \text{ mol ions}}{1 \text{ mol CaF}_2} = 1.54 \text{ mol ions}$$

$$\text{mass of solvent} = 1.00 \text{ L} \frac{1000 \text{ cm}^3}{\text{L}} \frac{1.00 \text{ g}}{\text{cm}^3} \frac{\text{kg}}{1000 \text{ g}} = 1.00 \text{ kg}$$

$$\text{overall ion molality} = \frac{0.684 + 1.54}{1.00 \text{ kg}} = 2.22 \text{ mol kg}^{-1}$$

Plugging into our formula:

$$\Delta T = i k_b m_{\text{solute}} = (0.51 \text{ } ^\circ\text{C kg mol}^{-1}) (2.22 \text{ mol kg}^{-1}) = 1.13 \text{ } ^\circ\text{C}$$

$$T_{\text{boiling point}} = 100^\circ\text{C} + 1.13^\circ\text{C} = 101.1^\circ\text{C}$$