Chemistry Lecture #80: Boiling Point Elevation and Freezing Point Depression, Part 1

Under normal conditions, water boils at 100 °C and freezes at 0 °C. However, when a non-volatile solute is added to water, the boiling point (bp) goes up, and the freezing point (fp) goes down. We can use the following formulas to calculate how much the freezing or boiling point changes.

$\Delta T_{bp} = k_b m$ $\Delta T_{fp} = k_f m$

ΔT_{bp} = change in boiling point
ΔT_{fp} = change in freezing point

K_b = 0.512 °C/m boiling point elevation constant for water
K_f = 1.86 °C/m freezing point depression constant for water

m = molality of the solution

k_b and k_f may have slightly different values depending on which textbook you use.

Sugar is added to water. The molality of the solution is 0.635 molal. Find the new boiling point and freezing point.

Answer

$\Delta T_{bp} = k_b m$

$$\Delta T_{bp} = \frac{(0.512\ ^{\circ}C)}{m}\,(0.635\ m)$$

$\Delta T_{bp} = 0.325\ ^{\circ}C$

The boiling point is elevated by 0.325 °C. Thus, the new boiling point of the water is 100 + 0.325 = 100.325 °C.

$\Delta T_{fp} = k_f m$

$$\Delta T_{fp} = \frac{(1.86\ ^{\circ}C)}{m}\,(0.635\ m)$$

$\Delta T_{fp} = 1.18\ ^{\circ}C$

The freezing point is lowered by 1.18 °C. Thus, the new freezing point of the water is 0 - 1.18 = -1.18 °C.

Salt is often poured on roads on cold, wet days. When the salt dissolves into the water on the road, it lowers the freezing point, making it less likely to freeze. The roads are then safer to drive since there is less ice on the road.

The greater the number of solute particles, the more the boiling and freezing point will change. Soluble ionic compounds will dissociate into two or more particles. Thus, the change in temperature is magnified when soluble ionic compounds are dissolved in water. The dissociation of ionic compounds must be factored into the calculation of the change in temperature.

I recommend that you review Chemistry Lecture #48 (Soluble and Insoluble Ionic Compounds) so that you can recognize when an ionic compound is soluble in water.

I also recommend that you review Chemistry Lecture #49 (Dissociation of Ionic Compounds) so you can determine how ionic compounds dissociate in water.

What is the freezing and boiling point of a 0.029 *m* aqueous solution of $CaCl_2$?

Answer

$CaCl_2$ is soluble in water, and dissociates as follows:

$$CaCl_2(s) \xrightarrow{H_2O} Ca^{2+}(aq) + 2Cl^-(aq)$$

One formula unit of $CaCl_2$ dissociates into three particles: one Ca^{2+} ion and two Cl^- ions. The molality of solute particles is three times larger after dissociation. Thus,

$$m = 0.029\ m \times 3 = 0.087\ m$$

$$\Delta T_{fp} = k_f m$$

$$\Delta T_{fp} = \frac{(1.86\ °C)}{m}(0.087\ m)$$

$$\Delta T_{fp} = 0.16\ °C \Rightarrow fp = 0 - 0.16 = -0.16\ °C$$

$$\Delta T_{bp} = k_b m$$

$$\Delta T_{bp} = \frac{(0.512\ °C)}{m}(0.087\ m)$$

$$\Delta T_{bp} = 0.045\ °C \Rightarrow bp = 100 + 0.045 = 100.045\ °C$$