Some sample colligative properties and concentration problems ...

What is the freezing point of a 41% solution of urea in water?

$(NH_2)_2CO$: urea, FW = 60.062 g/mol

$\Delta T_f = K_f \times Cm$ — K_f = 1.858°C/m

$Cm = \frac{\text{mol urea}}{\text{kg water}}$

PSOG: $K_{f,H_2O} = 1.858°C/m$

$T_{f,H_2O} = 0.000°C$

We need to find Cm ... the molal concentration. We need to find the moles of urea per kg of water. Let's look at what we have:

$\frac{41\text{ g urea}}{100\text{ g solution}}$ Use a basis of 100 grams of solution. Next, calculate the moles of urea based on 41 grams of urea. (mass mole conversion using formula weight!)

definition of mass percent

$$41\text{ g urea} \times \frac{\text{mol urea}}{60.062\text{ g urea}} = 0.682627911\text{ mol urea}$$

Now, calculate the mass of water in the solution by subtraction.

$$100\text{ g solution} - 41\text{ g urea} = 59\text{ g water} = 0.059\text{ kg water}$$

$$C_m = \frac{\text{mol urea}}{\text{kg water}} = \frac{0.682627911 \text{ mol urea}}{0.059 \text{ kg water}} = 11.56996627 \text{ m urea}$$

Now calculate delta Tf ...

$$\Delta T_f = K_f \times C_m = (1.858\ ^\circ C/m)(11.56996627 \text{ m urea})$$

$$\Delta T_f = 21\ ^\circ C$$

Find the new freeziing point by subtraction.

$$T_f = T_{f,\text{original}} - \Delta T_f = 0.000\ ^\circ C - 21\ ^\circ C = \boxed{-21\ ^\circ C}$$

0.2436 g of an unknown substance is dissolved in 20.0 mL of cyclohexane, C_6H_{12}
If the freezing point depression of this solution is 2.5 C, what is the molecular weight of the unknown? The density of cyclohexane at the temperature the cyclohexane volume was measured is 0.779 g/mL.

$\Delta T_F = K_F \times Cm$ — $= \frac{\text{mol unknown}}{\text{kg } C_6H_{12}}$

$\Delta T_F = 2.5^\circ C$

$K_F = 20.0^\circ C/m$

$pSOS: K_{F\,C_6H_{12}} = 20.0^\circ C/m$

First, we'll calculate Cm, the molal concentration of unknown. Then, we'll use Cm to find out how many moles of unknown there are.

$2.5^\circ C = (20.0\ ^\circ C/m) \times Cm$; $Cm = 0.125\,m = \frac{0.125 \text{ mol unknown}}{\text{kg } C_6H_{12}}$

If we find out the mass of cyclohexane (solvent), we can then multiply it by the molality to find out how many moles of unknown we actually have!

$20.0 \text{ mL } C_6H_{12} \times \frac{0.779 \text{ g}}{\text{mL}} = 15.58 \text{ g } C_6H_{12} = 0.01558 \text{ kg } C_6H_{12}$

$0.01558 \text{ kg } C_6H_{12} \times \frac{0.125 \text{ mol unknown}}{\text{kg } C_6H_{12}} = 0.0019475 \text{ mol unknown}$

Find molecular weight:

$MW = \frac{\text{g unknown}}{\text{mol unknown}} = \frac{0.2436 \text{ g}}{0.0019475 \text{ mol}} = \boxed{130 \text{ g/mol}}$

Commercial sulfuric acid is 18.0 M. If the density of the acid is 1.802 g/mL, what is the molality?

H_2SO_4, FW = 98.096 g/mol

$$\frac{18.0 \text{ mol } H_2SO_4}{\text{L solution}} \longrightarrow \frac{\text{mol } H_2SO_4}{\text{kg solvent}}$$

Definition of molarity

Definition of molality

Assume a basis of 1 L of solution. This allows us to know the moles of sulfuric acid, 18.0 moles. We'll need to figure out how many kg of solvent there is. Start by converting 1 L of solution to mass using density.

$$1000 \text{ mL} \times \frac{1.802 \text{ g}}{\text{mL}} = 1802 \text{ g solution}$$

(1 L)

Since the solution contains both sulfuric acid and solvent, we need to subtract out the sulfuric acid from the total mass!

Convert 18.0 moles sulfuric acid to mass.

$$18.0 \text{ mol } H_2SO_4 \times \frac{98.096 \text{ g } H_2SO_4}{\text{mol } H_2SO_4} = 1765.728 \text{ g } H_2SO_4$$

$$1802 \text{ g solution} - 1765.728 \text{ g } H_2SO_4 = 36.272 \text{ g solvent} = 0.036272 \text{ kg}$$

$$m = \frac{\text{mol } H_2SO_4}{\text{kg solvent}} = \frac{18.0 \text{ mol}}{0.036272 \text{ kg}} = \boxed{496 \text{ m } H_2SO_4}$$