The vapor pressure of a solvent in a solution is always lower than the vapor pressure of the pure solvent. The vapor pressure lowering is directly proportional to the mole fraction of the solute. This is Raoult’s Law

\[ P_{\text{solution}} = \chi_{\text{solvent}}P^o_{\text{solvent}} \label{RLaw} \]

where \(P^o_{\text{solvent}}\) is the vapor pressure of the pure solvent and \(\chi_{\text{solvent}}\) is the mole fraction of the solvent. Since this is a two-component system (solvent and solute), then

\[ \chi_{\text{solvent}} + \chi_{\text{solute}} = 1\]

where \(\chi_{\text{solute}}\) is the mole fraction of the solvent or solute. The change in vapor pressure (\(\Delta P\)) can be expressed

\[ \Delta P = P_{\text{solution}} - P^o_{\text{solvent}} = \chi_{\text{solvent}}P^o_{\text{solvent}} - P^o_{\text{solvent}} \]

or

\[ \Delta P = (\chi_{\text{solvent}} - 1)P^o_{\text{solvent}} = \chi_{\text{solute}}P^o_{\text{solvent}} \label{DP} \]

Example \(\PageIndex{1A}\): Non-electrolyte Solutions

Calculate the vapor pressure of a solution made by dissolving 50.0 g glucose, \(\text{C}_6\text{H}_{12}\text{O}_6\), in 500 g of water. The vapor pressure of pure water is 47.1 torr at 37°C

Solution

To use Raoult’s Law (Equation \(\ref{RLaw}\)), we need to calculate the mole fraction of water (the solvent) in this sugar-water solution.

\[ \chi_{\text{solvent}} = \dfrac{\text{moles of water}}{\text{moles of solute} + \text{moles of solvent}} \]

\[ \chi_{\text{solvent}} = \dfrac{n_{\text{water}}}{n_{\text{glucose}} + n_{\text{water}}} \]

The molar mass of glucose is 180.2 g/mol and of water is 18 g/mol. So

\[ n_{\text{water}} = \dfrac{500 \text{ g}}{18 \text{ g/mol}} = 27.7 \text{ mol} \]

and

\[ n_{\text{glucose}} = \dfrac{50 \text{ g}}{180.2 \text{ g/mol}} = 0.277 \text{ mol} \]

and

\[ \chi_{\text{solvent}} = \dfrac{27.7 \text{ mol}}{0.277 \text{ mol} + 27.7 \text{ mol}} = 0.99 \]

Note that this still relatively dilute. The pressure of the solution is then calculated via Raoult’s Law (Equation \(\ref{RLaw}\)):  

1
Example (\(\PageIndex{1B}\)): Electrolyte Solutions

Calculate the vapor pressure of a solution made by dissolving 50.0 g CaCl\(_2\), \((\text{C}_6\text{H}_{12}\text{O}_6)\), in 500 g of water. The vapor pressure of pure water is 47.1 torr at 37°C

Solution

To use Raoult’s Law (Equation \(\ref{RLaw}\)), we need to calculate the mole fraction of water (the solvent) in this salt-water solution.

\[
\chi_{\text{solvent}} = \frac{\text{moles of water}}{\text{moles of solute} + \text{moles of solvent}}
\]

\[
\chi_{\text{solvent}} = \frac{ n_{\text{water}}}{ n_{\text{solute}} + n_{\text{water}}} 
\]

The molar mass of \((\text{CaCl}_2)\) is 111 g/mol and of water is 18 g/mol. So

\[
n_{\text{water}} = \frac{500 \text{ g}}{18 \text{ g/mol}} = 27.7 \text{ mol} 
\]

and

\[
n_{\text{solute}} = \frac{50 \text{ g}}{111 \text{ g/mol}} = 0.45 \text{ mol} 
\]

but this is really:

- \( n_{\text{Ca}^+} = 0.45 \text{ mol} \)
- \( n_{\text{Cl}^-} = 0.9 \text{ mol} \)

and

\[
\chi_{\text{solvent}} = \frac{ 27.7 \text{ mol}}{ 0.45 \text{ mol} + 0.9 \text{ mol} + 27.7 \text{ mol} } = 0.953 \nonumber 
\]

Note that this still relatively dilute. The pressure of the solution is then calculated via Raoult’s Law (Equation \(\ref{RLaw}\)):

\[
P_{\text{solution}} = 0.953 \times 47.1 = 44.88 \text{ torr} \nonumber 
\]

A bigger change than the glucose in Example \(\PageIndex{1A}\).

Exercise \(\PageIndex{1}\): Electrolyte Solutions

At 25°C the vapor pressure of pure benzene is 93.9 torr. When a non-volatile solvent is dissolved in benzene, the vapor pressure of benzene is lowered to 91.5 torr. What is the concentration of the solute and the solvent, expressed in mole fraction?
Answer

Vapor pressure lowering \((\Delta P = 2.4 \text{; torr})\) with \((\chi_{\text{solute}} = 0.026)\).