13.1 Quantitative Expressions of Concentration

Units of Concentration – Molarity, Molality, Mole Fraction, Weight %

What is the **molality** of a **chromium(II) nitrate** solution made by dissolving **27.1g** of chromium(II) nitrate (**MM= 176.02**) in **513g** of water?

3
0.?

Chromium(II) nitrate = $Cr(NO_3)_2$: MM = 176.02 g mol^{-1}

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

Moles of solute : $27.1\,g\ Cr(NO_3)_2 \left| \frac{1\ mol}{176.02\,g} \right. = 0.154$

Kg of solvent : $513\,g \left| \frac{1\ kg}{1000\,g} \right. = 0.513$

$$\text{Molality} = \frac{0.154}{0.513} = 0.300\ m$$

13.1 Quantitative Expressions of Concentration

Units of Concentration – Molarity, Molality, Mole Fraction, Weight %

An aqueous solution is **6.00 % by mass hydrochloric acid**. What is the **mole fraction** of **hydrochloric acid** in the solution?

$$6.00\%\ HCl = \frac{6.00\ g\ HCl}{100\ g\ solvent} \qquad X = \frac{moles\ of\ solute}{moles\ of\ solute + moles\ of\ solvent}$$

Assume: 100 g of solution.

$\therefore$ 6 g of HCl + 94 g of H_2O

MM: $H_2O = 18.02\ g.mol^{-1}$; $HCl = 36.5\ g.mol^{-1}$

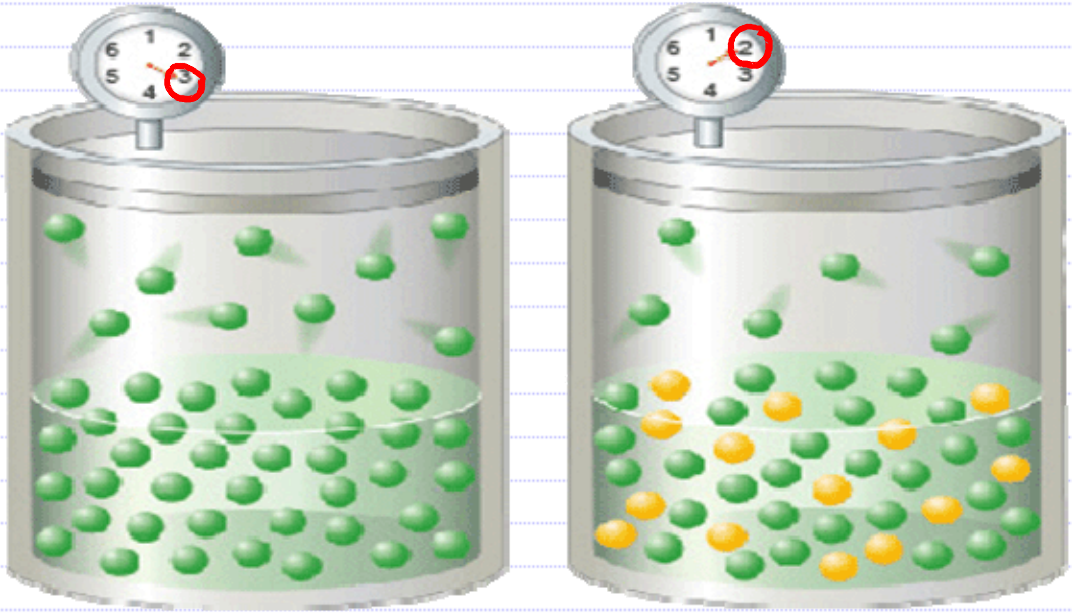
$$\text{Moles of solute: } \frac{6.00\ g\ HCl \mid 1\ mol}{36.5\ g} = 0.164$$

$$\text{Moles of solvent: } \frac{94.00\ g\ H_2O \mid 1\ mol}{18.02\ g} = 5.22$$

$$X = \frac{0.164}{0.164 + 5.22} = 0.0305$$

13.4 Colligative Properties

Vapor Pressure Lowering – Raoult's Law



Pure solvent

Solution with a nonvolatile solute

When a nonvolatile solute is added to a volatile solvent, the solute particles block some of the solvent molecules from escaping into the gas phase, thus lowering the Vapor Pressure.

Raoult's Law:

$P_{solution} = X_{solvent} \times P^{\circ}_{solvent}$

$P_{solution}$: Vapor Pressure of the solvent in the solution.

$X_{solvent}$: Mole fraction of the solvent.

$P^{\circ}_{solvent}$: Vapor Pressure of the pure solvent.

13.4 Colligative Properties

Vapor Pressure Lowering – Raoult's Law

The vapor pressure of **benzene** (C_6H_6) at 25 °C is **73.0 mm Hg**. What is the **vapor pressure of a solution** consisting of **303 g of benzene** and **0.170 mol** of a **solute that is a nonvolatile nonelectrolyte**?

?0.0 mmHg

↳ ~ 7

$P_{solution} = X_{benzene} \times P^{\circ}_{benzene}$

C_6H_6 : $MM = 78.12\ g.mol^{-1}$

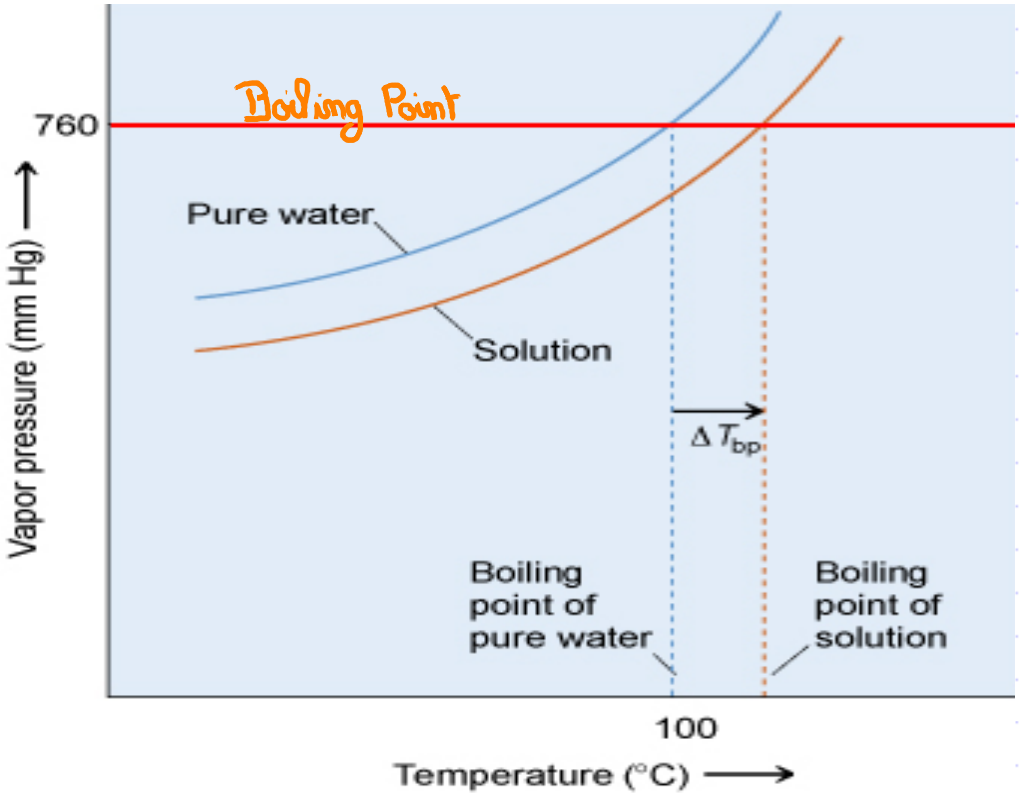
$$303\,g\ C_6H_6 \left| \frac{1\ mol}{78.12\,g} \right. = 3.88\ mol\ C_6H_6$$

$$X_{C_6H_6} = \frac{3.88}{3.88 + 0.17} = 0.958$$

$$P_{solution} = 0.958\,(73.0) = 69.9\ mm\ Hg$$

13.4 Colligative Properties

Vapor Pressure Lowering – Boiling Point Elevation



$\Delta T_{B.P.} = i \times K_{B.P.} \times m_{solute}$

$\Delta T_{B.P.}$: Change in Boiling Point.

$K_{B.P.}$: Boiling Point elevation constant for the solute.

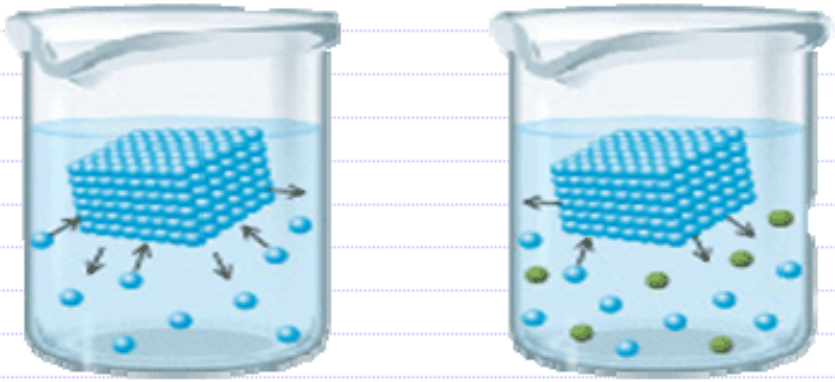
m_{solute} : Molality of the solute.

i : van't Hoff Factor.
For a nonelectrolyte, $i = 1$

13.4 Colligative Properties

Vapor Pressure Lowering – Freezing Point Depression

$$\Delta T_{fp} = i \times K_{fp} \times m_{solute}$$



(a) (b)

ΔT_{fp} : Change in freezing point.

K_{fp} : Freezing point depression constant for the solute.

m_{solute} : Molality of the solute.

i : van't Hoff factor. For a nonelectrolyte, $i = 1$.

13.4 Colligative Properties

Vapor Pressure Lowering – van't Hoff Factor?

In our disscussion of Raoults Law we have stuck with non volatile liquids (nonelectrolytes) that dissolve in water.

What if we used soluble ionic compounds?

$1M\ NaCl(aq) = 1M\ Na^+ + 1M\ Cl^-$: $i = 2$

$1M\ CaCl_2(aq) = 1M\ Ca^{2+} + 2M\ Cl^-$: $i = 3$

What about using a weak acid?

$1M\ HCN(aq) \rightleftharpoons ?M\ H^+ + ?M\ CN^-$: $i > 0$ but < 2

13.4 Colligative Properties

Vapor Pressure Lowering – van't Hoff Factor?

Which of the following solutions would have the **highest boiling point**?

a) **0.19m** NH_4NO_3 $NH_4^+ + NO_3^-$; $i = 2$ $2 \times 0.19 = 0.38$

b) **0.18m** KCH_3COO $K^+ + CH_3COO^-$; $i = 2$ $2 \times 0.18 = 0.36$

c) **0.21m** NaCl $Na^+ + Cl^-$; $i = 2$ $2 \times 0.21 = 0.42$

d) ✓ **0.44m** Glucose (nonelectrolyte) ; $i = 1$ $1 \times 0.44 = 0.44$ ✓