Colligative Properties Problem Set, Solutions

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1. For a mixture prepared by combining 200.0 mL of nitrobenzene and 1.00 L of water.
   a. Calculate the mole fraction of each compound in the mixture

Volume

$V_{nitrobenzene} := 200.0 \cdot mL$

$V_{water} := 1.00 \cdot L$

Density

$\rho_{nitrobenzene} := 1.2037 \cdot gm \cdot mL^{-1}$

$\rho_{water} := 0.998203 \cdot gm \cdot mL^{-1}$

Mass

$mass_{nitrobenzene} := V_{nitrobenzene} \cdot \rho_{nitrobenzene}$

$mass_{nitrobenzene} = 240.74 \cdot gm$

$mass_{water} := V_{water} \cdot \rho_{water}$

$mass_{water} = 998.203 \cdot gm$

Molecular Mass and Moles

$MW_{nitrobenzene} := (6 \cdot 12.0107 + 5 \cdot 1.00794 + 14.00674 + 2 \cdot 15.9994)\ gm \cdot mole^{-1}$

$MW_{nitrobenzene} = 123.109 \cdot mol^{-1} \cdot gm$

$mole_{nitrobenzene} := \frac{mass_{nitrobenzene}}{MW_{nitrobenzene}}$

$mole_{nitrobenzene} = 1.955 \cdot mol$

$$MW_{water} := (2 \cdot 1.00794 + 15.9994) \cdot gm \cdot mole^{-1}$$

$$MW_{water} = 18.015 \cdot gm \cdot mole^{-1}$$

$$mole_{water} := \frac{mass_{water}}{MW_{water}}$$

$$mole_{water} = 55.409 \cdot mol$$

Mole Fraction

$$X_{nitrobenzene} := \frac{mole_{nitrobenzene}}{mole_{nitrobenzene} + mole_{water}}$$

$$X_{nitrobenzene} = 0.034$$

$$X_{water} := \frac{mole_{water}}{mole_{nitrobenzene} + mole_{water}}$$

$$X_{water} = 0.966$$

b.Calculate the vapor pressure of each compound in the mixture

$$P_{nitrobenzene\_pure} := 55.1 \cdot Pa$$

$$P_{nitrobenzene\_mixture} := P_{nitrobenzene\_pure} \cdot X_{nitrobenzene}$$

$$P_{nitrobenzene\_mixture} = 1.878 \cdot Pa$$

$$P_{water\_pure} := 3167 \cdot Pa$$

$$P_{water\_mixture} := P_{water\_pure} \cdot X_{water}$$

$$P_{water\_mixture} = 3.059 \cdot 10^{3} \cdot Pa$$

c.Calculate the total vapor pressure of the mixture

$$P_{total} := P_{nitrobenzene\_mixture} + P_{water\_mixture}$$

$$P_{total} = 3.061 \cdot 10^{3} \cdot Pa$$

2.For a mixture prepared by mixing 5.00 g of caffeine (C8H10N4O2) with 250.0 mL of water. The final density of the mixture is 1.05 g mL^{-1}.

$mass_{caffeine} := 5.00 \cdot gm$

$MW_{caffeine} := (8 \cdot 12.0107 + 10 \cdot 1.00794 + 4 \cdot 14.00674 + 2 \cdot 15.9994) \cdot gm \cdot mole^{-1}$

$MW_{caffeine} = 194.191 \cdot gm \cdot mole^{-1}$

$$mole_{caffeine} := \frac{mass_{caffeine}}{MW_{caffeine}}$$

$mole_{caffeine} = 0.026 \cdot mol$

$V_{water} := 250.0 \cdot mL$

$\rho_{water} = 0.998 \cdot gm \cdot mL^{-1}$

$mass_{water} := V_{water} \cdot \rho_{water}$

$mass_{water} = 0.25 \cdot kg$

$\rho_{solution} := 1.05 \cdot gm \cdot mL^{-1}$

$$V_{solution} := \frac{mass_{water} + mass_{caffeine}}{\rho_{solution}}$$

$V_{solution} = 0.242 \cdot L$

$$M_{solution} := \frac{mole_{caffeine}}{V_{solution}} \qquad M_{solution} = 0.106 \cdot mole \cdot L^{-1}$$

$$m_{solution} := \frac{mole_{caffeine}}{mass_{water}} \qquad m_{solution} = 0.103 \cdot mol \cdot kg^{-1}$$

a.Calculate the boiling point of this mixture

$K_b := 0.512 \cdot K \cdot kg \cdot mole^{-1}$

$\Delta T_b := m_{solution} \cdot K_b$

$\Delta T_b = 0.053 \cdot K$

$T_{b\_pure} := 373.15 \cdot K$

$T_{b\_mixture} := T_{b\_pure} + \Delta T_b$

$T_{b\_mixture} = 373.203 \cdot K$

b.Calculate the vapor pressure of this mixture

$$mole_{water} := \frac{mass_{water}}{MW_{water}}$$

$mole_{water} = 13.852 \cdot mol$

$$X_{water} := \frac{mole_{water}}{mole_{water} + mole_{caffeine}}$$

$X_{water} = 0.998$

$P_{mixture} := X_{water} \cdot P_{water\_pure}$

$P_{mixture} = 3.161 \cdot 10^3 \cdot Pa$

c.Calculate the freezing point of this mixture

$K_f := 1.86 \cdot K \cdot kg \cdot mole^{-1}$

$\Delta T_f := m_{solution} \cdot K_f$

$\Delta T_f = 0.192 \cdot K$

$T_{f\_pure} := 273.15 \cdot K$

$T_{f\_mixture} := T_{f\_pure} - \Delta T_f$

$T_{f\_mixture} = 272.958 \cdot K$

d.Calculate the osmotic pressure of this mixture at 25 C.

$R := 8.314510 \cdot joule \cdot K^{-1} \cdot mole^{-1}$

$T := (273.15 + 25) \cdot K$

$\Pi := M_{solution} \cdot R \cdot T$

$\Pi = 2.633 \cdot 10^{5}\ kPa$

3.For a mixture prepared by mixing 10.0 g of sodium sulfate in 250 mL of water. The final density of the mixture is 1.10 g mL^{-1}.

$mass_{sodium\_sulfate} := 10.0 \cdot gm$

$MW_{sodium\_sulfate} := (2 \cdot 22.989770 + 32.066 + 4 \cdot 15.9994) \cdot gm \cdot mole^{-1}$

$mole_{sodium\_sulfate} := \frac{mass_{sodium\_sulfate}}{MW_{sodium\_sulfate}}$

$mole_{sodium\_sulfate} = 0.07 \cdot mol$

$mass_{water} = 0.25 \cdot kg$

$\rho_{solution} := 1.10 \cdot gm \cdot mL^{-1}$

$V_{solution} := \frac{mass_{water} + mass_{sodium\_sulfate}}{\rho_{solution}}$

$V_{solution} = 0.236\ L$

$M_{solution} := \frac{3 \cdot mole_{sodium\_sulfate}}{V_{solution}}$ $\quad M_{solution} = 0.895\ mole \cdot L^{-1}$

$m_{solution} := \frac{3 \cdot mole_{sodium\_sulfate}}{mass_{water}}$ $\quad m_{solution} = 0.846\ mol \cdot kg^{-1}$

NOTE: Multiply moles by 3, because sodium sulfate is a salt that dissociates into three ions (Na_2SO_4 -> $2Na^{1+} + SO_4^{2-}$) in water

a.Calculate the boiling point of this mixture

$K_b := 0.512 \cdot K \cdot kg \cdot mole^{-1}$

$\Delta T_b := m_{solution} \cdot K_b$

$\Delta T_b = 0.433 \cdot K$

$T_{b\_pure} := 373.15 \cdot K$

$T_{b\_mixture} := T_{b\_pure} + \Delta T_b$

$T_{b\_mixture} = 373.583 \cdot K$

b.Calculate the vapor pressure of this mixture

$$mole_{water} := \frac{mass_{water}}{MW_{water}}$$

$mole_{water} = 13.852 \cdot mol$

$$X_{water} := \frac{mole_{water}}{mole_{water} + mole_{sodium\_sulfate}}$$

$X_{water} = 0.995$

$P_{mixture} := X_{water} \cdot P_{water\_pure}$

$P_{mixture} = 3.151 \cdot 10^3 \cdot Pa$

c.Calculate the freezing point of this mixture

$K_f := 1.86 \cdot K \cdot kg \cdot mole^{-1}$

$\Delta T_f := m_{solution} \cdot K_f$

$\Delta T_f = 1.574 \cdot K$

$T_{f\_pure} := 273.15 \cdot K$

$T_{f\_mixture} := T_{f\_pure} - \Delta T_f$

$T_{f\_mixture} = 271.576 \cdot K$

d.Calculate the osmotic pressure of this mixture at 25 C.

$R := 8.314510 \cdot joule \cdot K^{-1} \cdot mole^{-1}$

$T := (273.15 + 25) \cdot K$

$\Pi := M_{solution} \cdot R \cdot T$

$\Pi = 2.219 \cdot 10^{6}\ kPa$

4.You are examining forensics data for a court case and need to identify an anelgesic (pain killer). It could be either acetylsalicylic acid (asprin), ibuprofen (advil) or acetaminophen (tylenol). A mixture of the unknown is prepared by mixing 10.0 grams of unknown and diluting to 250 mL with ethanol. The density of this solution is 0.80 g mL-1. Identify the unknown based upon the following:

a.The boiling point of this mixture is 78.8 °C.

b.The osmotic pressure of this mixture is 480 Pa at 25 °C.

Boiling Point Elevation:

$BP_{ethanol} := (273.15 + 78.5) \cdot K$

$BP_{mixture} := (273.15 + 78.8) \cdot K$

$\Delta T := BP_{mixture} - BP_{ethanol}$ $\Delta T = 0.3 \cdot K$

$\Delta T = m \cdot K_b$

$K_b := 1.22 \cdot K \cdot kg \cdot mole^{-1}$

$m_{mixture} := \frac{\Delta T}{K_b}$ $m_{mixture} = 0.246 \cdot mol \cdot kg^{-1}$

$mass_{mixture} := 250 \cdot mL \cdot 0.80 \cdot gm \cdot mL^{-1}$ $mass_{mixture} = 0.2 \cdot kg$

$mass_{unknown} := 10.0 \cdot gm$

$mass_{solvent} := mass_{mixture} - mass_{unknown}$

$mole_{unknown} := m_{mixture} \cdot mass_{solvent}$ $mole_{unknown} = 0.047 \cdot mol$

$MW_{unknown} := \frac{mass_{unknown}}{mole_{unknown}}$

$MW_{unknown} = 214.035\ gm \cdot mole^{-1}$

Osmotic Pressure:

$\Pi := 480400 \cdot Pa$

$T := (273.15 + 25) \cdot K$

$R := 8.31415 \cdot joule \cdot K^{-1} \cdot mole^{-1}$

$\Pi = C \cdot R \cdot T$

$C_{unknown} := \frac{\Pi}{R \cdot T}$

$C_{unknown} = 193.798 \cdot m^{-3} \cdot mol$

$C_{unknown} = 0.194 \cdot mol \cdot liter^{-1}$

$V_{mixture} := 250 \cdot mL$

$mole_{unknown} := C_{unknown} \cdot V_{mixture}$

$mole_{unknown} = 0.048 \cdot mol$

$MW_{unknown} := \frac{mass_{unknown}}{mole_{unknown}}$

$MW_{unknown} = 206.4 \cdot gm \cdot mole^{-1}$