# Worksheet: Solutions and Colligative Properties

Set A:

1) $[Al^{3+}] = \frac{0.165 \text{ mol } AlCl_3}{0.820 \text{ L}} \times \frac{1 \text{ mol } Al^{3+}}{1 \text{ mol } AlCl_3} = 0.201 \text{ M } Al^{3+}$

$[Cl^-] = \frac{0.165 \text{ mol } AlCl_3}{0.820 \text{ L}} \times \frac{3 \text{ mol } Cl^-}{1 \text{ mol } AlCl_3} = 0.603 \text{ M } Cl^-$

2) $M_{H^+} = \frac{0.027 \text{ L} \times \frac{.025 \text{ mol } HNO_3}{\text{L}} \times \frac{1 \text{ mol } H^+}{1 \text{ mol } HNO_3}}{0.027 \text{ L} + 0.036 \text{ L}} = 0.11 \text{ M } H^+$

$M_{Ca^{2+}} = \frac{0.036 \text{ L} \times \frac{0.42 \text{ mol } Ca(NO_3)_2}{\text{L}} \times \frac{1 \text{ mol } Ca^{2+}}{1 \text{ mol } Ca(NO_3)_2}}{0.027 \text{ L} + 0.036 \text{ L}}$

$= 0.24 \text{ M } Ca^{2+}$

$NO_3^-$ mol from $HNO_3 = .027 \text{ L} \times \frac{.25 \text{ mol } HNO_3}{\text{L soln}} \times \frac{1 \text{ mol } NO_3^-}{1 \text{ mol } HNO_3} = 6.8 \times 10^{-3} \text{ mol } NO_3^-$

$NO_3^-$ mol from $Ca(NO_3)_2 = 0.036 \text{ L} \times \frac{0.42 \text{ mol } Ca(NO_3)_2}{\text{L}} \times \frac{2 \text{ mol } NO_3^-}{1 \text{ mol } Ca(NO_3)_2}$

$= 3.0 \times 10^{-2} \text{ mol } NO_3^-$

$M_{NO_3^-} = \frac{(6.8 \times 10^{-3} + 3.0 \times 10^{-2}) \text{ mol } NO_3^-}{0.027 \text{ L} + 0.036 \text{ L}} = 0.58 \text{ M } NO_3^-$

3)

mol $K_2SO_4$

$$0.035\,L \times \frac{0.42\,mol\,K_2SO_4}{L} = 0.015\,mol\,K_2SO_4$$

mol $K_3PO_4$

$$0.027\,L \times \frac{0.17\,mol\,K_3PO_4}{L} = 4.6 \times 10^{-3}\,mol\,K_3PO_4$$

$$M_{SO_4^{2-}} = \frac{0.015\,mol\,K_2SO_4 \times \frac{1\,mol\,SO_4^{2-}}{1\,mol\,K_2SO_4}}{0.035\,L + 0.027\,L} = .24M\,SO_4^{2-}$$

$$M_{PO_4^{3-}} = \frac{4.6 \times 10^{-3}\,mol\,K_3PO_4 \times \frac{1\,mol\,PO_4^{3-}}{1\,mol\,K_3PO_4}}{0.035\,L + 0.027\,L} = 0.074M\,PO_4^{3-}$$

$$M_{K+} = \frac{\left(.015\,mol\,K_2SO_4 \times \frac{2\,mol\,K^+}{1\,mol\,K_2SO_4}\right) + \left(4.6 \times 10^{-3}\,mol\,K_3PO_4 \times \frac{3\,mol\,K^+}{1\,mol\,K_3PO_4}\right)}{0.035\,L + 0.027\,L}$$

$$= 0.71M\,K+$$

4) $Al(OH)_3(s) + 3HNO_3 \rightarrow 3H_2O + Al(NO_3)_3(aq)$

Total: $Al(OH)_3(s) + 3H^+ + 3NO_3^- \rightarrow 3H_2O + Al^{3+} + 3NO_3^-$

Initial mols, ions

$H^+$: $0.0500\,L \times 2.5\ \frac{mol\ HNO_3}{L} \times \frac{1\ mol\ H^+}{1\ mol\ HNO_3} = 0.13\ mol\ H^+$

$NO_3^-$: $0.0500\,L \times 2.5\ \frac{mol\ HNO_3}{L} \times \frac{1\ mol\ NO_3^-}{1\ mol\ HNO_3} = 0.13\ mol\ NO_3^-$

LR Calc:

$.300\ mol\ Al(OH)_3 \times \frac{1\ mol\ Al^{3+}}{1\ mol\ Al(OH)_3} = 0.300\ mol\ Al^{3+}$

$.13\ mol\ H^+$, initial $\times \frac{1\ mol\ Al^{3+}}{3\ mol\ H^+} = 0.042\ mol\ Al^{3+}$

↕ compare

↑ Lesser amt is produced

xs g $Al(OH)_3$

$$mol\ Al(OH)_3\ xs = .300\ mol\ Al(OH)_3\ (ini) - \left(.042\ mol\ Al^{3+} \times \frac{1\ mol\ Al(OH)_3}{1\ mol\ Al^{3+}}\right)$$

$$= .258\ mol\ Al(OH)_3\ xs$$

$$g\ Al(OH)_3\ xs = .258\ mol\ Al(OH)_3\ xs \times \frac{78.0\ g\ Al(OH)_3}{1\ mol}$$

$$= 20.2\ g\ Al(OH)_3\ xs$$

M ions after rxn:

$M_{NO_3^-} = \frac{0.13\ mol\ NO_3^-}{0.0500\ L} = 2.5\ M\ NO_3$ $\quad M_{H^+} = \emptyset$ (LR)

$M_{Al^{3+}} = \frac{0.042\ mol\ Al^{3+}}{0.0500\ L} = 0.83\ M$

5) $\text{mol}_{\text{Benzene}} = \frac{3.88\text{ g Benzene}}{78.0\text{ g/mol}} = 0.0497\text{ mol Benzene}$

$\text{mol}_{\text{Toluene}} = \frac{2.45\text{ g Toluene}}{92.0\text{ g/mol}} = 0.0266\text{ mol Toluene}$

$P_{\text{Total}} = P_{\text{Benzene}} + P_{\text{Toluene}}$

$= \chi_{\text{Benz}} P^{\circ}_{\text{Benzene}} + \chi_{\text{Tolu}} P^{\circ}_{\text{Toluene}}$

$= \frac{.0497\text{ mol Benz}}{(.0497+.0266)\text{ mol}_{\text{Total}}}(75\text{ torr}) + \frac{.0266\text{ mol Tol}}{(.0497+.0266)\text{ mol}_{\text{Tot}}}(22\text{ torr})$

$P_{\text{Total}} = 57\text{ torr}$

$\chi_{\text{Benzene in vapor}} = \frac{P_{\text{Benzene}}}{P_{\text{Total}}} = \frac{49\text{ torr}}{57\text{ torr}} = 0.86$

6) $\Delta T_f = i K_f m_{\text{glucose}}$

$0-(-10.3)^{\circ}\text{C} = (1)\left(1.86\ \frac{^{\circ}\text{C}}{m}\right)(m_{\text{glucose}})$

$m_{\text{glucose}} = 5.54\ m_{\text{glucose}} = \frac{5.54\text{ mol Glucose}}{1\text{ Kg } H_2O}$

$g_{\text{Glucose}} = 5.54\text{ mol Glucose} \times \frac{180.0\text{ g Glucose}}{1\text{ mol}}$

$= 997\text{ g Glucose}$

$g_{\text{soln}} = 1000\text{ g } H_2O + 997\text{ g Glucose} = 1997\text{ g soln}$

$\text{Vol}_{\text{soln}} = 1997\text{ g soln} \times \frac{1\text{ mL soln}}{1.50\text{ g soln}} = 1331\text{ mL soln}$

$M_{\text{Glucose}} = \frac{5.54\text{ mol Glucose}}{1.331\text{ L soln}} = 4.16\text{ M Glucose}$

set A

7) $2.70 \text{ mol KBr} \times \frac{119 \text{ g KBr}}{1 \text{ mol}} = 321 \text{ g KBr}$ in 1000 mL soln

$1000 \text{ mL soln} \times \frac{1.80 \text{ g soln}}{1 \text{ mL soln}} = 1.80 \times 10^3 \text{ g soln}$

<u>g $H_2O$ :</u>

$1800 \text{ g soln} - 321 \text{ g KBr} = 1479 \text{ g } H_2O$

$= 1.47 \text{ kg } H_2O$

$m_{H_2O} = \frac{2.70 \text{ mol KBr}}{1.47 \text{ kg } H_2O} = \frac{1.83 \text{ mol KBr}}{1 \text{ kg } H_2O}$

$\Delta T_b = i K_b m$

$= (2)\left(.512 \frac{^\circ C}{m}\right)(1.83 \text{ m KBr})$

$= 1.87^\circ C$

$BP = 100^\circ C + 1.87^\circ C = 101.9^\circ C$

Set A

8) $2\,K_2CO_3(aq) + 2\,CoCl_3(aq) \rightarrow 6\,KCl(aq) + Co_2(CO_3)_3(s)$

$6\,K^+ + 2\,CO_3^{2-} + 2\,Co^{3+} + 6\,Cl^- \rightarrow 6\,K^+ + 6\,Cl^- + Co_2(CO_3)_3(s)$

Initial mols, ions

$K^+$: $0.02800\,L \times \frac{0.670\,mol\,K_2CO_3}{L\,soln} \times \frac{2\,mol\,K^+}{1\,mol\,K_2CO_3} = 0.0375\,mol\,K^+$

$CO_3^{2-}$: $0.02800\,L \times \frac{0.670\,mol\,K_2CO_3}{L\,soln} \times \frac{1\,mol\,CO_3^{2-}}{1\,mol\,K_2CO_3} = 0.0188\,mol\,CO_3^{2-}$

$Co^{3+}$: $0.01500\,L \times \frac{0.940\,mol\,CoCl_3}{L\,soln} \times \frac{1\,mol\,Co^{3+}}{1\,mol\,CoCl_3} = 0.0141\,mol\,Co^{3+}$

$Cl^-$: $0.01500\,L \times \frac{.940\,mol\,CoCl_3}{L\,soln} \times \frac{3\,mol\,Cl^-}{1\,mol\,CoCl_3} = 0.0423\,mol\,Cl^-$

LR calc:

$0.0188\,mol\,CO_3^{2-} \times \frac{1\,mol\,Co_2(CO_3)_3}{3\,mol\,CO_3^{2-}} = 0.00627\,mol\,Co_2(CO_3)_3$ ← Lesser amt made

$0.0141\,mol\,Co^{3+} \times \frac{1\,mol\,Co_2(CO_3)_3}{2\,mol\,Co^{3+}} = 0.00705\,mol\,Co_2(CO_3)_3$ ↕ compare

$0.00627\,mol\,Co_2(CO_3)_3 \times \frac{297.8\,g\,Co_2(CO_3)_3}{1\,mol} = 1.87\,g\,Co_2(CO_3)_3\,ppt$

M ions after rxn

spectator ions: $M_{K^+} = \frac{0.0375\,mol\,K^+}{.02800\,L + .01500\,L} = 0.874M\ K^+$

$M_{Cl^-} = \frac{0.0423\,mol\,Cl^-}{.02800\,L + .01500\,L} = 0.986\ Cl^-$

LR: $M_{CO_3^{2-}} = 0$

$$xs\ Co^{3+} = \frac{0.0141\,mol\,Co^{3+} - \left(.00627\,mol\,Co_2(CO_3)_3 \times \frac{2\,mol\,Co^{3+}}{1\,mol\,Co_2(CO_3)_3}\right)}{0.02800\,L + 0.01500\,L}$$

$= 0.0363M\ Co^{3+}$

Set B

1) $\Delta T_f = i K_f m$

$(5.5 - 3.5)^\circ C = (1)\left(4.96 \frac{^\circ C}{m}\right) m_{solute}$

$m_{solute} = 0.383 \frac{mol\ solute}{Kg\ Benzene}$

$0.400 Kg\ Benzene \times \frac{0.383\ mol\ Solute}{Kg\ Benzene} = 0.153 mol\ solute$

$Molar\ mass = \frac{12.6 g\ Solute}{.153\ mol} = 82\ g/mol$

↑ 2 s.f. due to the $\Delta T_f$

2) Soln boils at 0.255 atm $\therefore P_{Total} = .255$ atm

$P_{Total} = \chi_{methanol} P^\circ_{methanol} + \chi_{chloroform} P^\circ_{chloroform}$

$0.255 atm = \chi_{methanol}(.192 atm) + (1 - \chi_{methanol})(.311 atm$

$\chi_{methanol} = 0.476$

$\chi_{chloroform} = 1 - .476 = 0.524$

3) a) $m_{CaI_2}$ calc: 1 L soln

$g\ soln = 1000 mL\ soln \times \frac{1.92 g\ soln}{1 mL\ soln} = 1920 g\ soln$

$g\ CaI_2 = 1.21 mol\ CaI_2 \times \frac{294 g\ CaI_2}{1 mol} = 356 g\ CaI_2$ (in 1 L soln)

$g\ H_2O = 1920 g\ soln - 356 g\ CaI_2$

$= 1564 g\ H_2O$ (in 1 L soln)

$m_{CaI_2} = \frac{1.21\ mol\ CaI_2}{1.564\ Kg\ H_2O} = 0.774 \frac{mol\ CaI_2}{Kg\ H_2O}$

b) $\Delta T_b = i K_b m$

$= (3)\left(.512 \frac{^\circ C}{m}\right)(.774 m_{CaI_2}) = 1.2^\circ C$

$Boiling\ Point = 100^\circ C + 1.2^\circ C$

$= 101.2^\circ C$

4. $\frac{36.0\ g\ Na_3PO_4}{100\ g\ soln}$

a) $m_{Na_3PO_4} = \dfrac{36.0\ g\ Na_3PO_4 \times \frac{1\ mol\ Na_3PO_4}{164\ g\ Na_3PO_4}}{(100\ g - 36.0\ g)\ g\ H_2O \times \frac{1\ kg}{1\ g}}$

$= 3.43\ m\ Na_3PO_4$

b) $\Delta T_f = i\ K_f\ m$

$= (4)\left(1.86\ \frac{^\circ C}{m}\right)\ 3.43\ m\ Na_3PO_4$

$= 25.5^\circ C$

$T_f = 0 - 25.5^\circ C = -25.5^\circ C$

5) Set B

$2\,Al(NO_3)_3(aq) + 3\,Na_2CO_3(aq) \rightarrow Al_2(CO_3)_3(s) + 6\,NaNO_3(aq)$

$2\,Al^{3+} + 6\,NO_3^- + 6\,Na^+ + 3\,CO_3^{2-} \rightarrow Al_2(CO_3)_3(s) + 6\,Na^+ + 6\,NO_3^-$

Initial mol, ions

$Al^{3+}$: $0.03200\,L \times 0.311\,\frac{mol\ Al(NO_3)_3}{L} \times \frac{1\ mol\ Al^{3+}}{1\ mol\ Al(NO_3)_3} = 9.95 \times 10^{-3}\ mol\ Al^{3+}$

$NO_3^-$: $0.03200\,L \times 0.311\,\frac{mol\ Al(NO_3)_3}{L} \times \frac{3\ mol\ NO_3^-}{1\ mol\ Al(NO_3)_3} = 0.0299\ mol\ NO_3^-$

$Na^+$: $0.06400\,L \times 0.177\,\frac{mol\ Na_2CO_3}{L} \times \frac{2\ mol\ Na^+}{1\ mol\ Na_2CO_3} = 0.0227\ mol\ Na^+$

$CO_3^{2-}$: $0.06400\,L \times 0.177\,\frac{mol\ Na_2CO_3}{L} \times \frac{1\ mol\ CO_3^{2-}}{1\ mol\ Na_2CO_3} = 0.0113\ mol\ CO_3^{2-}$

LR Calc

$9.95 \times 10^{-3}\ mol\ Al^{3+} \times \frac{1\ mol\ Al_2(CO_3)_3}{2\ mol\ Al^{3+}} = 4.98 \times 10^{-3}\ mol\ Al_2(CO_3)_3$

$0.0113\ mol\ CO_3^{2-} \times \frac{1\ mol\ Al_2(CO_3)_3}{3\ mol\ CO_3^{2-}} = 3.77 \times 10^{-3}\ mol\ Al_2(CO_3)_3$ ← Lesser amt.

$\therefore Al^{3+} = xs$
& $CO_3^{2-} = LR$

$3.77 \times 10^{-3}\ mol\ Al_2(CO_3)_3 \times \frac{234\ g\ Al_2(CO_3)_3}{mol} = 0.881\ g\ Al_2(CO_3)_3$ produced

xs reactant calc

$9.95 \times 10^{-3}\ mol\ Al^{3+}_{initial} - \left[3.77 \times 10^{-3}\ mol\ Al_2(CO_3)_3\ produced \times \frac{2\ mol\ Al^{3+}}{1\ mol\ Al_2(CO_3)_3}\right]$

$= 2.41 \times 10^{-3}\ mol\ Al^{3+}$, xs

$M_{CO_3^{2-}} = \emptyset$ (LR!)

$M_{Al^{3+}} = \frac{2.41 \times 10^{-3}\ mol\ Al^{3+}}{(.03200 + .06400)\,L} = 0.0251\ M\ Al^{3+}$

$M_{Na^+} = \frac{0.0227\ mol\ Na^+}{(.03200 + .06400)\,L} = 0.236\ M\ Na^+$

$M_{NO_3^-} = \frac{0.0299\ mol\ NO_3^-}{(.03200 + .06400)\,L} = 0.311\ M\ NO_3^-$

set C

1) $\Delta T_b = i K_b m$

a. $(101.40 - 100)^\circ C = (1)\ 0.512\ \frac{^\circ C}{m}\ m$

$$m_{C_6H_{12}O_6} = \frac{2.73\ mol\ C_6H_{12}O_6}{1\ kg\ H_2O}$$

b. $g\ C_6H_{12}O_6 = 2.73\ mol\ C_6H_{12}O_6 \times \frac{180.0\ g\ C_6H_{12}O_6}{1\ mol}$

$= 491\ g\ C_6H_{12}O_6$

c. $g\ soln = 491\ g\ C_6H_{12}O_6 + 1000\ g\ H_2O = 1491\ g\ C_6H_{12}O_6$

d. $Vol\ soln = 1491\ g\ C_6H_{12}O_6 \times \frac{1\ mL\ soln}{1.68\ g\ soln} = 888\ mL\ soln$

e. $M_{C_6H_{12}O_6} = \frac{2.73\ mol\ C_6H_{12}O_6}{0.888\ L\ soln} = 3.07\ M\ C_6H_{12}O_6$

2) a) $g\ C_{12}H_{22}O_{11} = 0.6837\ mol\ C_{12}H_{22}O_{11} \times \frac{342.2\ g\ C_{12}H_{22}O_{11}}{1\ mol}$

$= 234.0\ g\ C_{12}H_{22}O_{11}$

b. $g\ soln = 1000\ mL\ soln \times \left(\frac{1.35\ g\ soln}{1\ mL\ soln}\right) = 1350\ g\ soln$

c. $g\ H_2O = 1350\ g\ soln - 234.0\ g\ C_{12}O_{22}O_{11}$

$= 1116\ g\ H_2O$

d. $m_{C_{12}H_{22}O_{11}} = \frac{.6837\ mol\ C_{12}H_{22}O_{11}}{.1116\ kg\ H_2O} = .6126\ m\ C_{12}H_{22}O_{11}$

e. $\Delta T_f = i K_f m$

$= (1)\left(1.86\ \frac{^\circ C}{m}\right)(.6126\ m)$

$= 1.14^\circ C$

f. $T_f = (0 - 1.14)^\circ C = -1.14^\circ C$

3)

$$\text{moles}_{\text{Heptane}} = \frac{5.32\text{ g } C_7H_{16}}{100.1\text{ g/mol } C_7H_{16}} = .0531\text{ mol } C_7H_{16}$$

$$\text{moles}_{\text{octane}} = \frac{8.80\text{ g } C_8H_{18}}{114.2\text{ g/mol } C_8H_{18}} = 0.0771\text{ mol } C_8H_{18}$$

$$\text{Total Vapor Pressure} = P_{C_7H_{16}} + P_{C_8H_{18}}$$

$$\text{Total vapor Pressure} = \chi_{C_7H_{16}} P^{\circ}_{C_7H_{16}} + \chi_{C_8H_{18}} P^{\circ}_{C_8H_{18}}$$

$$= \left(\frac{.0531\text{ mol } C_7H_{16}}{.0771\text{ mol } C_8H_{18} + .0531\text{ mol } C_7H_{16}}\right).0522\text{ atm} + \left(\frac{.0771\text{ mol } C_8H_{18}}{.0771\text{ mol } C_8H_{18} + .0531\text{ mol } C_7H_{16}}\right).238\text{ atm}$$

$$= .213\text{ atm} + .141\text{ atm}$$

$$= .354\text{ atm total}$$

$$P_{C_8H_{18}} = \chi_{C_8H_{18}\text{ in vapor}} P_{\text{Total}}$$

$$.141\text{ atm} = \chi_{C_8H_{18}} (.354\text{ atm})$$

$$\chi_{C_8H_{18}} = .398$$

4) $\Delta T_f = i K_f m$

$$.307\,^{\circ}C = (1)\ 5.12\ \frac{^{\circ}C}{m}\ m_{\text{compd.}}$$

$$m_{\text{compd}} = 0.0600\ m\ \text{compd}$$

$$\text{mol compd} = 0.500\text{ Kg benzene} \times .0600\ \frac{\text{mol compd}}{\text{Kg benzene}}$$

$$= 0.0300\text{ mol compd}$$

$$\text{Molar mass}_{\text{compd}} = \frac{3.84\text{ g compd}}{0.0300\text{ mol compd}} = 128\ \frac{\text{g}}{\text{mol}}$$

$$\text{EF mass} = \left(4 \times 12.0\ \frac{\text{g}}{\text{mol}}\ C\right) + \left(2 \times 1.01\ \frac{\text{g}}{\text{mol}}\ H\right) + 14.0\ \frac{\text{g}}{\text{mol}}\ N$$

$$= 64.0\text{ g/mol } C_4H_2N$$

$$n = \frac{128\text{ g/mol compd}}{64.0\text{ g/mol } C_4H_2N} = 2$$

$$\therefore\quad 2 \times C_4H_2N = C_8H_4N_2$$

5) $P_{Total} = P_A + P_B$

$= \chi_A P^\circ_A + \chi_B P^\circ_B$

P at Normal Boiling Point

$1\,atm = \frac{.650\,mol\,A}{.650\,mol\,A + .250\,mol\,B}(.700\,atm) + \frac{.250\,mol\,B}{.650\,mol\,A + .250\,mol\,B}(P^\circ_B)$

$P^\circ_B = 1.72\,atm$

6) $\Pi = i\,M\,R\,T$

$\frac{12.7\,torr}{760\,torr/atm} = (1)\,M_{Protein}\left(.0821\,\frac{L\,atm}{mol\,K}\right)(273.1 + 25)\,K$

$M_{protein} = \frac{6.83 \times 10^{-4}\,mol\,Protein}{L\,soln}$

$moles_{protein} = .900\,L\,soln \times \frac{6.83 \times 10^{-4}\,mol\,Protein}{L\,soln}$

$= 6.15 \times 10^{-4}\,mol\,Protein$

$Molar\,mass_{protein} = \frac{30.0\,g\,Protein}{6.15 \times 10^{-4}\,mol\,Protein}$

$= 4.88 \times 10^4\,g/mol\,Protein$

Set C

7.

$$P_{Total} = \chi_{Acetone} P^{\circ}_{Acetone} + \chi_{methanol} P^{\circ}_{methanol}$$

$$.248\ atm = (1 - \chi_{meth})(.342\ atm) + \chi_{meth}(.188\ atm$$

Rem: $\chi_{Acetone} + \chi_{methanol} = 1$

$\chi_{Acetone} = 1 - \chi_{methanol}$

$$\chi_{methanol} = 0.610$$