Mole fraction, molality, weight percent

Suppose you add 1.2 kg of ethylene glycol, $HOCH_2CH_2OH$, as antifreeze to 4.0 kg of water in the radiator of your car. What are the mole fraction, molality and weight percent of ethylene glycol?

- $1200\ g\ EG \times \frac{1\ mol}{62.07\ g} = 19\ mol\ EG$ $\quad 4.0\times10^3\ g\ H_2O \times \frac{1\ mol}{18.015\ g} = 2.2\times10^2\ mol\ H_2O$
- Mole fraction: $\frac{19\ mol\ EG}{19\ mol\ EG + 220\ mol\ H_2O} = 0.080$
- Molality: $\frac{19\ mol\ EG}{4.0\ kg\ H_2O} = 4.7\ m$
- Weight percent: $\frac{1.2\ kg\ EG}{1.2\ kg\ EG + 4.0\ kg\ H_2O} \times 100 = 23\%$

Enthalpy of solution from ΔH_f data

- Another way to calculate enthalpy of solution
- Consider the process of dissolving NaCl (s) in water
- NaCl (s) → NaCl (aq) $\Delta H_{solution}$
- Na (s) + ½ Cl_2 (g) → NaCl (s) $\Delta H_f = -411.1$ kJ **flip**
- Na (s) + ½ Cl_2 (g) → NaCl (aq) $\Delta H_f = -407.3$ kJ **keep**
- $\Delta H_{solution} = -407.3 \text{ kJ} - (-411.1 \text{ kJ}) = +3.8 \text{ kJ}$

Henry's law

What is the concentration of O_2 (in g O_2 per kg of water) in a freshwater stream in equilibrium with air at 25 ˚C and at a pressure of 1.0 bar? The mole fraction of O_2 in air is 0.21. For O_2 at 25 ˚C, k_H = 1.3 x 10^{-3} mol kg^{-1} bar^{-1}.

- $P_{O2} = P_{total} x_{O2}$ = (1.0 bar)(0.21) = 0.21 bar
- $S_g = k_H P_g = \frac{1.3\times10^{-3} mol}{kg \times bar} \times 0.21\ bar = 2.7\times10^{-4} mol\ kg^{-1}$
- $\frac{2.7\times10^{-4}\ mol\ O_2}{1\ kg\ H_2O} \times \frac{31.9988\ g}{1\ mol\ O_2} = \mathbf{0.0087\ g\ O_2\ dissolve\ in\ 1\ kg\ water}$

Raoult's law

You dissolve 651 g of ethylene glycol, $HOCH_2CH_2OH$, in 1.50 kg of water. What is the vapor pressure of the water over the solution at 90 ˚C? Assume ideal behavior for the solution. The vapor pressure of pure water at 90 ˚C is 525.8 torr.

- 651 g EG = 10.5 mol EG   1.50 kg H_2O = 83.3 mol H_2O
- Mole fraction of H_2O = 0.888
- $P_{H2O} = P^{\circ}_{H2O} x_{H2O}$ = (525.8 torr)(0.888) = **467 torr**

Raoult's law

Glycerin ($C_3H_8O_3$) is a nonvolatile nonelectrolyte with a density of 1.26 g/mL at 25 ˚C. Calculate the vapor pressure at 25 ˚C of a solution made by adding 50.0 mL of glycerin to 500.0 mL of water. The vapor pressure of pure water at 25 ˚C is 23.8 torr and its density is 1.00 g/mL.

- $50.0\ mL\ C_3H_8O_3 \times \frac{1.26\ g}{1\ mL} \times \frac{1\ mol}{92.09382\ g} = 0.684\ mol\ C_3H_8O_3$
- $500.0\ mL\ H_2O \times \frac{1.00\ g}{1\ mL} \times \frac{1\ mol}{18.015\ g} = 27.7\ mol\ H_2O$
- $x_{H_2O} = \frac{27.7\ mol\ H_2O}{27.7\ mol\ H_2O + 0.684\ mol\ C_3H_8O_3} = 0.976$
- $\boldsymbol{P_{H_2O}} = x_{H_2O} P^{\circ}{}_{H_2O} = (0.976)(23.8\ torr) = \boldsymbol{23.2\ torr}$

Raoult's law (2 volatile components)

The vapor pressure of pure benzene (C_6H_6) and pure toluene ($C_6H_5CH_3$) at 25 ˚C are 95.1 torr and 28.4 torr, respectively. A solution is prepared in which the mole fractions of both benzene and toluene are 0.500.

a) What are the partial pressures of benzene and toluene above the solution? What is the total vapor pressure?

b) What are the mole fractions of benzene and toluene in the vapor phase?

- $\mathbf{P_{benzene}}$ = (95.1 torr)(0.500) = **47.5 torr**
- $\mathbf{P_{toluene}}$ = (28.4 torr)(0.500) = **14.2 torr**
- $\mathbf{P_{total}}$ = $P_{benzene}$ + $P_{toluene}$ = 47.5 torr + 14.2 torr = **61.7 torr**
- $\boldsymbol{x_{benzene}} = \frac{P_{benzene}}{P_{total}} = \frac{47.5\ torr}{61.7\ torr} = \mathbf{0.770}$
- $\boldsymbol{x_{toluene}} = \frac{P_{toluene}}{P_{total}} = \frac{14.2\ torr}{61.7\ torr} = \mathbf{0.230}$

Boiling point elevation

Eugenol, a compound found in nutmeg and cloves, has the formula $C_{10}H_{12}O_2$. What is the boiling point of a solution containing 0.144 g of this compound dissolved in 10.0 g of benzene?

- $\Delta T_{bp} = K_{bp}mi$
- For eugenol, $i = 1$
- 0.144 g eugenol = 8.77×10^{-4} mol
- $\frac{8.77\times10^{-4}\ mol}{0.0100\ kg} = 0.0877\ m$
- $\Delta T_{bp} = (2.53\ ^\circ C\ m^{-1})(0.0877\ m) = 0.222\ ^\circ C$
- BP = 80.1 ˚C + 0.222 ˚C = **80.3 ˚C**

Freezing point depression (electrolyte)

If 52.5 g of LiF is dissolved in 306 g of water, what is the expected freezing point of this solution?

- $\Delta T_{fp} = K_{fp}mi$
- 52.5 g LiF = 2.02 mol
- $\frac{2.02\ mol}{0.306\ kg} = 6.61\ m$
- $\Delta T_{fp} = (1.86\ ^{\circ}C\ m^{-1})(6.61\ m)(2)$
- $\Delta T_{fp} = 24.6\ ^{\circ}C$
- FP = 0 ˚C – 24.6 ˚C = –24.6 ˚C

Osmotic pressure

Beta-carotene is the most important of the A vitamins. Calculate the molar mass of β-carotene if 10.0 mL of a solution containing 7.68 mg of β-carotene has an osmotic pressure of 26.57 torr at 25.0 ˚C.

- Π = cRT
- 26.57 torr = c(62.36 L torr mol^{-1} K^{-1})(298.15 K)
- C = 1.429 x 10^{-3} M
- $\frac{1.429\times10^{-3}\ mol}{L}\times 0.0100\ L = 1.43\times10^{-5}\ mol\ \beta - carotene$
- $\frac{0.00768\ g}{1.43\times10^{-5}\ mol} = \mathbf{537\ g/mol}$