Recitation 2 Colligative Properties Name:______________________

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Piece #1 What is the Normal Boiling Point of ethanol (in kelvins)?

78.3 ºC

Piece #2 What is the enthalpy of vaporization of ethanol at its normal boiling point?

38,560 J/mol

Puzzle #1 What would the boiling point of ethanol be at the top of Mt. Everest where the average atmospheric pressure is 0.64 atm?

Clausius Clapeyron:

$$\ln\left(\frac{P_1}{P_2}\right) = \frac{-\Delta H_{vap}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

Lots of variables, but we know most of them:

We know the normal boiling point which is the boiling point at 1 atm, so:

P_1=1 atm

T_1=78.3ºC

ΔH_{vap} = 38,560 J/mol

R=8.314 J/mol K

P_2 = 0.64 atm at top of Everest

T_2 = ? Boiling point at 0.64 atm.

T_2 is the only thing we don't know.

As always, be careful of UNITS! UNITS! UNITS!

T must be in Kelvins

$$\ln\left(\frac{P_1}{P_2}\right) = \frac{-\Delta H_{vap}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$\ln\left(\frac{1\ atm}{0.64\ atm}\right) = \frac{-38{,}560\,\frac{J}{mol}}{8.314\,\frac{J}{molK}}\left(\frac{1}{(78.3 + 273.15\ K} - \frac{1}{T_2}\right)$$

We just need to solve for T_2:

$$0.4463 = -4638\left(\frac{1}{351.45} - \frac{1}{T_2}\right)$$

$$-9.622 \times 10^{-5} = \left(0.002845 - \frac{1}{T_2}\right)$$

$$-0.002941 = -\frac{1}{T_2}$$

$$T_2 = 340$$

Which makes sense. 340<351. So, when the pressure went down, so did the boiling point.

Puzzle #2 I want ethanol to boil at room temperature (298 K). What would I need to reduce the pressure to in order to accomplish this?

Clausius Clapeyron again!

$$\ln\left(\frac{P_1}{P_2}\right) = \frac{-\Delta H_{vap}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

P_1=1 atm

T_1=78.3ºC

ΔH_{vap} = 38,560 J/mol

R=8.314 J/mol K

P_2 = ? I don't know

T_2 = 298 K (my desired boiling point)

$$\ln\left(\frac{1\ atm}{x\ atm}\right) = \frac{-38{,}560\,\frac{J}{mol}}{8.314\,\frac{J}{molK}}\left(\frac{1}{(78.3 + 273.15\ K} - \frac{1}{298\ K}\right)$$

$$\ln\left(\frac{1}{x}\right) = -4638\ K^{-1}(0.002845 - 0.003356) = 3.316$$

$$\ln\left(\frac{1}{x}\right) = 2.37$$

$$e^{\ln\left(\frac{1}{x}\right)} = e^{2.37}$$

$$\frac{1}{x} = 10.70$$

$$x = 0.0946\ atm$$

Piece #1 What is the cryoscopic constant for water?

K_f = 1.86 ºC/molal

Piece #2 What is the cryoscopic constant for ethanol?

K_f = 1.99

Piece #3 What is the molar mass of water?

H_2O

2x1.008 g/mol + 16.00 g/mol = 18.02 g/mol

Piece #4 What is the molar mass of ethanol?

C_2H_5OH

2x12.011 g/mol + 6x1.008 g/mol + 1x16.00 g/mol = 46.07 g/mol

Piece #5 What is the density of water at 298 K?

1.0 g/mL at 277 K
0.99704 at 298 K (Wikipedia)

Piece #6 What is the density of ethanol at 298 K?

0.789 g/mL at 298 K

Piece #7 What is the freezing point of pure ethanol?

-114.1 ºC (159.05 K)

Piece #8 What is the freezing point of pure water?

0ºC

Piece #9 What is the mass (in g) of 10.00 mL of ethanol?

$$10.00\ mL\frac{0.789\ g}{mL} = 7.89\ g$$

Piece #10 What is the mass (in g) of 100.00 mL of water?

$$100.00\ mL\frac{0.997\ g}{mL} = 99.7\ g$$

Piece #11 How many moles is 10.0 mL of ethanol?

$$7.89\ g\,\frac{1\ mol}{46.07\ g} = 0.171\ mol$$

Piece #12 How many moles is 100.0 mL of water?

$$100.00\ mL\,\frac{0.997\ g}{mL} = 99.7\ g\,\frac{1\ mol}{18.02\ g} = 5.533\ mol$$

Piece #13 What are the UNITS! UNITS! UNITS! of Molarity?

$$\frac{mol\ solute}{L\ solution}$$

Piece #14 What are the UNITS! UNITS! UNITS! of molality?

$$\frac{mol\ solute}{kg\ solvent}$$

Piece #15 I add 10.0 mL of ethanol to 100.0 mL of water. What is the volume of the solution?

Volume adds (mostly)

100.0 mL + 10.0 mL = 110. 0 mL

Piece #16 I add 10.0 mL of ethanol to 100.0 mL of water. What is the mass of the solution?

Mass adds (always)

99.7 g + 7.89 g = 107.59 g

Piece #17 I add 10.0 mL of ethanol to 100.0 mL of water. What is the Molarity of the solution?

$$M = \frac{mol\ solute}{L\ solution} = \frac{mol\ ethanol}{L\ ethanol + water} = \frac{0.171\ mol\ eth}{0.110\ L\ total} = 1.555\ M$$

Piece #18 I add 10.0 mL of ethanol to 100.0 mL of water. What is the molality of the solution?

$$molality = \frac{mol\ solute}{kg\ solvent} = \frac{mol\ ethanol}{kg\ water} = \frac{0.171\ mol\ eth}{0.0997\ kg\ water} = 1.715\ molal$$

Puzzle #3 I add 10.0 mL of ethanol to 100.0 mL of water.   What is the freezing point of the solution?

$$\Delta T_f = -iK_f m$$

Ethanol is covalent so i should be “1”.

$$\Delta T_f = -iK_f m = -(1)\left(1.86\frac{℃}{molal}\right)(1.715\ molal) = -3.19℃$$

$$\Delta T_f = T_{f,solution} - T_{f,water} = T_{f,solution} - 0℃ = -3.19℃$$

$$T_{f,solution} - 0℃ = -3.19℃$$

$$T_{f,solution} = -3.19℃$$

Puzzle #4 I add 10.0 mL of water to 100.0 mL of ethanol. What is the freezing point of the solution?

Now, the ethanol is the solvent and the water is the solute.

Water is also covalent, so K_f should still be “1”

$$molality = \frac{mol\ water}{kg\ ethanol}$$

$$10.00\ mL\ water \frac{0.997\ g\ water}{mL\ water} \frac{1\ mol}{18.02\ g} = 0.553\ mol\ water$$

$$100.0\ mL\ ethanol \frac{0.789\ g}{mL} \frac{1\ kg}{1000\ g} = 0.0789\ kg$$

$$molality = \frac{mol\ water}{kg\ ethanol} = \frac{0.553\ mol\ water}{0.0789\ kg\ eth} = 7.009\ molal$$

$$\Delta T_f = -iK_f m = -(1)\left(1.99 \frac{℃}{molal}\right)(7.009\ molal) = -13.95℃$$

$$\Delta T_f = T_{f,solution} - T_{f,ethanol} = T_{f,solution} - (-114.1℃) = -13.95℃$$

$$T_{f,solution} - (-114.1℃) = -13.95℃$$

$$T_{f,solution} = -128℃$$

Puzzle #5 Instead of ethanol in Puzzle #3, I use the exact same number of moles of NaCl. What is the freezing point of the solution?

The molality of the solution will stay the same BUT i=1.9 for NaCl.

$$\Delta T_f = -iK_f m = -(1.9)\left(1.86\frac{°\mathrm{C}}{molal}\right)(1.715\ molal) = -6.06°\mathrm{C}$$

$$\Delta T_f = T_{f,solution} - T_{f,water} = T_{f,solution} - 0°\mathrm{C} = -6.06°\mathrm{C}$$

$$T_{f,solution} - 0°\mathrm{C} = -6.06°\mathrm{C}$$

$$T_{f,solution} = -6.06°\mathrm{C}$$

Puzzle #6 I want to make an ethanol/water solution that has a freezing point of 263 K. How many mL of ethanol should I add to 100.0 mL of water to end up with a solution that freezes at 263 K?

$$\Delta T_f = -iK_f m$$

$$T_{f,solution} - T_{f,water} = 263K - 273.15\ K = -10.15$$

$$-10.15 = iK_f m = -(1)\left(1.86\frac{°\mathrm{C}}{molal}\right)m$$

$$m = 5.457\ molal = \frac{5.457\ mol\ ethanol}{kg\ solvent}$$

$$0.0997\ kg\ water \frac{5.457\ mol\ ethanol}{kg\ water} = 0.544\ mol\ eth \frac{46.07\ g}{mol} \frac{1\ mL}{0.789} = 31.8\ mL$$