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Worksheet 4: Raoult's Law

Objective: To understand and apply Raoult's law.

When a nonvolatile solute is added to a liquid the vapor pressure of the resulting solution is lowered compared to the vapor pressure of the pure solvent at the same temperature.

$$P_{solution} = \chi_{solvent} \cdot P^0_{solvent}$$

Here $P_{solution}$ is the vapor pressure above the solution, $\chi_{solvent}$ is the mole fraction of the solvent in the solution, and $P^0_{solvent}$ is the vapor pressure of the pure solvent at the same temperature as the solution is.

This is strictly true only for an ideal solution. An ideal solution is one where the intermolecular forces between the solvent molecules for each other, the solute molecules for each other, and the intermolecular forces between the solvent and solute molecules are similar in strength.

When the solute–solvent intermolecular forces are stronger than the solute–solute and solvent–solvent intermolecular forces we observe a negative deviation from Raoult's law (from ideal behavior). We can tell this happens because the change in enthalpy for the process is negative (thermal energy is released), it is an exothermic process.

When the solute–solvent intermolecular forces are weaker than the solute–solute and solvent–solvent intermolecular forces we observe a positive deviation from Raoult's law (from ideal behavior). We can tell this happens because the change in enthalpy for the process is positive (thermal energy is absorbed), it is an endothermic process.

When a volatile solute is added to a liquid we use a slightly different form of Raoult's law. Suppose we have a volatile solute, A, and a volatile solvent, B. Then we would write Raoult's law this way:

$$P_{total} = P_A + P_B = \chi_A \cdot P^0_A + \chi_B \cdot P^0_B$$

Here P_{total} is the total vapor pressure above the solution, P_A is the partial pressure of A above the solution, P_B is the partial pressure of B above the solution, χ_A is the mole fraction of A in the solution, χ_B is the mole fraction of B in the solution, P^0_A is the vapor pressure of pure A at the same temperature as the solution, and P^0_B is the vapor pressure of pure B at the same temperature as the solution.

1.) Calculate the vapor pressure in torr of a solution that is made by dissolving 59.51 grams of glucose ($C_6H_{12}O_6$) in 112.2 mL of water at 26.7 °C. The vapor pressure of pure water at 26.7 °C is 26.271 torr and the density of water at that temperature is 0.99669 g/mL.

$P_{solution}$ = _____torr

2.) At a given temperature, you have a mixture of ethanol (vapor pressure of pure ethanol = 59.02 torr) and methanol (vapor pressure of pure methanol = 127.2 torr). The mole fraction of ethanol in the solution is 0.724. Assuming ideal behavior, calculate the mole fraction of methanol in the vapor above the solution in torr.

$\chi_{methanol_{vapor}}$ = _____

3.) Calculate the vapor pressure of a solution, in torr, that is prepared by dissolving 49.24 grams of magnesium chloride in 109.2 mL of water at 30. °C. The vapor pressure of pure water at 30. °C is 31.8 torr and the density of water at that temperature is 0.99565 g/mL. The van't Hoff factor for magnesium chloride is 2.7.

$P_{solution}$ = _____torr

4.) Which of the following will have the lowest total vapor pressure at 25 °C?
Pure H_2O (P_{water} = 23.8 torr at 25 °C) , a solution of glucose ($C_6H_{12}O_6$) where $\chi_{glucose}$ = 0.010, a solution of NaCl in water with χ_{NaCl} = 0.010 (van't Hoff factor =1.9 for NaCl), or a solution of methanol (CH_3OH) in water where $\chi_{methanol}$=0.20 ($P^0_{methanol}$=143 torr at 25 °C). Which would have the highest total vapor pressure?

Highest P_{vapor}_____

Lowest P_{vapor}_____

5.) Use the following table of data, which is for solutions of water/propanol ($CH_3CH_2CH_2OH$) all at 45 °C, to answer the questions below.

χ_{water}	P_{vapor} (torr)
0.00	74.0
0.15	77.3
0.37	80.2
0.54	81.6
0.69	80.6
0.83	78.2
1.00	71.9

a.) Is a solution of water/propanol ideal? Explain.

b.) Is the process of mixing propanol and water exothermic, endothermic, or neither? Explain.

c.) Which of the solutions in the table would have the lowest normal boiling point? Which would have the highest?