Name ________________________________ Chem 162, Section: _______ Group Number: ______

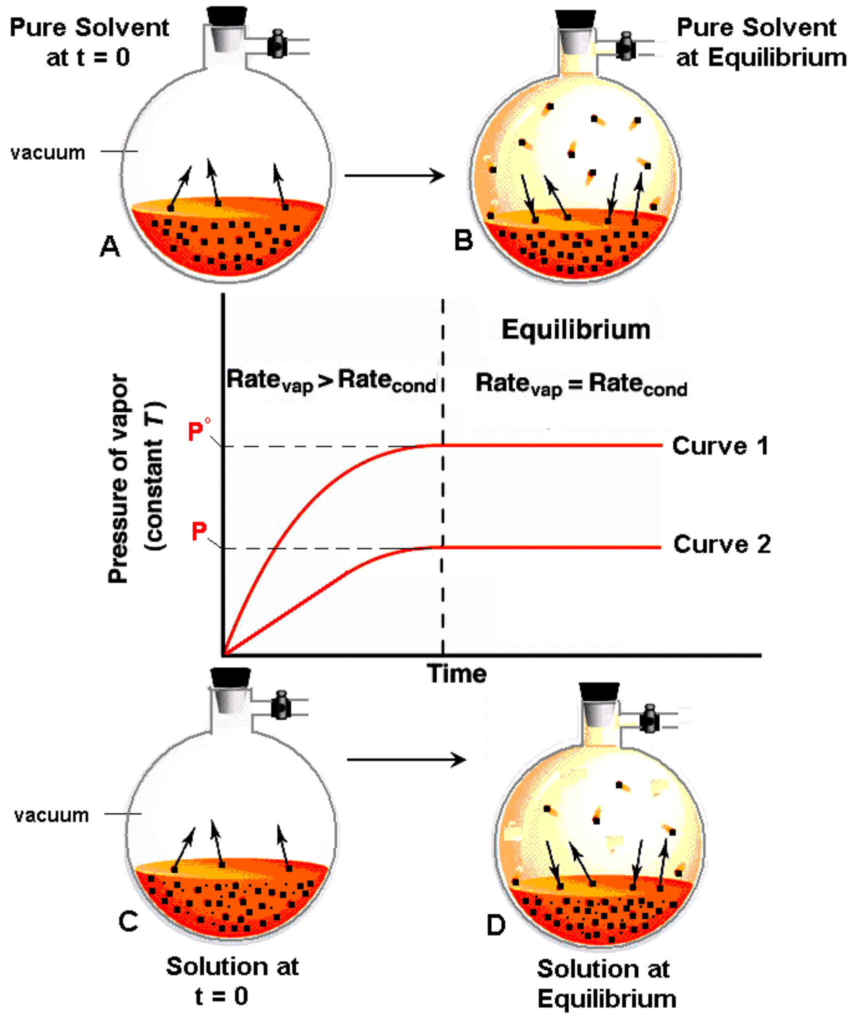
ALE 23. Colligative Properties (Part 1)

(Reference: 13.5 (molality on p. 523) and 13.6 *Silberberg 5th edition*)

Why is salt added to the boiling water in which we cook food?

The Model: Vapor Pressure Lowering

Suppose a pure liquid is placed in an otherwise evacuated container and the container is sealed as in flask A to the right. An equilibrium will be established between the liquid and its vapor (flask B). The **vapor pressure** of the liquid was measured with a pressure gauge (curve 1). Flask C contains a nonvolatile solute dissolved in the same liquid as in flask A. An equilibrium will be established between the solution and the vapor of the solvent (flask D) with the vapor pressure represented by curve 2.



Key Questions

1. The liquid in flask A is **volatile** (*i.e.*, it absorbs thermal energy from its surroundings and its molecules go into the gas phase). What does it mean for a substance to be "***nonvolatile***"?

2. Drawing upon specific evidence exhibited in the Model above, explain what happens to the vapor pressure of a liquid when a nonvolatile solute is dissolved in it. (**P°** represents the vapor pressure of the pure volatile liquid; **P** represents the vapor pressure of the liquid after a nonvolatile solute has been dissolved in it.)

The Model: Raoult's Law

Let us consider an ideally-behaving solution. In an ideal solution, each component obeys **Raoult's law**. Applied to the component which we'll simply label as "A", Raoult's law is:

$$P_A = X_A\, P_A^o$$

where P_A^o is the vapor pressure of *pure* liquid A and X_A is the **mole fraction** of A:

$$X_A = \frac{n_A}{n_{\text{total in solution}}}$$

Key Questions

3a. If the only two components in the solution are the solvent "A" and a *volatile* solute, "B", according to **Dalton's law of partial pressures**, what is the total vapor pressure of the solution of A and B?

$P_{soln} =$

b. Now suppose that B is *nonvolatile*. What is its vapor pressure contribution?

$P_B =$

c. With the knowledge that B is nonvolatile, apply Raoult's law to A and rewrite the expression for the vapor pressure of the solution.

$P_{soln} =$

4a. If you have a solution of A and B, which of the following is true concerning the mole fraction of solvent A? (Circle your choice.)

i) $X_A < 1$ ii) $X_A = 1$ iii) $X_A > 1$

b. Again, suppose you have a solution of a *nonvolatile* solute (B) in a volatile solvent (A). Use your answers to Questions 3c and 4a to compare the solution's vapor pressure to the pure vapor pressure of the solvent. (Circle your choice and check to see if it is consistent with your answer to Question 2.)

i) $P_{soln} < P_A^o$ ii) $P_{soln} = P_A^o$ iii) $P_{soln} > P_A^o$

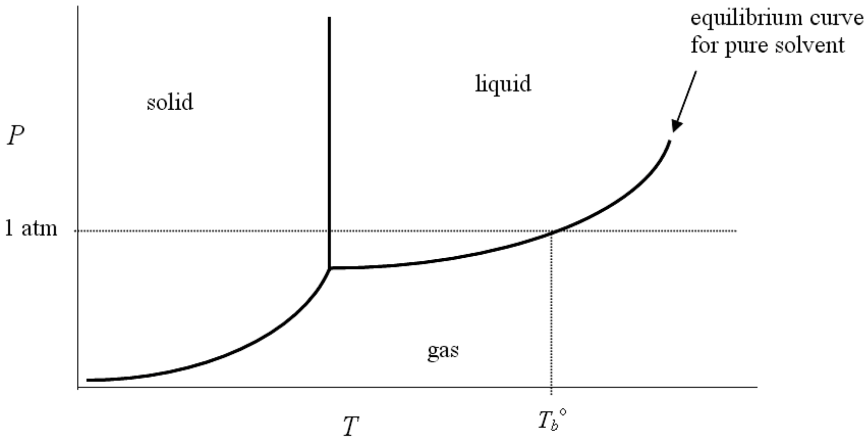
Exercise

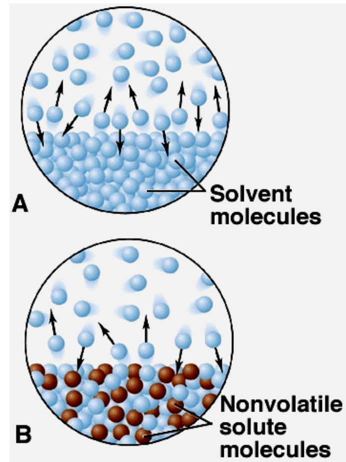
A. Suppose you dissolve 10.0 g of sugar (sucrose, $C_{12}H_{22}O_{11}$) in 50.0 g of water. What will the vapor pressure of the solution be (in mmHg) at 100. °C? [Hints: ① What are the molar masses of sucrose and of water? ② How many moles of each component are there in the solution? ③ What is the concentration of the water expressed as a mole fraction? ④ What is the pure vapor pressure of water (in mmHg) at 100. °C? (A substances **normal boiling point** is the temperature at which its vapor pressure equals 1 atm.) ⑤ What is the vapor pressure of the aqueous solution of sugar at 100 °C?]

Key Questions

5. Yes or No: Will the solution described in Exercise A boil at 100. °C? (Recall the definition of boiling point.)

6. To the left below is a phase diagram of a typical (pure) substance.





a. We've just learned that the pressure at which a liquid and its gas are in equilibrium with each other is lowered when a nonvolatile solute is dissolved in it—this illustrated at the molecular level in figures A and B above. (This property is called **vapor pressure lowering**.) This lowering of the vapor pressure occurs *at all temperatures*. *On the phase diagram above, draw an equilibrium curve between the liquid and gas regions when a nonvolatile solute has been dissolved in the liquid*.

b. Label the normal boiling point of the solution on the phase diagram above. Examine the phase diagram and the new curve that you've just drawn above. *What happens to the normal boiling point of a liquid when a nonvolatile solute is dissolved in it*. (Recall the definition of **normal boiling point**: the temperature at which its vapor pressure equals 1 atm.)

The Model: Molality and Boiling Point Elevation

The presence of solute particles results in an elevation of the boiling point because solute particles interfere with the escape of solvent molecules from the liquid to the gaseous phase. Hence the solvent molecules require higher kinetic energy (i.e. a higher temperature) to overcome the IMF's in order to vaporize. Just how much a liquid's boiling point is elevated, ΔT_b (Recall: The "Δ" means "change in".), is directly dependent on the concentration of solute put in solution. One unit of concentration that students of Chemistry most often use is molarity (moles of solute per liter of solution). However, we'd not want to make the change in boiling point (a temperature) related to a concentration that is itself *dependent on a temperature*. Instead we use **molality**, a unit of concentration that is independent of temperature.

$$\text{molality} = m = \frac{\text{moles solute}}{\text{kg solvent}}$$

where **kg solvent** is the mass of the *solvent* in kilograms. The **boiling point elevation** is given by the equation:

$$\Delta T_b = K_b\, m$$

K_b (the **boiling point elevation constant**) is a constant, the value of which is specific to the solvent of the solution.

Key Question

7. Explain how the ***molarity*** of a solution is dependent on the temperature of the solution. (*Hint*: How is molarity defined? What quantity in this definition is temperature dependent?)

8. Is the boiling point of 0.01 *m* $KF_{(aq)}$ higher or lower than that of aqueous 0.01 *m* glucose ($C_6H_{12}O_6$)? Explain—there is no need to do a calculation!

Exercise

B. ***Ethylene glycol*** ($HOCH_2CH_2OH$) is often added to the water put in an automobile's radiator. One of the advantages "antifreeze" offers is that the water will boil at a higher temperature than its normal boiling point. What is the boiling point of a 60.0 %-by-mass ethylene glycol solution (in °C)? [*Hints*: ① Assume a mass for the solution—e.g. 100. grams is convenient. How many grams of ethylene glycol are there? How many grams of water are there? ② How many kilograms of water are there?③ What is the molar mass of ethylene glycol? ④ How many moles of ethylene glycol are there?⑤ What is the *molality* of the solution? ⑥ What is the boiling point elevation constant for water? (Use your textbook to look it up!) ⑦ What is the change in the boiling point of the solution? ⑧ What is the boiling point of the solution?]

C. Two beakers were placed in a closed container (left side in the figure below). One beaker contained water, the other a concentrated aqueous sugar solution. With time, the solution volume increased, and the water volume decreased. Explain at the ***molecular level*** why this happened. *Hint*: Consider the vapor pressure of water vs. that of the sugar solution.