10.2 PROBLEMS - LIQUIDS AND GASES

1. Use the following table to answer these questions.

Vapor Pressures of Various Liquids

<table>
<thead>
<tr>
<th>Temp. (°C)</th>
<th>Ethyl alcohol (mmHg)</th>
<th>Benzene (mmHg)</th>
<th>Methyl salicylate (mmHg)</th>
<th>Water (mmHg)</th>
<th>Carbon tetrachloride (mmHg)</th>
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a. A beaker of benzene (C₆H₆) is at room temperature (20° C). What is its vapor pressure? **91 mmHg**

Is this vapor pressure large enough to cause the benzene to boil at sea level? **No**

b. When all of the liquids are heated to 80°C, which will boil when the air pressure is 760 mmHg? **Ethyl alcohol, benzene**

c. If the temperature remains unchanged, but the pressure above the liquids is reduced to 700 mmHg which liquids will now boil? **Ethyl alcohol, benzene, carbon tetrachloride**

d. A beaker of ethyl alcohol and a beaker of benzene both at room temperature (20° C) are placed on a hot plate when the air pressure is only 700 mmHg. Which one of the two liquids will start to boil first? **Benzene**

It will boil at about what temperature? **72°C**

e. A beaker of carbon tetrachloride is warmed to 60° C and connected to a vacuum pump so the air pressure above the liquid can be changed. The pump is turned on. At what pressure will the liquid start to boil? **389 mmHg**

What would this pressure be in atmospheres? **0.512 atm** [show work here]

\[
389 \text{ mmHg} \left( \frac{1 \text{ atm}}{760 \text{ mmHg}} \right) = 0.512 \text{ atm}
\]

f. At 75° C, in a place where the air pressure is only 650 mmHg, which substances will be boiling? **Ethyl alcohol, benzene**

g. The pressure above the five substances is adjusted to 550 mmHg. What is the approximate boiling point of each substance at this pressure? [methyl salicylate is excluded]

- Ethyl alcohol: 71°C
- Benzene: 66°C
- Water: 91°C
- Carbon tetrachloride: 70°C

h. At 550 mmHg, when the temperature is hot enough to get the ethyl alcohol to boil, will the carbon tetrachloride also be boiling? **Yes**

i. At 75° C, I start the pressure above the liquids at 760 mmHg and slowly reduce it using the vacuum pump. In which order will the substances boil?

- 1st **Benzene**
- 2nd **Ethyl alcohol**
- 3rd **Carbon tetrachloride**
- 4th **Water**
- 5th **Methyl salicylate**
j. Determine the approximate “**normal boiling point**” (boiling point at 760 mmHg) of each substance below:

- ethyl alcohol: 78°C
- benzene: 77°C
- water: 100°C
- carbon tetrachloride: 80°C

k. Study the chart of vapor pressures at 25°C. Rank the substances in order of increasing IMFs.

- Ethyl alcohol
- Benzene
- Carbon tetrachloride
- Water
- Methyl salicylate

1. Why doesn’t data for methyl salicylate start until 60°C? **It’s a solid below 60°C.**

2. The following graph shows vapor pressure curves for two substances, A and B:

   ![Graph](image)

   a. What is the vapor pressure of A at 35°C? **26.7°C**

   b. What is the vapor pressure of B at 35°C? **9°C**

   c. At what temperature is the vapor pressure of A equal to 106.6 kPa? **75°C**

   d. What is the vapor pressure of B at this temperature? **26.7°C**

3. An ideal gas occupies a volume of 10 L at 27°C. If the pressure on the gas is tripled at this temperature, the volume changes. To what value must the temperature change to restore the volume to the initial 10 L at the new pressure?

\[
\frac{P_1}{T_1} = \frac{P_2}{T_2} = \frac{3P_1}{T_2} = 900 \text{ K}
\]


   a. Calculate the root mean square speed of nitrogen gas at 25°C.

   \[
v = \sqrt{\frac{3R T}{M \text{M}}} = \sqrt{\frac{3(8.314 \text{ J/mol·K})(298 \text{ K})}{(28.02 \times 10^{-3} \text{ kg/mol})}} = 515 \text{ m/s}
   \]

   b. What happens to the rms speed if the temperature is doubled to 50°C?

   \[
v = (515 \text{ m/s})\sqrt{\frac{323 \text{ K}}{298 \text{ K}}} = 536 \text{ m/s}
   \]

   c. For nitrogen, the van der Waals constants a and b have values of 1.39 and 0.0391 respectively. Calculate the pressure of 5 moles of nitrogen gas confined to a 1.0 L vessel at a temperature of 300 K using the ideal gas equation and the van der Waals equation of state. Comment on the difference.

   **Ideal:**
   \[
P = \frac{nR T}{V} = \frac{(5 \text{ mol})(0.0821)(300 \text{ K})}{(1.0 \text{ L})} = 123 \text{ atm}
   \]

   **Real:**
   \[
   P + a \left(\frac{n}{V}\right)^2 [V - n \cdot b] = n \cdot R \cdot T
   \]
   \[
   P + (1.39)(5 \text{ mol})^2 [1.0 \text{ L} - (5 \text{ mol})(0.0391)] = (5 \text{ mol})(0.0821)(300 \text{ K})
   \]
   \[
P = 118 \text{ atm}
   \]
5. If 1.0 L of oxygen at 2.0 atm pressure, 2.00 L of nitrogen at 1.0 atm pressure, and 2.0 L of helium at 2.0 atm pressure, are all mixed in a 3.0 L vessel with no change in temperature, what is the final pressure of the mixture in the 3.0 L vessel?

\[ P_{O_2} = \frac{P_1 \cdot V_1}{V_2} = \frac{(2.0 \text{ atm})(1.0 \text{ L})}{3.0 \text{ L}} = 0.67 \text{ atm} \]

\[ P_{N_2} = \frac{P_1 \cdot V_1}{V_2} = \frac{(1.0 \text{ atm})(2.0 \text{ L})}{3.0 \text{ L}} = 0.67 \text{ atm} \]

\[ P_{He} = \frac{P_1 \cdot V_1}{V_2} = \frac{(2.0 \text{ atm})(2.0 \text{ L})}{3.0 \text{ L}} = 1.33 \text{ atm} \]

\[ P_{\text{total}} = P_{O_2} + P_{N_2} + P_{He} = (0.67 \text{ atm}) + (0.67 \text{ atm}) + (1.33 \text{ atm}) = 2.67 \text{ atm} \]

6. A gas diffuses 5/3 times faster than carbon dioxide. Which gas might it be?
   a. O\textsubscript{2}  b. N\textsubscript{2}  c. CO  d. He  e. CH\textsubscript{4}

\[ \frac{v_X}{v_{CO_2}} = \sqrt{\frac{MM_{CO_2}}{MM_X}} \]

\[ MM_X = 16 \text{ g/mol} \quad \text{CH}_4 \]

7. What is the density of the helium gas at 0.34 am and 33°C?

\[ D = \frac{P \cdot MM}{R \cdot T} = \frac{(0.34 \text{ atm})(4.026 \text{ g/mol})}{(0.0821)(306 \text{ K})} \]

\[ = 0.0545 \text{ g/L} \]

8. If the density of a gas is 1.2 g/L at 745 torr and 20°C, what is its molar mass?

\[ MM = \frac{D \cdot R \cdot T}{P} = \frac{(1.2 \text{ g/L})(0.0821)(293 \text{ K})}{(745/760 \text{ atm})} \]

\[ = 22.4 \text{ g/mol} \]

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**AP Chemistry 1988 #8**

The normal boiling and freezing points of argon are 87.3 K and 84.0 K, respectively. The triple point is at 82.7 K and 0.68 atmosphere.

(a) Use the data above to draw a phase diagram for argon. Label the axes and label the regions in which the solid, liquid, and gas phases are stable. On the phase diagram, show the position of the normal boiling point.

(b) Describe any changes that can be observed in a sample of solid argon when the temperature is increases from 40 K to 160 K at a constant pressure of 0.50 atmosphere.

   The solid argon sublimes.

(c) Describe any changes that can be observed in a sample of liquid argon the pressure is reduced from 10 atmospheres to 1 atmosphere at a constant temperature of 100 K, which is well below the critical temperature.

   The liquid argon boils.

(d) Does the liquid phase of argon have a density greater than, equal to, or less than the density of the solid phase? Explain your answer, using information given in the introduction to this question.

   The density of the liquid has a density less than that of the solid. As the pressure increases from 0.68 atm to 1.0 atm, the boiling point temperature increases from 82.7°C to 84.0°C, so between the two temperatures, the pressure of the solid is greater than the pressure of the liquid, so the density of the solid is greater than the density of the liquid.
AP Chemistry 2011B #6
Use principles of molecular structure, intermolecular forces, and kinetic molecular theory to answer the following questions.

(a) A complete Lewis electron-dot diagram of a molecule of ethyl methanoate is given below.

(i) Identify the hybridization of the valence electrons of the carbon atom labeled C_w.

(ii) Estimate the numerical value of the H_y–C_x–O bond angle in an ethyl methanoate molecule. Explain the basis of your estimate.

C_x is bonded to four atoms forming a tetrahedral arrangement with a bond angle 109.5°.

(b) Ethyl methanoate, CH_3CH_2OCHO, is synthesized in the laboratory from ethanol, C_2H_5OH, and methanoic acid, HCOOH, as represented by the following equation.

\[ C_2H_5OH(l) + HCOOH(l) \rightleftharpoons CH_3CH_2OCHO(l) + H_2O(l) \]

(i) In the box below, draw the complete Lewis electron-dot diagram of a methanoic acid molecule.

(ii) In the box below, draw the complete Lewis electron-dot diagrams of a methanoic acid molecule and a water molecule in an orientation that allows a hydrogen bond to form between them.

(c) A small amount of liquid ethyl methanoate (boiling point 54°C) was placed in a rigid closed 2.0 L container containing argon gas at an initial pressure of 1.00 atm and a temperature of 20°C. The pressure in the container was monitored for 70. seconds after the ethyl methanoate was added, and the data in the graph below were obtained. It was observed that some liquid ethyl methanoate remained in the flask after 70. seconds. (Assume that the volume of the remaining liquid is negligible compared to the total volume of the container.)

(i) Explain why the pressure in the flask increased during the first 60. seconds.

**Some of the ethyl methanoate evaporated during the first 60. seconds.**

(ii) Explain, in terms of processes occurring at the molecular level, why the pressure in the flask remained constant after 60. seconds.

**At 60. seconds, the rate of vaporization (liquid to gas) is equal to the rate of condensation (gas to liquid), so the pressure of the vapor reaches equilibrium.**
(iii) What is the value of the partial pressure of ethyl methanoate vapor in the container at 60. seconds?

\[ P_{\text{ethylmethanoate}} = P_{\text{total}} - P_{\text{argon}} = 1.25 \text{ atm} - 1.00 \text{ atm} = 0.25 \text{ atm} \]

(iv) After 80. seconds, additional liquid ethyl methanoate is added to the container at 20°C. Does the partial pressure of ethyl methanoate vapor in the container increase, decrease, or stay the same? Explain.

The partial pressure of ethyl methanoate remains the same because the system is already at equilibrium, so addition of the liquid would not change the position of equilibrium.

**AP Chemistry 2004B #2**

Answer the following questions related to hydrocarbons.

(a) Determine the empirical formula of a hydrocarbon that contains 85.7 percent carbon by mass.

\[
\begin{align*}
85.7 \text{ g C} &\rightarrow 7.136 \text{ mol C} \\
14.3 \text{ g H} &\rightarrow 14.187 \text{ mol H}
\end{align*}
\]

The empirical formula is \( \text{C}_7\text{H}_{13.16} \text{H}_{14.187/7.136} = \text{CH}_2 \)

(b) The density of the hydrocarbon in part (a) is 2.0 \text{ g L}^{-1} at 50°C and 0.948 atm.
   
   i. Calculate the molar mass of the hydrocarbon.
   
   \[
   \text{MM} = \frac{\text{D} \cdot \text{R} \cdot \text{T}}{\text{P}} = \frac{(2.0 \text{ g/L})(0.0821)(323 \text{ K})}{(0.948 \text{ atm})} = 55.9 \text{ g/mol}
   \]

   ii. Determine the molecular formula of the hydrocarbon.

   Mass of empirical formula = 1(12.01) = 2(1.008) = 14.03 g/mol

   Molecular Formula = \( \left( \frac{55.9 \text{ g/mol}}{14.03 \text{ g/mol}} \right) (\text{CH}_2) = \text{C}_4\text{H}_8 \)

(c) Two flasks are connected by a stopcock as shown below. The 5.0 L flask contains \( \text{CH}_4 \) at a pressure of 3.0 atm, and the 1.0 L flask contains \( \text{C}_2\text{H}_6 \) at a pressure of 0.55 atm. Calculate the total pressure of the system after the stopcock is opened. Assume that the temperature remains constant.

\[
\begin{align*}
P_{\text{CH}_4} &= \frac{P_1 \cdot V_1}{V_2} = \frac{(3.0 \text{ atm})(5.0 \text{ L})}{(6.0 \text{ L})} = 2.5 \text{ atm} \\
P_{\text{C}_2\text{H}_6} &= \frac{P_1 \cdot V_1}{V_2} = \frac{(0.55 \text{ atm})(1.0 \text{ L})}{(6.0 \text{ L})} = 0.092 \text{ atm} \\
P_{\text{total}} &= P_{\text{CH}_4} + P_{\text{C}_2\text{H}_6} = (2.5 \text{ atm}) + (0.092 \text{ atm}) = 2.6 \text{ atm}
\end{align*}
\]

(d) Octane, \( \text{C}_8\text{H}_{18} (\ell) \), has a density of 0.703 g mL\(^{-1}\) at 20°C. A 255 mL sample of \( \text{C}_8\text{H}_{18} (\ell) \) measured at 20°C reacts completely with excess oxygen as represented by the equation below.

\[
2 \text{C}_8\text{H}_{18} (\ell) + 25 \text{O}_2 (g) \rightarrow 16 \text{CO}_2 (g) + 18 \text{H}_2\text{O} (g)
\]

Calculate the total number of moles of gaseous products formed.

\[
\begin{align*}
255 \text{ mL} \text{ C}_8\text{H}_{18} &\rightarrow \frac{0.703 \text{ g C}_8\text{H}_{18}}{1 \text{ mL} \text{ C}_8\text{H}_{18}} \left( \frac{1 \text{ mol C}_8\text{H}_{18}}{114.224 \text{ g C}_8\text{H}_{18}} \right) \left( \frac{34 \text{ mol products}}{2 \text{ mol C}_8\text{H}_{18}} \right) = 26.7 \text{ mol products}
\end{align*}
\]