Name ____________________ **AP Chemistry** **___/___/___**

Chapter 5 Collected AP Exam Free Response Questions 1980 – 2010 - Answers

1982 - #5

(a) From the standpoint of the kinetic-molecular theory, discuss briefly the properties of gas molecules that cause deviations from ideal behavior. **Real molecules exhibit finite volumes, thus excluding some volume from compression. Real molecules exhibit attractive forces, thus leading to fewer collisions with the walls and a lower pressure.**

(b) At 25°C and 1 atmosphere pressure, which of the following gases shows the greatest deviation from ideal behavior? Give two reasons for your choice.

CH_4 SO_2 O_2 H_2

SO_2 is the least ideal gas. It has the largest size or volume. It has the strongest attractive forces (van der Waals forces or dipole-dipole interactions).

(c) Real gases approach ideality at low pressure, high temperature, or both. Explain these observations

High temperature results in high kinetic energies. This energy overcomes the attractive forces.
Low pressure increases the distance between molecules. (So molecules comprise a small part of volume or attractive forces are small)

1984- #4b

Give a scientific explanation for the following observations. Use equations of diagrams if they are relevant.

(b) Burning coal containing a significant amount of sulfur leads to "acid rain."

$S + O_2 \rightarrow SO_2$ (as coal is burned); $SO_2 + H_2O \rightarrow H_2SO_3$ (in the atmosphere)

1990 - #2

A mixture of $H_2(g)$, $O_2(g)$, and 2 milliliters of $H_2O(l)$ is present in 0.500-liter rigid container at 25°C. The number of moles of H_2 and the number of moles of O_2 are equal. The total pressure is 1,146 millimeters of mercury. (The equilibrium vapor pressure of pure water is 24 millimeters mercury.)

The mixture is sparked, and H_2 and O_2 react until one reactant is completely consumed.

(a) Identify the reactant remaining and calculate the number of moles of the reactant remaining.

H_2 is the limiting reagent. 7.55×10^{-3} mol O_2 is left.

(b) Calculate the total pressure in the container at the conclusion of the reaction if the final temperature is 90°C. (The equilibrium vapor pressure of water at 90°C is 526 millimeters mercury.) **868 mm Hg**

(c) Calculate the number of moles of water present as vapor in the container at 90°C. **0.0116 mol**

1993 - #9

Observations about real gases can be explained at the molecular level according to the kinetic molecular theory of gases and ideas about intermolecular forces. Explain how each of the following observations can be interpreted according to these concepts, including how the observation supports the correctness of these theories.

(a) When a gas-filled balloon is cooled, if shrinks in volume; this occurs no matter what gas is originally placed in the balloon.

Reducing the temperature of a gas reduces the average kinetic energy (or velocity) of the gas molecules. This would reduce the number (or frequency) of collisions of gas molecules with the surface of the balloon (or decrease the momentum change that occurs when the gas molecules strike the balloon surface.) In order to maintain a constant pressure vs. the external pressure, the volume must decrease.

(b) When the balloon described in part (a) is cooled further, the volume does not become zero; rather, the gas becomes a liquid or solid.

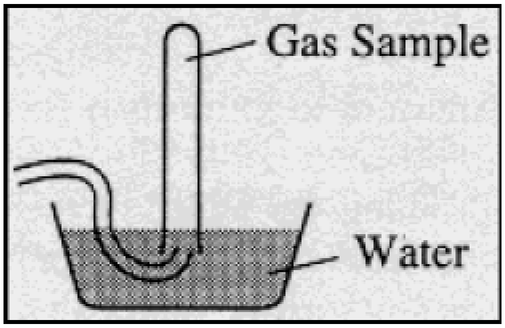
The molecules of the gas do have volume, when they are cooled sufficiently, the forces of attraction that exist between them cause them to liquefy or solidify.

(c) When NH_3 gas is introduced at one end of a long tube while HCl gas is introduced simultaneously at the other end, a ring of white ammonium chloride is observed to form in the tube after a few minutes.

This ring is closer to the HCl end of the tube than the NH_3 end. The molecules of a gas are in constant motion so the HCl and NH_3 diffuse along the tube. Where they meet, NH_4Cl is formed. Since HCl has a higher molar mass, its velocity (avg.) is lower. Therefore it doesn't diffuse as fast as the NH_3.

(d) A flag waves in the wind.
The wind is moving molecules of air that are going mostly in one direction. Upon encountering a flag, they transfer some of their energy (momentum) to it and cause it to move (flap!)

1994 - #3

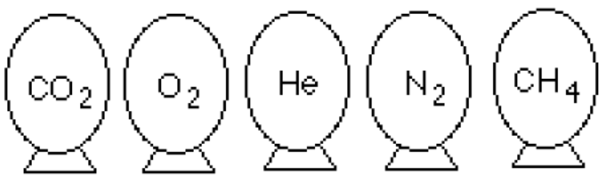


GAS SAMPLE DATA	
Volume of sample	90.0 mL
Temperature	25° C
Atmospheric Pressure	745 mm Hg
Equilibrium Vapor Pressure of H_2O (25° C)	23.8 mm Hg

A student collected a sample of hydrogen gas by the displacement of water as shown by the diagram above. The relevant data are given in the following table.

(a) Calculate the number of moles of hydrogen gas collected. **3.49×10^{-3} mol H_2**
(b) Calculate the number of molecules of water vapor in the sample of gas. **6.92×10^{19} molecules H_2O**
(c) Calculate the ratio of the average speed of the hydrogen molecules to the average speed of the water vapor molecules in the sample. **3 : 1**
(d) Which of the two gases, H_2 or H_2O, deviates more from ideal behavior? Explain your answer.
H_2O deviates more from ideal behavior.
Explanation: The volume of the H_2O molecule is larger than that of the H_2 molecule and the intermolecular forces among the H_2O molecules are stronger than those among H_2 molecules.

1996 - #5



Represented above are five identical balloons, each filled to the same volume at 25°C and 1.0 atmosphere pressure with the pure gas indicated.

(a) Which balloon contains the greatest mass of gas? Explain. **CO_2 b/c mass is largest**
(b) Compare the average kinetic energies of the gas molecules in the balloons. Explain.
All the same b/c temp is the same for all gases.
(c) Calculate the root mean square velocity of any two gases. Indicate the gases chosen.
CO_2 = 411 m/s; O_2 = 482 m/s; He = 1360 m/s; N_2 = 515 m/s; CH_4 = 681 m/s
(d) Twelve hours after being filled, all the balloons have decreased in size. Predict which balloon will be the smallest. Explain your reasoning. **He because it has the smallest molar mass**

2002B - #2

A rigid 8.20 L flask contains a mixture of 2.50 moles of H_2, 0.500 mole of O_2, and sufficient Ar so that the partial pressure of Ar in the flask is 2.00 atm. The temperature is 127ºC.

(a) Calculate the total pressure in the flask. **14.0 atm**

(b) Calculate the mole fraction of H_2 in the flask. **0.714**

(c) Calculate the density (in g L^{-1}) of the mixture in the flask. **5.00 g L^{-1}**

The mixture in the flask is ignited by a spark, and the reaction represented below occurs until one of the reactants is entirely consumed.

$$2\ H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

(d) Give the mole fraction of all species present in the flask at the end of the reaction.

H_2: 0.500; O_2: 0.0; H_2O: 0.333; Ar: 0.167

2003 - #2

A rigid 5.00 L cylinder contains 24.5 g of $N_2(g)$ and 28.0 g of $O_2(g)$.

(a) Calculate the total pressure, in atm, of the gas mixture in the cylinder at 298 K. **8.56 atm**

(b) The temperature of the gas mixture in the cylinder is decreased to 280 K. Calculate each of the following.

(i) The mole fraction of $N_2(g)$ in the cylinder **0.500**

(ii) The partial pressure, in atm, of $N_2(g)$ in the cylinder **4.02**

(c) If the cylinder develops a pinhole-sized leak and some of the gaseous mixture escapes, would the ratio $\frac{moles : Nitrogen}{moles : Oxygen}$ in the cylinder increase, decrease, or remain the same? Justify your answer. **Decrease because oxygen effuses slower because its molar mass is greater than nitrogen**.

A different rigid 5.00 L cylinder contains 0.176 mol of $NO(g)$ at 298 K. A 0.176 mol sample of $O_2(g)$ is added to the cylinder, where a reaction occurs to produce $NO_2(g)$.

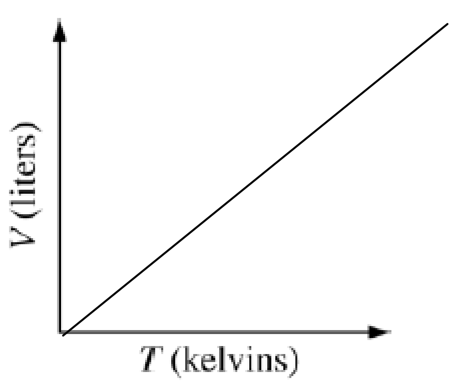
(d) Write the balanced equation for the reaction. **$2NO + O_2 \rightarrow 2NO_2$**

(e) Calculate the total pressure, in atm, in the cylinder at 298 K after the reaction is complete. **1.29 atm**

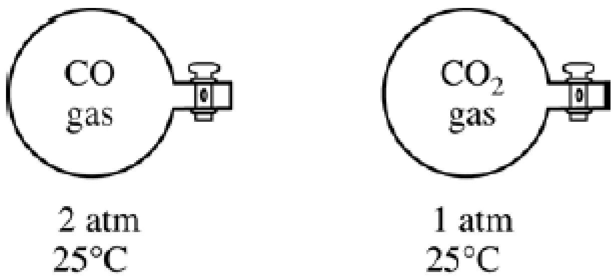
2004 - #8d & e

Answer the following questions about carbon monoxide, $CO(g)$, and carbon dioxide, $CO_2(g)$. Assume that both gases exhibit ideal behavior.

(d) A 1.0 mole sample of $CO(g)$ is heated at constant pressure. On the graph below, sketch the expected plot of volume versus temperature as the gas is heated.



(e) Samples of $CO(g)$ and $CO_2(g)$ are placed in 1 L containers at the conditions indicated in the diagram below.



(i) Indicate whether the average kinetic energy of the $CO_2(g)$ molecules is greater than, equal to, or less than the average kinetic energy of the $CO(g)$ molecules. Justify your answer. **Equal because kinetic energy is a function of temperature. Since both are at the same temperate, both have the same kinetic energy.**

(ii) Indicate whether the root-mean-square speed of the $CO_2(g)$ molecules is greater than, equal to, or less than the root-mean-square speed of the $CO(g)$ molecules. Justify your answer. **CO is faster because its molecular mass is lower than CO_2**

(iii) Indicate whether the number of $CO_2(g)$ molecules is greater than, equal to, or less than the number of $CO(g)$ molecules. Justify your answer. **More CO because pressure and moles are directly related. An increase in pressure is directly related to an increase in the number of moles.**

2004B - #2

Answer the following questions related to hydrocarbons.

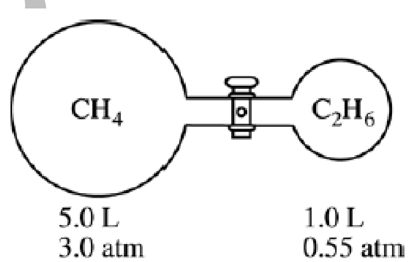
(a) Determine the empirical formula of a hydrocarbon that contains 85.7 percent carbon by mass. **CH_2**

(b) The density of the hydrocarbon in part (a) is 2.0 g L^{-1} at 50ºC and 0.948 atm.

(i) Calculate the molar mass of the hydrocarbon. **56 g/mol**

(ii) Determine the molecular formula of the hydrocarbon. **C_4H_8**

(c) Two flasks are connected by a stopcock as shown to the right. The 5.0 L flask contains CH_4 at a pressure of 3.0 atm, and the 1.0 L flask contains C_2H_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. **2.6 atm; P_{CH4} = 2.5 atm; P_{C2H6} = 0.092 atm**



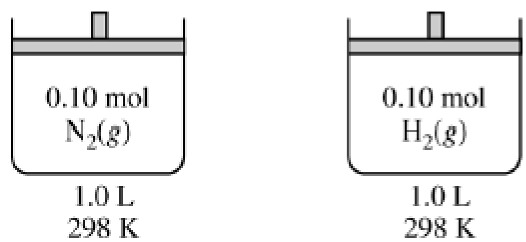
(d) Octane, $C_8H_{18}(l)$, has a density of 0.703 g mL^{-1} at 20ºC. A 255 mL sample of $C_8H_{18}(l)$ measured at 20ºC reacts completely with excess oxygen as represented by the equation below.

$2\ C_8H_{18}(l) + 25\ O_2(g) \rightarrow 16\ CO_2(g) + 18\ H_2O(g)$

Calculate the total number of moles of gaseous products formed. **26.7 moles**

2005B - #6

Consider two containers of volume 1.0 L at 298 K, as shown to the right. One container holds 0.10 mol $N_2(g)$ and the other holds 0.10 mol $H_2(g)$. The average kinetic energy of the $N_2(g)$ molecules is 6.2×10^{-21} J . Assume that the $N_2(g)$ and the $H_2(g)$ exhibit ideal behavior.



(a) Is the pressure in the container holding the $H_2(g)$ less than, greater than, or equal to the pressure in the container holding the $N_2(g)$? Justify your answer. **Equal. Since volume, temperature and moles are equal, pressures must be too.**

(b) What is the average kinetic energy of the $H_2(g)$ molecules? **6.2×10^{-21} J**

(c) The molecules of which gas, N_2 or H_2 , have the greater average speed? Justify your answer. **H_2 because H_2 has a lower molar mass than N_2.**

(d) What change could be made that would decrease the average kinetic energy of the $N_2(g)$ molecules in the container? **Decrease the temperature.**

(e) If the volume of the container holding the $H_2(g)$ was decreased to 0.50 L at 298 K, what would be the change in each of the following variables? In each case, justify your answer.

(i) The pressure within the container **A decrease in volume causes an increase in pressure. Pressure and volume are inversely related.**

(ii) The average speed of the $H_2(g)$ molecules **The average speed would not change because there is no change in temperature.**

2006 - #3b

A different compound, which has the empirical formula CH_2Br , has a vapor density of 6.00 g L^{-1} at 375 K and 0.983 atm. Using these data, determine the following.

(i) The molar mass of the compound **188 g/mol**

(ii) The molecular formula of the compound $\mathbf{C_2H_4Br_2}$

2006B - #8b

Use chemical and physical principles to account for the following.

The inside of a metal container was cleaned with steam and immediately sealed. Later, the container imploded.

Steam heated air expands. An increase in temperature causes an increase in volume. When the cap is placed on the container, there is less air in the container, so there is less pressure inside the container. The atmospheric pressure is greater than the pressure in the can, so the can implodes.

2007B - #3a

$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(l)$

In a hydrogen-oxygen fuel cell, energy is produced by the overall reaction represented above.

(a) When the fuel cell operates at 25°C and 1.00 atm for 78.0 minutes, 0.0746 mol of $O_2(g)$ is consumed. Calculate the volume of $H_2(g)$ consumed during the same time period. Express your answer in liters measured at 25°C and 1.00 atm. **3.65 L $\mathbf{H_2}$**

2008B - #1a

Answer the following questions regarding the decomposition of arsenic pentafluoride, $AsF_5(g)$.

(a) A 55.8 g sample of $AsF_5(g)$ is introduced into an evacuated 10.5 L container at 105°C.

(i) What is the initial molar concentration of $AsF_5(g)$ in the container? **0.0313 *M***

(ii) What is the initial pressure, in atmospheres, of the $AsF_5(g)$ in the container? **0.969 atm**

2009 - #2 National Average Score: 4.6 out of 10, Petras Average: 5.9 out of 10

A student was assigned the task of determining the molar mass of an unknown gas. The student measured the mass of a sealed 843 mL rigid flask that contained dry air. The student then flushed the flask with the unknown gas, resealed it, and measured the mass again. Both the air and the unknown gas were at 23.0°C and 750. torr.

The data for the experiment are shown in the table below.

Volume of sealed flask	843 mL
Mass of sealed flask and dry air	157.70 g
Mass of sealed flask and unknown gas	158.08 g

(a) Calculate the mass, in grams, of the dry air that was in the sealed flask. (The density of dry air is 1.18 g L^{-1} at 23.0°C and 750. torr.) **0.995 grams**

(b) Calculate the mass, in grams, of the sealed flask itself (i.e., if it had no air in it). **156.71 grams**

(c) Calculate the mass, in grams, of the unknown gas that was added to the sealed flask. **1.37 grams**

(d) Using the information above, calculate the value of the molar mass of the unknown gas. **40.1 g/mol**

After the experiment was completed, the instructor informed the student that the unknown gas was carbon dioxide (44.0 g mol^{-1}).

(e) Calculate the percent error in the value of the molar mass calculated in part (d). **8.9%**

(f) For each of the following two possible occurrences, indicate whether it by itself could have been responsible for the error in the student's experimental result. You need not include any calculations with your answer. For each of the possible occurrences, justify your answer.

Occurrence 1: The flask was incompletely flushed with $CO_2(g)$, resulting in some dry air remaining in the flask. **This occurrence could have been responsible. The dry air left in the flask is less dense (or has a lower molar mass) than $\mathbf{CO_2}$ gas at the given *T* and *P*. This would result in a lower mass of gas in the flask and a lower result for the molar mass of the unknown gas.**

Occurrence 2: The temperature of the air was 23.0°C, but the temperature of the $CO_2(g)$ was lower than the reported 23.0°C. **This occurrence could not have been responsible. The density of CO_2 is greater at the lower temperature. A larger mass of CO_2 would be in the flask than if the CO_2 had been at 23.0°C, resulting in a higher calculated molar mass for the unknown gas.**

(g) Describe the steps of a laboratory method that the student could use to verify that the volume of the rigid flask is 843 mL at 23.0°C. You need not include any calculations with your answer.
Valid methods include the following:
1. Find the mass of the empty flask. Fill the flask with a liquid of known density (e.g., water at 23°C), and measure the mass of the liquid-filled flask. Subtract to find the mass of the liquid. Using the known density and mass, calculate the volume.
2. Measure 843 mL of a liquid (e.g., water) in a 1,000 mL graduated cylinder and transfer the liquid quantitatively into the flask to see if the water fills the flask completely.

2009B – #3

$$2\ H_2O_2(aq) \rightarrow 2\ H_2O(l) + O_2(g)$$

The mass of an aqueous solution of H_2O_2 is 6.951 g. The H_2O_2 in the solution decomposes completely according to the reaction represented above. The $O_2(g)$ produced is collected in an inverted graduated tube over water at 23.4°C and has a volume of 182.4 mL when the water levels inside and outside of the tube are the same. The atmospheric pressure in the lab is 762.6 torr, and the equilibrium vapor pressure of water at 23.4°C is 21.6 torr.
(a) Calculate the partial pressure, in torr, of $O_2(g)$ in the gas-collection tube. **741.0 torr**
(b) Calculate the number of moles of $O_2(g)$ produced in the reaction. **7.304×10^{-3} mol**
(c) Calculate the mass, in grams, of H_2O_2 that decomposed. **0.497 g H_2O_2**
(d) Calculate the percent of H_2O_2, by mass, in the original 6.951 g aqueous sample. **7.15%**
(e) Write the oxidation number of the oxygen atoms in H2O2 and the oxidation number of the oxygen atoms in O_2 in the appropriate cells in the table below.

Substance	Oxidation Number of Oxygen Atoms
H_2O_2	**-1**
O_2	**0**

(f) Write the balanced oxidation half-reaction for the reaction. **$H_2O_2(aq) \rightarrow O_2(g) + 2\ H^+(aq) + 2e^-$**