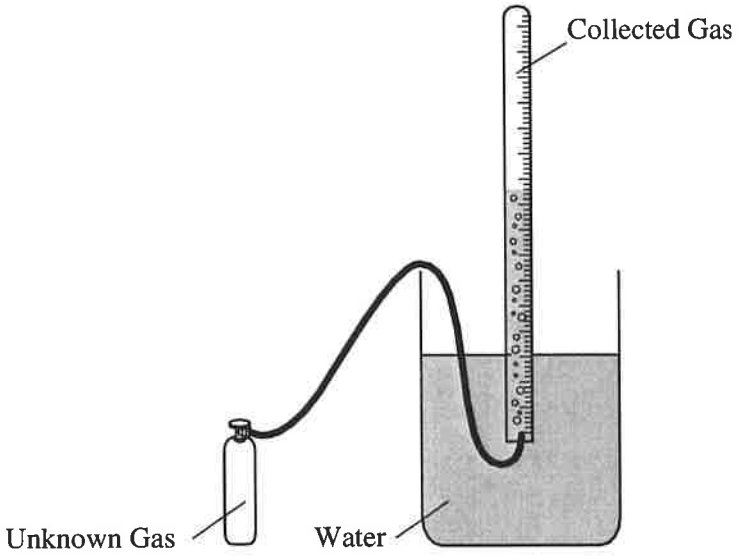
Your responses to the rest of the questions in this part of the examination will be graded on the basis of the accuracy and relevance of the information cited. Explanations should be clear and well organized. Examples and equations may be included in your responses where appropriate. Specific answers are preferable to broad, diffuse responses.

Answer BOTH Question 5 below AND Question 6 printed on the next page. Both of these questions will be graded. The Section II score weighting for these questions is 30 percent (15 percent each).




5. A student performs an experiment to determine the molar mass of an unknown gas. A small amount of the pure gas is released from a pressurized container and collected in a graduated tube over water at room temperature, as shown in the diagram above. The collection tube containing the gas is allowed to stand for several minutes, and its depth is adjusted until the water levels inside and outside the tube are the same. Assume that:

- the gas is not appreciably soluble in water
- the gas collected in the graduated tube and the water are in thermal equilibrium
- a barometer, a thermometer, an analytical balance, and a table of the equilibrium vapor pressure of water at various temperatures are also available.

(a) Write the equation(s) needed to calculate the molar mass of the gas. (start with $pv = nRT$)

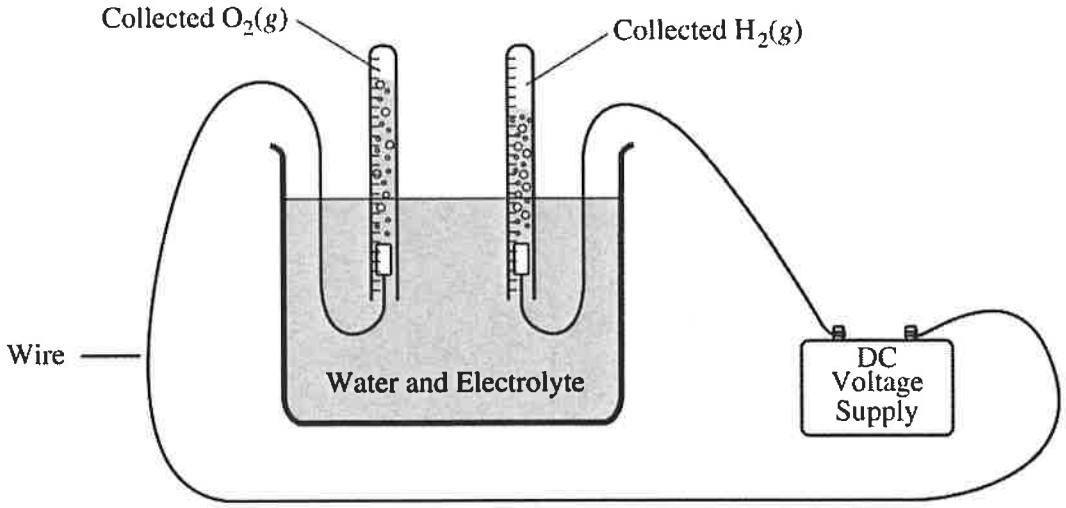
(b) List the measurements that must be made in order to calculate the molar mass of the gas.

(c) Explain the purpose of equalizing the water levels inside and outside the gas collection tube.

(d) The student determines the molar mass of the gas to be 64 g $mol^{-1}$. Write the expression (set-up) for calculating the percent error in the experimental value, assuming that the unknown gas is butane (molar mass 58 g $mol^{-1}$). Calculations are not required.

(e) If the student fails to use information from the table of the equilibrium vapor pressures of water in the calculation, the calculated value for the molar mass of the unknown gas will be smaller than the actual value. Explain.

Answer EITHER Question 2 below OR Question 3 printed on pages 8 and 9. Only one of these two questions will be graded. If you start both questions, be sure to cross out the question you do not want graded. The Section II score weighting for the question you choose is 20 percent.




2. Water was electrolyzed, as shown in the diagram above, for 5.61 minutes using a constant current of 0.513 ampere. A small amount of nonreactive electrolyte was added to the container before the electrolysis began. The temperature was 298 K and the atmospheric pressure was 1.00 atm.

   (a) Write the balanced equation for the half reaction that took place at the anode.

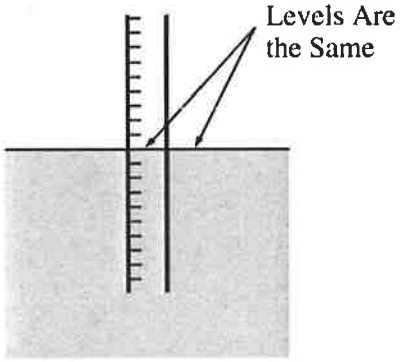
   (b) Calculate the amount of electric charge, in coulombs, that passed through the solution.

   (c) Why is the volume of $O_2(g)$ collected different from the volume of $H_2(g)$ collected, as shown in the diagram?

   (d) Calculate the number of moles of $H_2(g)$ produced during the electrolysis.

   (e) Calculate the volume, in liters, at 298 K and 1.00 atm of dry $H_2(g)$ produced during the electrolysis.

   (f) After the hydrolysis reaction was over, the vertical position of the tube containing the collected $H_2(g)$ was adjusted until the water levels inside and outside the tube were the same, as shown in the diagram below. The volume of gas in the tube was measured under these conditions of 298 K and 1.00 atm, and its volume was greater than the volume calculated in part (e). Explain.



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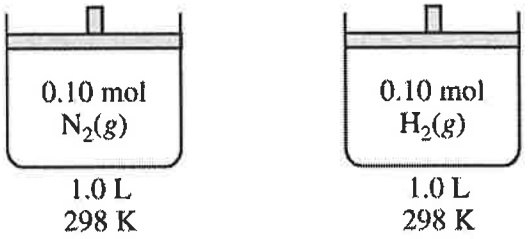



6. Consider two containers of volume 1.0 L at 298 K, as shown above. One container holds 0.10 mol $N_2(g)$ and the other holds 0.10 mol $H_2(g)$. The average kinetic energy of the $N_2(g)$ molecules is $6.2 \times 10^{-21}$ J. Assume that the $N_2(g)$ and the $H_2(g)$ exhibit ideal behavior.

(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.

(b) What is the average kinetic energy of the $H_2(g)$ molecules?

(c) The molecules of which gas, $N_2$ or $H_2$, have the greater average speed? Justify your answer.

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

(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

(ii) The average speed of the $H_2(g)$ molecules

$$8\ H^+(aq) + 4\ Cl^-(aq) + MnO_4^-(aq) \rightarrow 2\ Cl_2(g) + Mn^{3+}(aq) + 4\ H_2O(l)$$

3. $Cl_2(g)$ can be generated in the laboratory by reacting potassium permanganate with an acidified solution of sodium chloride. The net-ionic equation for the reaction is given above.

★ (a) A 25.00 mL sample of 0.250 *M* NaCl reacts completely with excess $KMnO_4(aq)$. The $Cl_2(g)$ produced is dried and stored in a sealed container. At 22°C the pressure of the $Cl_2(g)$ in the container is 0.950 atm.

(i) Calculate the number of moles of $Cl^-(aq)$ present before any reaction occurs.

(ii) Calculate the volume, in L, of the $Cl_2(g)$ in the sealed container.

An initial-rate study was performed on the reaction system. Data for the experiment are given in the table below.

| Trial | $[Cl^-]$ | $[MnO_4^-]$ | $[H^+]$ | Rate of Disappearance of $MnO_4^-$ in $M\ s^{-1}$ |
|---|---|---|---|---|
| 1 | 0.0104 | 0.00400 | 3.00 | $2.25 \times 10^{-8}$ |
| 2 | 0.0312 | 0.00400 | 3.00 | $2.03 \times 10^{-7}$ |
| 3 | 0.0312 | 0.00200 | 3.00 | $1.02 \times 10^{-7}$ |

(b) Using the information in the table, determine the order of the reaction with respect to each of the following. Justify your answers.

(i) $Cl^-$

(ii) $MnO_4^-$

(c) The reaction is known to be third order with respect to $H^+$. Using this information and your answers to part (b) above, complete both of the following:

(i) Write the rate law for the reaction.

(ii) Calculate the value of the rate constant, $k$, for the reaction, including appropriate units.

(d) Is it likely that the reaction occurs in a single elementary step? Justify your answer.

**STOP**

**If you finish before time is called, you may check your work on this part only.**
**Do not turn to the other part of the test until you are told to do so.**

6. In an experiment, all the air in a rigid 2.0 L flask is pumped out. Then some liquid ethanol is injected into the sealed flask, which is held at 35°C. The amount of liquid ethanol initially decreases, but after five minutes the amount of liquid ethanol in the flask remains constant. Ethanol has a boiling point of 78.5°C and an equilibrium vapor pressure of 100 torr at 35°C.

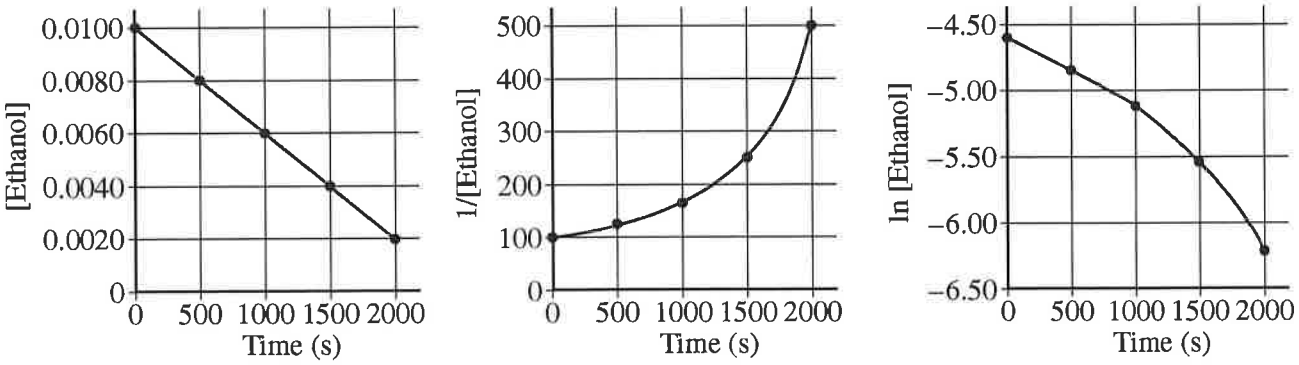
(a) When the amount of liquid ethanol in the flask is constant, is the pressure in the flask greater than, less than, or equal to 100 torr? Justify your answer.

(b) The flask is then heated to 45°C, and the pressure in the flask increases. In terms of kinetic molecular theory, provide TWO reasons that the pressure in the flask is greater at 45°C than at 35°C.

In a second experiment, which is performed at a much higher temperature, a sample of ethanol gas and a copper catalyst are placed in a rigid, empty 1.0 L flask. The temperature of the flask is held constant, and the initial concentration of the ethanol gas is 0.0100 *M*. The ethanol begins to decompose according to the chemical reaction represented below.

$$CH_3CH_2OH(g) \xrightarrow{Cu} CH_3CHO(g) + H_2(g)$$

The concentration of ethanol gas over time is used to create the three graphs below.




(c) Given that the reaction order is zero, one, or two, use the information in the graphs to respond to the following.

(i) Determine the order of the reaction with respect to ethanol. Justify your answer.

(ii) Write the rate law for the reaction.

(iii) Determine the rate constant for the reaction, including units.

(d) The pressure in the flask at the beginning of the experiment is 0.40 atm. If the ethanol completely decomposes, what is the final pressure in the flask?

**STOP**

**END OF EXAM**

2. An 8.55 mol sample of methanol, $CH_3OH$, is placed in a 15.0 L evacuated rigid tank and heated to 327°C. At that temperature, all of the methanol is vaporized and some of the methanol decomposes to form carbon monoxide gas and hydrogen gas, as represented in the equation below.

$$CH_3OH(g) \rightleftarrows CO(g) + 2\,H_2(g)$$

(a) The reaction mixture contains 6.30 mol of $CO(g)$ at equilibrium at 327°C.

(i) Calculate the number of moles of $H_2(g)$ in the tank.

(ii) Calculate the number of grams of $CH_3OH(g)$ remaining in the tank.

iii) Calculate the mole fraction of $H_2(g)$ in the tank.

(iv) Calculate the total pressure, in atm, in the tank at 327°C.

(b) Consider the three gases in the tank at 327°C: $CH_3OH(g)$, $CO(g)$, and $H_2(g)$.

(i) How do the average kinetic energies of the molecules of the gases compare? Explain.

(ii) Which gas has the highest average molecular speed? Explain.

(c) The tank is cooled to 25°C, which is well below the boiling point of methanol. It is found that small amounts of $H_2(g)$ and $CO(g)$ have dissolved in the liquid $CH_3OH$. Which of the two gases would you expect to be more soluble in methanol at 25°C ? Justify your answer.

2. A sample of a pure, gaseous hydrocarbon is introduced into a previously evacuated rigid 1.00 L vessel. The pressure of the gas is 0.200 atm at a temperature of 127°C.

(a) Calculate the number of moles of the hydrocarbon in the vessel.

(b) $O_2(g)$ is introduced into the same vessel containing the hydrocarbon. After the addition of the $O_2(g)$, the total pressure of the gas mixture in the vessel is 1.40 atm at 127°C. Calculate the partial pressure of $O_2(g)$ in the vessel.

The mixture of the hydrocarbon and oxygen is sparked so that a complete combustion reaction occurs, producing $CO_2(g)$ and $H_2O(g)$. The partial pressures of these gases at 127°C are 0.600 atm for $CO_2(g)$ and 0.800 atm for $H_2O(g)$. There is $O_2(g)$ remaining in the container after the reaction is complete.

(c) Use the partial pressures of $CO_2(g)$ and $H_2O(g)$ to calculate the partial pressure of the $O_2(g)$ consumed in the combustion.

(d) On the basis of your answers above, write the balanced chemical equation for the combustion reaction and determine the formula of the hydrocarbon.

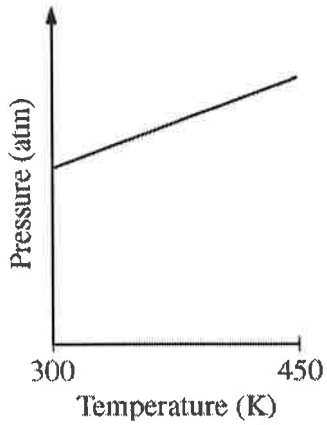
(e) Calculate the mass of the hydrocarbon that was combusted.

(f) As the vessel cools to room temperature, droplets of liquid water form on the inside walls of the container. Predict whether the pH of the water in the vessel is less than 7, equal to 7, or greater than 7. Explain your prediction.

Answer Question 5 and Question 6. The Section II score weighting for these questions is 15 percent each.

Your responses to these questions will be scored on the basis of the accuracy and relevance of the information cited. Explanations should be clear and well organized. Examples and equations may be included in your responses where appropriate. Specific answers are preferable to broad, diffuse responses.

5. A sample of $C_2H_4(g)$ is placed in a previously evacuated, rigid 2.0 L container and heated from 300 K to 450 K. The pressure of the sample is measured and plotted in the graph below.




☆ (a) Describe TWO reasons why the pressure changes as the temperature of the $C_2H_4(g)$ increases. Your descriptions must be in terms of what occurs at the molecular level.

$C_2H_4(g)$ reacts readily with $HCl(g)$ to produce $C_2H_5Cl(g)$, as represented by the following equation.

$$C_2H_4(g) + HCl(g) \rightarrow C_2H_5Cl(g) \qquad \Delta H^\circ = -72.6 \text{ kJ/mol}_{rxn}$$

(b) When $HCl(g)$ is injected into the container of $C_2H_4(g)$ at 450 K, the total pressure increases. Then, as the reaction proceeds at 450 K, the total pressure decreases. Explain this decrease in total pressure in terms of what occurs at the molecular level.

It is proposed that the formation of $C_2H_5Cl(g)$ proceeds via the following two-step reaction mechanism.

Step 1: $C_2H_4(g) + HCl(g) \rightarrow C_2H_5^+(g) + Cl^-(g)$ *rate-determining step*

Step 2: $C_2H_5^+(g) + Cl^-(g) \rightarrow C_2H_5Cl(g)$ *fast step*

(c) Write the rate law for the reaction that is consistent with the reaction mechanism above.

(d) Identify an intermediate in the reaction mechanism above.