CollegeBoard
Advanced Placement Program

AP® Chemistry
2005 Scoring Guidelines
Form B

Question 1

$$K_a = \frac{[H_3O^+][OCl^-]}{[HOCl]} = 3.2 \times 10^{-8}$$

Hypochlorous acid, HOCl, is a weak acid in water. The K_a expression for HOCl is shown above.

(a) Write a chemical equation showing how HOCl behaves as an acid in water.

$HOCl(aq) + H_2O(l) \rightarrow OCl^-(aq) + H_3O^+(aq)$	One point is earned for the correct chemical equation.

(b) Calculate the pH of a 0.175 *M* solution of HOCl.

$HOCl(aq) + H_2O(l) \rightleftarrows OCl^-(aq) + H_3O^+(aq)$ I: 0.175, –, 0, ~ 0 C: $-x$, –, $+x$, $+x$ E: $0.175 - x$, –, $+x$, $+x$ $K_a = \frac{[H_3O^+][OCl^-]}{[HOCl]} = \frac{(x)(x)}{(0.175 - x)}$ Assume that $0.175 - x \approx 0.175$ $3.2 \times 10^{-8} = \frac{x^2}{0.175}$ $x^2 = (3.2 \times 10^{-8})(0.175) = 5.6 \times 10^{-9}$ $x = [H_3O^+] = 7.5 \times 10^{-5}\ M$ $pH = -\log[H_3O^+] = -\log(7.5 \times 10^{-5}) = 4.13$	One point is earned for calculating the value of $[H_3O^+]$. One point is earned for calculating the pH.

(c) Write the net ionic equation for the reaction between the weak acid HOCl(*aq*) and the strong base NaOH(*aq*).

$HOCl(aq) + OH^-(aq) \rightarrow OCl^-(aq) + H_2O(l)$	One point is earned for both of the correct reactants. One point is earned for both of the correct products.

(d) In an experiment, 20.00 mL of 0.175 *M* HOCl(*aq*) is placed in a flask and titrated with 6.55 mL of 0.435 *M* NaOH(*aq*).

(i) Calculate the number of moles of NaOH(*aq*) added.

$mol_{NaOH} = 6.55\text{ mL} \times \frac{1\text{ L}}{1{,}000\text{ mL}} \times \frac{0.435\text{ mol NaOH}}{1\text{ L}}$ $mol_{NaOH} = 2.85 \times 10^{-3}$ mol NaOH	One point is earned for the correct number of moles of NaOH.

Question 1 (continued)

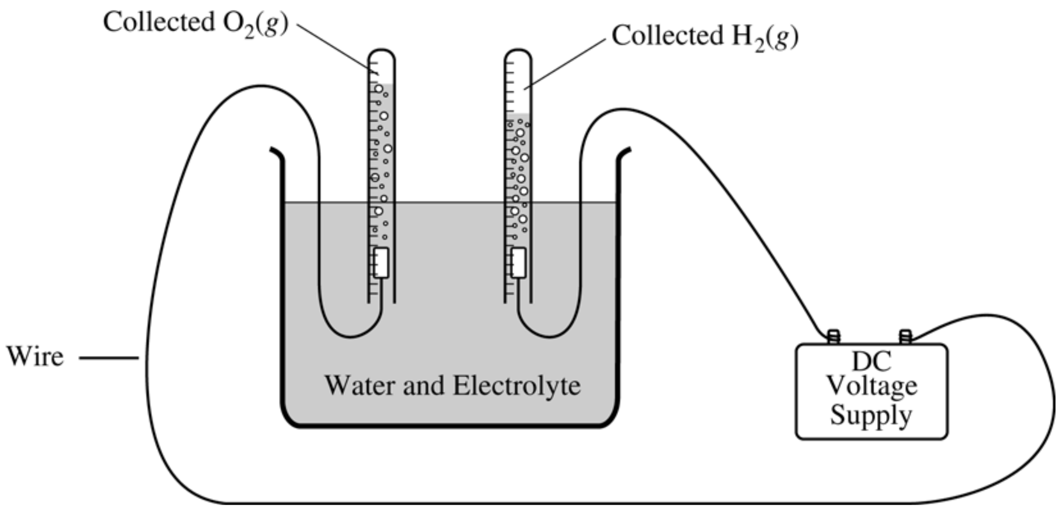
(ii) Calculate $[H_3O^+]$ in the flask after the $NaOH(aq)$ has been added.

$\text{mol}_{HOCl} = 20.00 \text{ mL} \times \frac{1 \text{ L}}{1{,}000 \text{ mL}} \times \frac{0.175 \text{ mol NaOH}}{1 \text{ L}} = 3.50 \times 10^{-3} \text{ mol}$ $OH^-(aq)$ is the limiting reactant, therefore all of it reacts	One point is earned for calculating the initial number of moles of HOCl.
$HOCl(aq) + OH^-(aq) \rightarrow OCl^-(aq) + H_2O(l)$ I: 0.00350, 0.00285, 0, – C: −0.00285, − 0.00285, + 0.00285, – E: 0.00065, 0, 0.00285, – $M_{HOCl} = \frac{0.00065 \text{ mol}}{0.02655 \text{ L}} = 0.0245\ M$ $M_{OCl^-} = \frac{0.00285 \text{ mol}}{0.02655 \text{ L}} = 0.107\ M$ $HOCl(aq) + H_2O(l) \rightarrow H_3O^+(aq) + OCl^-(aq)$ I: 0.0245, –, ~0, 0.107 C: $-x$, –, $+x$, $+x$ E: $0.0245 - x$, –, $+x$, $0.107 + x$	One point is earned for the concentration or number of moles of HOCl and OCl^- after the neutralization reaction.
$K_a = \frac{[H_3O^+][OCl^-]}{[HOCl]} = \frac{(x)(0.107+x)}{(0.0245-x)}$ Assume that $0.107 + x \approx 0.107$ and that $0.0245 - x \approx 0.0245$ $3.2 \times 10^{-8} = \frac{(x)(0.107)}{(0.0245)}$ $x = [H_3O^+] = 7.3 \times 10^{-9}\ M$	One point is earned for the correct $[H_3O^+]$.

(iii) Calculate $[OH^-]$ in the flask after the $NaOH(aq)$ has been added.

$[H_3O^+][OH^-] = 1.0 \times 10^{-14} = K_w$ $[OH^-] = \frac{1.0\times10^{-14}}{[H_3O^+]} = \frac{1.0\times10^{-14}}{7.3\times10^{-9}} = 1.4 \times 10^{-6}\ M$	One point is earned for the correct concentration of OH^-.

Question 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.

$2\ H_2O(l) \rightarrow O_2(g) + 4\ H^+(aq) + 4\ e^-$	One point is earned for the correct half reaction.

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

$0.513 \text{ amp} = 0.513\ \frac{\text{coul}}{\text{sec}}$ electric charge $= \left(0.513\ \frac{\text{coul}}{\text{sec}}\right) \times (5.61 \text{ min}) \times \left(\frac{60 \text{ sec}}{1 \text{ min}}\right) = 173$ coulombs	One point is earned for the setup. One point is earned for the answer.

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

When water decomposes according to the balanced chemical equation $2\ H_2O(l) \rightarrow O_2(g) + 2\ H_2(g)$, twice as many moles of hydrogen are produced than moles of oxygen.	One point is earned for the correct explanation based on the stoichiometry of the decomposition reaction.

Question 2 (continued)

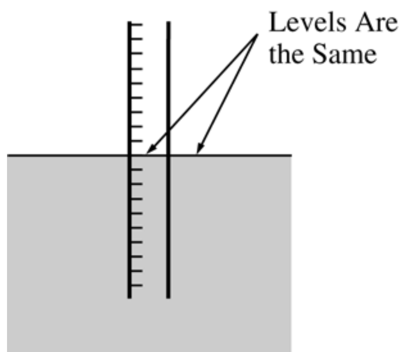
(d) Calculate the number of moles of $H_2(g)$ produced during the electrolysis.

The half-reaction that takes place at the cathode is: $$2\ H_2O(l) + 2\ e^- \rightarrow H_2(g) + OH^-(aq)$$ $$\text{mol}_{H_2} = 173 \text{ coulombs} \times \left(\frac{1 \text{ mol } e^-}{96{,}500 \text{ coulomb}}\right) \times \left(\frac{1 \text{ mol } H_2(g)}{2 \text{ mol } e^-}\right)$$ $$\text{mol}_{H_2} = 8.96 \times 10^{-4} \text{ mol}$$	One point is earned for the number of coulombs. One point is earned for recognizing the 1 **:** 2 stoichiometry.

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

$$V_{H_2} = \frac{n_{H_2}RT}{P}$$ $$V_{H_2} = \frac{(8.96 \times 10^{-4} \text{ mol}) \times \left(0.0821 \frac{\text{L atm}}{\text{mol K}}\right) \times (298 \text{ K})}{1 \text{ atm}} = 0.0219 \text{ L}$$	One point is earned for the substitution into the gas law equation. One point is earned for the correct answer.

(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 <u>greater</u> than the volume calculated in part (e). Explain.



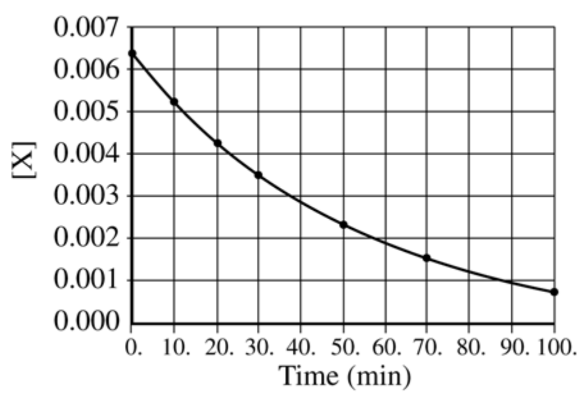
Because the electrolysis of water occurs in water, there is some water vapor in the tube of $H_2(g)$ that was collected. The volume calculated in part (e) was the volume of only the $H_2(g)$ in the tube at the given temperature and pressure. The presence of another gas (water vapor) results in a greater volume at the given temperature and pressure.	One point is earned for recognizing that there is some water vapor in the sample of hydrogen gas.

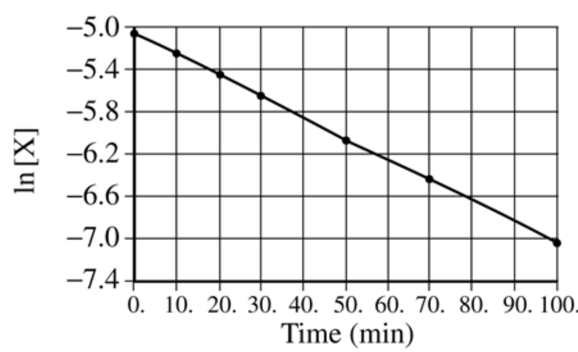
Question 3

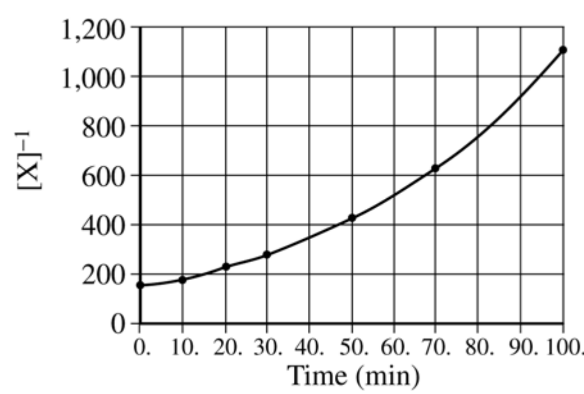
$$X \rightarrow 2\,Y + Z$$

The decomposition of gas X to produce gases Y and Z is represented by the equation above. In a certain experiment, the reaction took place in a 5.00 L flask at 428 K. Data from this experiment were used to produce the information in the table below, which is plotted in the graphs that follow.

Time (minutes)	[X] (mol L^{-1})	ln [X]	$[X]^{-1}$ (L mol^{-1})
0	0.00633	–5.062	158
10.	0.00520	–5.259	192
20.	0.00427	–5.456	234
30.	0.00349	–5.658	287
50.	0.00236	–6.049	424
70.	0.00160	–6.438	625
100.	0.000900	–7.013	1,110







(a) How many moles of X were initially in the flask?

[X] at 0 minutes = 0.00633, so $5.00\text{ L} \times 0.00633\ \dfrac{\text{mol X}}{\text{L}} = 3.17 \times 10^{-2}\text{ mol X}$	One point is earned for correct number of moles of X.

Question 3 (continued)

(b) How many molecules of Y were produced in the first 20. minutes of the reaction?

After 20. minutes of reaction, the number of moles of X remaining in the flask is $(5.00\text{ L}) \times (0.00427\ \frac{\text{mol X}}{\text{L}}) = 2.14 \times 10^{-2}$ mol X . Then the number of moles of X that reacted in the first 20 minutes is $(3.17 \times 10^{-2}\text{ mol X}) - (2.14 \times 10^{-2}\text{ mol X}) = 1.03 \times 10^{-2}$ mol X.	One point is earned for the number of moles of X that react or for the correct stoichiometry between X and Y.
Thus the number of molecules of Y produced in the first 20. minutes is $(1.03 \times 10^{-2}\text{ mol X}) \times \left(\frac{2\text{ mol Y produced}}{1\text{ mol X reacted}}\right) \times \left(\frac{6.02 \times 10^{23}\text{ molecules Y}}{1\text{ mol Y}}\right)$ $= 1.24 \times 10^{22}$ molecules Y produced	One point is earned for the number of molecules of Y produced.

(c) What is the order of this reaction with respect to X ? Justify your answer.

The reaction is first order with respect to X because a plot of ln [X] versus time produces a straight line with a negative slope.	One point is earned for the correct order and an explanation.

(d) Write the rate law for this reaction.

rate $= k[\text{X}]^1$	One point is earned for the rate law consistent with part (c).

(e) Calculate the specific rate constant for this reaction. Specify units.

$\ln \frac{[\text{X}]_t}{[\text{X}]_0} = -kt$ From the first two data points, $\ln\left(\frac{0.00520}{0.00633}\right) = -k\ (10\text{ min})$ $k = -\left(\frac{\ln 0.821}{10\text{ min}}\right) = 0.0197\text{ min}^{-1}$	One point is earned for the magnitude of the rate constant. One point is earned for the units.

Question 3 (continued

(f) Calculate the concentration of X in the flask after a total of 150. minutes of reaction.

$\ln \frac{[X]_t}{[X]_0} = -kt$ means the same thing as $\ln [X]_t - \ln[X]_0 = -kt$ $\ln [X]_{150} - \ln (0.00633) = -(0.0197 \text{ min}^{-1})(150 \text{ minutes})$ $\ln [X]_{150} = -(0.0197 \text{ min}^{-1})(150 \text{ minutes}) + \ln (0.00633)$ $\ln [X]_{150} = -(0.0197 \text{ min}^{-1})(150 \text{ minutes}) + (-5.062)$ $\ln [X]_{150} = -2.955 + (-5.062) = -8.017$ $e^{\ln[X]_{150}} = e^{-8.017} = 3.30 \times 10^{-4}$ [X] at 150. minutes = 3.30×10^{-4} *M*	One point is earned for substituting into the integrated rate law. One point is earned for the correct concentration of X.

Question 4

Write the formulas to show the reactants and the products for any FIVE of the laboratory situations described below. Answers to more than five choices will not be graded. In all cases, a reaction occurs. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solution as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. You need not balance the equations.

General Scoring: Three points are earned for each: 1 point for correct reactant(s) and 2 points for correct product(s).

(a) A solution of potassium carbonate is added a solution of strontium nitrate.

$$CO_3^{2-} + Sr^{2+} \rightarrow SrCO_3$$

(b) Propene is burned in air.

$$C_3H_6 + O_2 \rightarrow CO_2 + H_2O$$

(c) Excess ammonia is added to a solution of zinc nitrate.

$$NH_3 + Zn^{2+} \rightarrow Zn(NH_3)_6^{2+}$$

(d) Ethanoic acid (acetic acid) is added to a solution of barium hydroxide.

$$OH^- + HC_2H_3O_2 \rightarrow C_2H_3O_2^- + H_2O$$

(e) A small piece of potassium is added to water.

$$K + H_2O \rightarrow OH^- + H_2 + K^+$$

(f) Powdered iron metal is strongly heated with powdered sulfur.

$$Fe + S \rightarrow FeS$$

Note: Fe_2S_3 also acceptable as a product

(g) A solution of sodium fluoride is added to a solution of hydrochloric acid.

$$H^+ + F^- \rightarrow HF$$

(h) A strip of lead metal is added to a solution of silver nitrate.

$$Pb + Ag^+ \rightarrow Pb^{2+} + Ag$$

Question 5

$$2\ Al(s) + 2\ KOH(aq) + 4\ H_2SO_4(aq) + 22\ H_2O(l) \rightarrow 2\ KAl(SO_4)_2{\cdot}12H_2O(s) + 3\ H_2(g)$$

In an experiment, a student synthesizes alum, $KAl(SO_4)_2{\cdot}12H_2O(s)$, by reacting aluminum metal with potassium hydroxide and sulfuric acid, as represented in the balanced equation above.

(a) In order to synthesize alum, the student must prepare a 5.0 *M* solution of sulfuric acid. Describe the procedure for preparing 50.0 mL of 5.0 *M* H_2SO_4 using any of the chemicals and equipment listed below. Indicate specific amounts and equipment where appropriate.

10.0 *M* H_2SO_4	50.0 mL volumetric flask
Distilled water	50.0 mL buret
100 mL graduated cylinder	25.0 mL pipet
100 mL beaker	50 mL beaker

$(50.0\text{ mL})\left(\frac{1\text{ L}}{1{,}000\text{ mL}}\right)\left(\frac{5.0\text{ mol }H_2SO_4}{1\text{ L}}\right) = 0.25\text{ mol }H_2SO_4$ $(0.25\text{ mol }H_2SO_4)\left(\frac{1\text{ L}}{10.0\text{ mol }H_2SO_4}\right)\left(\frac{1{,}000\text{ mL}}{1\text{ L}}\right) = 25.0\text{ mL of }10.0\ M\ H_2SO_4$ Put on goggles. Measure approximately 20 mL of distilled water using the 100 mL graduated cylinder, and add the distilled water to the 50.0 mL volumetric flask. Measure 25.0 mL of the 10.0 *M* H_2SO_4 using the 25.0 mL pipet, and transfer the concentrated acid slowly, with occasional swirling , to the 50.0 mL volumetric flask containing the distilled water. After adding all the concentrated acid, carefully add distilled water until the meniscus of the solution is at the 50.0 mL mark on the neck of the flask at 20°C.	One point is earned for the volume of 10.0 *M* H_2SO_4. One point is earned for using a volumetric flask and the pipet. One point is earned for adding the acid to the water. One point is earned for filling to the mark with water.

(b) Calculate the minimum volume of 5.0 *M* H_2SO_4 that the student must use to react completely with 2.7 g aluminum metal.

$V_{H_2SO_4} = (2.7\text{ g Al})\left(\frac{1\text{ mol Al}}{27.0\text{ g Al}}\right)\left(\frac{4\text{ mol }H_2SO_4}{2\text{ mol Al}}\right)\left(\frac{1\text{ L}}{5.0\text{ mol }H_2SO_4}\right)$ $V_{H_2SO_4} = 0.040\text{ L}$	One point is earned for the number of moles of Al. One point is earned for the correct stoichiometry. One point is earned for the answer.

Question 5 (continued)

(c) As the reaction solution cools, alum crystals precipitate. The student filters the mixture and dries the crystals, then measures their mass.

(i) If the student weighs the crystals before they are completely dry, would the calculated percent yield be greater than, less than, or equal to the actual percent yield? Explain.

If the $KAl(SO_4)_2 \cdot 12H_2O(s)$ crystals have not been properly dried, there will be excess water present, making the mass of the product greater than it should be and the calculated percent yield too high. Therefore, the calculated percent yield will be greater than the actual percent yield.	One point is earned for the prediction and a correct explanation.

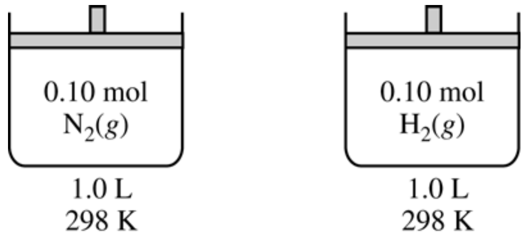
(ii) Cooling the reaction solution in an ice bath improves the percent yield obtained. Explain.

If the solubility of $KAl(SO_4)_2 \cdot 12H_2O(s)$ decreases with decreasing temperature, cooling the reaction solution would result in the precipitation of more $KAl(SO_4)_2 \cdot 12H_2O(s)$.	One point is earned for the correct explanation.

(d) The student heats crystals of pure alum, $KAl(SO_4)_2 \cdot 12H_2O(s)$, in an open crucible to a constant mass. The mass of the sample after heating is less than the mass before heating. Explain.

$KAl(SO_4)_2 \cdot 12H_2O(s)$ is a hydrate. For the mass of the sample to be less after heating, the water of hydration must be lost. Heating the sample of $KAl(SO_4)_2 \cdot 12H_2O(s)$ crystals will drive off the water first, decreasing the mass of the sample.	One point is earned for the correct explanation.

Question 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 6.2×10^{-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.

The pressure in the container holding the $H_2(g)$ is equal to the pressure in the container holding the $N_2(g)$ because there is an equal number of moles of both gases at the same temperature and volume ($P = nK$, *where the constant* $K = \frac{RT}{V}$).	One point is earned for the correct choice. One point is earned for the correct explanation.

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

The average kinetic energy of the $H_2(g)$ molecules is 6.2×10^{-21} J because both gases are at the same temperature.	One point is earned for the correct energy.

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

$H_2(g)$ molecules will have the greater average speed. Both gases have the same average kinetic energy, but $H_2(g)$ has the smaller molar mass. Therefore, the $H_2(g)$ molecules will have a greater average speed because, at a given temperature , the average (root-mean-square) speed of gas molecules is inversely proportional to the square root of the molar mass of the gas: $u_{rms} = \left(\sqrt{3RT}\right)\frac{1}{\sqrt{\mathbf{M}}}$	One point is earned for the correct answer with an explanation.

Question 6 (continued)

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

The average kinetic energy of a gas particle depends on the temperature of the gas sample. To decrease the average kinetic energy of the gas particles in a gas sample, the temperature of the $N_2(g)$ would have to be lowered.	One point is earned for the correct answer with an explanation.

(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

The pressure would be doubled. PV is a constant when the temperature and number of moles of gas are held constant. Therefore, if the volume is halved the pressure is doubled. $P_1V_1 = P_2V_2$ If $V_2 = \frac{1}{2}V_1$, then $P_1V_1 = P_2\left(\frac{1}{2}V_1\right) \Rightarrow P_1 = P_2\left(\frac{1}{2}\right) \Rightarrow$ $P_2 = 2P_1$	One point is earned for the correct answer. One point is earned for the correct explanation.

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

The average speed is unchanged when the volume of the gas sample is halved. Average speed depends on changes in temperature, not changes in volume.	One point is earned for the correct answer with an explanation.

Question 7

Answer the following questions about thermodynamics.

Substance	Combustion Reaction	Enthalpy of Combustion, ΔH°_{comb}, at 298 K (kJ mol^{-1})
$H_2(g)$	$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$	–290
$C(s)$	$C(s) + O_2(g) \rightarrow CO_2(g)$	–390
$CH_3OH(l)$		–730

(a) In the empty box in the table above, write a balanced chemical equation for the complete combustion of <u>one</u> mole of $CH_3OH(l)$. Assume products are in their standard states at 298 K. Coefficients do not need to be in whole numbers.

$CH_3OH(l) + \frac{3}{2}O_2(g) \rightarrow CO_2(g) + 2\,H_2O(l)$	One point is earned for the correct products. One point is earned for balancing the equation.

(b) On the basis of your answer to part (a) and the information in the table, determine the enthalpy change for the reaction $C(s) + H_2(g) + H_2O(l) \rightarrow CH_3OH(l)$.

Adding the following three equations, $C(s) + O_2(g) \rightarrow CO_2(g)$ –390 kJ mol^{-1} $H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$ –290 kJ mol^{-1} $CO_2(g) + 2\,H_2O(l) \rightarrow CH_3OH(l) + \frac{3}{2}O_2(g)$ +730 kJ mol^{-1} yields this equation: $C(s) + H_2(g) + H_2O(l) \rightarrow CH_3OH(l)$ +50 kJ mol^{-1}	One point is earned for the correct equations. One point is earned for the correct value of ΔH°.

(c) Write the balanced chemical equation that shows the reaction that is used to determine the enthalpy of formation for one mole of $CH_3OH(l)$.

$C(s) + 2\,H_2(g) + \frac{1}{2}O_2(g) \rightarrow CH_3OH(l)$	One point is earned for the correct equation.

Question 7 (continued)

(d) Predict the sign of $\Delta S°$ for the combustion of $H_2(g)$. Explain your reasoning.

$\Delta S°$ for the combustion of $H_2(g)$ is negative. Both reactants are in the gas phase and the product is in the liquid phase. The liquid phase is much more ordered than the gas phase, so the product is more ordered compared to the reactants, meaning that $\Delta S°$ is negative. (Note: There are fewer moles of products than reactants, which also favors a more ordered condition in the products, but the difference in phases is the more important factor.)	One point is earned for the correct sign of $\Delta S°$. One point is earned for a correct explanation.

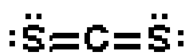
(e) On the basis of bond energies, explain why the combustion of $H_2(g)$ is exothermic.

The combustion of $H_2(g)$ is exothermic ($\Delta H° < 0$) because more energy is released during the formation of two moles of O–H bonds than is required to break one mole of H–H bonds and one-half of a mole of O–O bonds.	One point is earned for the correct explanation.

Question 8

Use principles of atomic structure, bonding, and intermolecular forces to answer the following questions. Your responses must include specific information about all substances referred to in each part.

(a) Draw a complete Lewis electron-dot structure for the CS_2 molecule. Include all valence electrons in your structure.

	One point is earned for the correct structure.

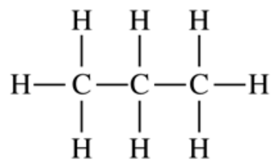
(b) The carbon-to-sulfur bond length in CS_2 is 160 picometers. Is the carbon-to-selenium bond length in CSe_2 expected to be greater than, less than, or equal to this value? Justify your answer.

The carbon-to-selenium bond length in CSe_2 is greater than the carbon-to-sulfur bond length in CS_2. Because the valence electrons in Se are in a higher shell $(n = 4)$ than the valence electrons in S $(n = 3)$, Se has a larger atomic radius than S has. Therefore, the carbon-to-selenium bond length is greater than the carbon-to-sulfur bond length.	One point is earned for indicating that the C-Se bond length is greater than the C-S bond length. One point is earned for indicating that Se is larger than S.

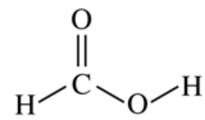
(c) The bond energy of the carbon-to-sulfur bond in CS_2 is 577 kJ mol^{-1}. Is the bond energy of the carbon-to-selenium bond in CSe_2 expected to be greater than, less than, or equal to this value? Justify your answer.

The carbon-to-selenium bond energy in CSe_2 is less than the carbon-to-sulfur bond energy in CS_2 because Se has a larger atomic radius than S. Because Se is a larger atom, the orbital overlap between the Se and C will be smaller than the orbital overlap between S and C.	One point is earned for indicating that the C-Se bond energy is less than the C-S bond energy. One point is earned for the explanation.

Question 8 (continued)



Propane



Methanoic Acid

(d) The complete structural formulas of propane, C_3H_8, and methanoic acid, HCOOH, are shown above. In the table below, write the type(s) of intermolecular attractive forces(s) that occur in each substance.

Substance	Boiling Point	Intermolecular Attractive Force(s)
Propane	229 K	
Methanoic acid	374 K	

Propane has dispersion forces. Methanoic acid has dispersion forces and hydrogen bonding forces.	One point is earned for IMFs in propane. One point is earned for IMFs in methanoic acid.

(e) Use principles of intermolecular attractive forces to explain why methanoic acid has a higher boiling point than propane.

Hydrogen bonding IMFs among methanoic acid molecules are much stronger than dispersion forces among propane molecules. The stronger the IMFs, the more energy it takes to overcome them. Therefore, methanoic acid has a higher boiling point than propane.	One point is earned for comparing the strengths of the IMFs.