2017

AP CollegeBoard

AP Chemistry

Sample Student Responses and Scoring Commentary

Inside:

- ☑ Free Response Question 1
- ☑ Scoring Guideline
- ☑ Student Samples
- ☑ Scoring Commentary

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AP® CHEMISTRY
2017 SCORING GUIDELINES

Question 1

$$CS_2(g) + 3\ Cl_2(g) \rightarrow CCl_4(g) + S_2Cl_2(g)$$

Carbon tetrachloride, $CCl_4(g)$, can be synthesized according to the reaction represented above. A chemist runs the reaction at a constant temperature of 120°C in a rigid 25.0 L container.

(a) Chlorine gas, $Cl_2(g)$, is initially present in the container at a pressure of 0.40 atm.

(i) How many moles of $Cl_2(g)$ are in the container?

$n = \frac{PV}{RT} = \frac{0.40\ \text{atm} \times 25.0\ \text{L}}{0.08206\ (\text{L} \cdot \text{atm})/(\text{mol} \cdot \text{K}) \times 393\ \text{K}} = 0.31\ \text{mol}\ Cl_2(g)$	1 point is earned for the correct answer with supporting work.

(ii) How many grams of carbon disulfide, $CS_2(g)$, are needed to react completely with the $Cl_2(g)$?

$0.31\ \text{mol}\ Cl_2 \times \frac{1\ \text{mol}\ CS_2}{3\ \text{mol}\ Cl_2} \times \frac{76.13\ \text{g}\ CS_2}{1\ \text{mol}\ CS_2} = 7.9\ \text{g}\ CS_2$	1 point is earned for using the correct mole ratio (may be implicit). 1 point is earned for the mass of CS_2.

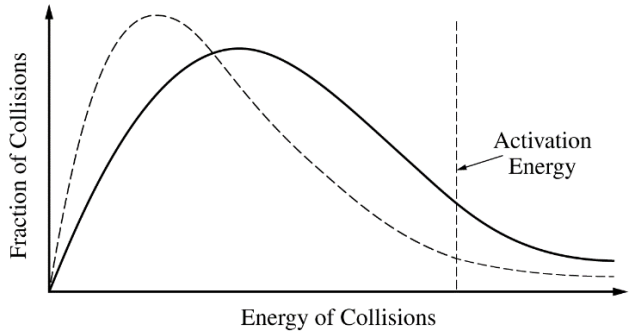
(b) At 30°C the reaction is thermodynamically favorable, but no reaction is observed to occur. However, at 120°C, the reaction occurs at an observable rate.

(i) Explain how the higher temperature affects the collisions between the reactant molecules so that the reaction occurs at an observable rate at 120°C.

At the higher temperature the particles have a greater average kinetic energy than at the lower temperature. Thus there are more collisions with sufficient energy to overcome the activation energy.	1 point is earned for an appropriate explanation that includes a reference to molecular collisions.

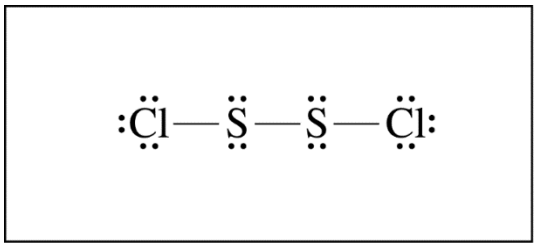
(ii) The graph below shows a distribution for the collision energies of reactant molecules at 120°C. Draw a second curve on the graph that shows the distribution for the collision energies of reactant molecules at 30°C.

Question 1 (continued)

	1 point is earned for a curve that has a peak above and to the left of the given curve. 1 point is earned for a curve that is below the given curve in the region beyond the activation energy.

(c) S_2Cl_2 is a product of the reaction.

(i) In the box below, complete the Lewis electron-dot diagram for the S_2Cl_2 molecule by drawing in all of the electron pairs.



See correct diagram above.	1 point is earned for a correctly drawn diagram.

(ii) What is the approximate value of the Cl–S–S bond angle in the S_2Cl_2 molecule that you drew in part (c)(i) ? (If the two Cl–S–S bond angles are not equal, include both angles.)

Any value between 104° and 110°	1 point is earned for an acceptable angle that is consistent with the Lewis diagram.

(d) $CCl_4(g)$ can also be produced by reacting $CHCl_3(g)$ with $Cl_2(g)$ at 400°C, as represented by the equation below.

$$CHCl_3(g) + Cl_2(g) \rightarrow CCl_4(g) + HCl(g)$$

At the completion of the reaction a chemist successfully separates the $CCl_4(g)$ from the $HCl(g)$ by cooling the mixture to 70°C, at which temperature the $CCl_4(g)$ condenses while the $HCl(g)$ remains in the gaseous state.

Question 1 (continued)

(i) Identify all types of intermolecular forces present in $HCl(l)$.

Dipole-dipole forces, London dispersion forces	1 point is earned for both types of forces.

(ii) What can be inferred about the relative strengths of the intermolecular forces in $CCl_4(l)$ and $HCl(l)$? Justify your answer in terms of the information above.

The intermolecular forces among CCl_4 molecules must be **stronger** than those among HCl molecules because the CCl_4 condenses at a higher temperature than HCl.	1 point is earned for the correct answer with a valid justification.

1A 1 of 3

CHEMISTRY

Section II

7 Questions

Time—1 hour and 45 minutes

YOU MAY USE YOUR CALCULATOR FOR THIS SECTION.

Directions: Questions 1–3 are long free-response questions that require about 23 minutes each to answer and are worth 10 points each. Questions 4–7 are short free-response questions that require about 9 minutes each to answer and are worth 4 points each.

Write your response in the space provided following each question. Examples and equations may be included in your responses where appropriate. For calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your answer. Pay attention to significant figures.

$$CS_2(g) + 3\ Cl_2(g) \rightarrow CCl_4(g) + S_2Cl_2(g)$$

1. Carbon tetrachloride, $CCl_4(g)$, can be synthesized according to the reaction represented above. A chemist runs the reaction at a constant temperature of 120°C in a rigid 25.0 L container.

   (a) Chlorine gas, $Cl_2(g)$, is initially present in the container at a pressure of 0.40 atm.

   (i) How many moles of $Cl_2(g)$ are in the container?

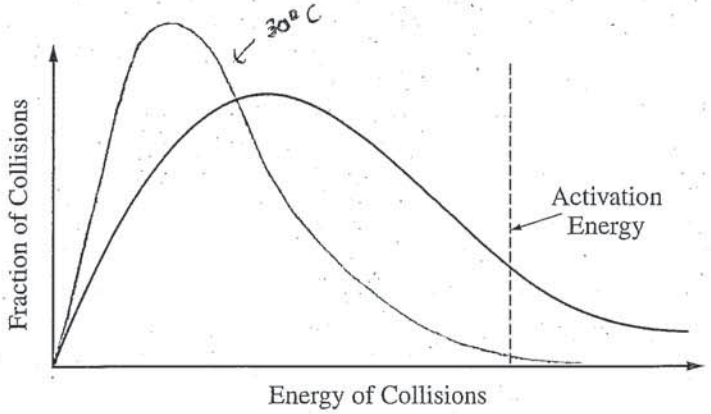
   (ii) How many grams of carbon disulfide, $CS_2(g)$, are needed to react completely with the $Cl_2(g)$?

   $\Delta G < 0$

   (b) At 30°C the reaction is thermodynamically favorable, but no reaction is observed to occur. However, at 120°C, the reaction occurs at an observable rate.

   (i) Explain how the higher temperature affects the collisions between the reactant molecules so that the reaction occurs at an observable rate at 120°C.

   (ii) The graph below shows a distribution for the collision energies of reactant molecules at 120°C. Draw a second curve on the graph that shows the distribution for the collision energies of reactant molecules at 30°C.



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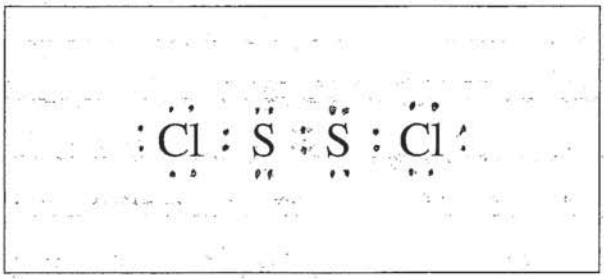
(c) S_2Cl_2 is a product of the reaction.

(i) In the box below, complete the Lewis electron-dot diagram for the S_2Cl_2 molecule by drawing in all of the electron pairs.

$12 + 14 = 26$
$26 - 4 = 22$
$22 - 12 = 10$
$10 - 4 = 6$

$26 - 16 = 10$

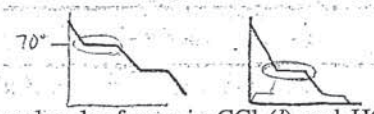


(ii) What is the approximate value of the Cl–S–S bond angle in the S_2Cl_2 molecule that you drew in part (c)(i) ? (If the two Cl–S–S bond angles are not equal, include both angles.)

(d) $CCl_4(g)$ can also be produced by reacting $CHCl_3(g)$ with $Cl_2(g)$ at 400°C, as represented by the equation below.

$$CHCl_3(g) + Cl_2(g) \rightarrow CCl_4(g) + HCl(g)$$

At the completion of the reaction a chemist successfully separates the $CCl_4(g)$ from the $HCl(g)$ by cooling the mixture to 70°C, at which temperature the $CCl_4(g)$ condenses while the $HCl(g)$ remains in the gaseous state.



(i) Identify all types of intermolecular forces present in $HCl(l)$.

(ii) What can be inferred about the relative strengths of the intermolecular forces in $CCl_4(l)$ and $HCl(l)$? Justify your answer in terms of the information above.

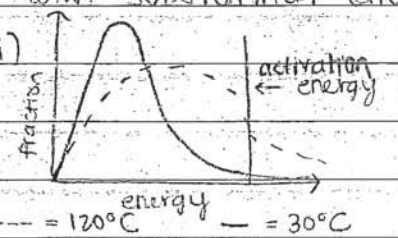
a) i) $PV = nRT \rightarrow n = \frac{PV}{RT}$

$n = \frac{(0.4\ atm)(25.0\ L)}{(0.0821 \frac{L\ atm}{mol\ K})(393\ K)} = 0.310\ mol\ Cl_2\ (g)$

ii) $0.310\ mol\ Cl_2 \cdot \frac{1\ mol\ CS_2}{3\ mol\ Cl_2} \cdot \frac{76.13\ g\ CS_2}{1\ mol\ CS_2} = 7.87\ g\ CS_2$

b) i) At 120° C, a higher percentage of reactant molecules are able to overcome the activation energy by colliding with substantial energy, thus increasing the reaction rate.

ii)



c) i) in box

ii) 180°

d) i) dipole - dipole, london dispersion

ii) The CCl_4 has stronger intermolecular forces than the HCl because it condenses at a higher temperature than the HCl. This means the CCl_4 has a higher boiling point than the HCl which means its forces are stronger.

1B 1 of 3

CHEMISTRY

Section II

7 Questions

Time—1 hour and 45 minutes

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Write your response in the space provided following each question. Examples and equations may be included in your responses where appropriate. For calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your answer. Pay attention to significant figures.

$$CS_2(g) + 3\ Cl_2(g) \rightarrow CCl_4(g) + S_2Cl_2(g)$$

1. Carbon tetrachloride, $CCl_4(g)$, can be synthesized according to the reaction represented above. A chemist runs the reaction at a constant temperature of 120°C in a rigid 25.0 L container.

   (a) Chlorine gas, $Cl_2(g)$, is initially present in the container at a pressure of 0.40 atm.

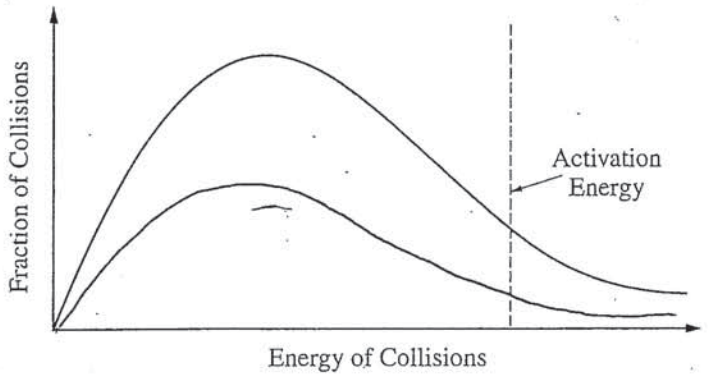
   (i) How many moles of $Cl_2(g)$ are in the container?

   (ii) How many grams of carbon disulfide, $CS_2(g)$, are needed to react completely with the $Cl_2(g)$?

   (b) At 30°C the reaction is thermodynamically favorable, but no reaction is observed to occur. However, at 120°C, the reaction occurs at an observable rate.

   (i) Explain how the higher temperature affects the collisions between the reactant molecules so that the reaction occurs at an observable rate at 120°C.

   (ii) The graph below shows a distribution for the collision energies of reactant molecules at 120°C. Draw a second curve on the graph that shows the distribution for the collision energies of reactant molecules at 30°C.



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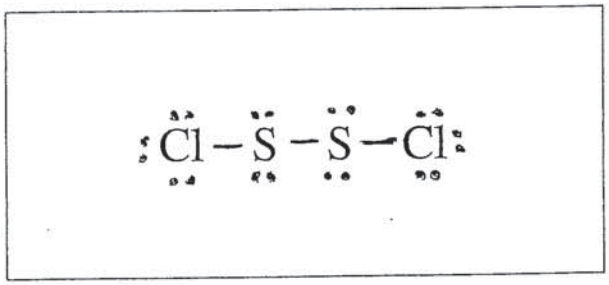
1B 2 of 3

(c) S_2Cl_2 is a product of the reaction.

(i) In the box below, complete the Lewis electron-dot diagram for the S_2Cl_2 molecule by drawing in all of the electron pairs.

26 e⁻



:Cl–S–S–Cl:

(ii) What is the approximate value of the Cl–S–S bond angle in the S_2Cl_2 molecule that you drew in part (c)(i) ? (If the two Cl–S–S bond angles are not equal, include both angles.)

(d) $CCl_4(g)$ can also be produced by reacting $CHCl_3(g)$ with $Cl_2(g)$ at 400°C, as represented by the equation below.

$$CHCl_3(g) + Cl_2(g) \rightarrow CCl_4(g) + HCl(g)$$

At the completion of the reaction a chemist successfully separates the $CCl_4(g)$ from the $HCl(g)$ by cooling the mixture to 70°C, at which temperature the $CCl_4(g)$ condenses while the $HCl(g)$ remains in the gaseous state.

H–Cl:

(i) Identify all types of intermolecular forces present in $HCl(l)$.

(ii) What can be inferred about the relative strengths of the intermolecular forces in $CCl_4(l)$ and $HCl(l)$? Justify your answer in terms of the information above.

a.) i.) $PV=nRT$ $T = 120°C + 273 = 393\ K$ $R = 0.0821$ $n = ?$ $P = 0.40\ atm$ $V = 25.0L$

$(0.40)(25.0) = n(0.0821)(393)$ $10 = 32.2653n$ $0.31\ mol\ Cl_{2(g)}$

ii.) $0.31\ mol\ Cl_2 \left| \frac{1\ mol\ CS_2}{3\ mol\ Cl_2} \right| \frac{76.13\ g\ CS_2}{1\ mol\ CS_2} = 7.9\ g\ CS_{2(g)}$

b.) i.) The higher temperature allows the molecules to move at a faster rate. Thus, the collisions are increased (i.e. there are more collisions over a shorter period of time). When more collisions occur, the reaction is more observable.

d.) ii.) 108.5° sp^3 tetrahedral

d.) i.) Dipole-dipole forces, London Dispersion forces

ii.) The intermolecular forces in the HCl must be stronger than the intermolecular forces in the CCl_4. This is because when the mixture is cooled at 70°C, the

GO ON TO THE NEXT PAGE.

1B 3 of 3

ADDITIONAL PAGE FOR ANSWERING QUESTION 1

HCl remains in its gaseous state, which signifies the strength of its intermolecular forces, while the CCl_4 condenses, which shows that it does not have as strong intermolecular forces since it changes phase/state. Since both molecules were subject to the same temperature change throughout, I can infer that the intermolecular forces in HCl are stronger than the intermolecular forces in CCl_4.

GO ON TO THE NEXT PAGE.

CHEMISTRY

Section II

7 Questions

Time—1 hour and 45 minutes

1C 1 of 3

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   (a) Chlorine gas, $Cl_2(g)$, is initially present in the container at a pressure of 0.40 atm.

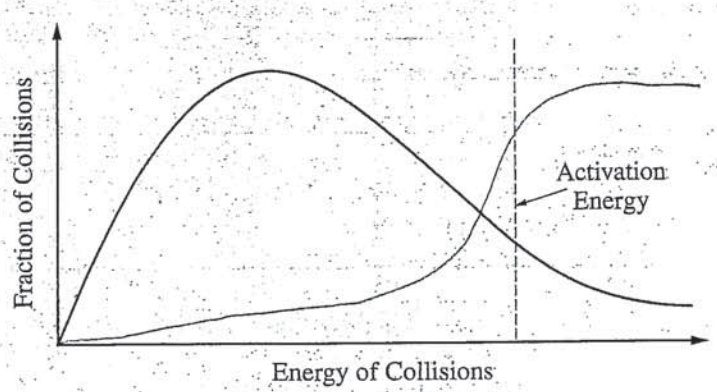
   (i) How many moles of $Cl_2(g)$ are in the container? $n = 0.31\ mol\ Cl_2$

   (ii) How many grams of carbon disulfide, $CS_2(g)$, are needed to react completely with the $Cl_2(g)$? $7.87\ g\ CS_2$

   (b) At 30°C the reaction is thermodynamically favorable, but no reaction is observed to occur. However, at 120°C, the reaction occurs at an observable rate.

   (i) Explain how the higher temperature affects the collisions between the reactant molecules so that the reaction occurs at an observable rate at 120°C.

   (ii) The graph below shows a distribution for the collision energies of reactant molecules at 120°C. Draw a second curve on the graph that shows the distribution for the collision energies of reactant molecules at 30°C.



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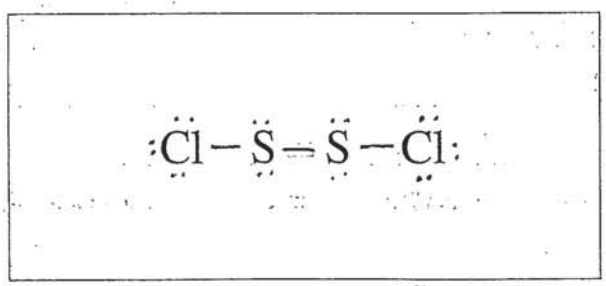
IC 2 of 3

(c) S_2Cl_2 is a product of the reaction.

(i) In the box below, complete the Lewis electron-dot diagram for the S_2Cl_2 molecule by drawing in all of the electron pairs.



(ii) What is the approximate value of the Cl–S–S bond angle in the S_2Cl_2 molecule that you drew in part (c)(i) ? (If the two Cl–S–S bond angles are not equal, include both angles.)

104°

(d) $CCl_4(g)$ can also be produced by reacting $CHCl_3(g)$ with $Cl_2(g)$ at 400°C, as represented by the equation below.

$$CHCl_3(g) + Cl_2(g) \rightarrow CCl_4(g) + HCl(g)$$

At the completion of the reaction a chemist successfully separates the $CCl_4(g)$ from the $HCl(g)$ by cooling the mixture to 70°C, at which temperature the $CCl_4(g)$ condenses while the $HCl(g)$ remains in the gaseous state.

(i) Identify all types of intermolecular forces present in $HCl(l)$. London Dispersion Forces

(ii) What can be inferred about the relative strengths of the intermolecular forces in $CCl_4(l)$ and $HCl(l)$? Justify your answer in terms of the information above.

1(a)(i): $PV = nRT$ $120°C + 273 = 393K$

$$n = \frac{PV}{RT} = \frac{(0.40\ atm)(25.0\ L)}{(0.08206\ \frac{L\ atm}{mol\ K})(393\ K)}$$

$n = 0.31\ mol\ Cl_2$

1(a)(ii): $\frac{0.31\ mol\ Cl_2}{1} \times \frac{1\ mol\ CS_2}{3\ mol\ Cl_2} \times \frac{76.13\ g\ CS_2}{1\ mol\ CS_2} = 7.87\ g\ CS_2$

molar mass of CS_2
$= 12.01\ g\ C + (2 \cdot 32.06\ g\ S) = 76.13\ g/mol\ CS_2$

1(b)(i): The higher temperature causes the molecules to move at a faster rate, because the kinetic energy increases when the temperature increases. When the collisions occur at a higher rate and the particles can be oriented to collide at

GO ON TO THE NEXT PAGE.

ADDITIONAL PAGE FOR ANSWERING QUESTION 1

1(b)(i) continued: ... a more favorable rate. When the kinetic energy increases, the activation energy decreases, making the reaction occur more easily.

1(c)(ii): 104°

1(d)(i): HCl H–Cl: HCl is a nonpolar molecule, so it has only London Dispersion Forces present.

1(d)(ii): HCl has much weaker London Dispersion Forces than CH_4. CH_4 is also nonpolar, but its intermolecular forces are stronger because the CH_4 condenses at 70°C since it has greater IMFs. The HCl's weak intermolecular forces cause it to be in a gaseous state at 70°C.

AP® CHEMISTRY
2017 SCORING COMMENTARY

Question 1

Overview

In order to answer this question, students were expected to draw on their knowledge and skills from a number of topic areas in the AP Chemistry curriculum. Some of the topics might have been taught initially in the first-year chemistry course. This question was a good example of the cumulative nature of chemistry. Students who retained the knowledge of topics presented over the span of their time in chemistry, as well as maintained the skills acquired in order to manipulate that knowledge in solving problems, had a decided advantage in presenting answers to the questions.

In this question the Learning Objectives (LO) assessed were 2.6, 2.13, 2.16, 2.21, 3.3, and 4.5. The Science Practices (SP) assessed were 1.4, 2.2, 2.3, 5.1, 6.2, and 6.4.

Part (a)(i) of the question dealt with simple stoichiometry of gaseous reactants. Students were required to use the Ideal Gas Law to apply relationships between macroscopic variables for a gas to calculate the number of moles of a gaseous reactant. Following the calculation of the number of moles of Cl_2 in the container, students were expected to display stoichiometry skills to calculate the number of grams of CS_2 required to react with all of the Cl_2. Part (b) of the question assessed student knowledge of Kinetic Molecular Theory as applied to gases. In part (b)(i) students were required to explain the results of an experiment where a change in the temperature affected the rate of the reaction relative to collision theory. The students were asked in part (b)(ii) to explain, using graphical techniques, how differences in the number and energetic quality of collisions led to some of those collisions being favorable, leading to a conversion of reactants to products .

Part (c) required students to display their knowledge of Lewis structures. In part (c)(i) students had to place electrons as bonding and nonbonding pairs around a skeleton structure provided in the prompt. Then the students had to refer to their drawings to predict two bond angles in the structure, using their knowledge of the number and type of pairs around the central atom, to lead them to an appropriate bond angle. Part (d) assessed students' knowledge of bond and molecular polarity and how that polarity might affect the types of intermolecular attractions and repulsions that might result. Part (d)(i) asked specifically about intermolecular forces between polar HCl molecules and part (d)(ii) asked students to predict the relative strengths of intermolecular forces by comparing two different types of molecules, using data about relative condensation points

Sample: 1A
Score: 9

This response earned 9 out of 10 possible points. The student earned 1 point in part (a)(i) for calculating the correct number of moles of Cl_2. The student earned 2 points in part (a)(ii) for determining the mass of CS_2 needed to react completely with the Cl_2. The response earned 1 point in part (b)(i) because the student correctly states that a higher percentage of reactant molecules have enough energy to overcome the activation energy. The response earned 2 points in part (b)(ii) for a correct plot and 1 point in part (c)(i) for a correct Lewis diagram. No point was earned in part (c)(ii) because the student gives the angle as 180°. The response earned 1 point in part (d)(i). The student correctly lists dipole-dipole forces and London dispersion forces. The response earned 1 point in part (d)(ii) because the student correctly states that CCl_4 has stronger intermolecular forces than HCl because CCl_4 condenses at a higher temperature and has a higher boiling point.

Question 1 (continued)

Sample: 1B
Score: 8

This response earned 8 out of 10 possible points. All of the points were earned in parts (a)(i), (a)(ii), (b)(i), (c)(i), (c)(ii), and (d)(i)**.** The student's curve in part (b)(ii) does not have a peak that is higher than the peak of the original curve, so it did not earn that point. It did earn the second point in part (b)(ii) because it is below the original curve to the right of the activation energy line. No point was earned in part (d)(ii) because the student states that the intermolecular forces in HCl are stronger than those in CCl_4.

Sample: 1C
Score: 6

This response earned 6 out of 10 possible points. The student earned all of the points available in part (a) and part(c). No point was earned in part (b)(i) because the student indicates incorrectly that the activation energy changes as the temperature changes. No points were earned for the student's curve in part (b)(ii). No point was earned in part (d)(i) because the student incorrectly identifies HCl as a nonpolar molecule and therefore misses the dipole-dipole intermolecular forces. The response earned 1 point in part (d)(ii) because the student correctly surmises that CCl_4 must have stronger intermolecular forces than HCl because CCl_4 is a liquid at 70°C, whereas HCl is still a gas at 70°C.