2024

AP® Chemistry

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 5

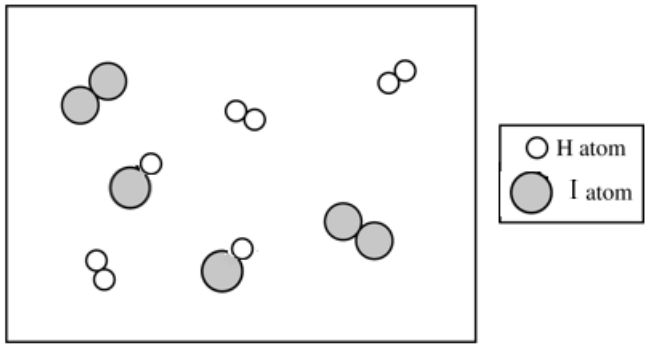
- ☑ **Scoring Guidelines**
- ☑ **Student Samples**
- ☑ **Scoring Commentary**

Question 5: Short Answer — 4 points

(a) For the correct expression: **1 point**

$$K_c = \frac{[HI]^2}{[H_2][I_2]}$$

(b) (i) For the correct drawing consistent with part (a): **1 point**



(ii) For a valid hypothesis: **1 point**

Accept one of the following:

- *Decreased the temperature.*
- *Added more* H_2 *and/or* I_2 *to the reaction vessel.*

(iii) For the correct answer and a valid justification: **1 point**

Accept one of the following:

- *Remain unchanged. The number of moles in the numerator and denominator of* Q *(or* K*) are equal; changing the volume of the container would not alter the value of* Q*, which is still equal to* K*, so the number of moles of* HI *will remain the same.*
- *Remain unchanged. The increase in volume will decrease the concentration of reactants and products by an equal proportion. Because there are equal moles of gaseous reactants and products in the balanced chemical equation, there is no shift in the equilibrium position, and the number of moles of* HI *will remain the same.*

Total for part (b) 3 points

Total for question 5 4 points

Question 5

Begin your response to **QUESTION 5** on this page.

5. Hydrogen gas and iodine gas react to form hydrogen iodide at an elevated temperature, as represented by the following equation.

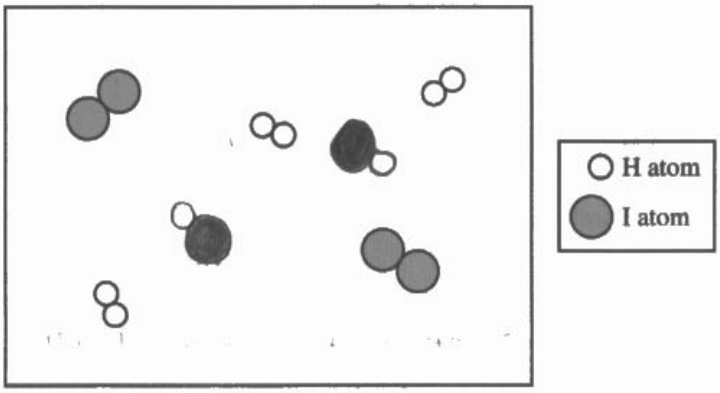
$$H_2(g) + I_2(g) \rightleftarrows 2\,HI(g) \qquad \Delta H_{rxn} = -12.19\ \text{kJ / mol}_{rxn}$$

(a) Write the expression for the equilibrium constant, K_c, for this reaction.

$$K_c = \frac{[HI]^2}{[H_2][I_2]}$$

(b) $H_2(g)$ and $I_2(g)$ are added to a previously evacuated container and allowed to react.

(i) At a certain time, the value of the reaction quotient, Q, is 0.67. The following particle diagram is an incomplete representation of the system at this time. The diagram shows the relative number of $H_2(g)$ and $I_2(g)$ molecules, but the $HI(g)$ molecules are not included. Draw the number of $HI(g)$ molecules needed to complete the diagram so that it accurately represents the system.



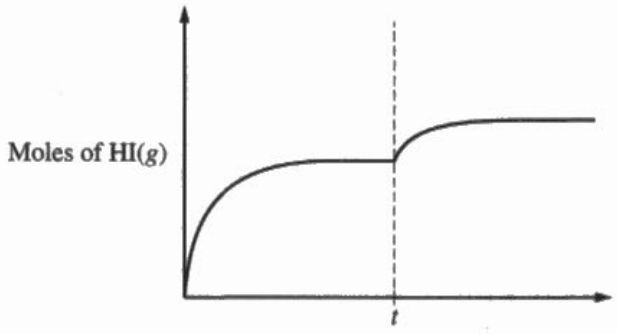
$$\frac{[HI]^2}{2 \cdot 3} = 0.67$$

$$[HI] = 2$$

Question 5

Continue your response to **QUESTION 5** on this page.

(ii) A student monitors the number of moles of $HI(g)$ over time. Hypothesize an experimental change that could have been applied to the system in the rigid container at time t to result in the change in the number of moles of $HI(g)$ shown in the graph. Assume that the student did not add more $HI(g)$ to the system.



The student could have added $I_2(g)$ to the system which would make $K > Q$ so the fwd reaction would be favored & $HI(g)$ would be produced until eq was established again.

(iii) After equilibrium is established, the mixture is transferred to a larger container at constant temperature. As a result, would the number of moles of $HI(g)$ increase, decrease, or remain the same? Justify your answer.

Stay the same since the conc of all species would decrease but since the numerator of Kc expression is squared and there are two terms in the denominator, the change in volume cancels out so $Q = K$ and reaction stays at equilibrium.

GO ON TO THE NEXT PAGE.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 5

Begin your response to **QUESTION 5** on this page.

5. Hydrogen gas and iodine gas react to form hydrogen iodide at an elevated temperature, as represented by the following equation.

$$H_2(g) + I_2(g) \rightleftarrows 2\,HI(g) \qquad \Delta H_{rxn} = -12.19\ \text{kJ / mol}_{rxn}$$

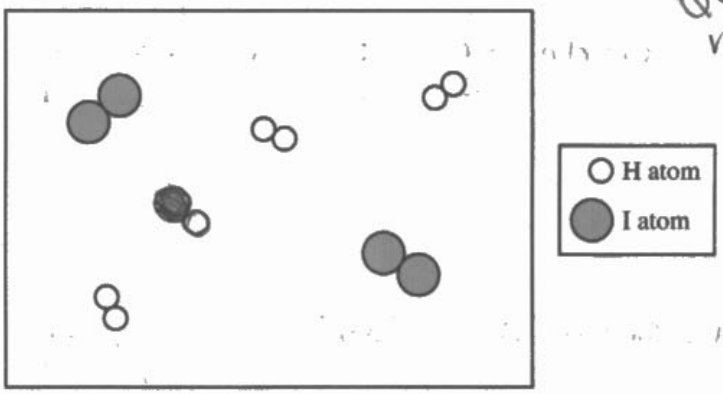
(a) Write the expression for the equilibrium constant, K_c, for this reaction.

$$K_C = \frac{[HI]^2}{[H_2][I_2]}$$

(b) $H_2(g)$ and $I_2(g)$ are added to a previously evacuated container and allowed to react.

(i) At a certain time, the value of the reaction quotient, Q, is 0.67. The following particle diagram is an incomplete representation of the system at this time. The diagram shows the relative number of $H_2(g)$ and $I_2(g)$ molecules, but the $HI(g)$ molecules are not included. Draw the number of $HI(g)$ molecules needed to complete the diagram so that it accurately represents the system.

Q<1
reactants



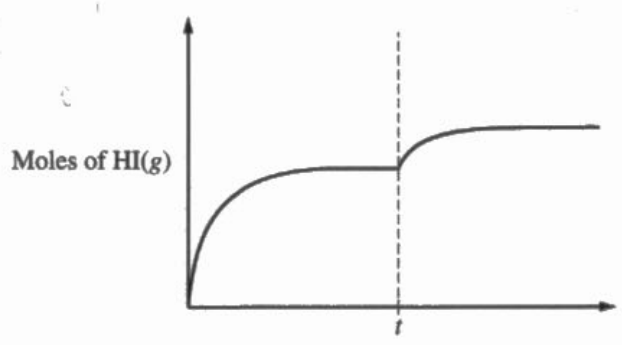
Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

0059431

Question 5

Continue your response to **QUESTION 5** on this page.

(ii) A student monitors the number of moles of $HI(g)$ over time. Hypothesize an experimental change that could have been applied to the system in the rigid container at time t to result in the change in the number of moles of $HI(g)$ shown in the graph. Assume that the student did not add more $HI(g)$ to the system.



the experimental change was an increase in pressure of the system.

(iii) After equilibrium is established, the mixture is transferred to a larger container at constant temperature. As a result, would the number of moles of $HI(g)$ increase, decrease, or remain the same? Justify your answer.

the number of moles of HI(g) would stay the same. Since volume would increase when the mixture was transfered to a larger container, this means the pressure would decrease. If the pressure decreases, the system will shift the reaction towards the side of the rxn (with more gas particles) to try and create more gas (according to Le Chatilier's principle). Since the number of reactant gas particles = the number of product gas particles (2=2), the moles of HI would stay the same.

GO ON TO THE NEXT PAGE.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 5

Begin your response to **QUESTION 5** on this page.

5. Hydrogen gas and iodine gas react to form hydrogen iodide at an elevated temperature, as represented by the following equation.

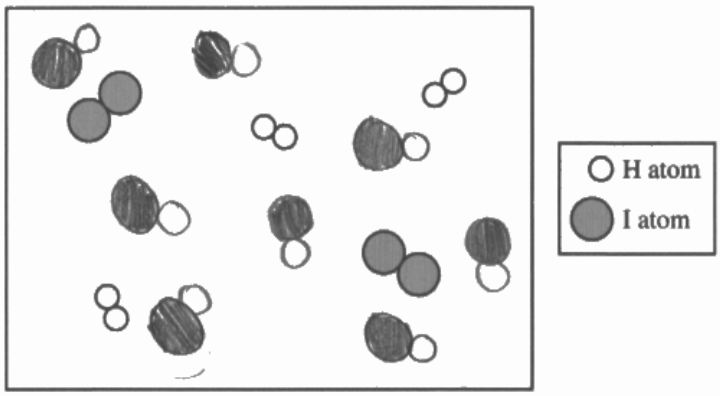
$$H_2(g) + I_2(g) \rightleftarrows 2\,HI(g) \qquad \Delta H_{rxn} = -12.19\ \text{kJ / mol}_{rxn}$$

(a) Write the expression for the equilibrium constant, K_c, for this reaction.

$$K_c = \frac{[HI]^2}{[H_2][I_2]}$$

(b) $H_2(g)$ and $I_2(g)$ are added to a previously evacuated container and allowed to react.

(i) At a certain time, the value of the reaction quotient, Q, is 0.67. The following particle diagram is an incomplete representation of the system at this time. The diagram shows the relative number of $H_2(g)$ and $I_2(g)$ molecules, but the $HI(g)$ molecules are not included. Draw the number of $HI(g)$ molecules needed to complete the diagram so that it accurately represents the system.



GO ON TO THE NEXT PAGE.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

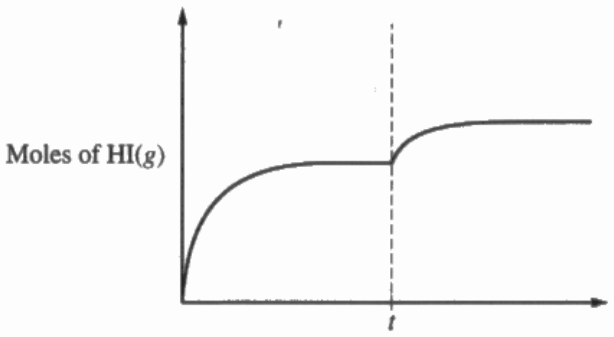
0124763

Q5233/14

Question 5

Continue your response to **QUESTION 5** on this page.

(ii) A student monitors the number of moles of HI(g) over time. Hypothesize an experimental change that could have been applied to the system in the rigid container at time t to result in the change in the number of moles of HI(g) shown in the graph. Assume that the student did not add more HI(g) to the system.



The temperature of the container could be the experimental change that occurred at time t.

(iii) After equilibrium is established, the mixture is transferred to a larger container at constant temperature. As a result, would the number of moles of HI(g) increase, decrease, or remain the same? Justify your answer.

The number of moles would increase because the volume of the new is larger. Looking at the molarity equation, $M = \frac{mol}{L}$, we can rearrange the equation to $mol = M \cdot L$. Thus, assuming concentration stays constant, as the volume goes up, the number of moles goes up.

GO ON TO THE NEXT PAGE.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 5

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

Question 5 presents students with a series of questions allowing them to demonstrate their understanding of dynamic equilibria and the effects related to disturbances in a gaseous system (Le Chatelier's principle).

Part (a) requires students to write a concentration-based equilibrium expression given a gaseous reaction involving the synthesis of hydrogen iodide from elemental hydrogen and iodine (Learning Objective TRA-7.A/7.3.A, Skill 5.B from the *AP Chemistry Course and Exam Description*).

Part (b)(i) requires students to analyze an incomplete particle diagram representation of the system. Given the relative quantities of $H_2(g)$ and $I_2(g)$ in the particle diagram, students were to use the equilibrium expression from part (a) to determine the appropriate number of HI(g) molecules to draw in the diagram to accurately represent the system (TRA-7.F/7.8.A, 3.B).

Part (b)(ii) requires students to hypothesize an experimental change responsible for an equilibrium shift represented by a provided graph that shows how the moles of HI(g) change as a function of time. At time t, there is an increase in the moles of HI(g) produced (TRA-8.A/7.9.A, 2.B).

Part (b)(iii) requires students to further demonstrate their understanding of Le Chatelier's principle given a new disturbance caused by moving the reaction system from its original container to another rigid container of larger volume (TRA-8.A/7.9.A, 6.D).

Sample: 5A
Score: 4

The response earned 4 points. In part (a) the point was earned for correctly writing the K_c expression. In part (b)(i) the point was earned for correctly drawing 2 molecules of HI. In part (b)(ii) the point was earned for correctly noting that an increase in the amount of I_2 would result in an increase in the amount of HI produced. In part (b)(iii) the point was earned for correctly noting that the number of moles of HI remains the same with the justification indicating that the change in volume does not alter the value of Q, resulting in Q being equal to K.

Sample: 5B
Score: 2

The response earned 2 points. In part (a) the point was earned for correctly writing the K_c expression. In part (b)(i) the point was not earned for drawing only one molecule of HI. Given that the reaction quotient is 0.67 and that there are 3 molecules of H_2 and 2 molecules of I_2, there should have been 2 molecules of HI drawn. In part (b)(ii) the point was not earned for stating that a [generic] increase of system pressure would result in an increased production of HI. A decrease in temperature or the addition of H_2 and/or I_2 would have created a shift in the equilibrium of the exothermic reaction toward the formation of product. In part (b)(iii) the point was earned for correctly noting that the number of moles of HI would remain the same with a justification indicating that since the moles of

Question 5 (continued)

gaseous reactants are equal to the moles of gaseous products in the reaction equation, no shift in equilibrium would occur.

Sample: 5C
Score: 1

The response earned 1 point. In part (a) the point was earned for correctly writing the K_c expression. In part (b)(i) the point was not earned for drawing 8 molecules. Given that the reaction quotient is 0.67 and that there are 3 molecules of H_2 and 2 molecules of I_2, there should have been 2 molecules of HI drawn. In part (b)(ii) the point was not earned for vaguely noting that temperature could be changed without indicating an increase or decrease in temperature. Given an exothermic reaction, the response should have referenced a decrease in temperature to increase the production of HI at time *t*. In part (b)(iii) the point was not earned for indicating that the number of moles of HI would increase after the transfer to a larger container.