

2023



AP[®] Chemistry

Sample Student Responses and Scoring Commentary

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Free-Response Question 5

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Question 5: Short Answer

4 points

(a) (i) For the correct calculated value: 1 point

$$n = \frac{PV}{RT} = \frac{(7.45 \text{ atm})(6.00 \text{ L})}{(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(296 \text{ K})} = 1.84 \text{ mol}$$

(ii) For the correct calculated value: 1 point

Accept one of the following:

- $\frac{P_1}{T_1} = \frac{P_2}{T_2}$

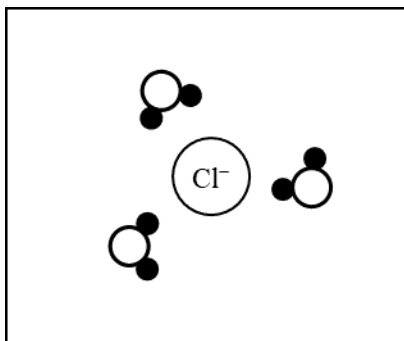
$$P_2 = \frac{(P_1)(T_2)}{T_1} = \frac{(7.45 \text{ atm})(271 \text{ K})}{296 \text{ K}} = 6.82 \text{ atm}$$

- $P = \frac{nRT}{V} = \frac{(1.84 \text{ mol})(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(271 \text{ K})}{6.00 \text{ L}} = 6.82 \text{ atm}$

Total for part (a) 2 points

(b) For a correct drawing: 1 point

The drawing should show three water molecules with a hydrogen atom (dark circle) oriented towards the Cl⁻ ion.



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

HNO₂. The diagram shows most of the molecules in their un-ionized form, indicating a weak acid with a K_a value less than 1, which is consistent with HNO₂.

Total for question 5 4 points

Question 5

Begin your response to QUESTION 5 on this page.

5. HCl is a molecular gas as a pure substance but acts as an acid in aqueous solution.

(a) A sample of HCl(g) is stored in a rigid 6.00 L container at 7.45 atm and 296 K.

(i) Calculate the number of moles of HCl(g) in the container.


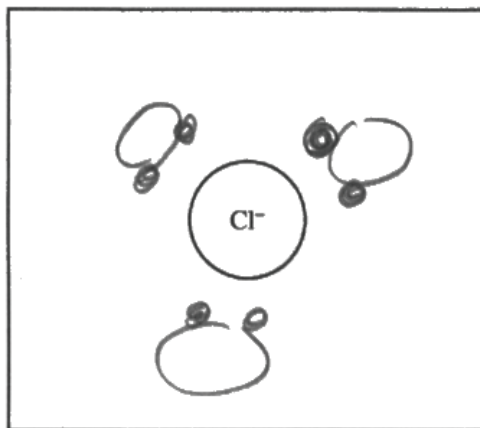
$$PV = nRT$$

$$\frac{PV}{RT} = n = \frac{(7.45 \text{ atm})(6.00 \text{ L})}{(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(296 \text{ K})} = 1.89 \text{ mol}$$

(ii) The rigid 6.00 L container of HCl(g) is cooled to a temperature of 271 K. Calculate the new pressure, in atm, of the HCl(g).

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{P_1}{T_1} T_2 = P_2 = \frac{(7.45 \text{ atm})(271 \text{ K})}{(296 \text{ K})} = 6.82 \text{ atm}$$

(b) When HCl ionizes in aqueous solution, Cl^- (aq) ions are formed. In the following box, draw three water molecules with proper orientation around the Cl^- ion. Use  to represent water molecules.

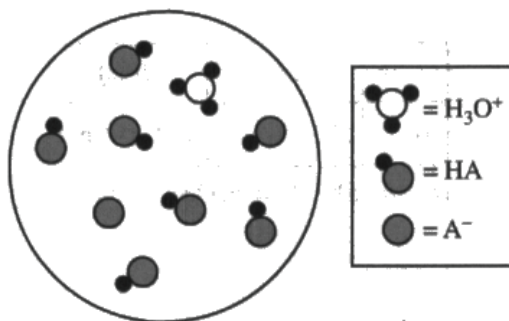
Question 5

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

Acid (HA)	Anion (A ⁻)	K _a Value
HNO ₂	NO ₂ ⁻	5.6 × 10 ⁻⁴
HCl	Cl ⁻	2.0 × 10 ⁷
HClO ₄	ClO ₄ ⁻	1.6 × 10 ¹⁵

The K_a values for three acids are shown in the preceding table.

- (c) The following particulate diagram represents the ionization of one of the acids in the data table. Water molecules have been omitted for clarity. Which acid (HNO₂, HCl, or HClO₄) is represented in the diagram? Justify your answer using the information in the table.



HNO₂. HNO₂ is a weak acid, since $K_a \ll 1$. Since it is a weak acid, only very little of it ionizes into NO₂⁻ and H₃O⁺. Most of it stays as HNO₂. The particulate diagram is majority HA, and only one H₃O⁺ and A⁻ molecule, so the acid is HNO₂.

Question 5

Begin your response to QUESTION 5 on this page.

5. HCl is a molecular gas as a pure substance but acts as an acid in aqueous solution.

(a) A sample of HCl(g) is stored in a rigid 6.00 L container at 7.45 atm and 296 K.


(i) Calculate the number of moles of HCl(g) in the container.

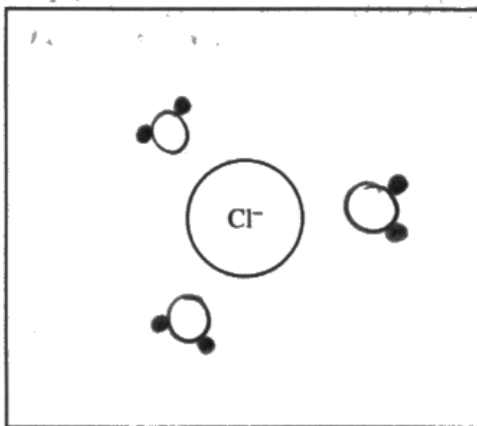
$$PV = nRT \rightarrow n = \frac{PV}{RT}$$

$$n = \frac{7.45 \text{ atm} \times 6.00 \text{ L}}{0.0821 \frac{\text{atm L}}{\text{mol K}} \times 296 \text{ K}} = 1.84 \text{ mol}$$

(ii) The rigid 6.00 L container of HCl(g) is cooled to a temperature of 271 K. Calculate the new pressure, in atm, of the HCl(g).

$$\frac{271 \text{ K}}{296 \text{ K}} (7.45 \text{ atm}) = 6.82 \text{ atm}$$

(b) When HCl ionizes in aqueous solution, $\text{Cl}^- (\text{aq})$ ions are formed. In the following box, draw three water molecules with proper orientation around the Cl^- ion. Use  to represent water molecules.



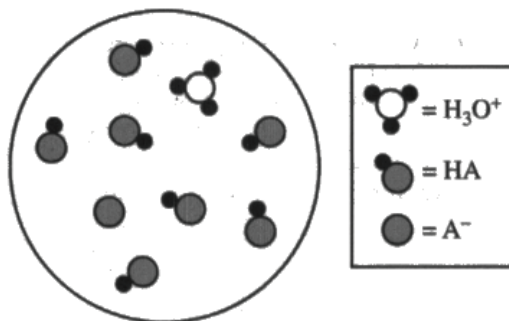
Question 5

Continue your response to QUESTION 5 on this page.

Acid (HA)	Anion (A^-)	K_a Value
HNO_2	NO_2^-	5.6×10^{-4}
HCl	Cl^-	2.0×10^7
$HClO_4$	ClO_4^-	1.6×10^{15}

The K_a values for three acids are shown in the preceding table.

- (c) The following particulate diagram represents the ionization of one of the acids in the data table. Water molecules have been omitted for clarity. Which acid (HNO_2 , HCl, or $HClO_4$) is represented in the diagram? Justify your answer using the information in the table.



The acid is HNO_2 . The particulate diagram shows much more HA (acid) than H_3O^+ or A^- (conjugate base), showing that the acid doesn't dissociate much and is weak. HNO_2 is the only weak acid out of the three since only HNO_2 has a small K_a which is less than 1.

Question 5

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

5. HCl is a molecular gas as a pure substance but acts as an acid in aqueous solution.

(a) A sample of HCl(g) is stored in a rigid 6.00 L container at 7.45 atm and 296 K.

(i) Calculate the number of moles of HCl(g) in the container.


$$7.45 \text{ atm} \cdot 6.00 \text{ L} = n \cdot \left(0.08206 \frac{\text{atm} \cdot \text{L}}{\text{mol} \cdot \text{K}}\right) \cdot 296 \text{ K}$$

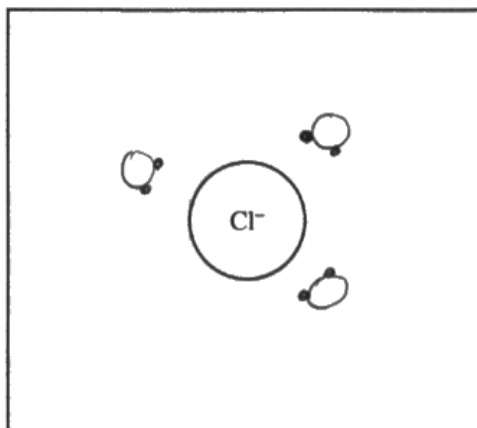
$$n = 1.84 \text{ mol HCl}$$

(ii) The rigid 6.00 L container of HCl(g) is cooled to a temperature of 271 K. Calculate the new pressure, in atm, of the HCl(g).

$$P \cdot 6.00 \text{ L} = 1.84 \text{ mol} \cdot \left(0.08206 \frac{\text{atm} \cdot \text{L}}{\text{mol} \cdot \text{K}}\right) \cdot 271 \text{ K}$$

$$P = .147 \text{ atm}$$

(b) When HCl ionizes in aqueous solution, Cl^- (aq) ions are formed. In the following box, draw three water molecules with proper orientation around the Cl^- ion. Use  to represent water molecules.



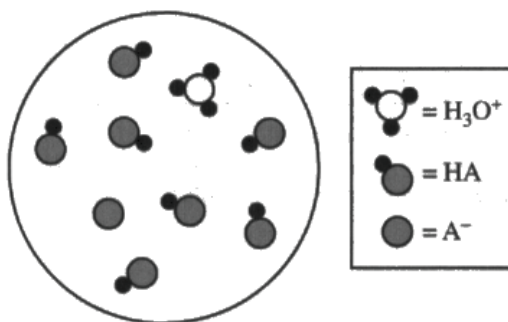
Question 5

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Acid (HA)	Anion (A ⁻)	K _a Value
HNO ₂	NO ₂ ⁻	5.6 × 10 ⁻⁴
HCl	Cl ⁻	2.0 × 10 ⁷
HClO ₄	ClO ₄ ⁻	1.6 × 10 ¹⁵

The K_a values for three acids are shown in the preceding table.

- (c) The following particulate diagram represents the ionization of one of the acids in the data table. Water molecules have been omitted for clarity. Which acid (HNO₂, HCl, or HClO₄) is represented in the diagram? Justify your answer using the information in the table.



HNO₂ because it has the highest K_a value which gives the most HA ions.

Question 5

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

Overview

Question 5 presented students with gas laws involving HCl gas, as well as representations of acid solutions.

Part (a) involved using the ideal gas law for a sample of HCl(*g*). In part (a)(i) the number of moles of gas was calculated given the pressure, volume, and temperature. Part (a)(ii) utilized the calculated moles of gas from (a)(i) to calculate a new pressure at a lower given temperature (Learning Objective SAP-7.A, Skill 5.F from the *AP Chemistry Course and Exam Description*).

In part (b) the students were asked to draw three water molecules around a given chloride ion with correct ion-dipole orientation (SPQ-3.B, 3.C).

Part (c) asked the students to select which acid is represented by a particle diagram, given three to choose from. The justification for the choice of acid is based on a table of given K_a values (SAP-9.F, 6.C).

Sample: 5A

Score: 4

This response earned 4 points. In part (a)(i) the point was earned for correctly calculating the number of moles of HCl(*g*). In part (a)(ii) the point was earned for correctly calculating the new pressure of HCl(*g*). In part (b) the point was earned for drawing three water molecules with hydrogen atoms oriented toward the Cl⁻ ion. In part (c) the point was earned for selecting HNO₂ as the acid in the diagram and including a valid justification.

Sample: 5B

Score: 3

This response earned 3 points. In part (a)(i) the point was earned for correctly calculating the number of moles of HCl (*g*). In part (a)(ii) the point was earned for correctly calculating the new pressure of HCl(*g*). In part (b) no point was earned because the drawing shows three water molecules oriented with the oxygen atom near the Cl⁻ ion. In part (c) the point was earned for selecting HNO₂ as the acid in the diagram and stating that the diagram represents a weak acid dissociation with a K_a less than one.

Sample: 5C

Score: 2

This response earned 2 points. In part (a)(i) the point was earned for correctly calculating the number of moles of HCl(*g*). In part (a)(ii) the point was not earned because the new pressure of HCl(*g*) is calculated incorrectly. In part (b) the point was earned for drawing three water molecules with hydrogen atoms oriented toward the Cl⁻ ion. In part (c) the point was not earned because the justification is incorrect.