2023

AP

AP® Chemistry

Sample Student Responses and Scoring Commentary

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Free-Response Question 6

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Question 6: Short Answer — 4 points

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

$HBr(l)$: *London dispersion forces, dipole-dipole attractions*

$HF(l)$: *London dispersion forces, dipole-dipole attractions, hydrogen bonding*

(b) (i) For a correct explanation: **1 point**

ΔH°_{vap} *is greater for* $HF(l)$ *than* $HBr(l)$ *because the overall intermolecular forces in* $HF(l)$ *are stronger than those in* $HBr(l)$ *due to hydrogen bonding attractions present in* $HF(l)$, *so more energy is required to separate the molecules in* $HF(l)$.

(ii) For the correct calculated value: **1 point**

$$6.85 \text{ g HF} \times \frac{1 \text{ mol}}{20.01 \text{ g}} \times \frac{25.2 \text{ kJ}}{1 \text{ mol}} = 8.63 \text{ kJ}$$

Total for part (b) 2 points

(c) For a correct explanation: **1 point**

Br *has two additional occupied electron shells (n = 3 and n = 4) compared to* F *(n = 2). The extra electron shells increase the distance between the* H *and* Br *nuclei, giving* HBr *the greater bond length.*

Total for question 6 4 points

Question 6

Begin your response to QUESTION 6 on this page.

6. Answer the following questions related to HBr(*l*) and HF(*l*).

(a) In the following table, list all of the types of intermolecular forces present in pure samples of HBr(*l*) and HF(*l*).

Liquid	HBr(*l*)	HF(*l*)
Intermolecular forces present	· London dispersion forces · Dipole-dipole ~~attract~~ interactions	· London dispersion forces · Dipole-dipole interactions · Hydrogen bonds

(b) The enthalpy of vaporization, ΔH°_{vap}, for each liquid is provided in the following table.

Liquid	HBr(*l*)	HF(*l*)
ΔH°_{vap}	17.3 kJ / mol	25.2 kJ / mol

(i) Based on the types and relative strengths of intermolecular forces, explain why ΔH°_{vap} of HF(*l*) is greater than that of HBr(*l*).

~~HBr~~ While both compounds ~~have~~ experience LDFs and dipole-dipole interactions, HF also experiences hydrogen bonding. The additional intermolecular force more strongly holds HF molecules together and requires more energy to break (H-bonds are the strongest) so ~~that~~ ΔH°_{vap} is higher for HF.

(ii) Calculate the amount of thermal energy, in kJ, required to vaporize 6.85 g of HF(*l*).

$$6.85 \text{ g HF} \cdot \frac{1 \text{ mol HF}}{20 \text{ g HF}} = .343 \text{ mol HF}$$

$$\frac{25.2 \text{ kJ}}{1 \text{ mol}} = \frac{x}{.343 \text{ mol}} \rightarrow \boxed{x = 8.64 \text{ kJ}}$$

Question 6

Continue your response to **QUESTION 6** on this page.

(c) Based on the arrangement of electrons in the Br and F atoms, explain why the bond length in an HBr molecule is greater than that in an HF molecule.

Br has more energy levels than F, so it has a greater atomic radius. This places it further from H, so ~~H~~ HBr has a greater bond length.

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

Question 6

Begin your response to QUESTION 6 on this page.

6. Answer the following questions related to HBr(l) and HF(l).

(a) In the following table, list all of the types of intermolecular forces present in pure samples of HBr(l) and HF(l).

Liquid	HBr(l)	HF(l)
Intermolecular forces present	London Dispersion Dipole - Dipole	London Dispersion Hydrogen Bonding Dipole - Dipole

(b) The enthalpy of vaporization, ΔH°_{vap}, for each liquid is provided in the following table.

Liquid	HBr(l)	HF(l)
ΔH°_{vap}	17.3 kJ / mol	25.2 kJ / mol

(i) Based on the types and relative strengths of intermolecular forces, explain why ΔH°_{vap} of HF(l) is greater than that of HBr(l).

As HF (l) has hydrogen bonding (the strongest intermolecular force), it takes a greater amount of heat to overcome the stronger force (compared to London dispersion and dipole-dipole).

(ii) Calculate the amount of thermal energy, in kJ, required to vaporize 6.85 g of HF(l).

$$\frac{6.85 \text{ g HF(l)}}{1} \cdot \frac{1 \text{ mol HF(l)}}{18 \text{ g HF(l)}}$$

$$\frac{1 \text{ mol HF (l)}}{1} \cdot \frac{25.2 \text{ kJ}}{\sout{25.2}\ 1 \text{ mol}} = \boxed{9.59 \text{ kJ}}$$

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Question 6

Continue your response to **QUESTION 6** on this page.

(c) Based on the arrangement of electrons in the Br and F atoms, explain why the bond length in an HBr molecule is greater than that in an HF molecule.

The bond length in HBr is greater than that in HF as Br is a larger atom and therefore has more shells of electrons (each further away from the nucleus). The valence electrons on Br are therefore further positioned from the nucleus than those of F, which leads to a larger bond length.

Question 6

Begin your response to QUESTION 6 on this page.

6. Answer the following questions related to HBr(*l*) and HF(*l*).

(a) In the following table, list all of the types of intermolecular forces present in pure samples of HBr(*l*) and HF(*l*).

Liquid	HBr(*l*)	HF(*l*)
Intermolecular forces present	LDF Dipole- Dipole	LDF Dipole - Dipole Hydrogeon bond

(b) The enthalpy of vaporization, ΔH°_{vap}, for each liquid is provided in the following table.

Liquid	HBr(*l*)	HF(*l*)
ΔH°_{vap}	17.3 kJ / mol	25.2 kJ / mol

(i) Based on the types and relative strengths of intermolecular forces, explain why ΔH°_{vap} of HF(*l*) is greater than that of HBr(*l*).

Since HF's intermolecular is greater, HF needs more heat to break.

(ii) Calculate the amount of thermal energy, in kJ, required to vaporize 6.85 g of HF(*l*).

$$6.85g \times \frac{1\,mol}{1+19} = 0.3425\,mol$$

$$q = 0.3425\,mol \times 25.2 = 8.631\,kJ$$

Question 6

Continue your response to **QUESTION 6** on this page.

(c) Based on the arrangement of electrons in the Br and F atoms, explain why the bond length in an HBr molecule is greater than that in an HF molecule.

HF has ~~less~~ electrons, which minimizes the repulsion between electrons. Therefore, it has shorter bond length than HBr does.

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Question 6

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

Overview

Question 6 prompted students to respond to various prompts regarding the properties of HBr(*l*) and HF(*l*).

Part (a) asked students to list all types of intermolecular forces of attraction present in pure samples of each of the two liquids (Learning Objective SAP-5.A, Skill 1.B from the *AP Chemistry Course and Exam Description*).

In part (b) students had the opportunity to earn 2 points.

Part (b)(i) required students to explain why the molar enthalpy of vaporization of HF(*l*) is greater than that of HBr(*l*), based on the types and relative strengths of intermolecular forces of attraction present in each liquid. Successful responses provided an explanation that identified the strong hydrogen bonding present in HF(*l*), which is absent in HBr(*l*), as the reason for the difference (SAP-5.B, 4.C).

Part (b)(ii) asked students to determine the amount of heat required to vaporize a sample of liquid HF(*l*) given the mass of the sample; therefore, students were required to convert from the mass of HF(*l*) to moles, and then to kilojoules using the value of ΔH°_{vap} provided in the table (ENE-2.F, 5.F).

Part (c) required students to explain why the H–Br bond is longer than the H–F bond using principles of electron arrangements in the respective atoms. Successful responses indicated that the two additional occupied electron shells in Br versus F accounted for the difference in bond length (SAP-3.B, 4.A).

Sample: 6A
Score: 4

This response earned 4 points. In part (a) the point was earned for identifying all the intermolecular forces of attraction present in both HBr(*l*) and HF(*l*). In part (b)(i) the point was earned for stating that the strength of the intermolecular forces of attraction in HF(*l*) are greater than those in HBr(*l*), and for identifying hydrogen bonding as the force responsible for the greater enthalpy of vaporization. In part (b)(ii) the point was earned for the correct setup and calculation of the energy required to vaporize 6.85 g of HF(*l*). In part (c) the point was earned for the correct explanation of why the bond length is longer in HBr by referencing the larger atomic radius of bromine due to a greater number of occupied energy levels in bromine versus fluorine.

Sample: 6B
Score: 3

This response earned 3 points. In part (a) the point was earned for identifying all the intermolecular forces of attraction present in both HBr(*l*) and HF(*l*). In part (b)(i) the point was earned for stating that

Question 6 (continued)

HF(*l*) has hydrogen bonding (the strongest intermolecular force), so it takes more heat to overcome the stronger intermolecular forces of attraction in HF(*l*) compared to the forces present in HBr(l*)*. In part (b)(ii) the point was not earned because the incorrect molar mass value for HF(*l*) is used, leading to an incorrect energy value. In part (c) the point was earned for the correct explanation of why the bond length is greater in HBr.

Sample: 6C
Score: 2

This response earned 2 points. In part (a) the point was earned for identifying all the intermolecular forces of attraction present in both HBr(*l*) and HF(*l*). In part (b)(i) the point was not earned because while the response states that intermolecular forces of attraction in HF(*l*) are greater, it does not identify hydrogen bonding as the force responsible for the difference in enthalpy. In part (b)(ii) the point was earned for the correct setup and calculation of the energy required to vaporize 6.85 g of HF(*l*). In part (c) the point was not earned because, while the response states that there are fewer electrons in HF, it references electron–electron repulsion and not the electron energy level arrangement differences between HBr and HF.