2025

AP® Chemistry

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 2

☑ Scoring Guidelines

☑ Student Samples

☑ Scoring Commentary

Question 2: Long Answer 10 points

A (i) For the correct calculated value: **Point 01**

$$2.883 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} = 0.1600 \text{ mol } H_2O$$

(ii) For the correct calculated number of moles of H (may be implicit): **Point 02**

$$0.1600 \text{ mol } H_2O \times \frac{2 \text{ mol H}}{1 \text{ mol } H_2O} = 0.3200 \text{ mol H}$$

For the correct empirical formula. **Point 03**

Examples of acceptable responses may include the following:

- $x : y : z$ = (moles of C):(moles of H):(moles of O)

  $x : y : z = 0.2400 : 0.3200 : 0.2400 = 3 : 4 : 3$

  Therefore, the empirical formula of ascorbic acid is $C_3H_4O_3$.

- $0.2400 \text{ mol } CO_2 \times \frac{1 \text{ mol C}}{1 \text{ mol } CO_2} = 0.2400 \text{ mol C}$

  $\frac{0.3200 \text{ mol H}}{0.2400 \text{ mol C}} = \frac{4 \text{ H}}{3 \text{ C}}$

  Given that the ratio of C:O *is* 1:1, *the empirical formula of ascorbic acid is* $C_3H_4O_3$.

B (i) For the correct calculated value: **Point 04**

$$0.0160 \text{ L NaOH} \times \frac{0.0550 \text{ mol NaOH}}{1 \text{ L NaOH}} \times \frac{1 \text{ mol HAsc}}{1 \text{ mol NaOH}} = 8.80 \times 10^{-4} \text{ mol HAsc}$$

$$\frac{8.80 \times 10^{-4} \text{ mol HAsc}}{0.0100 \text{ L}} = 0.0880 \ M \text{ HAsc}$$

(ii) For the correct pK_a: **Point 05**

4.1 (*acceptable range:* 4.0 – 4.3)

(iii) For the correct ratio, consistent with part B (ii): **Point 06**

Using the Henderson-Hasselbalch equation:

$$pH = pK_a + \log\left(\frac{[Asc^-]}{[HAsc]}\right)$$

$$4.7 = 4.1 + \log\left(\frac{[Asc^-]}{[HAsc]}\right)$$

$$\frac{[Asc^-]}{[HAsc]} = 10^{0.6} = 4.0$$

C	(i) For a correct explanation. Examples of acceptable responses may include the following: • $\dfrac{4.914 \times 10^{-4}}{2.457 \times 10^{-4}} = \left(\dfrac{0.900}{0.450}\right)^{a}$, thus $a = 1$ • *Comparing trials 1 and 3, the rate doubles when the concentration of ascorbic acid is doubled and the triiodide ion concentration is constant, indicating that the process is first order with respect to ascorbic acid.*	**Point 07**
	(ii) For the correct calculated value: $rate = k[\text{HAsc}][\text{I}_3^{\,-}]$ *Using trial 1 data:* $k = \dfrac{rate}{[\text{HAsc}][\text{I}_3^{\,-}]} = \dfrac{2.457 \times 10^{-4}\ M/\text{s}}{(0.450\ M)(1.200\ M)} = 4.55 \times 10^{-4} M^{-1}\ \text{s}^{-1}$	**Point 08**
	For the correct units: $M^{-1}\ \text{s}^{-1}$	**Point 09**
D	For the correct answer: *Ion-dipole attractions are present between* $\text{I}_3^{\,-}$ *ions and water but not between* I_2 *molecules and water.*	**Point 10**

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

Question 2

Part A

i. $2.883 g\, H_2O \cdot \frac{1\ mol\ H_2O}{18.02 g\, H_2O} = 0.1600\ mol\ H_2O$

ii. $0.2400\ mol\ CO_2 \cdot \frac{1\ mol\ C}{1\ mol\ CO_2} = 0.2400\ mol\ C$

$0.1600\ mol\ H_2O \cdot \frac{2\ mol\ H}{1\ mol\ H_2O} = 0.3200\ mol\ H$

$\frac{0.3200\ mol\ H}{0.2400\ mol\ C} = \frac{4\ mol\ H}{3\ mol\ C}$

Empirical formula = $C_3H_4O_3$

Part B

i. $16.0\ mL\ NaOH \cdot \frac{1\ L}{1000\ mL} \cdot \frac{0.0550\ mol\ NaOH}{1\ L} = 8.80 \cdot 10^{-4}\ mol\ NaOH$

$\frac{8.80 \cdot 10^{-4}\ mol\ HAsc}{10.0\ mL\ HAsc} \cdot \frac{1000\ mL}{1\ L} = 0.0880\ M$ of HAsc

ii. Equivalence point = 16.0 mL → Half-equivalence point = 8.0 mL

At 8.0 mL, pH = pKa → $pK_a \doteq 4.1$

iii. $pH = pK_a + \log_{10}\left(\frac{[Asc^-]}{[HAsc]}\right)$

$4.7 = 4.1 + \log_{10}\left(\frac{[Asc^-]}{[HAsc]}\right)$

$0.6 = \log_{10}\left(\frac{[Asc^-]}{[HAsc]}\right)$

$10^{0.6} = \frac{[Asc^-]}{[HAsc]}$

$\frac{[Asc^-]}{[HAsc]} = 4.0$

Question 2 is continued on the next page.

Question 2

Part C

i. Using trials 1 and 3, we can see that the reaction rate is 2 times greater when [HAsc] is 2 times greater, so it is first order with respect to [HAsc].

ii. $2.457 \cdot 10^{-4} \frac{M}{s} = k \cdot 0.450M \cdot 1.200M$

$k = 4.55 \cdot 10^{-4} s^{-1} M^{-1}$

Part D

Because I_3^- is an ion unlike I_2, it experiences ion-dipole forces with H_2O. The I_3^- ion is attracted to the partially positive H atoms in H_2O, making I_3^- soluble.

Continue to Question 3.

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

Question 2

Part A

i) mol H_2O = $2.883 g\ H_2O \times \frac{1\ mol\ H_2O}{18.02 g\ H_2O}$

= $0.1600\ mol\ H_2O$

ii) mol H = $0.1600\ mol\ H_2O \times \frac{2\ mol\ H}{1\ mol\ H_2O} = \frac{0.32\ mol}{0.24\ mol} = 1.3 \times 3 = 4$

mol C = $0.2400\ mol\ CO_2 \times \frac{1\ mol\ C}{1\ mol\ CO_2} = \frac{0.24\ mol}{0.24\ mol} = 1 \times 3 = 3$

∴ $C_3H_4O_3$

Part B

i) pOH = $-\log(0.0550 M)$

= 1.26

pH = 12.74

[HAsc] = 1.82×10^{-13} M

ii) pKa = 7.5

iii) $\frac{1}{3}$

Question 2 is continued on 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 2

Part C

i) The concentration from trial 1 to 3 for [HAsc] doubles while the initial rate of formation for those same trials also doubles. The represents a first reaction order because both the concentration and the initial rate doubled instead of quadrupling or staying the same.

ii) Rate = k [HAsc][I_2]

2.457×10^{-4} M/s = k [0.450M][1.200M]

2.457×10^{-4} M/s = $0.54 M^2$ k

k = 4.55×10^{-4} S/M

Part D

I_3^- and water contain both london dispersion forces as well as dipole-dipole forces. on the other hand, I_2 and water only contain london dispersion forces.

Continue to Question 3.

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

Question 2

Part A $C_x H_y O_x \rightarrow$

i) $\frac{2.883 g\ H_2O}{} \left| \frac{1 mol}{18.016 g} \right. = 0.1600244 \approx 0.1600 mol\ H_2O$

ii) The EF should be CHO because it's a 1 : 1 ratio meaning they're equal the divide by the smallest which gives CO_2 to 1.5 so $C_{1.5} H\ O_{1.5}$

Part B

i) $K_c = \frac{[H_3O^+][Asc^-]}{[HAsc]}$

ii) $pKa = 1 \leftarrow -\log\left(\frac{1}{10}\right)$

iii) the value is around $\frac{12}{2.5}$ ~~6~~ or 13.

Question 2 is continued on 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 2

Part C

1) It's first order with respect to [HAsc] because in trials 1 & 3 when [HAsc] doubles & $[I_3^-]$ remans constant, the initial rate also doubles.

ii) rate = $K[HAsc][I_3^-]$ $\ln[A]_t - \ln[A]_0 = -kt$

$K = 1/[HAsc][I_3^-]$

Part D

LDF & D-D where I_3^- hase a neg charge to attract H_2O.

Continue to Question 3.

Q5521/07

Question 2

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

Overview

NEW for 2025: The question overviews can be found in the *Chief Reader Report on Student Responses* on AP Central.

Sample: 2A
Score: 10

Point 01: 1
Part A (i): The point was earned for correctly calculating the number of moles of H_2O and showing the supporting setup.

Point 02: 1
Part A (ii): The point was earned for correctly calculating the number of moles of H .

Point 03: 1
Part A (ii): The point was earned for correctly determining the empirical formula of the ascorbic acid.

Point 04: 1
Part B (i): The point was earned for correctly calculating the number of moles of NaOH and correlating that value to moles of HAsc to find the molarity of the ascorbic acid solution.

Point 05: 1
Part B (ii): The point was earned for determining that pK_a equals pH at the half-equivalence point.

Point 06: 1
Part B (iii): The point was earned for correctly calculating the $[Asc^-] / [HAsc]$ using the Henderson-Hasselbalch equation.

Point 07: 1
Part C (i): The point was earned for correctly explaining that "[u]sing trials 1 and 3, we can see that the reaction rate is 2 times greater when [HAsc] is 2 times greater, so it is first order with respect to [HAsc]." In trials 1 and 3, the concentration of the triiodide ion is held constant.

Point 08: 1
Part C (ii): The point was earned for correctly calculating the value of the rate constant using data from one of the trials.

Point 09: 1
Part C (ii): The point was earned for correctly stating the units of *k*.

Point 10: 1
Part D: The point was earned for correctly identifying that because I_3^- is an ion (unlike I_2), ion-dipole forces exist between I_3^- and H_2O .

Question 2 (continued)

Sample: 2B
Score: 5

Point 01: 1
Part A (i): The point was earned for correctly calculating the number of moles of H_2O and showing the supporting setup.

Point 02: 1
Part A (ii): The point was earned for correctly calculating the number of moles of H.

Point 03: 1
Part A (ii): The point was earned for correctly determining the empirical formula of the ascorbic acid.

Point 04: 0
Part B (i): The point was not earned because the molarity of the [HAsc] is not correctly calculated. The calculation shown for [HAsc] finds the hydrogen ion concentration in the 0.0550 M NaOH(aq) solution instead of using the information in the titration curve to find [HAsc].

Point 05: 0
Part B (ii): The point was not earned because an incorrect pK_a value is given. The pK_a value reported is the pH at the equivalence point rather than the pH at the half-equivalence point.

Point 06: 0
Part B (iii): The point was not earned because the $[Asc^-]$ / [HAsc] is not correctly determined and no supporting calculation is shown.

Point 07: 1
Part C (i): The point was earned for correctly identifying "a first reaction order" because the concentration of [HAsc] doubles from trials 1 to 3 while the initial rate of formation for those same trials also doubles. In trials 1 and 3, the concentration of the triiodide ion is held constant.

Point 08: 1
Part C (ii): The point was earned for correctly calculating the value of the rate constant from one of the trials (trial 1).

Point 09: 0
Part C (ii): The point was not earned because the incorrect units of k are stated.

Point 10: 0
Part D: The point was not earned because the response incorrectly states that dipole-dipole forces are present between I_3^- and H_2O instead of identifying the ion-dipole forces between I_3^- and H_2O.

Question 2 (continued)

Sample: 2C
Score: 2

Point 01: 1
Part A (i): The point was earned for correctly calculating the number of moles of H_2O and showing the supporting setup.

Point 02: 0
Part A (ii): The point was not earned because the moles of H are not calculated.

Point 03: 0
Part A (ii): The point was not earned because an incorrect empirical formula of the ascorbic acid is reported.

Point 04: 0
Part B (i): The point was not earned because the molarity of the [HAsc] is not correctly calculated. The response sets up a K_c expression instead of using the titration data to calculate [HAsc].

Point 05: 0
Part B (ii): The point was not earned because it does not correlate that the pH at the half-equivalence point is the pK_a of the weak acid.

Point 06: 0
Part B (iii): The point was not earned because the $[Asc^-]$ / [HAsc] is not correctly determined, and no supporting calculation setup is shown.

Point 07: 1
Part C (i): The point was earned for explaining, "It's first order with respect to [HAsc] because in trials 1 & 3 when [HAsc] doubles & $[I_3^-]$ remains constant, the initial rate also doubles."

Point 08: 0
Part C (ii): The point was not earned because the rate constant value is not calculated. The response does not use data from one of the experimental trials to calculate *k*.

Point 09: 0
Part C (ii): The point was not earned because the incorrect units of *k* are stated.

Point 10: 0
Part D: The point was not earned because it identifies one intermolecular force (London dispersion forces) that is present between I_3^- and H_2O that is also present between I_2 and H_2O, and it identifies an incorrect intermolecular force (dipole-dipole) between I_3^- and H_2O.