Past-paper walk-through

Elemental Composition of Pure Substances ▪ 1.3

eXercise

Questions in this set

- 2025 Q2
- 2014 Q1

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 2

2025 ▪ Q2

Answer the following questions about ascorbic acid (vitamin C).

(a) A student combusts a sample of ascorbic acid, $C_xH_yO_x$, to determine its chemical composition. The only products of the reaction are 0.2400 mol of CO_2 and 2.883 g of H_2O.

(a)(i) Calculate the number of moles of H_2O produced.

(a)(ii) The mole ratio of carbon (C) to oxygen (O) is 1:1 in ascorbic acid. Based on this information and your answer to part A (i), determine the empirical formula of ascorbic acid.

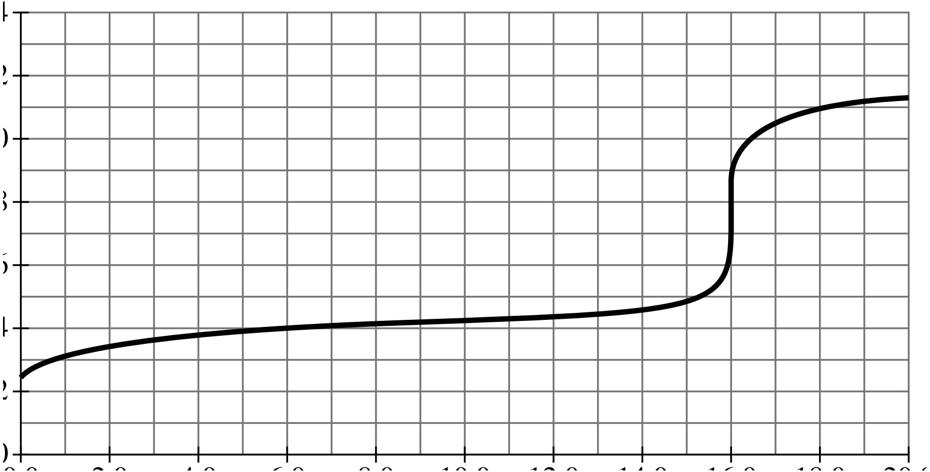
Question 2

Trial	[HAsc] (M)	$[I_3^-]\,(M)$	Initial Rate of DHAsc Formation (M/s)
1	0.450	1.200	2.457×10^{-4}
2	0.450	0.600	1.229×10^{-4}
3	0.900	1.200	4.914×10^{-4}

i. The rate law for the reaction is $rate = k[\mathrm{HAsc}][\mathrm{I_3^-}]$. Explain how the data in the table support the conclusion that the reaction is first order with respect to $[\mathrm{HAsc}]$.

ii. Calculate the value of the rate constant k for the reaction. Include units with your

Question 2



Question 2

2025 ▪ Q2

Answer the following questions about ascorbic acid (vitamin C).

(b) Ascorbic acid, HAsc(aq), acts as a weak acid, as shown in the equation.

$$\text{HAsc}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{Asc}^-(aq)$$

The following titration curve was produced when a 10.0 mL sample of HAsc(aq) was titrated using 0.0550 M NaOH(aq).

[Titration curve graph: x-axis "Volume of 0.0550 M NaOH Added (mL)" from 0.0 to 20.0 in increments of 2.0; y-axis "pH" from 0 to 14 in increments of 2. The curve starts at about (0.0, 2.6), rises gradually and levels into a broad buffer region around pH 4 from about 2 mL to 14 mL, has a small inflection/bump near (14.0, 4.5)-(15.0,

Question 2

5.2), then rises steeply (equivalence point) through the region 15.0-16.5 mL up to about pH 10.5, then levels off gradually approaching about (20.0, 11.3).]

(b)(i) Calculate the molar concentration of the ascorbic acid solution.

(b)(ii) From the titration curve, determine the approximate pK_a of ascorbic acid.

(b)(iii) What is the value of the ratio $\frac{[\mathrm{Asc}^-]}{[\mathrm{HAsc}]}$ when the pH of the solution is 4.7?

Question 2

2025 ▪ Q2

Answer the following questions about ascorbic acid (vitamin C).

(c) Dehydroascorbic acid (DHAsc) can be produced by reacting ascorbic acid with the triiodide ion, I_3^-, as represented by the following equation.

$$\mathrm{HAsc} + \mathrm{I_3^-} \rightarrow \mathrm{DHAsc} + 3\,\mathrm{I^-} + 2\,\mathrm{H^+}$$

The student runs three trials of the reaction with different initial concentrations of HAsc and I_3^-, producing the following data.

Trial	[HAsc] (M)	$[I_3^-]$ (M)	Initial Rate of DHAsc Formation (M/s)
1	0.450	1.200	2.457×10^{-4}
2	0.450	0.600	1.229×10^{-4}
3	0.900	1.200	4.914×10^{-4}

Question 2

(c)(i) The rate law for the reaction is $\textit{rate} = k[\mathrm{HAsc}][\mathrm{I_3^-}]$. Explain how the data in the table support the conclusion that the reaction is first order with respect to $[\mathrm{HAsc}]$.
(c)(ii) Calculate the value of the rate constant, k, for the reaction. Include units with your answer.

Question 2

2025 ▪ Q2

Answer the following questions about ascorbic acid (vitamin C).

(d) The triiodide ion, I_3^-, is significantly more soluble in water than elemental iodine, I_2, is. Identify an intermolecular force between I_3^- and water that is **not** present between I_2 and water, which could explain the difference in solubility. Lewis diagrams for I_2 and I_3^- are provided.

[Lewis structures: I_2 shown as two iodine atoms singly bonded together, each with three lone pairs. I_3^- shown in brackets with an overall negative charge, as three iodine atoms in a row connected by single bonds (I—I—I), each terminal iodine with three lone pairs and the central iodine with two lone pairs.]

Solution 2

(a)

Mark scheme

- No separate response required — this is the context/stem describing the combustion of ascorbic acid ($C_xH_yO_x$) producing 0.2400 mol CO_2 and 2.883 g H_2O, which parts (i) and (ii) below use.

(a)(i)

Mark scheme

- moles $H_2O = 2.883 \text{ g } H_2O \times \dfrac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} = 0.1600 \text{ mol } H_2O$.

Solution 2

(a)(ii)

Mark scheme

- moles H $= 0.1600$ mol $H_2O \times \dfrac{2 \text{ mol H}}{1 \text{ mol } H_2O} = 0.3200$ mol H (this step may be left implicit). Using mol C $= 0.2400$ mol $CO_2 \times \dfrac{1 \text{ mol C}}{1 \text{ mol } CO_2} = 0.2400$ mol C and the given 1:1 C:O ratio:
  $x : y : z = (\text{mol C}) : (\text{mol H}) : (\text{mol O}) = 0.2400 : 0.3200 : 0.2400 = 3 : 4 : 3.$
  Therefore the empirical formula of ascorbic acid is $C_3H_4O_3$.

Solution 2

(b)

Mark scheme

- No separate response required — this is the context/stem describing HAsc(aq) as a weak acid and presenting the titration curve (10.0 mL HAsc titrated with 0.0550 M NaOH) that parts (i)–(iii) below refer to.

Solution 2

(b)(i)

Mark scheme

- Reading the volume of NaOH at the equivalence point (16.0 mL) from the curve:

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

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

Solution 2

(b)(ii)

Mark scheme

- From the titration curve, the pK_a (the pH at the half-equivalence point) is approximately 4.1 (acceptable range 4.0–4.3).

Solution 2

(b)(iii)

Mark scheme

- Using the Henderson–Hasselbalch equation: $\mathrm{pH} = \mathrm{p}K_a + \log\left(\frac{[\mathrm{Asc}^-]}{[\mathrm{HAsc}]}\right)$.

  $4.7 = 4.1 + \log\left(\frac{[\mathrm{Asc}^-]}{[\mathrm{HAsc}]}\right)$, so $\frac{[\mathrm{Asc}^-]}{[\mathrm{HAsc}]} = 10^{0.6} = 4.0$.

Solution 2

(c)

Mark scheme

- No separate response required — this is the context/stem describing the reaction of ascorbic acid (HAsc) with triiodide (I_3^-) to form DHAsc, and the table of three trials' initial concentrations and rates, that parts (i) and (ii) below use.

Solution 2

(c)(i)

Mark scheme

- Comparing trials 1 and 3: $\dfrac{4.914 \times 10^{-4}}{2.457 \times 10^{-4}} = \left(\dfrac{0.900}{0.450}\right)^{a}$, thus $a = 1$. The rate doubles when [HAsc] is doubled while $[I_3^-]$ is held constant, indicating the reaction is first order with respect to [HAsc].

Solution 2

(c)(ii)

Mark scheme

- Using rate $= k[\mathrm{HAsc}][\mathrm{I}_3^-]$ and trial 1 data: $k = \dfrac{\text{rate}}{[\mathrm{HAsc}][\mathrm{I}_3^-]} = \dfrac{2.457 \times 10^{-4}\ M/\mathrm{s}}{(0.450\ M)(1.200\ M)} = 4.55 \times 10^{-4}\ M^{-1}\mathrm{s}^{-1}$. Units: $M^{-1}\mathrm{s}^{-1}$.

Solution 2

(d)

Mark scheme

- Ion-dipole attractions are present between I_3^- ions and water but not between I_2 molecules and water. Because I_3^- is a charged ion, it attracts the polar water molecules via ion-dipole forces, giving it much greater solubility than the neutral, nonpolar I_2.

Question 1

2014 ▪ Q1

[Table of experimental data:]

Mass of KI tablet	0.425 g
Mass of thoroughly dried filter paper	1.462 g
Mass of filter paper + precipitate after first drying	1.775 g
Mass of filter paper + precipitate after second drying	1.699 g
Mass of filter paper + precipitate after third drying	1.698 g

A student is given the task of determining the I^- content of tablets that contain KI and an inert, water-soluble sugar as a filler. A tablet is dissolved in 50.0 mL of distilled water, and an excess of 0.20 M $Pb(NO_3)_2(aq)$ is added to the solution. A yellow precipitate forms, which is then filtered, washed, and dried. The data from the experiment are shown in the table above.

(a)(i) For the chemical reaction that occurs when the precipitate forms, write a balanced, net-ionic equation for the reaction.

Question 1

(a)(ii) For the chemical reaction that occurs when the precipitate forms, explain why the reaction is best represented by a net-ionic equation.

Question 1

Mass of KI tablet	0.425 g
Mass of thoroughly dried filter paper	1.462 g
Mass of filter paper + precipitate after first drying	1.775 g
Mass of filter paper + precipitate after second drying	1.699 g
Mass of filter paper + precipitate after third drying	1.698 g

Question 1

2014 ▪ Q1

[Table of experimental data:]

Mass of KI tablet	0.425 g
Mass of thoroughly dried filter paper	1.462 g
Mass of filter paper + precipitate after first drying	1.775 g
Mass of filter paper + precipitate after second drying	1.699 g
Mass of filter paper + precipitate after third drying	1.698 g

A student is given the task of determining the I^- content of tablets that contain KI and an inert, water-soluble sugar as a filler. A tablet is dissolved in 50.0 mL of distilled water, and an excess of 0.20 M $Pb(NO_3)_2(aq)$ is added to the solution. A yellow precipitate forms, which is then filtered, washed, and dried. The data from the experiment are shown in the table above.

(b) Explain the purpose of drying and weighing the filter paper with the precipitate three times.

Question 1

2014 ▪ Q1

[Table of experimental data:]

Mass of KI tablet	0.425 g
Mass of thoroughly dried filter paper	1.462 g
Mass of filter paper + precipitate after first drying	1.775 g
Mass of filter paper + precipitate after second drying	1.699 g
Mass of filter paper + precipitate after third drying	1.698 g

A student is given the task of determining the I^- content of tablets that contain KI and an inert, water-soluble sugar as a filler. A tablet is dissolved in 50.0 mL of distilled water, and an excess of 0.20 M $Pb(NO_3)_2(aq)$ is added to the solution. A yellow precipitate forms, which is then filtered, washed, and dried. The data from the experiment are shown in the table above.

(c) In the filtrate solution, is $[K^+]$ greater than, less than, or equal to $[NO_3^-]$? Justify your answer.

Question 1

2014 ▪ Q1

[Table of experimental data:]
| Mass of KI tablet | 0.425 g | |—|—| | Mass of thoroughly dried filter paper | 1.462 g | | Mass of filter paper + precipitate after first drying | 1.775 g | | Mass of filter paper + precipitate after second drying | 1.699 g | | Mass of filter paper + precipitate after third drying | 1.698 g |

A student is given the task of determining the I^- content of tablets that contain KI and an inert, water-soluble sugar as a filler. A tablet is dissolved in 50.0 mL of distilled water, and an excess of 0.20 M $Pb(NO_3)_2(aq)$ is added to the solution. A yellow precipitate forms, which is then filtered, washed, and dried. The data from the experiment are shown in the table above.

(d) Calculate the number of moles of precipitate that is produced in the experiment.

Question 1

2014 ▪ Q1

[Table of experimental data:]

Mass of KI tablet	0.425 g
Mass of thoroughly dried filter paper	1.462 g
Mass of filter paper + precipitate after first drying	1.775 g
Mass of filter paper + precipitate after second drying	1.699 g
Mass of filter paper + precipitate after third drying	1.698 g

A student is given the task of determining the I^- content of tablets that contain KI and an inert, water-soluble sugar as a filler. A tablet is dissolved in 50.0 mL of distilled water, and an excess of 0.20 M $Pb(NO_3)_2(aq)$ is added to the solution. A yellow precipitate forms, which is then filtered, washed, and dried. The data from the experiment are shown in the table above.

(e) Calculate the mass percent of I^- in the tablet.

Question 1

2014 ▪ Q1

[Table of experimental data:]
| Mass of KI tablet | 0.425 g | |—|—| | Mass of thoroughly dried filter paper | 1.462 g | | Mass of filter paper + precipitate after first drying | 1.775 g | | Mass of filter paper + precipitate after second drying | 1.699 g | | Mass of filter paper + precipitate after third drying | 1.698 g |

A student is given the task of determining the I^- content of tablets that contain KI and an inert, water-soluble sugar as a filler. A tablet is dissolved in 50.0 mL of distilled water, and an excess of 0.20 M $Pb(NO_3)_2(aq)$ is added to the solution. A yellow precipitate forms, which is then filtered, washed, and dried. The data from the experiment are shown in the table above.

(f) In another trial, the student dissolves a tablet in 55.0 mL of water instead of 50.0 mL of water. Predict whether the experimentally determined mass percent of I^- will be greater than, less than, or equal to the amount calculated in part (e). Justify your answer.

Question 1

2014 ▪ Q1

[Table of experimental data:]
| Mass of KI tablet | 0.425 g | |—|—| | Mass of thoroughly dried filter paper | 1.462 g | | Mass of filter paper + precipitate after first drying | 1.775 g | | Mass of filter paper + precipitate after second drying | 1.699 g | | Mass of filter paper + precipitate after third drying | 1.698 g |

A student is given the task of determining the I^- content of tablets that contain KI and an inert, water-soluble sugar as a filler. A tablet is dissolved in 50.0 mL of distilled water, and an excess of 0.20 M $Pb(NO_3)_2(aq)$ is added to the solution. A yellow precipitate forms, which is then filtered, washed, and dried. The data from the experiment are shown in the table above.

(g)(i) A student in another lab also wants to determine the I^- content of a KI tablet but does not have access to $Pb(NO_3)_2$. However, the student does have access to 0.20 M $AgNO_3$, which reacts with $I^-(aq)$ to produce $AgI(s)$. The value of K_{sp} for AgI is 8.5×10^{-17}.

Question 1

Will the substitution of $AgNO_3$ for $Pb(NO_3)_2$ result in the precipitation of the I^- ion from solution? Justify your answer.

(g)(ii) The student only has access to one KI tablet and a balance that can measure to the nearest 0.01 g. Will the student be able to determine the mass of AgI produced to three significant figures? Justify your answer.

Solution 1

(a)(i)

Mark scheme

- Balanced net-ionic equation: $\mathrm{Pb}^{2+}(aq) + 2\,\mathrm{I}^-(aq) \to \mathrm{PbI}_2(s)$. Full credit requires correct formulas/charges and coefficients balanced for both mass and charge.

Solution 1

(a)(ii)

Mark scheme

- The net-ionic equation is best because it shows only the species that actually react to form the precipitate — $PbI2(s)$ forming from $Pb2+(aq)$ and $I-(aq)$ — while omitting the spectator ions that do not participate, $K+(aq)$ and $NO3-(aq)$.

Solution 1

(b)

Mark scheme

- The filter paper and precipitate must be dried and weighed repeatedly (to a constant mass, i.e. until successive weighings agree) to ensure that all of the water/moisture has been driven off, so the recorded mass reflects only the dry PbI2 precipitate.

Solution 1

(c)

Mark scheme

- $[K^+]$ is less than $[NO_3^-]$, because the source of NO3-, the 0.20 M Pb(NO3)2(aq), was added in excess (beyond what was needed to precipitate all the I-), so leftover NO3- remains in solution without a matching amount of K$+$.

Solution 1

(d)

Mark scheme

- Mass of precipitate = 1.698 g − 1.462 g = 0.236 g PbI2(s). Moles of PbI2 = 0.236 g × (1 mol PbI2 / 461.0 g PbI2) = 5.12×10^{-4} mol PbI2.

Solution 1

(e)

Mark scheme

- Moles I- $= 5.12 \times 10^{-4}$ mol PbI2 $\times$ (2 mol I-/1 mol PbI2) $= 1.02 \times 10^{-3}$ mol I- (1 point for the moles of I-). Mass I- $= 1.02 \times 10^{-3}$ mol $\times$ 126.91 g/mol = 0.130 g I-; mass percent = 0.130 g / 0.425 g KI tablet = 0.306 = 30.6

Solution 1

(f)

Mark scheme

- The mass percent of I- will be the same (equal to part e), because Pb2+(aq) was added in excess, ensuring essentially all I- is precipitated regardless of the extra water; the additional water is removed during filtration and drying, leaving the same mass of dried precipitate.

Solution 1

(g)(i)

Mark scheme

- Yes. Addition of excess 0.20 M AgNO3(aq) will precipitate essentially all of the I- ion present in solution because AgI is very insoluble, as shown by its very small Ksp value (8.5×10^{-17}).

(g)(ii)

Mark scheme

- No. Since masses can only be measured to ± 0.01 g, and the dry AgI(s) precipitate produced will have a mass less than 1 g, the mass will be known to only two significant figures, not three.