Past-paper walk-through

Moles and Molar Mass ▪ 1.1

eXercise

Questions in this set

- 2025 Q2
- 2024 Q1
- 2024 Q2
- 2024 Q7
- 2023 Q1
- 2022 Q4
- 2019 Q1
- 2018 Q1
- 2016 Q3

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.

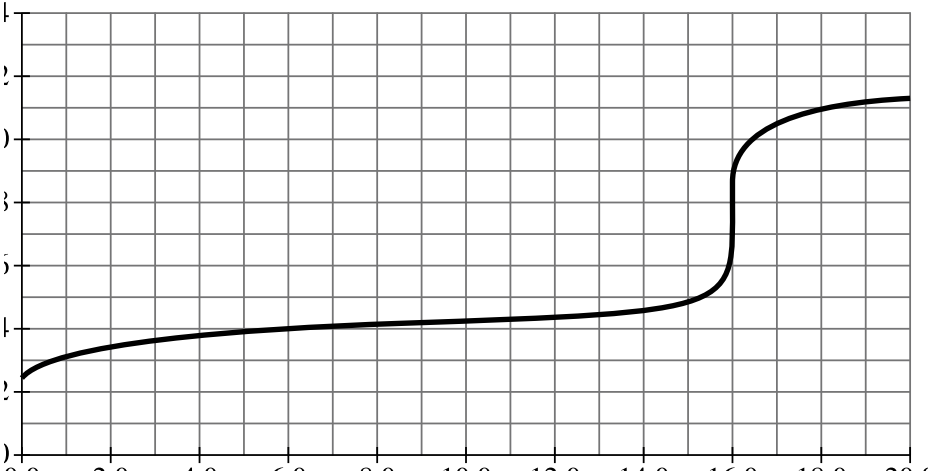
Question 2

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

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.

$$\mathrm{HAsc}(aq) + \mathrm{H_2O}(l) \rightleftharpoons \mathrm{H_3O^+}(aq) + \mathrm{Asc^-}(aq)$$

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 $\frac{[\text{Asc}^-]}{[\text{HAsc}]}$ 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.

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

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 $rate = k[\text{HAsc}][\text{I}_3^-]$. Explain how the data in the table support the conclusion that the reaction is first order with respect to [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 $H_2O = 2.883$ g $H_2O \times \dfrac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} = 0.1600$ 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: $\mathrm{pH} = \mathrm{p}K_a + \log\left(\dfrac{[\mathrm{Asc}^-]}{[\mathrm{HAsc}]}\right)$.

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

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: $\frac{4.914 \times 10^{-4}}{2.457 \times 10^{-4}} = \left(\frac{0.900}{0.450}\right)^{a}$, 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 $= k[\text{HAsc}][\text{I}_3^-]$ and trial 1 data: $k = \dfrac{\text{rate}}{[\text{HAsc}][\text{I}_3^-]} = \dfrac{2.457 \times 10^{-4}\ M/\text{s}}{(0.450\ M)(1.200\ M)} = 4.55 \times 10^{-4}\ M^{-1}\text{s}^{-1}$. Units: $M^{-1}\text{s}^{-1}$.

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

2024 ▪ Q1

$$C_3H_6O_3(aq) + NaOH(aq) \rightarrow NaC_3H_5O_3(aq) + H_2O(l)$$

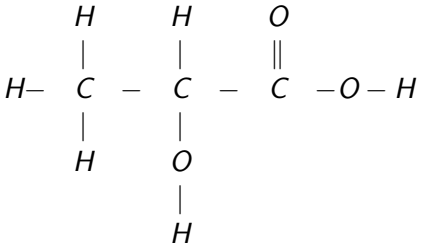
1. A student is studying the reaction between lactic acid, $C_3H_6O_3$, and sodium hydroxide, NaOH, as represented in the balanced equation above.

(a) The structural formula of lactic acid is shown in the following diagram. Circle the hydrogen atom that most readily participates in the chemical reaction with sodium hydroxide.

[Structural (Lewis) formula of lactic acid: a chain H—C—C—C(=O)—O—H, drawn as: Top row: H, H, O(double bond) The first carbon bears an H above, an H below, and a bond to the second carbon. The second carbon bears an OH group below it (O bonded down to an H). The third carbon is a carbonyl carbon (C=O, double bond to

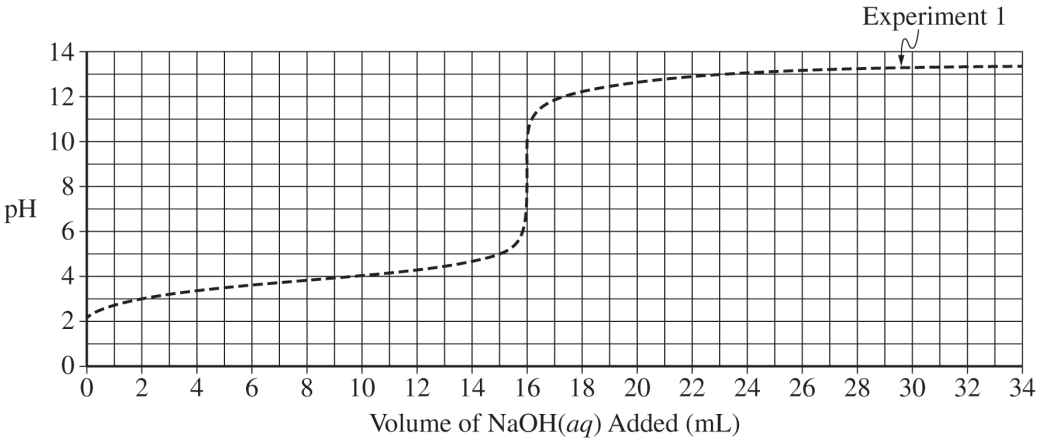
Question 1

O above) bonded to an —O—H (single-bonded hydroxyl oxygen then H) on the right. Full skeleton:

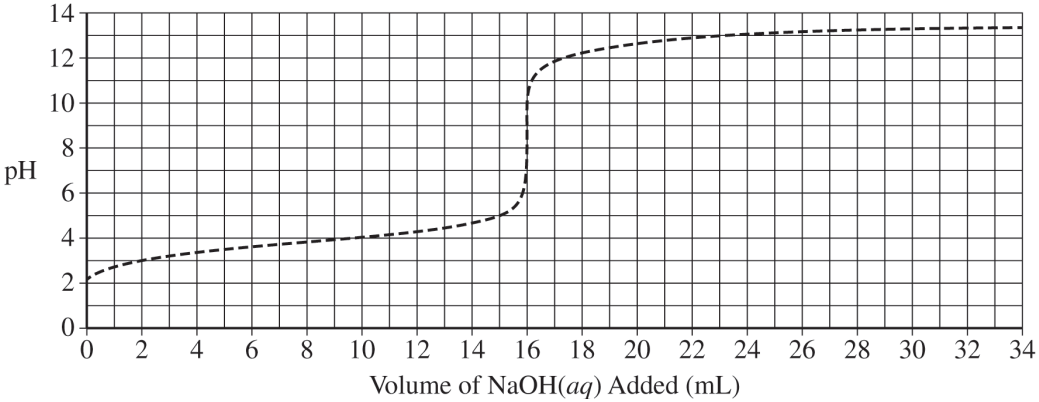


The hydrogen to circle is the one on the hydroxyl oxygen attached to the carbonyl carbon (the carboxylic acid —C(=O)—O—H proton).]

Question 1


Experiment 1
pH
14
12
10
8
6
4
2
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
Volume of NaOH(aq) Added (mL)

Question 1


pH
14
12
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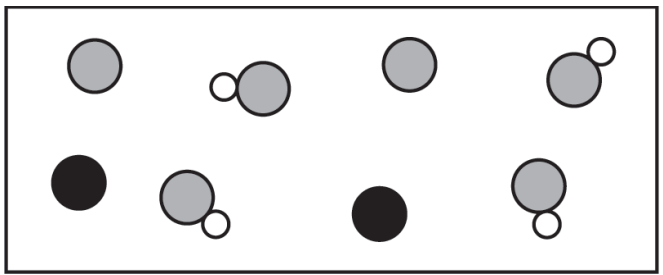
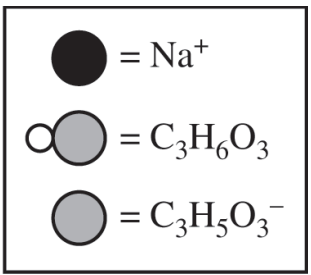
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
Volume of NaOH(aq) Added (mL)

Question 1





Question 1

2024 ▪ Q1

$$C_3H_6O_3(aq) + NaOH(aq) \rightarrow NaC_3H_5O_3(aq) + H_2O(l)$$

1. A student is studying the reaction between lactic acid, $C_3H_6O_3$, and sodium hydroxide, NaOH, as represented in the balanced equation above.

(b) The student begins the experiment by dissolving 10.22 g of sodium hydroxide (molar mass 40.00 g/mol) in enough water to produce 500. mL of solution. Calculate the molarity of the sodium hydroxide solution.

Question 1

2024 ▪ Q1

$$C_3H_6O_3(aq) + NaOH(aq) \rightarrow NaC_3H_5O_3(aq) + H_2O(l)$$

1. A student is studying the reaction between lactic acid, $C_3H_6O_3$, and sodium hydroxide, NaOH, as represented in the balanced equation above.

(c) The student uses the sodium hydroxide solution from part (b), a buret, a pH meter, and a 100 mL Erlenmeyer flask to titrate a 25.0 mL sample of lactic acid. The student's data are shown in the following graph.

[Graph: titration curve of pH vs. Volume of NaOH(aq) Added (mL); x-axis 0 to 34 mL in increments of 2, y-axis pH 0 to 14 in increments of 2. Curve starts near pH 2-3 at V=0, rises slowly/gradually (buffer region) from about V=2 to V=14, then shows a

Question 1

steep equivalence-point jump between about V=15 and V=17 (pH rising sharply from about 4 to about 11-12), then levels off and rises slowly to about pH 13 by V=34.]
Use the information in the graph to determine the approximate pK_a of lactic acid.

_____

Question 1

2024 ▪ Q1

$$C_3H_6O_3(aq) + NaOH(aq) \rightarrow NaC_3H_5O_3(aq) + H_2O(l)$$

1. A student is studying the reaction between lactic acid, $C_3H_6O_3$, and sodium hydroxide, NaOH, as represented in the balanced equation above.

(d)(i) [Particle diagram box showing the relative amounts of major species in a sample of the solution in the flask at one point during the titration. Water molecules are omitted. Key: solid black circle = Na^+; circle half-white/half-gray (with a small white circle attached) = $C_3H_6O_3$; circle half-black/half-gray (with a small white circle attached) = $C_3H_5O_3^-$. The box contains 2 large gray/white two-tone circles (labeled as $C_3H_6O_3$-type), 2 large gray/black two-tone circles (labeled as $C_3H_5O_3^-$-type), and 2

Question 1

small solid black circles (Na^+), with small white circles attached to some of the larger circles.]

The preceding diagram represents the relative amounts of major species in a sample of the solution in the flask at one point during the titration. (Note that water molecules are omitted.)

Draw an X on the preceding titration curve at a point in the titration where the reaction mixture would be represented by this diagram.

(d)(ii) Justify your answer.

Question 1

2024 ▪ Q1

$$C_3H_6O_3(aq) + NaOH(aq) \rightarrow NaC_3H_5O_3(aq) + H_2O(l)$$

1. A student is studying the reaction between lactic acid, $C_3H_6O_3$, and sodium hydroxide, NaOH, as represented in the balanced equation above.

(e) The following table shows two experiments:

Experiment	**Mass of NaOH(s) (grams)**	**Volume of Solution (mL)**	**Titration Curve**
1	10.22	500.	Already shown on graph
2	20.44	500.	?

Question 1

The student repeats the experiment but uses a solution of NaOH(*aq*) with twice the concentration, as shown in the preceding table. On the following graph, draw the titration curve that would be expected for experiment 2.
[Blank graph titled "Experiment 1" with a faint curve of Experiment 1 shown as reference (pH vs. Volume of NaOH(aq) Added (mL), x-axis 0 to 34 mL, y-axis pH 0 to 14); student draws the Experiment 2 curve on the same axes.]

Question 1

2024 ▪ Q1

$$C_3H_6O_3(aq) + NaOH(aq) \rightarrow NaC_3H_5O_3(aq) + H_2O(l)$$

1. A student is studying the reaction between lactic acid, $C_3H_6O_3$, and sodium hydroxide, NaOH, as represented in the balanced equation above.

(f) In a third experiment, the student investigates the enthalpy of the reaction between lactic acid and sodium hydroxide. The student combines 100.0 mL of a 0.500 *M* lactic acid solution at 20.0°C with 100.0 mL of a 0.500 *M* NaOH solution at 20.0°C in a calorimeter. The final temperature of the resulting combined solution is 23.2°C. Assume the density of each solution before combining is 1.00 g/mL and that the specific heat capacity of the combined solution is 4.2 J/(g · °C).

Calculate the quantity of heat produced in the reaction, in J.

Question 1

(f)(ii) Calculate the molar enthalpy of reaction, in kJ/mol$_{rxn}$. Include the sign in your answer.

(f)(iii) The student claims that if heat is lost from the calorimeter to the surrounding air during the reaction, then the experimental value of the molar enthalpy of reaction will be smaller in magnitude than the actual value. Do you agree or disagree with the student's claim? Justify your answer.

Solution 1

(a)

Mark scheme

- Circle the rightmost hydrogen atom — the acidic O–H proton on the carboxylic acid group ($-\mathrm{C}(=\mathrm{O})-\mathrm{O}-\mathrm{H}$). This H is the most acidic (bonded to O, adjacent to the electron-withdrawing carbonyl) and is the one that reacts with NaOH in the acid–base neutralization.

Solution 1

(b)

Mark scheme

- Molarity $= \dfrac{(10.22\ \text{g})\left(\dfrac{1\ \text{mol}}{40.00\ \text{g}}\right)}{0.500\ \text{L}} = 0.511\ M.$

Solution 1

(c)

Mark scheme

- pK_a = 3.9 (acceptable range: 3.7–4.0), read as the pH at the half-equivalence point of the titration curve (where pH = pK_a).

Solution 1

(d)(i)

Mark scheme

- The particle diagram shows more lactic acid (HA) particles than lactate (A^-) particles present in solution at that point during the titration. The X should be placed on the titration curve (from part c) at a volume ≥ 3 mL and < 8 mL — i.e., before the half-equivalence point, consistent with acid predominating over conjugate base at that point.

Solution 1

(d)(ii)

Mark scheme

- Justification: more acid (HA) particles are present than conjugate base (A^-) particles, meaning the titration is before the half-equivalence point (where $[HA] = [A^-]$).

Solution 1

(e) Mark scheme

- Draw the titration curve expected for Experiment 2 (NaOH solution with twice the concentration titrating the same lactic acid sample). Two criteria are scored: (1) Equivalence point — doubling the NaOH concentration means HALF the volume is needed to deliver the same moles of base, so the new equivalence point should be at 8 mL (half of Experiment 1's 16 mL equivalence volume), NOT at 16 mL. (2) Shape — the drawn curve should begin at the same initial pH as Experiment 1's curve, rise gradually through a buffer region, rise sharply at a volume different from 16 mL (i.e., near 8 mL), and end (plateau) at a final pH similar to Experiment 1's curve.

Solution 1

(f)

Mark scheme

- $q = mc\Delta T = (200.0\ \text{g})(4.2\ \text{J/(g} \cdot {}^\circ\text{C}))(23.2{}^\circ\text{C} - 20.0{}^\circ\text{C}) = 2700\ \text{J}$ (heat absorbed by the combined solution).

Solution 1

(f)(ii)

Mark scheme

- $q_{rxn} = -q_{soln} = -2700\ \text{J} = -2.7\ \text{kJ}$.
  $\Delta H_{rxn} = \dfrac{q_{rxn}}{\text{mol}} = \dfrac{-2.7\ \text{kJ}}{(0.100\ \text{L})(0.500\ \text{mol/L})} = -54\ \text{kJ/mol}_{rxn}$. (Sign must be included: negative, exothermic.)

Solution 1

(f)(iii)

Mark scheme

- Agree. Heat lost from the system to the surroundings would result in a lower final (measured) temperature, which produces smaller measured values of ΔT, q_{soln}, and thus $|\Delta H_{rxn}|$ than the true (actual) value — so the experimental molar enthalpy will be smaller in magnitude than the actual value.

Question 2

2024 ▪ Q2

$$H_2C_4H_2O_4(aq) + 2\,NaHCO_3(aq) \rightarrow 2\,CO_2(g) + 2\,H_2O(l) + Na_2C_4H_2O_4(aq)$$

2. A chemical reaction between maleic acid ($H_2C_4H_2O_4$) and sodium bicarbonate ($NaHCO_3$) occurs in the presence of water to produce carbon dioxide and sodium maleate ($Na_2C_4H_2O_4$), as represented by the following equation.

(a)(i) A student combines equal masses of $H_2C_4H_2O_4(s)$ chunks and $NaHCO_3(s)$ chunks with sufficient water at 20.0°C. The student determines that 0.0114 mol of $CO_2(g)$ is produced after the reaction goes to completion.

Calculate the number of grams of $CO_2(g)$ produced.

(a)(ii) The $CO_2(g)$ produced from the reaction at 20.0°C was collected and found to have a pressure of 1.25 atm. Calculate the volume of $CO_2(g)$, in liters.

Question 2

2024 ▪ Q2

$$H_2C_4H_2O_4(aq) + 2\,NaHCO_3(aq) \rightarrow 2\,CO_2(g) + 2\,H_2O(l) + Na_2C_4H_2O_4(aq)$$

2. A chemical reaction between maleic acid ($H_2C_4H_2O_4$) and sodium bicarbonate ($NaHCO_3$) occurs in the presence of water to produce carbon dioxide and sodium maleate ($Na_2C_4H_2O_4$), as represented by the following equation.

(b)(i) The student performs a second experiment that is identical to the first except that the student grinds the chunks of $H_2C_4H_2O_4(s)$ and $NaHCO_3(s)$ into powder before combining the powder with water.

What happens to the surface area of the reactants when the student grinds the chunks into powder?

Question 2

(b)(ii) The rate-determining step for the overall reaction is the dissolving of the solids. Would the time required for the dissolving of the solids in the second experiment be longer than, shorter than, or the same as the time required in the first experiment? Justify your answer based on the collisions between particles.

(b)(iii) When the reaction is complete, will the volume of $CO_2(g)$ at the end of the second experiment be greater than, less than, or equal to the volume at the end of the first experiment? Justify your answer.

Question 2

2024 ▪ Q2

$$H_2C_4H_2O_4(aq) + 2\,NaHCO_3(aq) \rightarrow 2\,CO_2(g) + 2\,H_2O(l) + Na_2C_4H_2O_4(aq)$$

2. A chemical reaction between maleic acid ($H_2C_4H_2O_4$) and sodium bicarbonate ($NaHCO_3$) occurs in the presence of water to produce carbon dioxide and sodium maleate ($Na_2C_4H_2O_4$), as represented by the following equation.

(c) The student conducts additional trials of the experiment and produces the following data table.

Trial	Mass of $H_2C_4H_2O_4$ (grams)	Mass of $NaHCO_3$ (grams)	Moles of CO_2 Produced (mol)
3	1.543	1.251	0.01489
4	1.543	1.686	0.02007

Based on the student's data, identify the limiting reactant in trial 3. Justify your answer.

Question 2

2024 ▪ Q2

$$H_2C_4H_2O_4(aq) + 2\,NaHCO_3(aq) \rightarrow 2\,CO_2(g) + 2\,H_2O(l) + Na_2C_4H_2O_4(aq)$$

2. A chemical reaction between maleic acid ($H_2C_4H_2O_4$) and sodium bicarbonate ($NaHCO_3$) occurs in the presence of water to produce carbon dioxide and sodium maleate ($Na_2C_4H_2O_4$), as represented by the following equation.

(d) The reaction has a value of ΔS° greater than zero. Using particle-level reasoning, explain why the entropy increases as the reaction progresses.

Question 2

2024 ▪ Q2

$$H_2C_4H_2O_4(aq) + 2\,NaHCO_3(aq) \rightarrow 2\,CO_2(g) + 2\,H_2O(l) + Na_2C_4H_2O_4(aq)$$

2. A chemical reaction between maleic acid ($H_2C_4H_2O_4$) and sodium bicarbonate ($NaHCO_3$) occurs in the presence of water to produce carbon dioxide and sodium maleate ($Na_2C_4H_2O_4$), as represented by the following equation.

(e) The student notices that the temperature of the reaction mixture decreases as the reaction takes place and correctly determines that the reaction is endothermic.
The student claims that the reaction is thermodynamically favorable at all temperatures because $\Delta S^\circ_{rxn} > 0$ and the reaction is endothermic. Do you agree or disagree with the student's claim? Justify your answer.

Question 2

2024 ▪ Q2

$$H_2C_4H_2O_4(aq) + 2\,NaHCO_3(aq) \rightarrow 2\,CO_2(g) + 2\,H_2O(l) + Na_2C_4H_2O_4(aq)$$

2. A chemical reaction between maleic acid ($H_2C_4H_2O_4$) and sodium bicarbonate ($NaHCO_3$) occurs in the presence of water to produce carbon dioxide and sodium maleate ($Na_2C_4H_2O_4$), as represented by the following equation.

(f) Next, the student investigates the acid-base behavior of maleic acid. The student notes that maleic acid is a diprotic acid. The two acid dissociation processes that occur are represented by the following equations.

$$H_2C_4H_2O_4 + H_2O \rightleftharpoons HC_4H_2O_4^- + H_3O^+ \qquad K_{a_1} = 1.5 \times 10^{-2}$$

$$HC_4H_2O_4^- + H_2O \rightleftharpoons C_4H_2O_4^{2-} + H_3O^+ \qquad K_{a_2} = 8.5 \times 10^{-7}$$

Question 2

Calculate the pK_{a_2} value for the $HC_4H_2O_4^-$ ion.

Question 2

2024 ▪ Q2

$$H_2C_4H_2O_4(aq) + 2\,NaHCO_3(aq) \rightarrow 2\,CO_2(g) + 2\,H_2O(l) + Na_2C_4H_2O_4(aq)$$

2. A chemical reaction between maleic acid ($H_2C_4H_2O_4$) and sodium bicarbonate ($NaHCO_3$) occurs in the presence of water to produce carbon dioxide and sodium maleate ($Na_2C_4H_2O_4$), as represented by the following equation.

(g) A buffer solution with a pH of 7.00 is prepared using $C_4H_2O_4^{2-}$ and $HC_4H_2O_4^-$. Calculate the ratio

$$\frac{[C_4H_2O_4^{2-}]}{[HC_4H_2O_4^-]}$$

in this solution.

Solution 2

(a)(i)

Mark scheme

- 0.0114 mol $CO_2 \times \dfrac{44.01\ \text{g}}{1\ \text{mol}} = 0.502\ \text{g}\ CO_2$.

Solution 2

(a)(ii)

Mark scheme

- Using $PV = nRT$:
  $$V = \frac{nRT}{P} = \frac{(0.0114\ \text{mol})(0.08206\ \text{L} \cdot \text{atm}/(\text{mol} \cdot \text{K}))(293\ \text{K})}{1.25\ \text{atm}} = 0.219\ \text{L}.$$

Solution 2

(b)(i)

Mark scheme

- Claim: the surface area of the solid reactants increases when the chunks are ground into powder.

(b)(ii)

Mark scheme

- Shorter than. The powdered solids have a larger surface area than the solid chunks, so collisions between water molecules and the solid surface particles occur more frequently, resulting in a faster rate of dissolution and a shorter time to dissolve the solids.

Solution 2

(b)(iii)

Mark scheme

- Equal to. Both experiments begin with the same amount (mass) of reactants, so they produce the same number of moles of $CO_2(g)$ under the same conditions of pressure and temperature; therefore the final volume of CO_2 will be the same regardless of particle size (rate changes, but the final amount/volume does not).

Solution 2

(c) Mark scheme

- $NaHCO_3$ is the limiting reactant (accept either justification): changing the mass of $NaHCO_3$ alters the amount of CO_2 produced, OR $NaHCO_3$ has the smaller theoretical yield of CO_2:
  1.543 g $H_2C_4H_2O_4 \times \dfrac{1 \text{ mol}}{116.07 \text{ g}} \times \dfrac{2 \text{ mol } CO_2}{1 \text{ mol acid}} = 0.02659$ mol CO_2 (if acid were limiting) vs. 1.251 g $NaHCO_3 \times \dfrac{1 \text{ mol}}{84.01 \text{ g}} \times \dfrac{2 \text{ mol } CO_2}{2 \text{ mol } NaHCO_3} = 0.01489$ mol CO_2 (if $NaHCO_3$ limiting) — the smaller value ($NaHCO_3$) is the actual limiting reactant, matching the trial's observed 0.01489 mol CO_2.

Solution 2

(d)

Mark scheme

- The entropy change is positive because the aqueous/solid reactants produce 2 moles of gas (CO_2) particles, according to the balanced equation. Gases are far more dispersed (occupy many more microstates) than condensed (solid/aqueous) phases, so the entropy of the products is greater than that of the reactants.

Solution 2

(e)

Mark scheme

- Disagree. Accept either justification: (1) The reaction is endothermic ($\Delta H > 0$) with a positive entropy change ($\Delta S > 0$), so it is only thermodynamically favorable at a high enough temperature where the magnitude of $-T\Delta S$ exceeds ΔH — NOT at all temperatures. (2) For a reaction to be thermodynamically favorable ($\Delta G < 0$) at ALL temperatures, it must be exothermic ($\Delta H < 0$) AND have $\Delta S > 0$ — this reaction is endothermic, so it fails that requirement.

Solution 2

(f)

Mark scheme

- Given $K_{a_2} = 8.5 \times 10^{-7}$ for the second dissociation of maleic acid: $\mathrm{p}K_{a_2} = -\log(8.5 \times 10^{-7}) = 6.07$.

Solution 2

(g)

Mark scheme

- Using the Henderson–Hasselbalch equation: $\mathrm{pH} = \mathrm{p}K_{a_2} + \log \dfrac{[\mathrm{C_4H_2O_4^{2-}}]}{[\mathrm{HC_4H_2O_4^-}]}$.

  Solving: $\dfrac{[\mathrm{C_4H_2O_4^{2-}}]}{[\mathrm{HC_4H_2O_4^-}]} = 10^{(\mathrm{pH}-\mathrm{p}K_{a_2})} = 10^{(7.00-6.07)} = 8.5.$

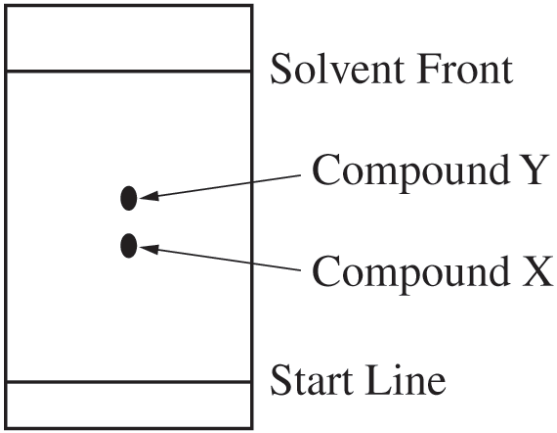
Question 7

2024 ▪ Q7

1. A student conducts a chromatography experiment and needs to prepare 100.0 mL of 0.340 M NaCl(aq) to use as the solvent.

(a) Calculate the mass of solid NaCl (molar mass 58.44 g/mol) needed to prepare the 100.0 mL of 0.340 M NaCl(aq).

Question 7



Question 7

2024 ▪ Q7

1. A student conducts a chromatography experiment and needs to prepare 100.0 mL of 0.340 *M* NaCl(*aq*) to use as the solvent.

(b) In the following table, briefly list the additional steps necessary to prepare the 100.0 mL of 0.340 *M* NaCl(*aq*) solution using only materials selected from the choices given. Assume that all appropriate safety measures are already in place. Not all materials in the list may be needed.

Question 7

Materials available: Solid NaCl, Distilled water, Weighing paper and scoop, Balance, 100.0 mL volumetric flask, 50.0 mL graduated cylinder, Pipet, 150 mL beakers, Chromatography paper.

Step	Step Description and Materials Used
1.	Use the weighing paper and scoop to measure the correct mass of solid NaCl on the balance.
2.	_____ (student fills in)
3.	Swirl the mixture to dissolve the solid NaCl.
4.	_____ (student fills in)
5.	Stopper and invert the mixture several times to ensure that the mixture is homogeneous.

Question 7

Fill in steps 2 and 4.

Question 7

2024 ▪ Q7

1. A student conducts a chromatography experiment and needs to prepare 100.0 mL of 0.340 *M* NaCl(*aq*) to use as the solvent.

(c) The student uses the NaCl(*aq*) solvent to separate a mixture of compounds X and Y in a chromatography experiment. After 30 minutes, the student removes the chromatography paper from the chamber. The results of the experiment are shown. [Diagram: a rectangular chromatography-paper strip inside a chamber. From top to bottom: a horizontal line labeled “Solvent Front” near the top; below it, two spot markers close together labeled with arrows — the upper spot labeled “Compound Y” and, just below it, the lower spot labeled “Compound X”; near the bottom, a horizontal line labeled “Start Line”.]

Question 7

A second student conducts the same chromatography experiment but removes the chromatography paper from the chamber after 15 minutes instead of 30 minutes. Predict the effect, if any, this would have on the separation distance between compounds X and Y in the new experiment. Explain your reasoning.

Solution 7

(a)

Mark scheme

- Mass of NaCl needed $= 0.1000\ \text{L} \times \dfrac{0.340\ \text{mol}}{1\ \text{L}} \times \dfrac{58.44\ \text{g}}{1\ \text{mol}} = 1.99\ \text{g NaCl}.$

Solution 7

(b)

Mark scheme

- Step 2: Combine the solid NaCl and some distilled water in a 100.0 mL volumetric flask (to dissolve the solid). Step 4: Fill the volumetric flask with distilled water to the calibration (100.0 mL) mark (bring the solution to its final, precise volume).

Solution 7

(c)

Mark scheme

- The separation between compounds X and Y would decrease: the solvent front will not travel as far up the chromatography paper, so the two spots have less distance/time over which to separate before the paper is removed from the chamber.

Question 1

2023 ▪ Q1

Answer the following questions related to manganese compounds.

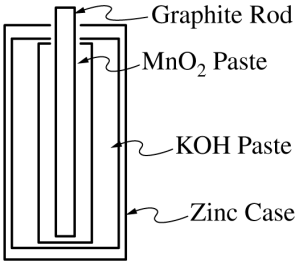
(a)(i) Manganese has several common oxidation states.

Write the complete electron configuration for an Mn atom in the ground state.

(a)(ii) When manganese forms cations, electrons are lost from which subshell first?

Identify both the number and letter associated with the subshell.

Question 1



Reduction Half-Reaction	$E°$ (V)
$Zn^{2+}(aq) + 2\ e^- \rightarrow Zn(s)$	−0.76
$ZnO(s) + H_2O(l) + 2\ e^- \rightarrow Zn(s) + 2\ OH^-(aq)$	−1.28
$2\ MnO_2(s) + H_2O(l) + 2\ e^- \rightarrow Mn_2O_3(s) + 2\ OH^-(aq)$	0.15

Question 1

2023 ▪ Q1

Answer the following questions related to manganese compounds.

(b) A student performs an experiment to produce a manganese salt of unknown composition, $Mn_xCl_y(aq)$, and determine its empirical formula. The student places a sample of $Mn(s)$ in a beaker containing excess $HCl(aq)$, as represented by the following equation.

$$x\ Mn(s) + y\ HCl(aq) \rightarrow Mn_xCl_y(aq) + \frac{y}{2}H_2(g)$$

The student heats the resulting mixture until only $Mn_xCl_y(s)$ remains in the beaker. The data are given in the following table.

Question 1

Quantity	Value
Mass of empty beaker	60.169 g
Mass of beaker and $Mn(s)$	61.262 g
Mass of beaker and Mn_xCl_y after heating to constant mass	62.673 g

Calculate the mass of Cl in the sample of $Mn_xCl_y(s)$ remaining in the beaker.

Question 1

2023 ▪ Q1

Answer the following questions related to manganese compounds.

(c) Calculate the number of moles of Cl in the sample of $Mn_xCl_y(s)$ remaining in the beaker.

Question 1

2023 ▪ Q1

Answer the following questions related to manganese compounds.

(d) The student determines that 0.0199 mol of Mn was used in the experiment. Use the data to determine the empirical formula of the $Mn_xCl_y(s)$.

Question 1

2023 ▪ Q1

Answer the following questions related to manganese compounds.

(e) The student repeats the experiment using the same amounts of Mn and HCl and notices that some of the Mn_xCl_y splatters out of the beaker as it is heated to dryness. Will the number of moles of Cl calculated for this trial be greater than, less than, or equal to the number calculated in part (c)? Justify your answer.

Question 1

2023 ▪ Q1

Answer the following questions related to manganese compounds.

(f) Another compound of manganese, MnO_2, is used in alkaline batteries, represented by the following diagram.

[Diagram of an alkaline battery: a graphite rod runs through the center, surrounded by MnO_2 paste, then KOH paste, enclosed by a zinc case.]

Some half-reactions are given in the table.

Reduction Half-Reaction	E° (V)
$Zn^{2+}(aq) + 2\,e^- \rightarrow Zn(s)$	-0.76
$ZnO(s) + H_2O(l) + 2\,e^- \rightarrow Zn(s) + 2\,OH^-(aq)$	-1.28
$2\,MnO_2(s) + H_2O(l) + 2\,e^- \rightarrow Mn_2O_3(s) + 2\,OH^-(aq)$	0.15

(f)(i) Based on the half-reactions given in the table, write the balanced net ionic equation for the reaction that has the greatest thermodynamic favorability.

(f)(ii) Calculate the value of E°_{cell} for the overall reaction.

Question 1

(f)(iii) Calculate the value of ΔG° in kJ/mol_{rxn}.
(f)(iv) A student claims that the total mass of an alkaline battery decreases as the battery operates because the anode loses mass. Do you agree with the student's claim? Justify your answer.

Solution 1

(a)(i)

Mark scheme

- Ground-state Mn (Z=25) electron configuration: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^5$ (equivalently $[\mathrm{Ar}] 4s^2 3d^5$). Either full or noble-gas-core notation is accepted.

(a)(ii)

Mark scheme

- Electrons are lost first from the 4s subshell (number = 4, letter = s) when Mn forms cations, consistent with the configuration in part (a)(i) — the 4s electrons are removed before the 3d electrons.

Solution 1

(b)

Mark scheme

- Mass of Cl in the sample = mass of dry beaker + Mn_xCl_y minus mass of the empty beaker: 62.673 g − 61.262 g = 1.411 g Cl.

Solution 1

(c)

Mark scheme

- Convert mass of Cl to moles: 1.411 g Cl $\times \dfrac{1 \text{ mol Cl}}{35.45 \text{ g Cl}} = 0.03980$ mol Cl.

Solution 1

(d)

Mark scheme

- Mole ratio Cl:Mn $= \dfrac{0.03980 \text{ mol Cl}}{0.0199 \text{ mol Mn}} = \dfrac{2 \text{ mol Cl}}{1 \text{ mol Mn}}$, so the empirical formula is $MnCl_2$.

Solution 1

(e)

Mark scheme

- Less than. If some of the mass of aqueous Mn_xCl_y is lost due to splattering, the final mass of the dry beaker and Mn_xCl_y will be decreased, which will decrease the calculated mass and number of moles of chlorine in the dry solid.

Solution 1

(f)

Mark scheme

- This is introductory/stem text describing the alkaline battery (MnO_2/Zn cell) and giving the reduction half-reaction table; it poses no separate question of its own. The scoring guidelines award all 4 points for this context across parts (f)(i)–(f)(iv) below, so no points are attached to this stem leaf.

Solution 1

(f)(i)

Mark scheme

- Combine the MnO_2 reduction half-reaction with the reverse of the less-favorable Zn/ZnO half-reaction: $2\,MnO_2(s) + H_2O(l) + 2e^- \rightarrow Mn_2O_3(s) + 2\,OH^-(aq)$ and $Zn(s) + 2\,OH^-(aq) \rightarrow ZnO(s) + H_2O(l) + 2e^-$. Adding gives the overall balanced net ionic equation: $2\,MnO_2(s) + Zn(s) \rightarrow Mn_2O_3(s) + ZnO(s)$.

Solution 1

(f)(ii)

Mark scheme

- $E^{\circ}_{cell} = E^{\circ}_{cathode} - E^{\circ}_{anode} = 0.15\ \text{V} - (-1.28\ \text{V}) = 1.43\ \text{V}.$

Solution 1

(f)(iii)

Mark scheme

- $\Delta G^\circ = -nFE^\circ = -\dfrac{2 \text{ mol } e^-}{1 \text{ mol}_{rxn}} \times 96{,}485 \text{ C} \times \dfrac{1.43 \text{ J}}{1 \text{ C}} \times \dfrac{1 \text{ kJ}}{1000 \text{ J}} = -276 \text{ kJ/mol}_{rxn}.$

Solution 1

(f)(iv)

Mark scheme

- Disagree. The battery is enclosed (sealed), so no mass enters or leaves the system — no change in total mass will occur. (Also accept: all reactants and products are in the solid phase, so with no gases entering or exiting the sealed battery, the total mass stays the same.)

Question 4

2022 ▪ Q4

Answer the following questions about the compounds NH_2Cl and NCl_3. The Lewis electron-dot diagrams of the two compounds are shown.

[Two Lewis electron-dot structures shown side by side. Left (NH_2Cl): a central N atom bonded to two H atoms and one Cl atom, with one lone pair on N and three lone pairs on Cl — drawn as H–N(–H)–Cl with the lone pair over N and three lone pairs around Cl. Right (NCl_3): a central N atom bonded to three Cl atoms, with one lone pair on N and three lone pairs on each Cl atom — drawn as Cl–N(–Cl)–Cl with a lone pair over N and three lone pairs around each Cl.]

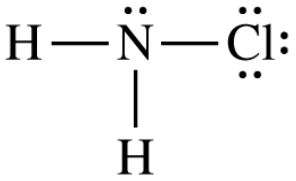
(a) Calculate the number of moles of NH_2Cl (molar mass 51.48 g/mol) present in 1.0 L of a solution in which the concentration of NH_2Cl is 0.0016 g/L.

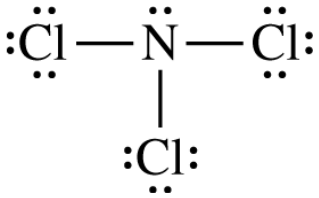
Question 4

(b) NH_2Cl is highly soluble in water, whereas NCl_3 is nearly insoluble. Explain this observation in terms of the types and relative strengths of the intermolecular forces between each of the solutes and water.

(c) The value of $\Delta H^{\circ}_{vaporization}$ for $NCl_3(l)$ is 32.9 kJ/mol. Calculate the amount of energy required to vaporize a 15.0 g sample of NCl_3 (molar mass 120.36 g/mol).

Question 4





Solution 4

(a)

Mark scheme

- 1 L $\times$ (0.0016 g / 1 L) $\times$ (1 mol / 51.48 g) $= 3.1 \times 10^{-5}$ mol.

Solution 4

(b)

Mark scheme

- Identification of intermolecular forces (1 point): both NH2Cl and NCl3 can participate in hydrogen bonding with water (or equivalently, both have dipole-dipole attractions to water). Explanation (1 point): the intermolecular forces between NH2Cl molecules and water are stronger than those between NCl3 molecules and water, which leads to the greater solubility of NH2Cl in water.

Solution 4

(c)

Mark scheme

- 15.0 g NCl_3 $\times$ (1 mol / 120.36 g) $\times$ (32.9 kJ / 1 mol) $=$ 4.10 kJ.

Question 1

2019 ▪ Q1

[Complete Lewis electron-dot diagram of urea: H—N(H)—C(=O)—N(H)—H, with the carbon double-bonded to oxygen (two lone pairs on O), and each nitrogen bonded to two H atoms and bearing one lone pair, and the central carbon bonded to both nitrogens]

The compound urea, H_2NCONH_2, is widely used in chemical fertilizers. The complete Lewis electron-dot diagram for the urea molecule is shown above.

(a) Identify the hybridization of the valence orbitals of the carbon atom in the urea molecule.

Question 1

Polystyrene Cup

Thermometer

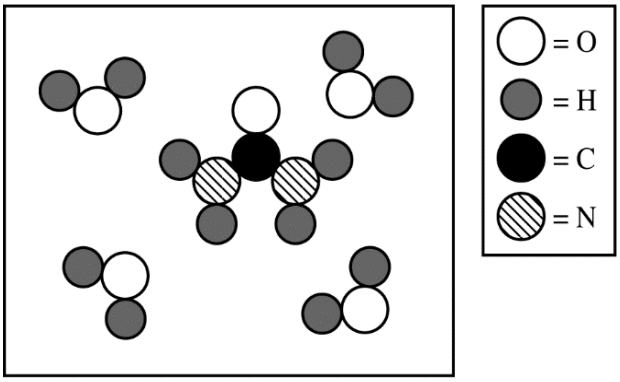
Stirring Rod

Bottle of Urea

Balance

Distilled Water

Question 1



$$H_2NCONH_2(s) \rightleftarrows H_2NCONH_2(aq)$$

Question 1

	$S°$ (J/(mol·K))
$H_2NCONH_2(s)$	104.6
$H_2NCONH_2(aq)$	?

Question 1

2019 ▪ Q1

[Complete Lewis electron-dot diagram of urea: H—N(H)—C(=O)—N(H)—H, with the carbon double-bonded to oxygen (two lone pairs on O), and each nitrogen bonded to two H atoms and bearing one lone pair, and the central carbon bonded to both nitrogens]

The compound urea, H_2NCONH_2, is widely used in chemical fertilizers. The complete Lewis electron-dot diagram for the urea molecule is shown above.

(b) Urea has a high solubility in water, due in part to its ability to form hydrogen bonds. A urea molecule and four water molecules are represented in the box below. Draw ONE dashed line (—-) to indicate a possible location of a hydrogen bond between a water molecule and the urea molecule.

[Diagram: a box containing one urea molecule (drawn with spheres: white = O, gray = H, black = C, hatched = N) surrounded by four separate water molecules, each

Question 1

water molecule drawn as one white (O) sphere bonded to two gray (H) spheres; legend: white circle = O, gray circle = H, black circle = C, hatched circle = N]

$$H_2NCONH_2(s) \rightleftharpoons H_2NCONH_2(aq)$$

The dissolution of urea is represented by the equation above. A student determines that 5.39 grams of H_2NCONH_2 (molar mass 60.06 g/mol) can dissolve in water to make 5.00 mL of a saturated solution at 20.°C.

Question 1

2019 ▪ Q1

[Complete Lewis electron-dot diagram of urea: H—N(H)—C(=O)—N(H)—H, with the carbon double-bonded to oxygen (two lone pairs on O), and each nitrogen bonded to two H atoms and bearing one lone pair, and the central carbon bonded to both nitrogens]

The compound urea, H_2NCONH_2, is widely used in chemical fertilizers. The complete Lewis electron-dot diagram for the urea molecule is shown above.

(c) Calculate the concentration of urea, in mol/L, in the saturated solution at 20.°C.

Question 1

2019 ▪ Q1

[Complete Lewis electron-dot diagram of urea: H—N(H)—C(=O)—N(H)—H, with the carbon double-bonded to oxygen (two lone pairs on O), and each nitrogen bonded to two H atoms and bearing one lone pair, and the central carbon bonded to both nitrogens]

The compound urea, H_2NCONH_2, is widely used in chemical fertilizers. The complete Lewis electron-dot diagram for the urea molecule is shown above.

(d) The student also determines that the concentration of urea in a saturated solution at 25°C is 19.8 *M*. Based on this information, is the dissolution of urea endothermic or exothermic? Justify your answer in terms of Le Chatelier's principle.

[Diagram: row of laboratory equipment icons, labelled left to right: Polystyrene Cup, Thermometer, Stirring Rod, Bottle of Urea, Balance, Distilled Water]

Question 1

2019 ▪ Q1

[Complete Lewis electron-dot diagram of urea: H—N(H)—C(=O)—N(H)—H, with the carbon double-bonded to oxygen (two lone pairs on O), and each nitrogen bonded to two H atoms and bearing one lone pair, and the central carbon bonded to both nitrogens]

The compound urea, H_2NCONH_2, is widely used in chemical fertilizers. The complete Lewis electron-dot diagram for the urea molecule is shown above.

(e) The equipment shown above is provided so that the student can determine the value of the molar heat of solution for urea. Knowing that the specific heat of the solution is 4.18 J/(g·°C), list the specific measurements that are required to be made during the experiment.

| | S° (J/(mol·K)) | |—|—| | $H_2NCONH_2(s)$ | 104.6 | | $H_2NCONH_2(aq)$ | ? |

Question 1

2019 ▪ Q1

[Complete Lewis electron-dot diagram of urea: H—N(H)—C(=O)—N(H)—H, with the carbon double-bonded to oxygen (two lone pairs on O), and each nitrogen bonded to two H atoms and bearing one lone pair, and the central carbon bonded to both nitrogens]

The compound urea, H_2NCONH_2, is widely used in chemical fertilizers. The complete Lewis electron-dot diagram for the urea molecule is shown above.

(f) The entropy change for the dissolution of urea, ΔS°_{soln}, is 70.1 J/(mol·K) at 25°C. Using the information in the table above, calculate the absolute molar entropy, S°, of aqueous urea.

Question 1

2019 ▪ Q1

[Complete Lewis electron-dot diagram of urea: H—N(H)—C(=O)—N(H)—H, with the carbon double-bonded to oxygen (two lone pairs on O), and each nitrogen bonded to two H atoms and bearing one lone pair, and the central carbon bonded to both nitrogens]

The compound urea, H_2NCONH_2, is widely used in chemical fertilizers. The complete Lewis electron-dot diagram for the urea molecule is shown above.

(g) Using particle-level reasoning, explain why ΔS°_{soln} is positive for the dissolution of urea in water.

Question 1

2019 ▪ Q1

[Complete Lewis electron-dot diagram of urea: H—N(H)—C(=O)—N(H)—H, with the carbon double-bonded to oxygen (two lone pairs on O), and each nitrogen bonded to two H atoms and bearing one lone pair, and the central carbon bonded to both nitrogens]

The compound urea, H_2NCONH_2, is widely used in chemical fertilizers. The complete Lewis electron-dot diagram for the urea molecule is shown above.

(h) The student claims that ΔS° for the process contributes to the thermodynamic favorability of the dissolution of urea at 25°C. Use the thermodynamic information above to support the student's claim.

Solution 1

(a)

Mark scheme

- sp^2. The carbon atom in urea is bonded to three groups (two N atoms and one O atom, one bond of which is a double bond) with no lone pairs, giving trigonal-planar sp^2 hybridization. 1 point for stating sp^2.

Solution 1

(b)

Mark scheme

- A dashed line should connect a hydrogen atom of a water molecule to a nitrogen or oxygen atom of urea, OR an oxygen atom of a water molecule to a hydrogen atom of urea (an H-bond donor H drawn near an H-bond acceptor lone pair). 1 point is earned for any correctly placed dashed line matching this pattern.

Solution 1

(c)

Mark scheme

- Moles of urea: 5.39 g H2NCONH2 $\times$ (1 mol / 60.06 g) $=$ 0.0897 mol (1 point, may be implicit). Molarity: 0.0897 mol / 0.00500 L $=$ 17.9 M (1 point for the correct molarity).

Solution 1

(d)

Mark scheme

- Endothermic. The increased solubility at the higher temperature (19.8 M at 25°C vs. 17.9 M at 20.°C) implies the dissolution of urea is endothermic. By Le Chatelier's principle: heating a saturated solution stresses the equilibrium, and that stress is counteracted by more urea dissolving (the endothermic direction is favored). 1 point for the correct answer (endothermic) with this justification.

Solution 1

(e)

Mark scheme

- To determine the molar heat of solution calorimetrically, the student must measure: the mass of urea and the mass of water used (1 point); and the initial temperature of the water and the final temperature of the resulting solution (1 point). With the given specific heat 4.18 $J/(g \cdot °C)$, these give $q = mc\Delta T$, which is then divided by moles of urea for the molar heat of solution.

Solution 1

(f)

Mark scheme

- $\Delta S°soln = S°(H2NCONH2(aq)) - S°(H2NCONH2(s))$; $70.1\ J/(mol \cdot K) = S°(aq) - 104.6\ J/(mol \cdot K)$; $S°(H2NCONH2(aq)) = 174.7\ J/(mol \cdot K)$. 1 point for the correct answer.

Solution 1

(g)

Mark scheme

- Urea molecules in aqueous solution have a much greater number of possible arrangements/microstates (free to move and interact throughout the solution) than in the ordered solid, so dissolution increases the number of accessible microstates, giving a positive ΔS°soln. 1 point for a correct particle-level explanation along these lines.

Solution 1

(h)

Mark scheme

- Thermodynamic favorability at standard conditions is determined by the sign of ΔG°, where $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$. Since ΔS° is positive, the $-T\Delta S^\circ$ term is negative, making ΔG° smaller (more negative) and thus making the dissolution more thermodynamically favorable — supporting the student's claim. 1 point for this reasoning.

Question 1

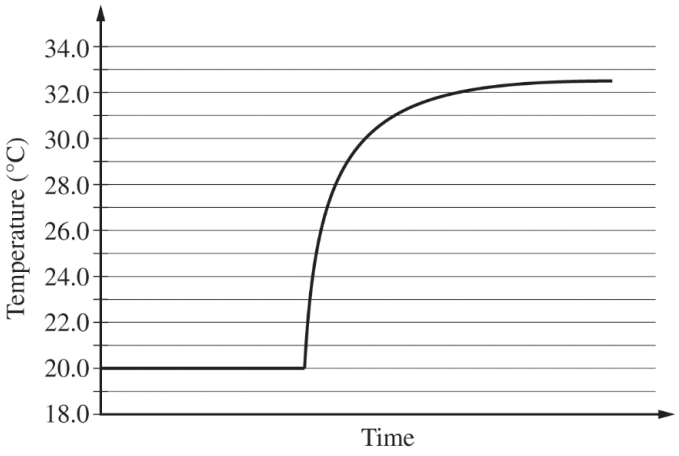
2018 ▪ Q1

$$Na_2S_2O_3(aq) + 4\,NaOCl(aq) + 2\,NaOH(aq) \rightarrow 2\,Na_2SO_4(aq) + 4\,NaCl(aq) + H_2O(l)$$

A student performs an experiment to determine the value of the enthalpy change, ΔH°_{rxn}, for the oxidation-reduction reaction represented by the balanced equation above.

(a) Determine the oxidation number of Cl in NaOCl.

Question 1



Question 1

Solution	Concentration (M)	Volume (mL)
$Na_2S_2O_3(aq)$	0.500	10.0
$NaOCl(aq)$	0.500	10.0
$NaOH(aq)$	0.500	10.0

Question 1

Solution	Concentration (M)	Volume (mL)
$Na_2S_2O_3(aq)$	0.500	5.00
$NaOCl(aq)$	0.500	5.00
$NaOH(aq)$	0.500	5.00

Question 1

2018 ▪ Q1

$$Na_2S_2O_3(aq) + 4\,NaOCl(aq) + 2\,NaOH(aq) \rightarrow 2\,Na_2SO_4(aq) + 4\,NaCl(aq) + H_2O(l)$$

A student performs an experiment to determine the value of the enthalpy change, ΔH°_{rxn}, for the oxidation-reduction reaction represented by the balanced equation above.

(b) Calculate the number of grams of $Na_2S_2O_3$ needed to prepare 100.00 mL of 0.500 M $Na_2S_2O_3(aq)$.

In the experiment, the student uses the solutions shown in the table below.

Solution	Concentration (M)	Volume (mL)
$Na_2S_2O_3(aq)$	0.500	5.00
$NaOCl(aq)$	0.500	5.00
$NaOH(aq)$	0.500	5.00

Question 1

2018 ▪ Q1

$$Na_2S_2O_3(aq) + 4\,NaOCl(aq) + 2\,NaOH(aq) \rightarrow 2\,Na_2SO_4(aq) + 4\,NaCl(aq) + H_2O(l)$$

A student performs an experiment to determine the value of the enthalpy change, ΔH°_{rxn}, for the oxidation-reduction reaction represented by the balanced equation above.

(c) Using the balanced equation for the oxidation-reduction reaction and the information in the table above, determine which reactant is the limiting reactant. Justify your answer.

The solutions, all originally at 20.0°C, are combined in an insulated calorimeter. The temperature of the reaction mixture is monitored, as shown in the graph below.

[Graph of Temperature (°C) vs. Time. Y-axis: Temperature (°C) from 18.0 to 34.0 in increments of 2.0. X-axis: Time (unlabeled scale). The curve starts flat at about 20.0°C, then rises steeply in an S-shaped curve, leveling off at approximately 32.5°C.]

Question 1

2018 ▪ Q1

$$Na_2S_2O_3(aq) + 4\,NaOCl(aq) + 2\,NaOH(aq) \rightarrow 2\,Na_2SO_4(aq) + 4\,NaCl(aq) + H_2O(l)$$

A student performs an experiment to determine the value of the enthalpy change, ΔH°_{rxn}, for the oxidation-reduction reaction represented by the balanced equation above.

(d) According to the graph, what is the temperature change of the reaction mixture?

Question 1

2018 ▪ Q1

$$Na_2S_2O_3(aq) + 4\,NaOCl(aq) + 2\,NaOH(aq) \rightarrow 2\,Na_2SO_4(aq) + 4\,NaCl(aq) + H_2O(l)$$

A student performs an experiment to determine the value of the enthalpy change, ΔH°_{rxn}, for the oxidation-reduction reaction represented by the balanced equation above.

(e)(i) The mass of the reaction mixture inside the calorimeter is 15.21 g. Calculate the magnitude of the heat energy, in joules, that is released during the reaction. Assume that the specific heat of the reaction mixture is 3.94 J/(g · °C) and that the heat absorbed by the calorimeter is negligible.

(e)(ii) Using the balanced equation for the oxidation-reduction reaction and your answer to part (c), calculate the value of the enthalpy change of the reaction, ΔH°_{rxn}, in kJ/mol$_{rxn}$. Include the appropriate algebraic sign with your answer.

Question 1

The student repeats the experiment, but this time doubling the volume of each of the reactants, as shown in the table below.

Solution	Concentration (M)	Volume (mL)
$Na_2S_2O_3(aq)$	0.500	10.0
NaOCl(aq)	0.500	10.0
NaOH(aq)	0.500	10.0

Question 1

2018 ▪ Q1

$$Na_2S_2O_3(aq) + 4\,NaOCl(aq) + 2\,NaOH(aq) \rightarrow 2\,Na_2SO_4(aq) + 4\,NaCl(aq) + H_2O(l)$$

A student performs an experiment to determine the value of the enthalpy change, ΔH°_{rxn}, for the oxidation-reduction reaction represented by the balanced equation above.

(f) The magnitude of the enthalpy change, ΔH°_{rxn}, in kJ/mol$_{rxn}$, calculated from the results of the second experiment is the same as the result calculated in part (e)(ii). Explain this result.

Question 1

2018 ▪ Q1

$$Na_2S_2O_3(aq) + 4\,NaOCl(aq) + 2\,NaOH(aq) \rightarrow 2\,Na_2SO_4(aq) + 4\,NaCl(aq) + H_2O(l)$$

A student performs an experiment to determine the value of the enthalpy change, ΔH°_{rxn}, for the oxidation-reduction reaction represented by the balanced equation above.

(g) Write the balanced net ionic equation for the given reaction.

Solution 1

(a)

Mark scheme

- Oxidation number of Cl in NaOCl is $+1$. (Na is $+1$, O is -2, so Cl must be $+1$ for the compound to be neutral.) 1 point is earned for the correct answer of $+1$.

Solution 1

(b)

Mark scheme

- 100.00 mL x (0.500 mol Na2S2O3/1000 mL) x (158.10 g Na2S2O3/1 mol Na2S2O3) = 7.90 g Na2S2O3. 1 point for the correct number of moles of Na2S2O3 (0.0500 mol, may be implicit); 1 point for the correct mass consistent with that number of moles.

Solution 1

(c)

Mark scheme

- NaOCl is the limiting reactant. Given that equal numbers of moles of each reactant (Na2S2O3, NaOCl, NaOH) were present initially (same concentration and volume), it follows from the coefficients of the balanced equation Na2S2O3 + 4 NaOCl + 2 NaOH -> 2 Na2SO4 + 4 NaCl + H2O (which requires NaOCl in the largest relative amount) that NaOCl will be depleted first. 1 point is earned for identifying the limiting reactant AND providing a valid justification.

Solution 1

(d)

Mark scheme

- From the graph, the final temperature is 32.5 degrees C and the initial temperature is 20.0 degrees C. Delta T = Tf - Ti = 32.5 - 20.0 = 12.5 degrees C. 1 point is earned for the correct value of Delta T.

Solution 1

(e)(i)

Mark scheme

- q = mcDeltaT = (15.21 g)(3.94 J/(g times degree C))(12.5 degrees C) = 749 J. 1 point is earned for the correct calculation of q, consistent with the Delta T value from part (d).

Solution 1

(e)(ii)

Mark scheme

- n(NaOCl) = 5.00 mL x 0.500 mol NaOCl/1000 mL = 0.00250 mol NaOCl. n_rxn = 0.00250 mol NaOCl x (1 mol_rxn/4 mol NaOCl) = 0.000625 mol_rxn (using the limiting reactant from part c). DeltaH_rxn = -0.749 kJ / 0.000625 mol_rxn = -1.20x10^3 kJ/mol_rxn. 1 point is earned for correctly calculating mol_rxn consistent with the limiting reactant in part (c); 1 point is earned for a negative DeltaH_rxn obtained by dividing the calculated q by the calculated mol_rxn.

Solution 1

(f)

Mark scheme

- By doubling the volumes, the number of moles of the reactants are doubled, which doubles the amount of energy produced. Therefore the amount of heat per mole (DeltaH_rxn) remains the same. Equivalently, DeltaH_rxn = (2mcDeltaT)/(2n) = mcDeltaT/n, so the magnitude is unchanged. 1 point is earned for a valid explanation.

Solution 1

(g)

Mark scheme

- Net ionic equation: S2O3^2-(aq) + 4 OCl^-(aq) + 2 OH^-(aq) -> 2 SO4^2-(aq) + 4 Cl^-(aq) + H2O(l). 1 point is earned for the correct net ionic equation (Na+ spectator ions removed, charge and atoms balanced).

Question 3

2016 ▪ Q3

$$M + I_2 \rightarrow MI_2$$

To determine the molar mass of an unknown metal, M, a student reacts iodine with an excess of the metal to form the water-soluble compound MI_2, as represented by the equation above. The reaction proceeds until all of the I_2 is consumed. The $MI_2(aq)$ solution is quantitatively collected and heated to remove the water, and the product is dried and weighed to constant mass. The experimental steps are represented below, followed by a data table.

[Diagram: a sequence of process illustrations. First row: a beaker on a balance reading 125.457 g; an arrow labeled "Add M" points to a beaker on a balance reading 126.549 g (with solid M added); an arrow labeled "Add I2" points to a beaker on a balance

Question 3

reading 127.570 g (with solid I2 added, shown as a darker layer on top of the M). Second row: an arrow labeled "Add H2O" points from the beaker with M and I2 to a beaker where "reaction occurs" (labeled MI2(aq) at the bottom with "leftover M" also labeled); an arrow labeled "solution collected" points to a test tube containing MI2(aq); an arrow labeled "heat" points to a test tube; an arrow labeled "reheat" points to a final test tube containing solid MI2(s) at the bottom.]

| Data for Unknown Metal Lab | | |—|—| | Mass of beaker | 125.457 g | | Mass of beaker + metal M | 126.549 g | | Mass of beaker + metal M + I_2 | 127.570 g | | Mass of MI_2, first weighing | 1.284 g | | Mass of MI_2, second weighing | 1.284 g |

(a) Given that the metal M is in excess, calculate the number of moles of I_2 that reacted.

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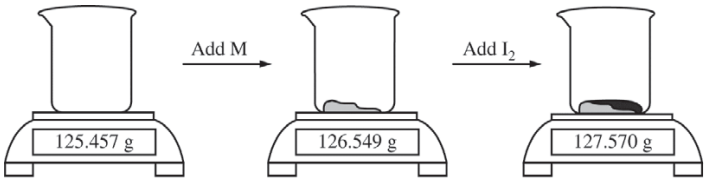
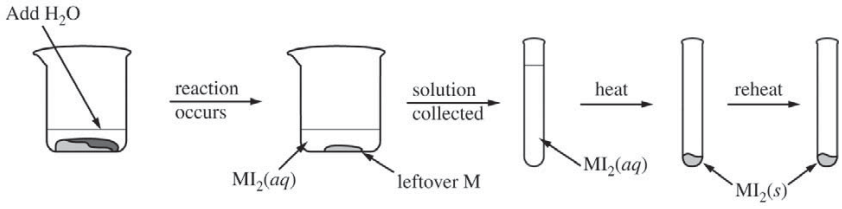

Add M
Add I_2
125.457 g
126.549 g
127.570 g


Add H_2O
reaction occurs
solution collected
heat
reheat
$MI_2(aq)$
leftover M
$MI_2(aq)$
$MI_2(s)$

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Data for Unknown Metal Lab	
Mass of beaker	125.457 g
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Mass of beaker + metal M + I_2	127.570 g
Mass of MI_2, first weighing	1.284 g
Mass of MI_2, second weighing	1.284 g

Question 3

Half reaction	E° (V)
$S_4O_6^{2-}(aq) + 2\ e^- \rightarrow 2\ S_2O_3^{2-}(aq)$	0.08
$I_2(s) + 2\ e^- \rightarrow 2\ I^-(aq)$	0.54
$O_2(g) + 2\ H^+(aq) + 2\ e^- \rightarrow H_2O_2(aq)$	0.68

Question 3

2016 ▪ Q3

$$M + I_2 \rightarrow MI_2$$

To determine the molar mass of an unknown metal, M, a student reacts iodine with an excess of the metal to form the water-soluble compound MI_2, as represented by the equation above. The reaction proceeds until all of the I_2 is consumed. The $MI_2(aq)$ solution is quantitatively collected and heated to remove the water, and the product is dried and weighed to constant mass. The experimental steps are represented below, followed by a data table.

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Question 3

points to a test tube containing MI2(aq); an arrow labeled "heat" points to a test tube; an arrow labeled "reheat" points to a final test tube containing solid MI2(s) at the bottom.]

| Data for Unknown Metal Lab | | |—|—| | Mass of beaker | 125.457 g | | Mass of beaker + metal M | 126.549 g | | Mass of beaker + metal M + I_2 | 127.570 g | | Mass of MI_2, first weighing | 1.284 g | | Mass of MI_2, second weighing | 1.284 g |

(b) Calculate the molar mass of the unknown metal M.

Question 3

2016 ▪ Q3

$$M + I_2 \rightarrow MI_2$$

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Question 3

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Mass of MI_2, second weighing	1.284 g

(c) The student hypothesizes that the compound formed in the synthesis reaction is ionic.

Propose an experimental test the student could perform that could be used to support the hypothesis. Explain how the results of the test would support the hypothesis if the substance was ionic.

Question 3

2016 ▪ Q3

$$M + I_2 \rightarrow MI_2$$

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Mass of MI_2, first weighing	1.284 g
Mass of MI_2, second weighing	1.284 g

(d) The student hypothesizes that Br_2 will react with metal M more vigorously than I_2 did because Br_2 is a liquid at room temperature.

Explain why I_2 is a solid at room temperature whereas Br_2 is a liquid. Your explanation should clearly reference the types and relative strengths of the intermolecular forces present in each substance.

Question 3

2016 ▪ Q3

$$M + I_2 \rightarrow MI_2$$

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Question 3

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(e) While cleaning up after the experiment, the student wishes to dispose of the unused solid I_2 in a responsible manner. The student decides to convert the solid I_2 to $I^-(aq)$ anion. The student has access to three solutions, $H_2O_2(aq)$, $Na_2S_2O_3(aq)$, and $Na_2S_4O_6(aq)$, and the standard reduction table shown below.

| Half reaction | E° (V) | |—|—| | $S_4O_6^{2-}(aq) + 2e^- \rightarrow 2S_2O_3^{2-}(aq)$ | 0.08 | | $I_2(s) + 2e^- \rightarrow 2I^-(aq)$ | 0.54 | | $O_2(g) + 2H^+(aq) + 2e^- \rightarrow H_2O_2(aq)$ | 0.68 |

Which solution should the student add to $I_2(s)$ to reduce it to $I^-(aq)$? Circle your answer below. Justify your answer, including a calculation of E° for the overall reaction.

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$H_2O_2(aq)$ $Na_2S_2O_3(aq)$ $Na_2S_4O_6(aq)$

Question 3

2016 ▪ Q3

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Question 3

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(f) Write the balanced net-ionic equation for the reaction between I_2 and the solution you selected in part (e).

Solution 3

(a)

Mark scheme

- Mass of I2 reacted = 127.570 g − 126.549 g = 1.021 g I2. 1.021 g I2 × (1 mol I2 / 253.80 g I2) = 0.004023 mol I2. 1 point for the correct number of moles of I2.

Solution 3

(b)

Mark scheme

- Because M + I2 → MI2, moles of M = moles of I2 = 0.004023 mol. Mass of M = mass of MI2 − mass of I2 = 1.284 g − 1.021 g = 0.263 g M. Molar mass of M = 0.263 g / 0.004023 mol = 65.4 g/mol. 1 point for the correct number of grams of M, 1 point for the correct molar mass of M (≈65.4 g/mol).

Solution 3

(c)

Mark scheme

- Dissolve the compound in water (or melt it) and test whether the solution/melt conducts electricity; conduction indicates mobile ions are present, supporting that the compound is ionic. (Equivalently: heat the compound and observe its melting/boiling point — a very high melting/boiling point supports it being ionic.) 1 point for proposing an appropriate test, 1 point for correctly explaining how the results would support the ionic hypothesis.

Solution 3

(d) Mark scheme

- Both Br2 and I2 are nonpolar molecules, so the only intermolecular forces present are London dispersion forces. These forces are stronger in I2 because it is larger, with more electrons and/or a more polarizable electron cloud; the stronger dispersion forces give I2 a higher melting point, making it a solid at room temperature, while Br2 (weaker dispersion forces) is a liquid. 1 point for identifying London dispersion forces as the relevant IMF in both substances, 1 point for explaining why the forces are stronger in I2 than in Br2 (larger size / more electrons / more polarizable electron cloud).

Solution 3

(e)

Mark scheme

- Na2S2O3(aq) should be circled. The reaction between S2O3^2−(aq) and I2(s) is thermodynamically favorable because E°cell is positive: E° = E°(reduction of I2 to I−, 0.54 V) − E°(reduction of S4O6^2− to S2O3^2−, 0.08 V) = +0.46 V, and $\Delta G^\circ = -nFE^\circ$ is therefore negative. 1 point for the correct choice (Na2S2O3), 1 point for a correct justification including the E° calculation (+0.46 V, positive, so favorable).

Solution 3

(f)

Mark scheme

- I2 + 2 S2O3^2− → 2 I− + S4O6^2−. 1 point for the correct, balanced net-ionic equation.