Apex Exam Guidebook

Chemistry

Year 12 QCE

Queensland Curriculum

2026 Edition

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Apex Exam Guidebook
Chemistry
Year 12 QCE

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Unit 3 – Equilibrium, acid and redox

Unit 3 – Topic 1: Chemical equilibrium systems

Paper 1 Section 1

2024 Paper 1 Section 1 Question 5 **Chemical equilibrium systems**	Titration is a volumetric analysis method used to (A) measure the pH of an analyte. (B) determine the volume of a titrant. (C) calculate the concentration of an identified solution. (D) prepare a standard solution of known concentration and volume.

2024 Paper 1 Section 1 Question 6 **Chemical equilibrium systems**	The equivalence point of an acid–base titration occurs when the (A) pH equals the pK_a. (B) pH stops changing. (C) indicator changes colour. (D) titrant completely neutralises the analyte.

2024 Paper 1 Section 1 Question 10 **Chemical equilibrium systems**	The acid dissociation constant (K_a) represents the (A) pH of an acid solution. (B) strength of an acid solution. (C) concentration of an acid solution. (D) conjugate acid–base pairs of an acid solution.

2024 Paper 1 Section 1 Question 11 **Chemical equilibrium systems**	A Brønsted–Lowry acid (A) accepts a proton to form its base. (B) donates a proton to form its base. (C) accepts a proton to form its conjugate base. (D) donates a proton to form its conjugate base.

2024 Paper 1 Section 1 Question 12 **Chemical equilibrium systems**	The following equilibrium law expression is given for a specific reaction. $$K_c = \frac{[H_2O]^4[CO_2]^3}{[C_3H_8][O_2]^5}$$ Determine which of the following is a product of this reaction. (A) $CO_2(g)$ (B) $C_3H_8(l)$ (C) $H_2O(l)$ (D) $O_2(g)$

2024 Paper 1 Section 1 Question 20

Chemical equilibrium systems

Identify the polyprotic acid.

(A) $NH_3(aq)$

(B) $H_3PO_4(aq)$

(C) $(NH_4)_3PO_4(aq)$

(D) $CH_3COOH(aq)$

2023 Paper 1 Section 1 Question 1

Chemical equilibrium systems

In a chemical equation at equilibrium, a reversible arrow ($\rightleftharpoons$) symbolises that

(A) the forward reaction has stopped but can be reversed.

(B) the moles of reactants and products present are equal.

(C) half of the reactants have been converted into products.

(D) the concentration of reactants and products remains constant.

2023 Paper 1 Section 1 Question 2

Chemical equilibrium systems

Determine which expression represents the hydrogen ion (H^+) concentration at a pH of 8.4.

(A) $1 \times 10^{-8.4}$

(B) $1 \times 10^{-5.6}$

(C) $1 \times 10^{-0.9}$

(D) $1 \times 10^{-0.8}$

2023 Paper 1 Section 1 Question 3

Chemical equilibrium systems

Two 0.1 M acidic solutions, X and Y, are 100% dissociated. Solution X has an electrical conductivity approximately twice that of solution Y. Identify solutions X and Y.

	Solution X	**Solution Y**
(A)	HCl	CH_3COOH
(B)	HNO_3	H_2SO_4
(C)	H_3PO_4	HNO_3
(D)	H_2SO_4	HCl

2023 Paper 1 Section 1 Questions 4-5

Chemical equilibrium systems

Questions 4–5 refer to the decomposition of hydrogen iodide gas (HI) to produce hydrogen gas (H_2) and iodine gas (I_2) in a sealed 1-litre container.

$$\underset{\text{Colourless}}{2HI(g)} \rightleftharpoons \underset{\text{Colourless}}{H_2(g)} + \underset{\text{Purple}}{I_2(g)} \qquad \Delta H = +53.6 \text{ kJ mol}^{-1}$$

Question 4

Identify which change would shift the system from light purple to dark purple.

(A) adding HI(g)

(B) adding a catalyst

(C) decreasing the temperature

(D) increasing the concentration of $H_2(g)$

Question 5

Determine the equilibrium expression (K_c) for the reaction.

(A) $K_c = \dfrac{[H_2][I_2]}{2[HI]}$

(B) $K_c = \dfrac{[H_2][I_2]}{[HI]^2}$

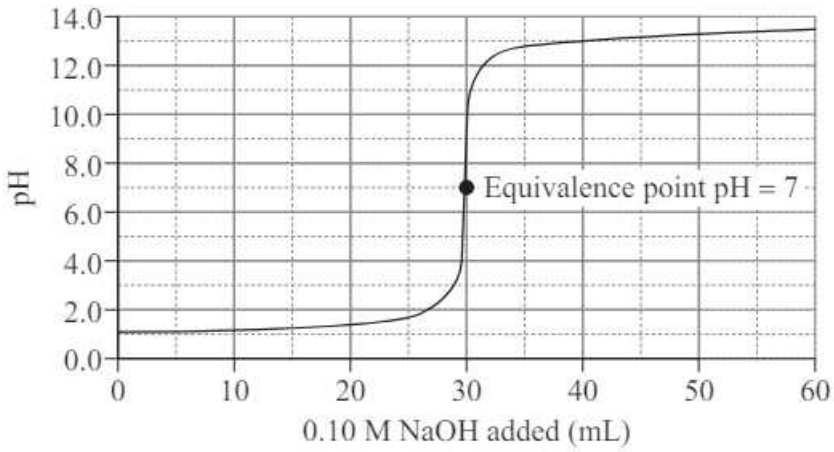
(C) $K_c = \dfrac{2[H]2[I]}{2[HI]}$

(D) $K_c = \dfrac{2[H]2[I]}{[HI]^2}$

2023 Paper 1 Section 1 Questions 9-10

Chemical equilibrium systems

Questions 9–10 refer to the titration curve shown, which is produced when 60.00 mL of an unknown monoprotic acid solution is titrated with 0.10 M NaOH(aq).



Question 9
Compared to 0.10 M NaOH, the unknown monoprotic acid is more

(A) dilute and weak.
(B) dilute and strong.
(C) concentrated and weak.
(D) concentrated and strong.

Question 10
Determine the concentration of the unknown acid.

(A) 0.05 M
(B) 0.10 M
(C) 0.20 M
(D) 0.30 M

2023 Paper 1 Section 1 Question 15

Chemical equilibrium systems

Predict how a buffer solution, consisting of carbonic acid (H_2CO_3) and hydrogen carbonate ions (HCO_3^-), would react to resist a change in pH when a small amount of hydrochloric acid is added.

$$H_2CO_3(aq) \rightleftharpoons HCO_3^-(aq) + H^+(aq) \rightleftharpoons CO_3^{2-}(aq) + 2H^+(aq)$$

(A) Equilibrium shifts to the right and the $[H^+](aq)$ increases.

(B) Equilibrium shifts to the left and the $[CO_3^{2-}](aq)$ increases.

(C) Equilibrium shifts to the left and the $[H_2CO_3](aq)$ increases.

(D) Equilibrium shifts to the right and the $[HCO_3^-](aq)$ increases.

2022 Paper 1 Section 1 Question 6

Chemical equilibrium systems

The equilibrium concentration of A is 2.8×10^{-4} M and B is 1.2×10^{-4} M.

A (g) ⇌ B (g) $\Delta H > 0$

Which option represents the ratio of molecules present in a sample of the gaseous mixture when the temperature is decreased and a new equilibrium established?

(A) 8 molecules of A and 2 molecules of B
(B) 5 molecules of A and 5 molecules of B
(C) 3 molecules of A and 7 molecules of B
(D) 2 molecules of A and 8 molecules of B

2022 Paper 1 Section 1 Question 8 Chemical equilibrium systems	Predict how the system shown will respond when a small amount of aqueous sodium hydroxide is added. $CH_3COOH(aq) + H_2O(l) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$ (A) Equilibrium shifts to the left and the pH decreases. (B) Equilibrium shifts to the right and the pH increases. (C) Equilibrium shifts to the left and the pH remains the same. (D) Equilibrium shifts to the right and the pH remains the same.

2022 Paper 1 Section 1 Question 10 Chemical equilibrium systems	The midpoint of the colour change of a weak acid indicator occurs when (A) $[In^-] = [H^+]$ (B) $[In^-] = [HIn]$ (C) $[H^+] = [OH^-]$ (D) $[HIn] = [OH^-]$

2022 Paper 1 Section 1 Question 13 Chemical equilibrium systems	Determine the K_a of an unknown weak acid (HA) with an aqueous concentration of 0.12 M and a pH of 3.2. (A) 5.2×10^{-3} (B) 6.3×10^{-4} (C) 3.3×10^{-6} (D) 4.0×10^{-7}

2022 Paper 1 Section 1 Question 18 Chemical equilibrium systems	Determine the K_b expression for the weak base shown in the equilibrium equation. $NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$ (A) $K_b = \frac{[NH_3][H_2O]}{[NH_4^+]}$ (B) $K_b = \frac{[NH_3][H_2O]}{[OH^-]}$ (C) $K_b = \frac{[NH_4^+][OH^-]}{[NH_3]}$ (D) $_b = \frac{[NH_4^+][OH^-]}{[H_2O]}$

2021 Paper 1 Section 1 Question 4 Chemical equilibrium systems	The cleaning action of soap is impaired in hard water because the (A) hydrophilic end reacts with calcium ions to form insoluble salts. (B) hydrophobic end reacts with calcium ions to form insoluble salts. (C) hydrophilic end reacts with calcium ions to form insoluble fatty acids. (D) hydrophobic end reacts with calcium ions to form insoluble fatty acids.

2021 Paper 1 Section 1 Question 5 Chemical equilibrium systems	A 10.0 M solution of ethanoic acid is best described as a (A) dilute solution of a weak acid. (B) dilute solution of a strong acid. (C) concentrated solution of a weak acid. (D) concentrated solution of a strong acid.

2021 Paper 1 Section 1 Question 10

Chemical equilibrium systems

Determine which system at equilibrium will shift to the right (products) if the total pressure on the system is increased.

(A) $N_2O_4(g) \rightleftharpoons 2NO_2(g)$

(B) $2H_2O(g) \rightleftharpoons 2H_2(g) + O_2(g)$

(C) $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

(D) $CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$

2021 Paper 1 Section 1 Question 11

Chemical equilibrium systems

Enzymes can act as biological catalysts because they

(A) can be denatured.
(B) lower the activation energy.
(C) are sensitive to pH and temperature changes.
(D) increase the equilibrium constant for the reaction.

2021 Paper 1 Section 1 Question 14

Chemical equilibrium systems

Acid	K_a value
Nitrous acid	$K_a = 4.00 \times 10^{-4}$
Ethanoic acid	$K_a = 1.76 \times 10^{-5}$
Hydrofluoric acid	$K_a = 7.20 \times 10^{-4}$
Chloroethanoic acid	$K_a = 1.40 \times 10^{-3}$

Analyse the data to determine the relative strengths of acids from strongest to weakest.

(A) chloroethanoic, ethanoic, nitrous, hydrofluoric
(B) chloroethanoic, hydrofluoric, nitrous, ethanoic
(C) ethanoic, nitrous, hydrofluoric, chloroethanoic
(D) ethanoic, hydrofluoric, nitrous, chloroethanoic

2021 Paper 1 Section 1 Question 17

Chemical equilibrium systems

Determine the concentration of hydrogen ions (H^+) in an aqueous solution containing 1.2×10^{-3} M hydroxide ions (OH^-).

(A) 1.2×10^{11}
(B) 8.3×10^{-12}
(C) 8.3×10^{-17}
(D) 1.2×10^{-17}

2020 Paper 1 Section 1 Question 5

Chemical equilibrium systems

The equilibrium constants of four different reactions are given.

In which reaction does the equilibrium lie furthest to the left?

	Reaction	K_c
(A)	$PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$	2.4×10^{1}
(B)	$AgIO_3(s) \rightleftharpoons Ag^+(aq) + IO_3^-(aq)$	3.0×10^{-8}
(C)	$Cl_2(g) + H_2O(l) \rightleftharpoons HOCl(aq) + Cl^-(aq) + H^+(aq)$	4.0×10^{-4}
(D)	$HSO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + SO_3^{2-}(aq)$	6.3×10^{-8}

2020 Paper 1 Section 1 Question 7

Chemical equilibrium systems

Acid	Concentration (M)	pH
H_3PO_4	2.0×10^{-2}	1.9
HCN	1.5×10^{-1}	5.0
H_2SO_4	9.0×10^{-2}	1.0
CH_3COOH	1.0×10^{-1}	2.8

Analyse the experimental data to determine the relative strength of the acids from strongest to weakest.

(A) $H_2SO_4 > H_3PO_4 > HCN > CH_3COOH$

(B) $H_2SO_4 > H_3PO_4 > CH_3COOH > HCN$

(C) $HCN > CH_3COOH > H_2SO_4 > H_3PO_4$

(D) $HCN > CH_3COOH > H_3PO_4 > H_2SO_4$

2020 Paper 1 Section 1 Question 9

Chemical equilibrium systems

Phosgene gas ($COCl_2$) is formed by the following reaction.

$$CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g) \quad \Delta H = -110 \text{ kJ mol}^{-1}$$

Which of the following statements is true for the system at equilibrium?

(A) Removing $Cl_2(g)$ will increase the yield of phosgene and keep the K_c value constant.

(B) Adding a catalyst will increase the yield of phosgene and keep the K_c value constant.

(C) Increasing the pressure will increase the yield of phosgene and keep the K_c value constant.

(D) Decreasing the temperature will decrease the yield of phosgene and keep the K_c value constant.

2020 Paper 1 Section 1 Question 14

Chemical equilibrium systems

Ammonia gas reacts with oxygen gas in the following equilibrium reaction.

$$4NH_3(g) + 3O_2(g) \rightleftharpoons 2N_2(g) + 6H_2O(g)$$

The equilibrium expression for the reaction is

(A) $\dfrac{[NH_3][O_2]}{[N_2][H_2O]}$

(B) $\dfrac{[N_2][H_2O]}{[NH_3][O_2]}$

(C) $\dfrac{[NH_3]^4[O_2]^3}{[N_2]^2[H_2O]^6}$

(D) $\dfrac{[N_2]^2[H_2O]^6}{[NH_3]^4[O_2]^3}$

2020 Paper 1 Section 1 Question 18

Chemical equilibrium systems

Solution A has a pH of 3 and solution B has a pH of 6. This indicates that solution A is

(A) less acidic and has 0.5 times the concentration of hydrogen ions in solution B.
(B) more acidic and has 2 times the concentration of hydrogen ions in solution B.
(C) less acidic and has 0.001 times the concentration of hydrogen ions in solution B.
(D) more acidic and has 1000 times the concentration of hydrogen ions in solution B.

Paper 1 Section 2

2024 **Paper 1** **Section 2** **Question 21** **Chemical equilibrium systems**	Reactants A and B are placed in a 1.00 L container and react to form product C. The reaction then reaches equilibrium. $$A(g) + B(g) \rightleftharpoons C(g) \quad (K_c = 9.9 \times 10^2)$$ a) Explain why a reversible arrow (⇌) is used to symbolise this reaction. [1 mark] b) Deduce whether the equilibrium for the reaction lies towards the reactants or products. Explain your reasoning. [2 marks]

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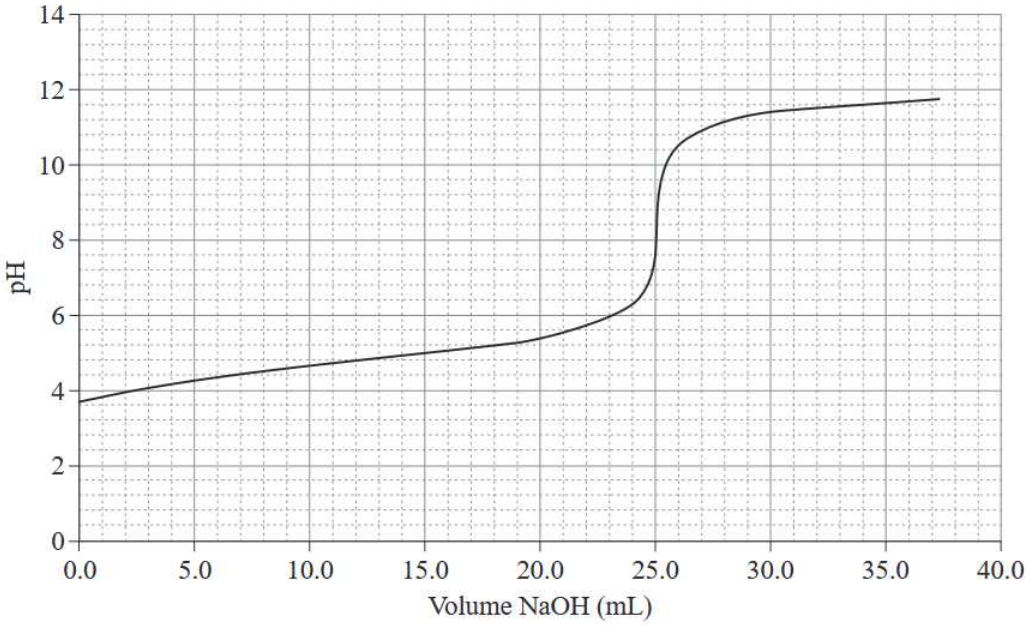
Chemical equilibrium systems

An aqueous solution of sodium hydroxide (NaOH) was titrated against a 30.0 mL aliquot of a 0.012 M potassium hydrogen phthalate (KHP) standard aqueous solution. The balanced chemical equation for the reaction is shown.

$$KHP(aq) + NaOH(aq) \rightarrow KNaP(aq) + H_2O(l)$$

The results are shown in the titration curve.



a) Determine whether KHP is a strong or weak acid. Identify one feature from the titration curve to support your reasoning. [2 marks]

b) Explain why KHP(aq) is used as the standard solution rather than NaOH(aq). [1 mark]

c) Calculate the concentration of NaOH(aq). Show your working. [2 marks]

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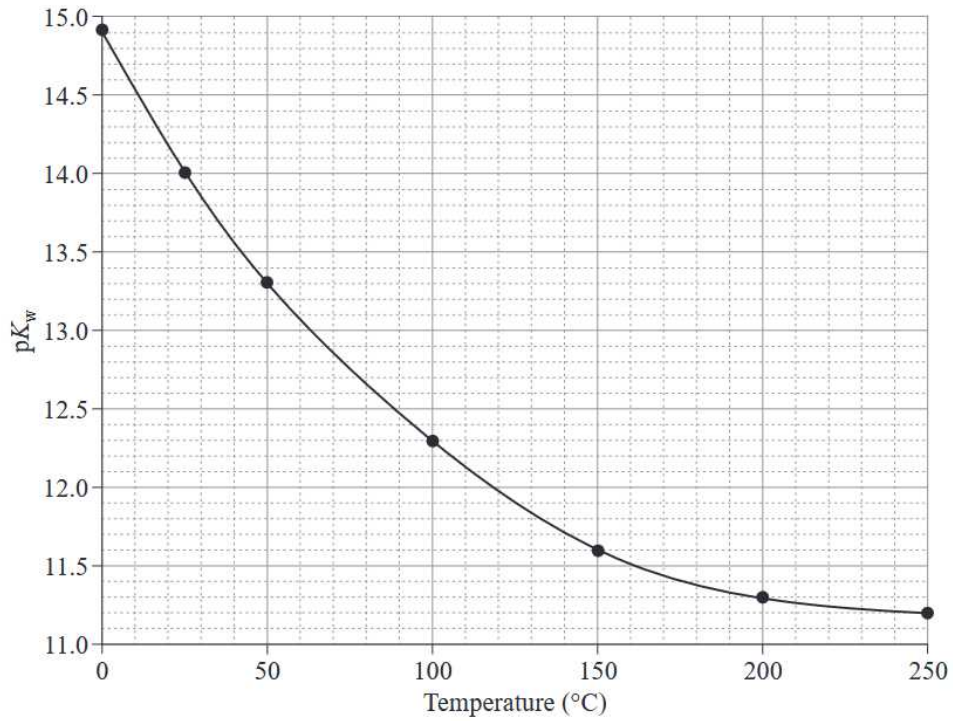
Chemical equilibrium systems

The pK_w of pure water at various temperatures was determined, to investigate the effect of temperature on the equilibrium position of self-ionisation of water.

The results are shown.



Explain the effect of increasing the temperature on the pH of water by considering the enthalpy of the forward reaction.

2024 Paper 1 Section 2 Question 29

Chemical equilibrium systems

Methylamine is a weak base that forms a buffer solution when mixed with methylammonium ($CH_3NH_3^+$)(aq).

$$\text{methylamine} + H_2O(l) \rightleftharpoons CH_3NH_3^+(aq) + OH^-(aq)$$

a) Describe, using a diagram, the structural formula of methylamine. [1 mark]

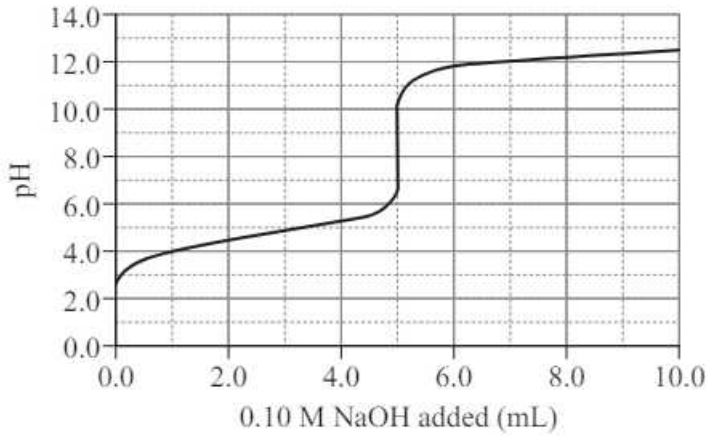
b) Apply Le Châtelier's principle to explain how the methylamine–methylammonium buffer solution would resist a change in pH if a small amount of NaOH was added. [2 marks]

2023 Paper 1 Section 2 Question 21 Chemical equilibrium systems	$CO(g)$ reacts with $O_2(g)$ in a sealed container producing $CO_2(g)$ to reach equilibrium. $$2CO(g) + O_2(g) \rightleftharpoons 2CO_2(g)$$ Apply collision theory to explain how increasing the concentration of O_2 at equilibrium will affect the concentration of CO_2 if the temperature and volume are held constant. [4 marks]

2023 Paper 1 Section 2 Question 27

Chemical equilibrium systems

An unknown monoprotic acid solution was titrated with 0.1 M NaOH(aq).



(a) Use Le Châtelier's principle to explain why phenolphthalein is a suitable indicator for this titration. [4 marks]

(b) Predict whether the pH of the equivalence point and the volume of NaOH required to neutralise the acid would change if the concentration of NaOH was doubled to 0.2 M. [2 marks]

2022 Paper 1 Section 2 Question 25 Chemical equilibrium systems	Three unknown gases are combined in a sealed flask and allowed to reach equilibrium as shown by the equation. $$3A_2(g) + X_2(g) \rightleftharpoons 2XA_3(g)$$ a) Determine whether the gases reach a state of dynamic equilibrium. Explain your reasoning. [3 marks] b) Determine if the relative position of equilibrium lies towards the products or reactants, if the molar concentrations at equilibrium are 3.4 mol L^{-1} for A_2, 1.8 mol L^{-1} for X_2 and 4.2 mol L^{-1} for XA_3. Explain your reasoning. [2 marks]

2022 Paper 1 Section 2 Question 26

Chemical equilibrium systems

Three unknown 0.1 M solutions, A, B and C, are found to have the following properties.

Solution	$[H^+]$ (mol L^{-1})	pH	pOH
A	0.0001		10.0
B		2.0	
C	0.063		

a) Determine the pH of solution A. [1 mark]

pH = _____ (to one decimal place)

b) Determine the concentration of hydrogen ions $[H^+]$ in solution B. [1 mark]

$[H^+]$ in solution B = _____ mol L^{-1} (to two significant figures)

c) Calculate the pOH of solution C. Show your working. [2 marks]

pOH = _____ (to one decimal place)

2022 Paper 1 Section 2 Question 27

Chemical equilibrium systems

Five colourless 0.1 M solutions of NH_3, HCl, KOH, H_2SO_4 and CH_3CH_2COOH have lost their labels. The substances are randomly relabelled A, B, C, D and E. The conductivity of each solution and the colour of the solution when phenol red was added are shown.

Solution	Conductivity (S/m)	Colour with phenol red
A	4.1	yellow
B	0.14	red
C	0.08	yellow
D	6.7	yellow
E	4.9	red

Identify the five solutions. Explain your reasoning. [5 marks]

2021 Paper 1 Section 2 Question 21 Chemical equilibrium systems	Calculate the pH of a 0.1M aqueous solution of $Ba(OH)_2$, assuming complete dissociation. Show your working. pH = _____ (to one decimal place)

2021 Paper 1 Section 2 Question 25 Chemical equilibrium systems	An equilibrium is formed between two differently coloured cobalt species, $Co(H_2O)_6^{2+}(aq)$, which is pink, and $CoCl_4^{2-}(aq)$, which is blue. The equation for this equilibrium is shown. $$Co(H_2O)_6^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons CoCl_4^{2-}(aq) + 6H_2O(l)$$ Apply Le Châtelier's principle to predict the visible effect of adding AgNO3 to an aqueous, blue-coloured solution containing $Co(H_2O)_6^{2+}$ and $CoCl_4^{2-}$ ions. Explain your reasoning. [3 marks] b) When a sample of the equilibrium mixture is put into hot water, the mixture turns more blue. Determine whether the forward reaction of the equation is exothermic or endothermic. Explain your reasoning. [2 marks]

2021
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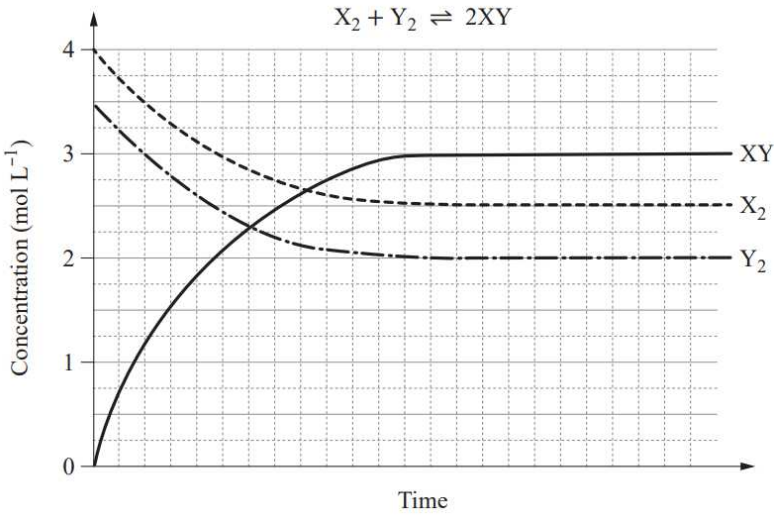
Question 26

Chemical equilibrium systems

The graph represents changes in concentration over time for three gaseous molecules (X_2, Y_2 and XY) in a closed system at constant temperature and pressure.



a) Identify whether XY is the reactant or the product. [1 mark]

b) Calculate the equilibrium constant (K_c) value. [2 marks]

$K_c =$ _____ (to two significant figures)

c) Determine whether the position of equilibrium favours the reactants or products. Explain your reasoning. [2 marks]

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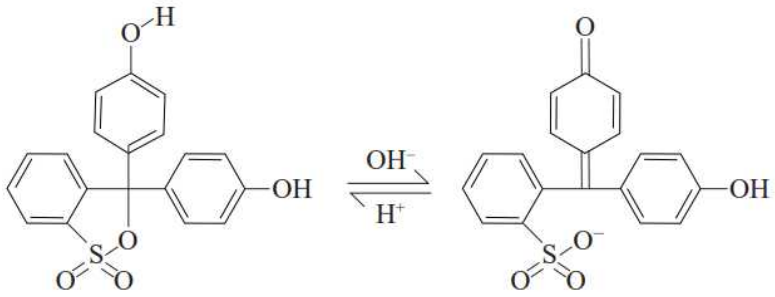
Chemical equilibrium systems

The structures of phenol red when in either an acidic or a basic solution are shown in the equation.



a) Identify the species that acts as the conjugate base by circling it in the equation. [1 mark]

Note: If you make a mistake, draw a line through this equation and use the additional equation provided on page 13 of this question and response book.

b) A solution of phenol red at equilibrium and 50 °C was found to contain 2.0×10^{-4} M of the conjugate base and 0.034 M of the acid. Determine the pK_a for the system, assuming all the protons present come from dissociation of the acid. [3 marks]

pK_a = _____ (to two significant figures)

c) Explain the relationship between the pH range of phenol red and its pKa value. [3 marks]

2020 Paper 1 Section 2 Question 24

Chemical equilibrium systems

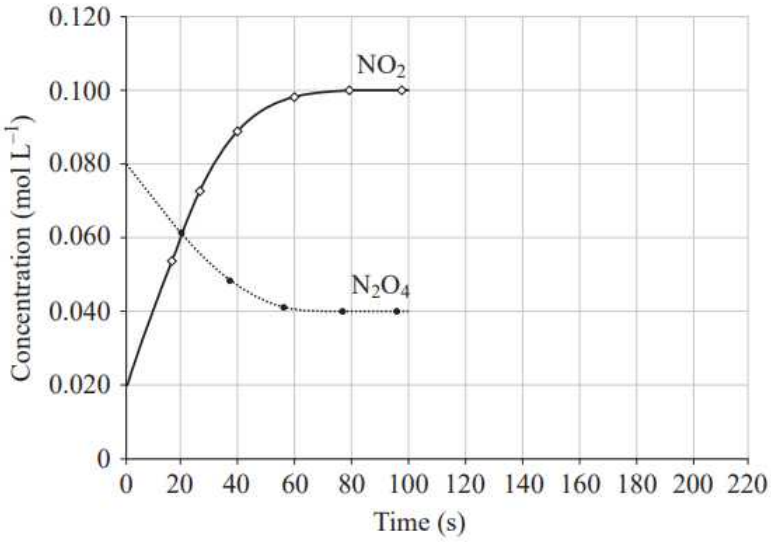
This table shows the effect of temperature on the pH of pure water.

Temperature (°C)	pH
10	7.27
15	7.17
20	7.08
25	7.00
30	6.92
50	6.63

a) Analyse the data to explain whether the self-ionisation of water is endothermic or exothermic. Explain your reasoning. [3 marks]

b) Calculate the K_w of pure water at 50 °C. Show your working. [2 marks]

K_w = _____ (to three significant figures)

2020 Paper 1 Section 2 Question 25 Chemical equilibrium systems	This graph depicts the changes in concentration over time for a nitrogen dioxide / dinitrogen tetroxide gaseous equilibrium in a closed system at constant temperature.  a) Determine the balanced chemical equation for the reaction in this system. [1 mark] b) Identify the time at which equilibrium is reached. [1 mark] c) If temperature is held constant, predict the effect that doubling the volume at 100 seconds would have on the closed system by sketching the change that would occur and the approximate position of the new equilibrium on the graph. [3 marks] Note: If you make a mistake, draw a line through this graph and use the additional graph provided on page 13 of this question and response book.

2020 Paper 1 Section 2 Question 27

Chemical equilibrium systems

Four unknown metals Q, X, Z and A were placed into separate test tubes containing a 0.1 M solution of their respective nitrate solutions. The results are shown in the table.

Metal	$Q(NO_3)_2$ solution	$X(NO_3)_2$ solution	$Z(NO_3)_2$ solution	$A(NO_3)_2$ solution
Q	Not tested	No reaction	No reaction	No reaction
X	Coating formed	Not tested	No reaction	No reaction
Z	Coating formed	Coating formed	Not tested	Coating formed
A	Coating formed	Coating formed	No reaction	Not tested

a) Identify the species oxidised in the reaction between Z and $X(NO_3)_2$. [1 mark]

b) Identify the oxidising agent in the reaction between Z and $Q(NO_3)_2$. [1 mark]

c) Determine the products formed from the reaction between Z and $A(NO_3)_2$. [1 mark]

d) Predict the standard reduction potential table for the metals Q, X, Z and A by listing their reduction half-equations from strongest to weakest reducing agent. Explain your reasoning. [4 marks]

2024 Paper 2 Section 1 Question 1 **Chemical equilibrium systems**	A 30.00 mL aliquot of aqueous hydrochloric acid (HCl) with a pH of 2.00 was diluted with 2970.00 mL of water to make up a final volume of 3.00 L of aqueous HCl solution. a) Determine the concentration of hydrogen ions in the original 30.00 mL aliquot of HCl(aq). [1 mark] b) Calculate the pH of the final 3.00 L solution of HCl(aq). Show your working. [2 marks]

2024 Paper 2 Section 1 Question 2 **Chemical equilibrium systems**	Phenol red (HIn) is a weak acid that acts as an indicator as shown. $$HIn(aq) \rightleftharpoons In^-(aq) + H^+(aq)$$ a) Identify the conjugate base of phenol red. [1 mark] b) Determine the dissociation constant (K_a) of phenol red. [1 mark] c) Explain the relationship between the pH range of colour change for phenol red and its p K_a value. [4 marks]

2024 Paper 2 Section 1 Question 3

Chemical equilibrium systems

The concentration, pH and dissociation constant (K_a) of aqueous solutions of ethanoic acid and two unknown monoprotic acids, I and II, are shown.

Acid	Concentration (M)	pH	K_a
$CH_3COOH(aq)$	0.2		1.8×10^{-5}
I	0.2	1.9	6.6×10^{-4}
II	0.1	1.1	1.3×10^{6}

a) Compare the relative strength of an aqueous solution of acid I and $CH_3COOH(aq)$. *[3 marks]*

Similarity:

Difference:

Significance:

b) Determine whether an aqueous solution of acid I or acid II would have a higher electrical conductivity. Explain your reasoning. [3 marks]

c) Calculate the pH of 0.2 M $CH_3COOH(aq)$. Show your working. [3 marks]

2023 Paper 2 Section 1 Question 5

Chemical equilibrium systems

The table gives the properties of four monoprotic acids.

Acid	Concentration (mol L^{-1})	$[H^+]$ (mol L^{-1})	pH	K_a
1	0.200	7.90×10^{-5}		
2	0.100	4.20×10^{-3}	2.34	1.80×10^{-4}
$CH_3COOH(aq)$	0.100			1.78×10^{-5}
HCl(aq)	0.010	1.00×10^{-2}	2.00	>1

(a) Determine the relative strength of acids 1 and 2 by contrasting their K_a values. [3 marks]

b) Write a balanced chemical equation for the dissociation of ethanoic acid (CH_3COOH) in water. [2 marks]

(c) Identify whether the conjugate base of ethanoic acid ($CH_3COOH(aq)$) is amphiprotic. Explain your reasoning. [2 marks]

(d) Calculate the pH of the aqueous solution of ethanoic acid CH_3COOH). Show your working. [3 marks]

(e) Determine the volume of water that would need to be added to 100.0 mL of HCl(aq) to change the pH from 2.00 to 3.00. Explain your reasoning. [3 marks]

2023 Paper 2 Section 1 Question 7

Chemical equilibrium systems

When heated in a sealed container, solid mercury(II) oxide (HgO) decomposed to form metallic mercury (Hg) and oxygen gas (O_2).

$$\underset{\text{Orange}}{2HgO(s)} \rightleftharpoons \underset{\text{Silver}}{2Hg(l)} + \underset{\text{Colourless}}{O_2(g)}$$

(a) Identify whether the reaction occurs in an open or closed system. [1 mark]

(b) Explain why the colour of the system does not change once equilibrium is established. [3 marks]

2023 Paper 2 Section 1 Question 8

Chemical equilibrium systems

Two experiments were conducted to investigate the effect of temperature on the equilibrium formed during the decomposition of hydrogen iodide (HI).

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g) \qquad \Delta H = +53.6 \text{ kJ mol}^{-1}$$

Experiment	Initial concentration (mol L^{-1})			Equilibrium concentration (mol L^{-1})			K_c
	[HI]	$[H_2]$	$[I_2]$	[HI]	$[H_2]$	$[I_2]$	
1	0.08	0.00	0.00		0.01		2.78×10^{-2}
2	0.00	0.06	0.06	0.06	0.03	0.03	

(a) Determine the concentration of HI(g) and I_2(g) at equilibrium for experiment 1. [2 marks]

[HI]:

$[I_2]$:

(b) Calculate the equilibrium constant (K_c) for experiment 2. Show your working. [2 marks]

(c) Determine which experiment was conducted at a higher temperature. Explain your reasoning. [3 marks]

2022 Paper 2 Section 1 Question 2

Chemical equilibrium systems

The reaction shows part of the contact process used to produce sulfuric acid.

$$2SO_2(g) + O_2 \rightleftharpoons[V_2O_5] 2SO_3(g)$$

The equilibrium constant (K_c) for this reaction at different temperatures is shown.

Temperature (K)	Equilibrium constant, K_c (mol L^{-1})
298	9.77×10^{25}
500	8.61×10^{11}

a) Deduce if the forward reaction is exothermic or endothermic. Explain your reasoning. [2 marks]

b) Calculate the equilibrium concentration of SO3 at 500 K given the equilibrium concentrations. [2 marks]

$[SO_2] = 0.860$ M; $[O_2] = 0.330$ M

Concentration = _____ M (to three significant figures)

c) Apply Le Châtelier's principle to explain whether halving the reaction vessel's volume at 500 K would affect the position of the equilibrium or the value of the equilibrium constant. [4 marks]

2022 Paper 2 Section 1 Question 3

Chemical equilibrium systems

A 50.0 mL solution of ethanoic acid (CH_3COOH) was titrated with 15.0 mL of 0.10 M sodium hydroxide (NaOH) solution to reach the equivalence point (pK_a ethanoic acid = 4.76).

a) Write a balanced chemical equation to indicate how ethanoic acid acts as a Brønsted-Lowry acid during the titration and identify its conjugate base. [2 marks]

b) Determine the K_b of the conjugate base of ethanoic acid. [1 mark]

K_b = _____ (to two decimal places)

c) Calculate the concentration of the conjugate base at the equivalence point. Show your working. [2 marks]

Concentration = _____ M (to three significant figures)

d) Calculate the pH at the equivalence point. Show your working. [4 marks]

pH = _____ (to one decimal place)

2021 Paper 2 Section 1 Question 1

Chemical equilibrium systems

Phosphoric acid (H_3PO_4) is a common triprotic acid that dissociates fully in three stages. The dissociation equations are shown in the table.

Stage	Dissociation equation	K_a
1	$H_3PO_4(aq) + H_2O(l) \rightleftharpoons H_2PO_4^-(aq) + H_3O^+(aq)$	7.1×10^{-3}
2	$H_2PO_4^-(aq) + H_2O(l) \rightleftharpoons HPO_4^{2-}(aq) + H_3O^+(aq)$	6.5×10^{-8}
3	$HPO_4^{2-}(aq) + H_2O(l) \rightleftharpoons PO_4^{3-}(aq) + H_3O^+(aq)$	4.5×10^{-13}

a) Use the information to determine the strongest Brønsted-Lowry acid and its conjugate base. Explain your reasoning. [3 marks]

Acid:

Conjugate base:

Reasoning:

b) Identify an amphiprotic species from the dissociation reactions. Explain your reasoning. [2 marks]

c) Determine the K_b value for the strongest conjugate base formed when H_3PO_4 has fully dissociated. Show your working. [2 marks]

K_b = _____ (to two significant figures)

d) Calculate the pH of a 0.05 M solution of dihydrogen phosphate ($H_2PO_4^-$). Show your working and state any assumptions made. [4 marks]

pH = _____ (to one decimal place)

2021 Paper 2 Section 1 Question 4

Chemical equilibrium systems

5.00×10^{-4} moles of hydrogen gas is mixed with 1.00×10^{-3} moles of iodine vapour in a sealed 1.00 L vessel at 455.0 °C. The concentration of hydrogen iodide gas formed at equilibrium is 9.30×10^{-4} M.

The balanced equation for the reaction is shown.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

a) Write the equilibrium law expression for the reaction. [1 mark]

b) Calculate the equilibrium constant (Kc) for the reaction at 455.0 °C.
Show your working. [5 marks]

$K_c =$ _____ (to three significant figures)

c) Predict the effect that adding a catalyst would have on the reaction rates, position of the equilibrium and value of K_c. [3 marks]

2020 Paper 2 Section 1 Question 2

Chemical equilibrium systems

Salicylic acid reacts with ethanoic anhydride in an aqueous solution to produce acetylsalicylic acid, as shown in the equation. Acetylsalicylic acid is commonly known as aspirin.

a) Identify the type of chemical reaction used to produce aspirin. [1 mark]

b) Write the equilibrium expression, K_c, for the reaction. [1 mark]

c) At 20 °C, the equilibrium constant (K_c) for the reaction is 2×10^{-3} . Determine whether the concentration of the reactants or products is greater at equilibrium at this temperature. [2 marks]

d) Calculate the minimum mass of salicylic acid required to produce 500.0 mg of aspirin if the yield of aspirin is 45.0%. Show your working. [4 marks]

Mass = _____ mg (to three significant figures)

e) When the reaction is heated to 40 °C and equilibrium is re-established, the concentration of acetylsalicylic acid and ethanoic acid increases. Apply Le Châtelier's principle to predict if the forward reaction is exothermic or endothermic. Explain your reasoning. [4 marks]

2020 Paper 2 Section 1 Question 5

Chemical equilibrium systems

Compound A reacts with water to produce compound B and hydroxide ions.

$$\underset{\text{A}}{CH_3CH_2NH_2(aq)} + H_2O(l) \; \textit{f} \; \underset{\text{B}}{C_2H_5NH_3^+(aq)} + OH^-(aq)$$

a) Apply IUPAC rules to name compound A. [1 mark]

b) Identify the Brønsted-Lowry acids in the equation. [2 marks]

c) A small amount of hydrochloric acid is added to the equilibrium mixture. Predict the effect of this on the concentration of compound A in the mixture. Explain your reasoning. [3 marks]

d) Calculate the pH of a 2.0 M solution of compound A. State any assumptions. Show your working. ($K_b = 5.6 \times 10^{-4}$) [6 marks]

pH = _____ (to one decimal place)

	e) Describe, using a balanced chemical equation, how Compound A could be made from bromomethane. Include relevant conditions and reagents in your response. [5 marks]

Marking Guide – Paper 1 Section 1

2024 Paper 1 Section 1 Question 5 Chemical equilibrium systems	Titration is a volumetric analysis method used to (A) measure the pH of an analyte. (B) determine the volume of a titrant. **(C) calculate the concentration of an identified solution. – Answer** (D) prepare a standard solution of known concentration and volume.

2024 Paper 1 Section 1 Question 6 Chemical equilibrium systems	The equivalence point of an acid–base titration occurs when the (A) pH equals the pK_a. (B) pH stops changing. (C) indicator changes colour. **(D) titrant completely neutralises the analyte. – Answer**

2024 Paper 1 Section 1 Question 10 Chemical equilibrium systems	The acid dissociation constant (K_a) represents the (A) pH of an acid solution. **(B) strength of an acid solution. – Answer** (C) concentration of an acid solution. (D) conjugate acid–base pairs of an acid solution.

2024 Paper 1 Section 1 Question 11 Chemical equilibrium systems	A Brønsted–Lowry acid (A) accepts a proton to form its base. (B) donates a proton to form its base. (C) accepts a proton to form its conjugate base. (D) donates a proton to form its conjugate base. **Answer is D.**

2024 Paper 1 Section 1 Question 12 Chemical equilibrium systems	The following equilibrium law expression is given for a specific reaction. $$K_c = \frac{[H_2O]^4[CO_2]^3}{[C_3H_8][O_2]^5}$$ Determine which of the following is a product of this reaction. (A) $CO_2(g)$ (B) $C_3H_8(l)$ (C) $H_2O(l)$ (D) $O_2(g)$ **Answer is A.**

2024 Paper 1 Section 1 Question 20

Chemical equilibrium systems

Identify the polyprotic acid.

(A) $NH_3(aq)$

(B) $H_3PO_4(aq)$

(C) $(NH_4)_3PO_4(aq)$

(D) $CH_3COOH(aq)$

Answer is B.

2023 Paper 1 Section 1 Question 1

Chemical equilibrium systems

In a chemical equation at equilibrium, a reversible arrow ($\rightleftharpoons$) symbolises that

(A) the forward reaction has stopped but can be reversed.

(B) the moles of reactants and products present are equal.

(C) half of the reactants have been converted into products.

(D) the concentration of reactants and products remains constant.

Answer is D.

2023 Paper 1 Section 1 Question 2

Chemical equilibrium systems

Determine which expression represents the hydrogen ion (H^+) concentration at a pH of 8.4.

(A) $1 \times 10^{-8.4}$

(B) $1 \times 10^{-5.6}$

(C) $1 \times 10^{-0.9}$

(D) $1 \times 10^{-0.8}$

Answer is A.

2023 Paper 1 Section 1 Question 3

Chemical equilibrium systems

Two 0.1 M acidic solutions, X and Y, are 100% dissociated. Solution X has an electrical conductivity approximately twice that of solution Y. Identify solutions X and Y.

	Solution X	**Solution Y**
(A)	HCl	CH_3COOH
(B)	HNO_3	H_2SO_4
(C)	H_3PO_4	HNO_3
(D)	H_2SO_4	HCl

Answer is D.

2023 Paper 1 Section 1 Questions 4-5

Chemical equilibrium systems

Questions 4–5 refer to the decomposition of hydrogen iodide gas (HI) to produce hydrogen gas (H_2) and iodine gas (I_2) in a sealed 1-litre container.

$$\underset{\text{Colourless}}{2HI(g)} \rightleftharpoons \underset{\text{Colourless}}{H_2(g)} + \underset{\text{Purple}}{I_2(g)} \qquad \Delta H = +53.6 \text{ kJ mol}^{-1}$$

Question 4

Identify which change would shift the system from light purple to dark purple.

(A) adding HI(g)

(B) adding a catalyst

(C) decreasing the temperature

(D) increasing the concentration of $H_2(g)$

Question 4 Answer is A.

Question 5

Determine the equilibrium expression (K_c) for the reaction.

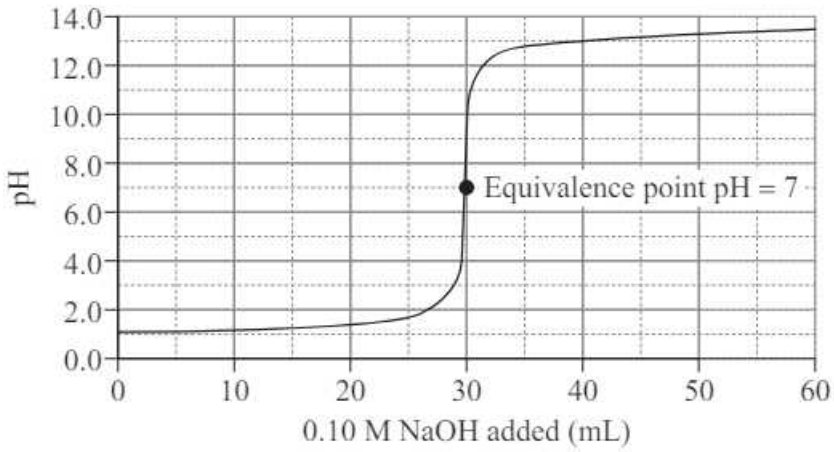
(A) $K_c = \dfrac{[H_2][I_2]}{2[HI]}$

(B) $K_c = \dfrac{[H_2][I_2]}{[HI]^2}$

(C) $K_c = \dfrac{2[H]2[I]}{2[HI]}$

(D) $K_c = \dfrac{2[H]2[I]}{[HI]^2}$

Question 5 Answer is B.

2023 Paper 1 Section 1 Questions 9-10 Chemical equilibrium systems	Questions 9–10 refer to the titration curve shown, which is produced when 60.00 mL of an unknown monoprotic acid solution is titrated with 0.10 M NaOH(aq).  **Question 9** Compared to 0.10 M NaOH, the unknown monoprotic acid is more (A) dilute and weak. (B) dilute and strong. (C) concentrated and weak. (D) concentrated and strong. **Answer is B.** **Question 10** Determine the concentration of the unknown acid. (A) 0.05 M (B) 0.10 M (C) 0.20 M (D) 0.30 M **Answer is A.**

2023 Paper 1 Section 1 Question 15 Chemical equilibrium systems	Predict how a buffer solution, consisting of carbonic acid (H_2CO_3) and hydrogen carbonate ions (HCO_3^-), would react to resist a change in pH when a small amount of hydrochloric acid is added. $$H_2CO_3(aq) \rightleftharpoons HCO_3^-(aq) + H^+(aq) \rightleftharpoons CO_3^{2-}(aq) + 2H^+(aq)$$ (A) Equilibrium shifts to the right and the $[H^+](aq)$ increases. (B) Equilibrium shifts to the left and the $[CO_3^{2-}](aq)$ increases. (C) Equilibrium shifts to the left and the $[H_2CO_3](aq)$ increases. (D) Equilibrium shifts to the right and the $[HCO_3^-](aq)$ increases. **Answer is C.**

2022 Paper 1 Section 1 Question 6 Chemical equilibrium systems	The equilibrium concentration of A is 2.8×10^{-4} M and B is 1.2×10^{-4} M. A (g) ⇌ B (g) $\Delta H > 0$ Which option represents the ratio of molecules present in a sample of the gaseous mixture when the temperature is decreased and a new equilibrium established? **(A) 8 molecules of A and 2 molecules of B – Answer** (B) 5 molecules of A and 5 molecules of B (C) 3 molecules of A and 7 molecules of B (D) 2 molecules of A and 8 molecules of B

2022 Paper 1 Section 1 Question 8 Chemical equilibrium systems	Predict how the system shown will respond when a small amount of aqueous sodium hydroxide is added. $CH_3COOH(aq) + H_2O(l) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$ (A) Equilibrium shifts to the left and the pH decreases. (B) Equilibrium shifts to the right and the pH increases. (C) Equilibrium shifts to the left and the pH remains the same. **(D) Equilibrium shifts to the right and the pH remains the same. – Answer**

2022 Paper 1 Section 1 Question 10 Chemical equilibrium systems	The midpoint of the colour change of a weak acid indicator occurs when (A) $[In^-] = [H^+]$ (B) $[In^-] = [HIn]$ (C) $[H^+] = [OH^-]$ (D) $[HIn] = [OH^-]$ **Answer is B.**

2022 Paper 1 Section 1 Question 13 Chemical equilibrium systems	Determine the K_a of an unknown weak acid (HA) with an aqueous concentration of 0.12 M and a pH of 3.2. (A) 5.2×10^{-3} (B) 6.3×10^{-4} **(C) 3.3×10^{-6} – Answer** (D) 4.0×10^{-7}

2022 Paper 1 Section 1 Question 18 Chemical equilibrium systems	Determine the K_b expression for the weak base shown in the equilibrium equation. $NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$ (A) $K_b = \frac{[NH_3][H_2O]}{[NH_4^+]}$ (B) $K_b = \frac{[NH_3][H_2O]}{[OH^-]}$ (C) $K_b = \frac{[NH_4^+][OH^-]}{[NH_3]}$ (D) $_b = \frac{[NH_4^+][OH^-]}{[H_2O]}$ **Answer is C.**

2021 Paper 1 Section 1 Question 4 Chemical equilibrium systems	The cleaning action of soap is impaired in hard water because the **(A) hydrophilic end reacts with calcium ions to form insoluble salts. – Answer** (B) hydrophobic end reacts with calcium ions to form insoluble salts. (C) hydrophilic end reacts with calcium ions to form insoluble fatty acids. (D) hydrophobic end reacts with calcium ions to form insoluble fatty acids.

2021 Paper 1 Section 1 Question 5 Chemical equilibrium systems	A 10.0 M solution of ethanoic acid is best described as a (A) dilute solution of a weak acid. (B) dilute solution of a strong acid. **(C) concentrated solution of a weak acid. – Answer** (D) concentrated solution of a strong acid.

2021 Paper 1 Section 1 Question 10 Chemical equilibrium systems	Determine which system at equilibrium will shift to the right (products) if the total pressure on the system is increased. (A) $N_2O_4(g) \rightleftharpoons 2NO_2(g)$ (B) $2H_2O(g) \rightleftharpoons 2H_2(g) + O_2(g)$ (C) $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ (D) $CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$ **Answer is C.**

2021 Paper 1 Section 1 Question 11 Chemical equilibrium systems	Enzymes can act as biological catalysts because they (A) can be denatured. **(B) lower the activation energy. – Answer** (C) are sensitive to pH and temperature changes. (D) increase the equilibrium constant for the reaction.

2021 Paper 1 Section 1 Question 14

Chemical equilibrium systems

Acid	K_a value
Nitrous acid	$K_a = 4.00 \times 10^{-4}$
Ethanoic acid	$K_a = 1.76 \times 10^{-5}$
Hydrofluoric acid	$K_a = 7.20 \times 10^{-4}$
Chloroethanoic acid	$K_a = 1.40 \times 10^{-3}$

Analyse the data to determine the relative strengths of acids from strongest to weakest.

(A) chloroethanoic, ethanoic, nitrous, hydrofluoric
(B) chloroethanoic, hydrofluoric, nitrous, ethanoic – Answer
(C) ethanoic, nitrous, hydrofluoric, chloroethanoic
(D) ethanoic, hydrofluoric, nitrous, chloroethanoic

2021 Paper 1 Section 1 Question 17

Chemical equilibrium systems

Determine the concentration of hydrogen ions (H^+) in an aqueous solution containing 1.2×10^{-3} M hydroxide ions (OH^-).

(A) 1.2×10^{11}
(B) 8.3×10^{-12} – Answer
(C) 8.3×10^{-17}
(D) 1.2×10^{-17}

2020 Paper 1 Section 1 Question 5

Chemical equilibrium systems

The equilibrium constants of four different reactions are given.

In which reaction does the equilibrium lie furthest to the left?

	Reaction	K_c
(A)	$PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$	2.4×10^{1}
(B)	$AgIO_3(s) \rightleftharpoons Ag^+(aq) + IO_3^-(aq)$	3.0×10^{-8}
(C)	$Cl_2(g) + H_2O(l) \rightleftharpoons HOCl(aq) + Cl^-(aq) + H^+(aq)$	4.0×10^{-4}
(D)	$HSO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + SO_3^{2-}(aq)$	6.3×10^{-8}

Answer is B.

2020 Paper 1 Section 1 Question 7

Chemical equilibrium systems

Acid	Concentration (M)	pH
H_3PO_4	2.0×10^{-2}	1.9
HCN	1.5×10^{-1}	5.0
H_2SO_4	9.0×10^{-2}	1.0
CH_3COOH	1.0×10^{-1}	2.8

Analyse the experimental data to determine the relative strength of the acids from strongest to weakest.

(A) $H_2SO_4 > H_3PO_4 > HCN > CH_3COOH$
(B) $H_2SO_4 > H_3PO_4 > CH_3COOH > HCN$
(C) $HCN > CH_3COOH > H_2SO_4 > H_3PO_4$
(D) $HCN > CH_3COOH > H_3PO_4 > H_2SO_4$

Answer is B.

2020 Paper 1 Section 1 Question 9 Chemical equilibrium systems	Phosgene gas ($COCl_2$) is formed by the following reaction. $CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g) \quad \Delta H = -110 \text{ kJ mol}^{-1}$ Which of the following statements is true for the system at equilibrium? (A) Removing $Cl_2(g)$ will increase the yield of phosgene and keep the K_c value constant. (B) Adding a catalyst will increase the yield of phosgene and keep the K_c value constant. (C) Increasing the pressure will increase the yield of phosgene and keep the K_c value constant. (D) Decreasing the temperature will decrease the yield of phosgene and keep the K_c value constant. **Answer is C.**

2020 Paper 1 Section 1 Question 14 Chemical equilibrium systems	Ammonia gas reacts with oxygen gas in the following equilibrium reaction. $4NH_3(g) + 3O_2(g) \rightleftharpoons 2N_2(g) + 6H_2O(g)$ The equilibrium expression for the reaction is (A) $\dfrac{[NH_3][O_2]}{[N_2][H_2O]}$ (B) $\dfrac{[N_2][H_2O]}{[NH_3][O_2]}$ (C) $\dfrac{[NH_3]^4[O_2]^3}{[N_2]^2[H_2O]^6}$ (D) $\dfrac{[N_2]^2[H_2O]^6}{[NH_3]^4[O_2]^3}$ **Answer is D.**

2020 Paper 1 Section 1 Question 18 Chemical equilibrium systems	Solution A has a pH of 3 and solution B has a pH of 6. This indicates that solution A is (A) less acidic and has 0.5 times the concentration of hydrogen ions in solution B. (B) more acidic and has 2 times the concentration of hydrogen ions in solution B. (C) less acidic and has 0.001 times the concentration of hydrogen ions in solution B. **(D) more acidic and has 1000 times the concentration of hydrogen ions in solution B. – Answer**

2024 Paper 1 Section 2 Question 21

Chemical equilibrium systems

Reactants A and B are placed in a 1.00 L container and react to form product C. The reaction then reaches equilibrium.

$$A(g) + B(g) \rightleftharpoons C(g) \quad (K_c = 9.9 \times 10^2)$$

a) Explain why a reversible arrow (⇌) is used to symbolise this reaction. [1 mark]

Sample response	The response
The reversible arrow indicates that the reaction occurs in both directions (forward and reverse) simultaneously.	• explains that forward and reverse reactions occur simultaneously **[1 mark]**

b) Deduce whether the equilibrium for the reaction lies towards the reactants or products.
Explain your reasoning. [2 marks]

Sample response	The response
K_c is greater than 1, therefore the equilibrium for the reaction lies towards the products.	• deduces the equilibrium lies towards the products **[1 mark]** • explains that K_c is greater than 1 **[1 mark]**

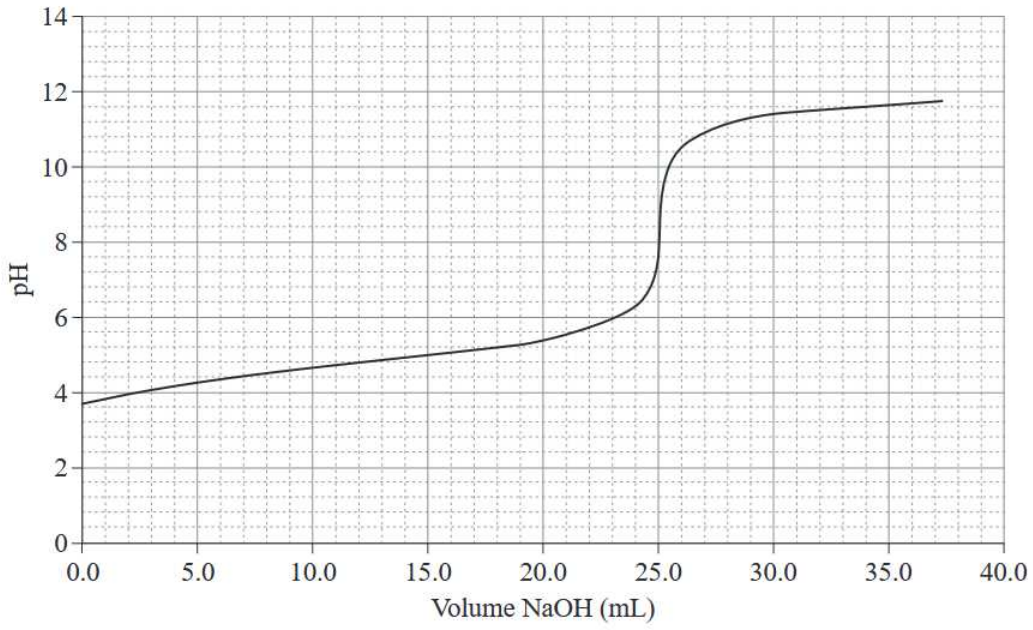
2024 Paper 1 Section 2 Question 23

Chemical equilibrium systems

An aqueous solution of sodium hydroxide (NaOH) was titrated against a 30.0 mL aliquot of a 0.012 M potassium hydrogen phthalate (KHP) standard aqueous solution. The balanced chemical equation for the reaction is shown.

$$KHP(aq) + NaOH(aq) \rightarrow KNaP(aq) + H_2O(l)$$

The results are shown in the titration curve.



a) Determine whether KHP is a strong or weak acid. Identify one feature from the titration curve to support your reasoning. [2 marks]

Sample response	The response
KHP is a weak acid. The titration curve contains a buffer region.	• determines KHP is a weak acid **[1 mark]** • identifies the buffer region **[1 mark]**

b) Explain why KHP(aq) is used as the standard solution rather than NaOH(aq). [1 mark]

Sample response	The response
KHP does not absorb water from the air; therefore, an accurate concentration can be determined for KHP.	• explains that [KHP] does not change due to absorption of water from the air **[1 mark]**

c) Calculate the concentration of NaOH(aq). Show your working. [2 marks]

Sample response	The response
$n\text{KHP} = 0.03 \times 0.012 = 0.00036$ mol $n\text{KHP} = n\text{NaOH}$ $[\text{NaOH}] = \frac{0.00036}{0.025} = 0.0144 \text{ mol L}^{-1}$	• provides suitable substitution **[1 mark]** • calculates [NaOH] **[1 mark]**

2024
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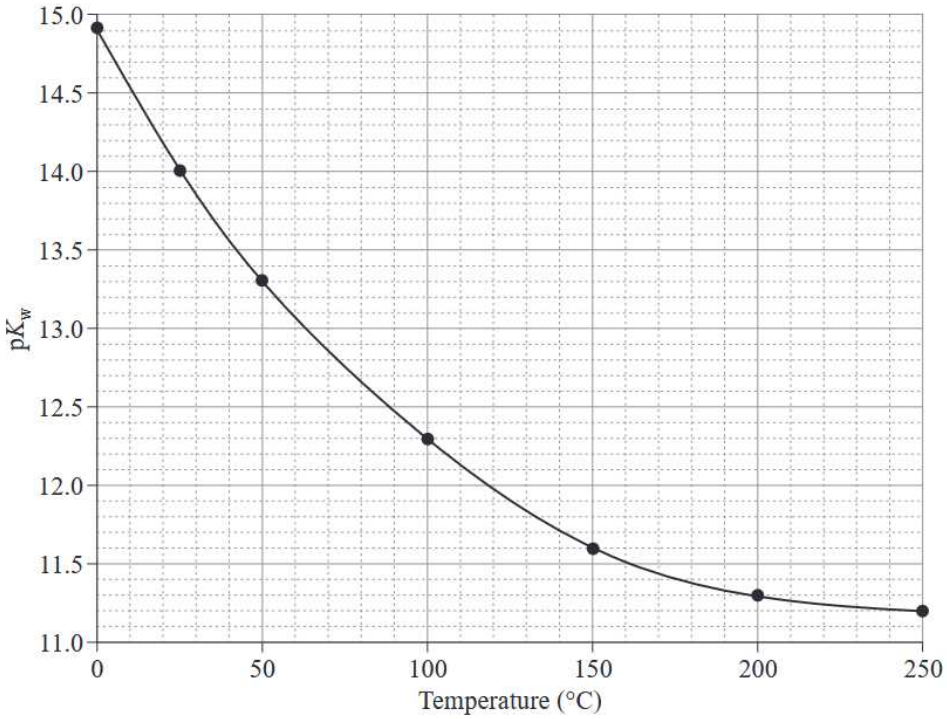
Section 2
Question 24

Chemical equilibrium systems

The pK_w of pure water at various temperatures was determined, to investigate the effect of temperature on the equilibrium position of self-ionisation of water.

The results are shown.



Explain the effect of increasing the temperature on the pH of water by considering the enthalpy of the forward reaction.

Sample response	The response
As temperature increases, pK_w decreases (K_w increases), indicating that equilibrium shifts towards the products. Therefore, the forward reaction is endothermic and increasing the temperature increases $[H^+]$ and decreases pH.	• identifies that pK_w decreases as temperature increases **[1 mark]** • determines that the forward reaction is endothermic **[1 mark]** • explains that increasing temperature shifts the equilibrium toward products **[1 mark]** • explains that increasing temperature decreases pH **[1 mark]**

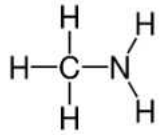
2024 Paper 1 Section 2 Question 29

Chemical equilibrium systems

Methylamine is a weak base that forms a buffer solution when mixed with methylammonium ($CH_3NH_3^+$)(aq).

$$\text{methylamine} + H_2O(l) \rightleftharpoons CH_3NH_3^+(aq) + OH^-(aq)$$

a) Describe, using a diagram, the structural formula of methylamine. [1 mark]

Sample response	The response
	• describes the structural formula for methylamine **[1 mark]**

b) Apply Le Châtelier's principle to explain how the methylamine–methylammonium buffer solution would resist a change in pH if a small amount of NaOH was added. [2 marks]

Sample response	The response
Added OH^- would react and accept a proton from $CH_3NH_3^+$ to form water and CH_3NH_2 (weak base). Thus, equilibrium would shift to the left (reactants) and resist a change in pH.	• explains $CH_3NH_3^+$ reacts with excess OH^- ions **[1 mark]** • explains equilibrium would shift to the left and resist a change in pH **[1 mark]**

2023 Paper 1 Section 2 Question 21

Chemical equilibrium systems

CO(g) reacts with O_2(g) in a sealed container producing CO_2(g) to reach equilibrium.

$$2CO(g) + O_2(g) \rightleftharpoons 2CO_2(g)$$

Apply collision theory to explain how increasing the concentration of O_2 at equilibrium will affect the concentration of CO_2 if the temperature and volume are held constant.

[4 marks]

Sample response	The response
Increasing the concentration of O_2 increases the number of O_2 molecules. This increases the frequency of collisions between O_2 and CO. Therefore, the rate of the forward reaction increases and equilibrium shifts to the right (products) to increase the concentration of CO_2.	• identifies that increasing concentration of O_2 increases the number of O_2 molecules **[1 mark]** • explains that an increase in $[O_2]$ increases collisions between O_2 and CO **[1 mark]** • explains that the rate of forward reaction increases **[1 mark]** • identifies that equilibrium shifts to the right and concentration of CO_2 increases **[1 mark]**

2023
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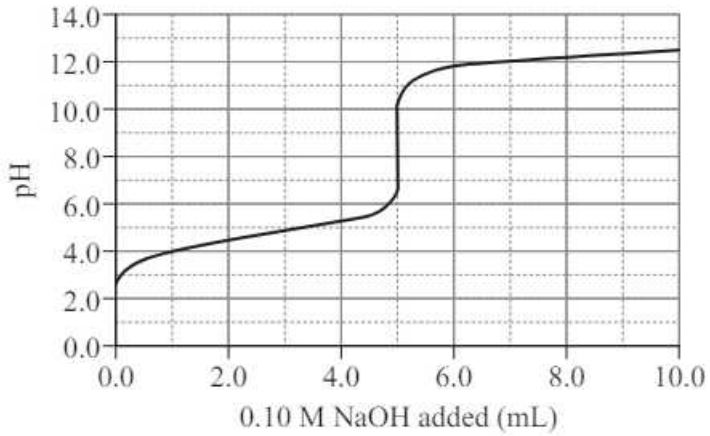
Question 27

Chemical equilibrium systems

An unknown monoprotic acid solution was titrated with 0.1 M NaOH(aq).



(a) Use Le Châtelier's principle to explain why phenolphthalein is a suitable indicator for this titration. [4 marks]

Sample response	The response
$HIn(aq) \rightleftharpoons In^-(aq) + H^+(aq)$ Phenolphthalein is colourless in its acidic form. Adding hydroxide ions removes hydrogen ions and shifts the equilibrium for the indicator towards the coloured anion, turning the indicator pink. The pH of the equivalence point lies within the pH range for the colour change for phenolphthalein, thus making it a suitable indicator for this titration.	• explains phenolphthalein is colourless in its acidic form **[1 mark]** • explains adding $OH^-(aq)$ removes $H^+(aq)$ **[1 mark]** • explains equilibrium shifts toward the coloured anion **[1 mark]** • explains pH equivalence point lies within the pH range of the colour change **[1 mark]**

(b) Predict whether the pH of the equivalence point and the volume of NaOH required to neutralise the acid would change if the concentration of NaOH was doubled to 0.2 M. [2 marks]

Sample response	The response
The pH of the equivalence would remain the same. However, the volume of NaOH required to reach the equivalence point would be halved to 2.5 mL because the $[OH^-]$ has doubled.	• determines the pH of the equivalence point would remain the same **[1 mark]** • determines the volume of NaOH required to reach the equivalence would be halved **[1 mark]**

2022 Paper 1 Section 2 Question 25

Chemical equilibrium systems

Three unknown gases are combined in a sealed flask and allowed to reach equilibrium as shown by the equation.

$$3A_2(g) + X_2(g) \rightleftharpoons 2XA_3(g)$$

a) Determine whether the gases reach a state of dynamic equilibrium. Explain your reasoning. [3 marks]

Sample Response	The response
The reaction occurred in a closed system, therefore matter is not exchanged with the surroundings. This means the system can reach a steady state, where the rate of the forward reaction (conversion of reactants to products) equals the rate of the reverse reaction (products are converted back into reactants) to establish a state of dynamic equilibrium.	• identifies gases reach dynamic equilibrium [1 mark] • explains matter is not exchanged with surrounds [1 mark] • explains rate of forward reaction is equal to rate of reverse reaction [1 mark]

b) Determine if the relative position of equilibrium lies towards the products or reactants, if the molar concentrations at equilibrium are 3.4 mol L^{-1} for A_2, 1.8 mol L^{-1} for X_2 and 4.2 mol L^{-1} for XA_3. Explain your reasoning. [2 marks]

Sample Response	The response
$K_c = \frac{[XA_3]^2}{[A_2]^3[X_2]}$ $K_c = \frac{[4.2]^2}{[3.4]^3[1.8]}$ $K_c = \frac{17.64}{70.7472} = 0.25$ $K_c < 1$ therefore equilibrium lies to the left	• determines $K_c = 0.25$ [1 mark] • indicates that since $K_c < 1$, equilibrium lies towards the reactants [1 mark]

2022 Paper 1 Section 2 Question 26

Chemical equilibrium systems

Three unknown 0.1 M solutions, A, B and C, are found to have the following properties.

Solution	$[H^+]$ (mol L^{-1})	pH	pOH
A	0.0001		10.0
B		2.0	
C	0.063		

a) Determine the pH of solution A. [1 mark]

Sample Response	The response
pH = 4.0	• determines pH for solution A is 4.0 [1 mark]

b) Determine the concentration of hydrogen ions $[H^+]$ in solution B. [1 mark]

Sample Response	The response
$[H^+]$ in Solution B = 0.010 mol L^{-1}	• determines $[H^+]$ for solution B is 0.01 [1 mark]

c) Calculate the pOH of solution C. Show your working. [2 marks]

Sample Response	The response
pH = –log [0.063] = 1.2 pOH = 14 – 1.2 = 12.8	• provides relevant working [1 mark] • calculates pOH = 12.8 [1 mark]

2022 Paper 1 Section 2 Question 27

Chemical equilibrium systems

Five colourless 0.1 M solutions of NH_3, HCl, KOH, H_2SO_4 and CH_3CH_2COOH have lost their labels. The substances are randomly relabelled A, B, C, D and E. The conductivity of each solution and the colour of the solution when phenol red was added are shown.

Solution	Conductivity (S/m)	Colour with phenol red
A	4.1	yellow
B	0.14	red
C	0.08	yellow
D	6.7	yellow
E	4.9	red

Identify the five solutions. Explain your reasoning. [5 marks]

Sample Response	The response
Solutions A, C and D are acids and solutions B and E are bases, because phenol red is yellow when pH < 6.8 and red when pH > 8.4. Solution C is a weak electrolyte (from low conductivity), therefore C is propanoic acid. Solution D has higher conductivity than solution A, therefore D is sulfuric acid and solution A is HCl, because H2SO4 is diprotic acid and will give a higher concentration of ions in solution than monoprotic HCl. Solution E is KOH as it has a higher conductivity and therefore is a strong base. Solution B has a lower conductivity and therefore is ammonia, a weak base.	• identifies all five solutions [1 mark] • uses indicator data to identify acids and bases [1 mark] • uses conductivity data to identify relative strength of bases [1 mark] • uses conductivity data to identify relative strength of acids [1 mark] • identifies the diprotic acid is more conductive than monoprotic acid [1 mark]

2021 Paper 1 Section 2 Question 21

Chemical equilibrium systems

Calculate the pH of a 0.1M aqueous solution of $Ba(OH)_2$, assuming complete dissociation.
Show your working.

Sample Response	The response	Notes
$[OH^-] = 2 \times [Ba(OH)_2] = 2 \times 0.1 = 0.2$ M $pOH = -\log[OH^-] = -\log 0.2 = 0.7$ $pH = 14 - pOH = 14 - 0.7 = 13.3$ pH = 13.3 (to one decimal place)	• correctly determines $[OH^-]$ = 0.2 M [1 mark] • determines pOH = 0.7 [1 mark] • determines pH = 13.3 [1 mark]	Allow FT error for pOH and pH from OH^- = 0.1 M only. Do not penalise for incorrect decimal places/significant figures.

2021 Paper 1 Section 2 Question 25

Chemical equilibrium systems

An equilibrium is formed between two differently coloured cobalt species, $Co(H_2O)_6^{2+}(aq)$, which is pink, and $CoCl_4^{2-}(aq)$, which is blue. The equation for this equilibrium is shown.

$$Co(H_2O)_6^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons CoCl_4^{2-}(aq) + 6H_2O(l)$$

Apply Le Châtelier's principle to predict the visible effect of adding AgNO3 to an aqueous, blue-coloured solution containing $Co(H_2O)_6^{2+}$ and $CoCl_4^{2-}$ ions.
Explain your reasoning. [3 marks]

Sample Response	The response	Notes
Adding $AgNO_3$ produces Ag^+ ions, which react with Cl− ions to form insoluble AgCl, therefore decreasing the concentration of Cl^- ions. Equilibrium shifts to reactants (left) to counteract the decrease by increasing the concentration of Cl^- ions. The blue solution will become lighter (pinker).	• correctly identifies that Cl^- decreases [1 mark] • identifies that equilibrium shifts to left (reactants) to counteract the change [1 mark] • identifies that the blue solution becomes lighter [1 mark]	Allow FT error for equilibrium shift and change in solution from Cl^- increases. Acceptable responses may be: - solution becomes pinker - solution decreases in intensity - or other responses consistent with a reasonable understanding. Do not penalise students who mention the formation of a white precipitate, i.e. AgCl.

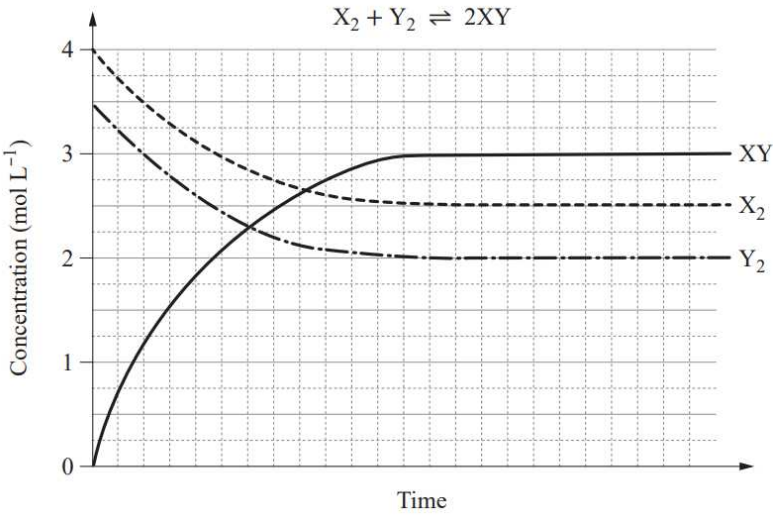
b) When a sample of the equilibrium mixture is put into hot water, the mixture turns more blue. Determine whether the forward reaction of the equation is exothermic or endothermic. Explain your reasoning. [2 marks]

Sample Response	The response	Notes
Adding heat shifts equilibrium towards the endothermic direction and produces $CoCl_4^{2-}$ ions, which are blue. Therefore, the forward reaction is endothermic.	• identifies that the forward reaction has been favoured [1 mark] • determines that the forward reaction is endothermic [1 mark]	

2021 Paper 1 Section 2 Question 26

Chemical equilibrium systems

The graph represents changes in concentration over time for three gaseous molecules (X_2, Y_2 and XY) in a closed system at constant temperature and pressure.



a) Identify whether XY is the reactant or the product. [1 mark]

Sample Response	The response	Notes
XY is the product.	• identifies XY as the product [1 mark]	

b) Calculate the equilibrium constant (K_c) value. [2 marks]

Sample Response	The response	Notes
$K_c = \frac{[XY]^2}{[X][Y]} = \frac{3^2}{2 \times 2.5} = 1.8$ (to two significant figures)	• indicates correct substitution [1 mark] • determines $K_c = 1.8$ [1 mark]	Allow FT error for K_c. Do not penalise for incorrect decimal places/significant figures.

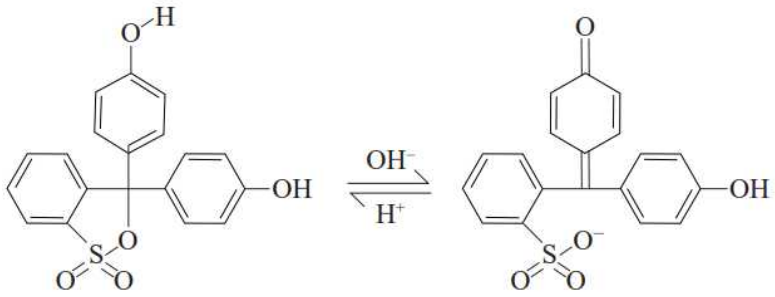
c) Determine whether the position of equilibrium favours the reactants or products. Explain your reasoning. [2 marks]

Sample Response	The response	Notes
$K_c > 1$. Therefore, equilibrium favours the products.	• identifies $K_c > 1$ [1 mark] • concludes that equilibrium favours products [1 mark]	Allow FT error for K_c.

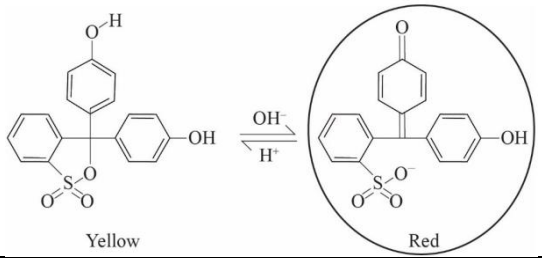
2020 Paper 1 Section 2 Question 22

Chemical equilibrium systems

The structures of phenol red when in either an acidic or a basic solution are shown in the equation.



a) Identify the species that acts as the conjugate base by circling it in the equation. [1 mark]

Sample Response	The response
	• circles the red species [1 mark]

Note: If you make a mistake, draw a line through this equation and use the additional equation provided on page 13 of this question and response book.

b) A solution of phenol red at equilibrium and 50 °C was found to contain 2.0×10^{-4} M of the conjugate base and 0.034 M of the acid. Determine the pK_a for the system, assuming all the protons present come from dissociation of the acid. [3 marks]

Sample Response	The response	Notes
$K_a = \frac{[2.0 \times 10^{-4}][2.0 \times 10^{-4}]}{0.034}$ $= 1.18 \times 10^{-6}$ $pK_a = -\log [1.18 \times 10^{-6}] = 5.9$ $pK_a = 5.9$ (to two significant figures)	• demonstrates substitution correctly performed **[1 mark]** • determines $K_a = 1.2 \times 10^{-6}$ **[1 mark]** • determine pK_a = 5.9 **[1 mark]**	Allow FT error for K_a. Do not penalise for incorrect decimal places/ significant figures.

c) Explain the relationship between the pH range of phenol red and its pKa value. [3 marks]

Sample Response	The response
Phenol red changes colour over a pH range because the molecular form (HIn(aq)) and ionic form (In^-(aq)) are different colours. When [HIn(aq)] = [In^-(aq)], the pH = pK_a and phenol red changes colour. When pH < pK_a, the [HIn(aq)] > [In^-(aq)] and phenol red turns yellow. When pH > pK_a, the [HIn(aq)] < [In^-(aq)] and phenol red turns red.	• indicates pH colour range is due to molecular form and ionic form being different colours [1 mark] • identifies phenol red changes colour when pH = pK_a [1 mark] • indicates when pH < pK_a equilibrium favours the molecular form (HIn), the solution is yellow. When pH > pK_a equilibrium favours the ionic form (In^-), the solution is red [1 mark]

2020 Paper 1 Section 2 Question 24

Chemical equilibrium systems

This table shows the effect of temperature on the pH of pure water.

Temperature (°C)	pH
10	7.27
15	7.17
20	7.08
25	7.00
30	6.92
50	6.63

a) Analyse the data to explain whether the self-ionisation of water is endothermic or exothermic. Explain your reasoning. [3 marks]

Sample Response	The response	Notes
As the temperature increases, the $[H_3O^+]$ increases. $2H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$ Therefore, the equilibrium shifts towards the products. Increasing temperature shifts equilibrium in the endothermic direction, therefore the self-ionisation of water is endothermic.	• identifies $[H_3O^+]$ increases as temperature increases [1 mark] • identifies equilibrium shifts towards the products and the endothermic direction [1 mark] • determines self-ionisation of water is endothermic [1 mark]	Allow FT error for: - equilbrium shifts to the reactants - self-ionisation of water decreases.

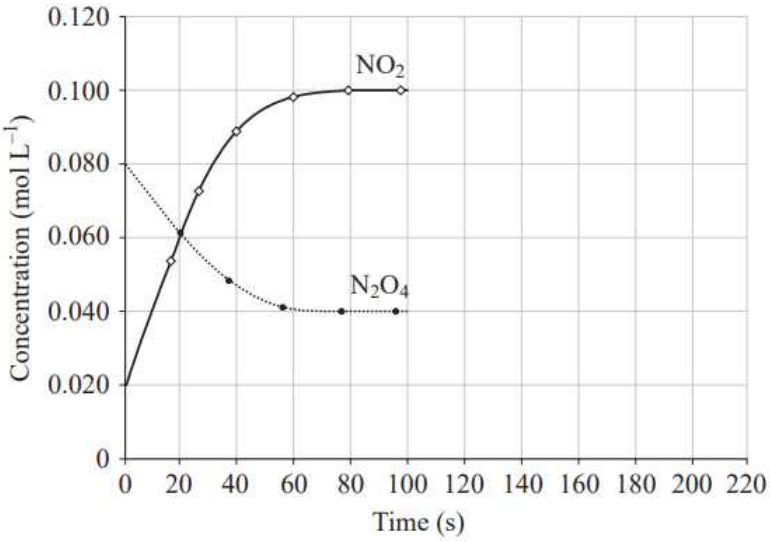
b) Calculate the K_w of pure water at 50 °C. Show your working. [2 marks]

Sample Response	The response	Notes
pH $= -\log [H^+] = 6.63$ $[H^+] = 10^{-6.63}$ $= 2.34 \times 10^{-7}$ $K_w = [H^+][OH^-]$ $= (2.34 \times 10^{-7})^2$ $K_w = 5.48 \times 10^{-14}$ (to 3 significant figures)	• determines $[H^+] = 2.34 \times 10^{-7}$ [1 mark] • determines consequentially correct K_w [1 mark]	Allow FT error from $[H^+]$. Do not penalise for incorrect decimal places/significant figures.

2020 Paper 1 Section 2 Question 25

Chemical equilibrium systems

This graph depicts the changes in concentration over time for a nitrogen dioxide / dinitrogen tetroxide gaseous equilibrium in a closed system at constant temperature.



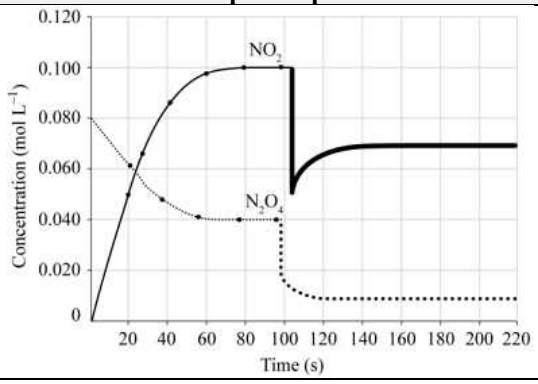
a) Determine the balanced chemical equation for the reaction in this system. [1 mark]

Sample Response	The response
$N_2O_4(g) \rightleftharpoons 2NO_2(g)$	• provides $N_2O_4(g) \rightleftharpoons 2NO_2(g)$ **[1 mark]**

b) Identify the time at which equilibrium is reached. [1 mark]

Sample Response	The response	Notes
80 seconds	• identifies time as 80 [1 mark]	Accept values between 70 and 90 inclusive.

c) If temperature is held constant, predict the effect that doubling the volume at 100 seconds would have on the closed system by sketching the change that would occur and the approximate position of the new equilibrium on the graph. [3 marks]

Sample Response	The response
	• indicates that at 100 s concentration of N_2O_4 and NO_2 would halve [1 mark] • indicates that after 100 s concentration of N2O4 would decrease to a new equilibrium at a lower concentration [1 mark] • indicates that after 100 s concentration of NO2 would increase to a new equilibrium at a higher concentration [1 mark]

2020 Paper 1 Section 2 Question 27

Chemical equilibrium systems

Four unknown metals Q, X, Z and A were placed into separate test tubes containing a 0.1 M solution of their respective nitrate solutions. The results are shown in the table.

Metal	$Q(NO_3)_2$ solution	$X(NO_3)_2$ solution	$Z(NO_3)_2$ solution	$A(NO_3)_2$ solution
Q	Not tested	No reaction	No reaction	No reaction
X	Coating formed	Not tested	No reaction	No reaction
Z	Coating formed	Coating formed	Not tested	Coating formed
A	Coating formed	Coating formed	No reaction	Not tested

a) Identify the species oxidised in the reaction between Z and $X(NO_3)_2$. [1 mark]

Sample Response	The response
Z	• provides Z [1 mark]

b) Identify the oxidising agent in the reaction between Z and $Q(NO_3)_2$. [1 mark]

Sample Response	The response	Notes
Q^{2+}	• provides Q^{2+} [1 mark]	For Q^{2+} accept Q in $Q(NO_3)_2$

c) Determine the products formed from the reaction between Z and $A(NO_3)_2$. [1 mark]

Sample Response	The response
$Z(NO_3)_2(aq)$ and A(s)	• provides $Z(NO_3)_2(aq)$ and A(s) [1 mark]

d) Predict the standard reduction potential table for the metals Q, X, Z and A by listing their reduction half-equations from strongest to weakest reducing agent. Explain your reasoning. [4 marks]

Sample Response	The response
$Z^{2+} + 2e^- \rightleftharpoons Z$ $A^{2+} + 2e^- \rightleftharpoons A$ $X^{2+} + 2e^- \rightleftharpoons X$ $Q^{2+} + 2e^- \rightleftharpoons Q$ Z can reduce X^{2+}, Q^{2+} and A^{2+}, therefore it is the strongest reducing agent. X can only reduce Q^{2+} therefore it is the second weakest reducing agent. Q cannot reduce any metal ions, therefore it is the weakest reducing agent.	• provides half-equations in correct order [1 mark] • provides reasoning for - Z as strongest reducing agent [1 mark] - Q as weakest reducing agent [1 mark] - A as stronger reducing agent than X [1 mark]

2024 Paper 2 Section 1 Question 1

Chemical equilibrium systems

A 30.00 mL aliquot of aqueous hydrochloric acid (HCl) with a pH of 2.00 was diluted with 2970.00 mL of water to make up a final volume of 3.00 L of aqueous HCl solution.

a) Determine the concentration of hydrogen ions in the original 30.00 mL aliquot of HCl(aq). [1 mark]

Sample response	The response
$[H^+]=10^{(-pH)}$ $[H^+] = 10^{-2} = 0.01 \text{ mol L}^{-1}$	• determines $[H^+]$ is 0.01 mol L^{-1} **[1 mark]**

b) Calculate the pH of the final 3.00 L solution of HCl(aq). Show your working. [2 marks]

Sample response	The response
$C_1V_1 = C_2V_2$ Let $C_2 = [H^+]$ $[H^+] = \frac{0.01 \text{ M} \times 30 \text{ mL}}{3000 \text{ mL}} = 0.0001 \text{ mol L}^{-1}$	• determines $[H^+]$ **[1 mark]**
$pH = -\log_{10}[10^{-4}]$ $pH = 4$	• calculates pH **[1 mark]**

2024 Paper 2 Section 1 Question 2

Chemical equilibrium systems

Phenol red (HIn) is a weak acid that acts as an indicator as shown.

$$HIn(aq) \rightleftharpoons In^-(aq) + H^+(aq)$$

a) Identify the conjugate base of phenol red. [1 mark]

Sample response	The response
Conjugate base is In^-.	• identifies conjugate base is In^- **[1 mark]**

b) Determine the dissociation constant (K_a) of phenol red. [1 mark]

Sample response	The response
$K_a = 10^{-pK_a}$ $K_a = 10^{-7.9} = 1.26 \times 10^{-8}$	• determines K_a is 1.26×10^{-8} **[1 mark]**

c) Explain the relationship between the pH range of colour change for phenol red and its p K_a value. [4 marks]

Sample response	The response
Phenol red changes colour when the concentration of the yellow weak acid form (HIn) equals the concentration of the red conjugate base form (In^-). When [HIn] = $[In^-]$, the K_a of phenol red equals $[H^+]$ and pH equals the pK_a (7.9). However, the colour change of phenol red occurs over a pH range equal to pK_a ±1, because visible colour change can be observed when the [HIn] : $[In^-]$ changes by a ratio of 1:10.	• identifies that colour change occurs when the [HIn] = $[In^-]$ **[1 mark]** • explains that when [HIn] = $[In^-]$, the K_a of phenol red equals $[H^+]$, and therefore pH equals the pK_a **[1 mark]** • identifies that the pH range of colour change is pK_a ±1 **[1 mark]** • explains that the pH range of colour change occurs either side of pK_a because colour change is detected when the [HIn] : $[In^-]$ changes **[1 mark]**

2024 Paper 2 Section 1 Question 3

Chemical equilibrium systems

The concentration, pH and dissociation constant (K_a) of aqueous solutions of ethanoic acid and two unknown monoprotic acids, I and II, are shown.

Acid	Concentration (M)	pH	K_a
$CH_3COOH(aq)$	0.2		1.8×10^{-5}
I	0.2	1.9	6.6×10^{-4}
II	0.1	1.1	1.3×10^{6}

a) Compare the relative strength of an aqueous solution of acid I and $CH_3COOH(aq)$. *[3 marks]*

Sample response	The response
Similarity: both weak acids Difference: ethanoic acid (CH_3COOH) is weaker than acid I Significance: Ethanoic acid dissociates less to produce a lower $[H^+]$	• identifies that both acids are weak acids **[1 mark]** • identifies that ethanoic acid is weaker than acid I **[1 mark]** • explains that ethanoic acid dissociates less to produce a lower $[H^+]$ **[1 mark]**

b) Determine whether an aqueous solution of acid I or acid II would have a higher electrical conductivity. Explain your reasoning. [3 marks]

Sample response	The response
Acid II has a K_a greater than 1 and is therefore a strong acid, while acid I is a weak acid due to small K_a. Acid II dissociates to produce more ions in an aqueous solution than acid I. Therefore, acid II has a higher electrical conductivity than acid I.	• identifies that acid II is stronger than acid I **[1 mark]** • explains that acid II dissociates to produce more ions in solution **[1 mark]** • determines that the electrical conductivity of acid II will be greater than acid I **[1 mark]**

c) Calculate the pH of 0.2 M $CH_3COOH(aq)$. Show your working. [3 marks]

Sample response	The response
$[H_3O^+] = [CH_3COO^-] = x$	• identifies $[H_3O^+] = [CH_3COO^-]$ **[1 mark]**
$[CH_3COOH] = \frac{[H_3O^+][CH_3COO^-]}{K_a}$ $0.2 = \frac{(x)^2}{1.8 \times 10^{-5}}$ $[H_3O^+] = 1.9 \times 10^{-3}$ M	• determines $[H_3O^+]$ **[1 mark]**
$pH = -\log_{10}[H_3O^+]$ pH = 3	• calculates pH **[1 mark]**

2023 Paper 2 Section 1 Question 5

Chemical equilibrium systems

The table gives the properties of four monoprotic acids.

Acid	Concentration (mol L^{-1})	$[H^+]$ (mol L^{-1})	pH	K_a
1	0.200	7.90×10^{-5}		
2	0.100	4.20×10^{-3}	2.34	1.80×10^{-4}
$CH_3COOH(aq)$	0.100			1.78×10^{-5}
HCl(aq)	0.010	1.00×10^{-2}	2.00	>1

(a) Determine the relative strength of acids 1 and 2 by contrasting their K_a values. [3 marks]

Sample response	The response
Acid 1: $K_a = \frac{[H^+][A^-]}{[HA]} = \frac{(7.90\times10^{-5})^2}{0.200} = 3.12\times10^{-8}$ Acid 2 has a larger K_a than acid 1. Therefore, acid 2 is a stronger acid.	• calculates K_a for acid 1 as 3.12×10^{-8} **[1 mark]** • identifies the K_a for acid 2 is greater than acid 1 **[1 mark]** • determines acid 2 is stronger **[1 mark]**

b) Write a balanced chemical equation for the dissociation of ethanoic acid (CH_3COOH) in water. [2 marks]

Sample response	The response
$CH_3COOH(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CH_3COO^-(aq)$	• states balanced equation **[1 mark]** • uses an equilibrium arrow **[1 mark]**

(c) Identify whether the conjugate base of ethanoic acid ($CH_3COOH(aq)$) is amphiprotic. Explain your reasoning. [2 marks]

Sample response	The response
Conjugate base of ethanoic acid, CH_3COO^-, is not amphiprotic as it can accept a H^+ ion but cannot donate one.	• identifies the conjugate base, CH_3COO^-, is not amphiprotic **[1 mark]** • explains that CH_3COO^- can accept but not donate a H^+ ion **[1 mark]**

(d) Calculate the pH of the aqueous solution of ethanoic acid CH_3COOH). Show your working. [3 marks]

Sample response	The response
$1.78\times10^{-5} = \frac{[H^+][A^-]}{[HA]} = \frac{x^2}{0.100}$ $x = [H^+] = \sqrt{(1.78\times10^{-5})\times0.1} = 1.33\times10^{-3}\ M$ $pH = -\log(1.33\times10^{-3}) = 2.87$	• identifies $[CH_3COO^-]$ equals $[H^+]$ **[1 mark]** • determines $[H^+]$ is 1.33×10^{-3} **[1 mark]** • calculates pH **[1 mark]**

(e) Determine the volume of water that would need to be added to 100.0 mL of HCl(aq) to change the pH from 2.00 to 3.00. Explain your reasoning. [3 marks]

Sample response	The response
$[H^+]$ is 10x greater at pH 2.0 than at pH 3.0. Therefore, final volume needs to be 1 L (0.1000 L x 10 = 1.000 L). Therefore, 1.000 – 0.1000 = 0.900 L of water is needed.	• identifies $[H^+]$ at pH 2.0 is 10 times greater than pH 3.0 **[1 mark]** • determines final volume would be 1 L **[1 mark]** • determines 0.900 L of water needs to be added **[1 mark]**

2023 Paper 2 Section 1 Question 7

Chemical equilibrium systems

When heated in a sealed container, solid mercury(II) oxide (HgO) decomposed to form metallic mercury (Hg) and oxygen gas (O_2).

$$\underset{\text{Orange}}{2HgO(s)} \rightleftharpoons \underset{\text{Silver}}{2Hg(l)} + \underset{\text{Colourless}}{O_2(g)}$$

(a) Identify whether the reaction occurs in an open or closed system. [1 mark]

Sample response	The response
Closed system	• identifies closed system **[1 mark]**

(b) Explain why the colour of the system does not change once equilibrium is established. [3 marks]

Sample response	The response
At equilibrium there is no net change in the concentration of the reactants and the products. The forward and reverse reactions are still occurring. As the forward reaction is equal to the rate of the reverse reaction the colour of the system at equilibrium remains constant.	• identifies the concentration of the reactants and products remain constant at equilibrium **[1 mark]** • explains that the forward and reverse reactions are occurring simultaneously **[1 mark]** • explains forward reaction is equal to reverse reaction and therefore there is no colour change **[1 mark]**

2023 Paper 2 Section 1 Question 8

Chemical equilibrium systems

Two experiments were conducted to investigate the effect of temperature on the equilibrium formed during the decomposition of hydrogen iodide (HI).

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g) \qquad \Delta H = +53.6 \text{ kJ mol}^{-1}$$

Experiment	Initial concentration (mol L^{-1})			Equilibrium concentration (mol L^{-1})			K_c
	[HI]	$[H_2]$	$[I_2]$	[HI]	$[H_2]$	$[I_2]$	
1	0.08	0.00	0.00		0.01		2.78×10^{-2}
2	0.00	0.06	0.06	0.06	0.03	0.03	

(a) Determine the concentration of HI(g) and I_2(g) at equilibrium for experiment 1. [2 marks]

Sample response	The response
$[HI]$: 0.06 mol L^{-1} $[I_2]$: 0.01 mol L^{-1}	• determines $[HI]$ is 0.06 **[1 mark]** • determines $[I_2]$ is 0.01 **[1 mark]**

(b) Calculate the equilibrium constant (K_c) for experiment 2. Show your working. [2 marks]

Sample response	The response
$K_c = \frac{[H_2][I_2]}{[HI]^2}$ $K_c = \frac{(0.03)^2}{(0.06)^2} = 0.25$	• uses appropriate substitution **[1 mark]** • calculates K_c is 0.25 **[1 mark]**

(c) Determine which experiment was conducted at a higher temperature. Explain your reasoning. [3 marks]

Sample response	The response
Temperature was higher for experiment 2. The K_c value was larger for experiment 2, indicating that the equilibrium shifted towards the products (endothermic direction) to compensate for the increase in temperature.	• determines experiment 2 was conducted at a higher temperature **[1 mark]** • explains that K_c value for experiment 2 is larger **[1 mark]** • explains higher K_c value indicates equilibrium shifts to the right **[1 mark]**

2022 Paper 2 Section 1 Question 2

Chemical equilibrium systems

The reaction shows part of the contact process used to produce sulfuric acid.

$$2SO_2(g) + O_2 \rightleftharpoons[V_2O_5] 2SO_3(g)$$

The equilibrium constant (K_c) for this reaction at different temperatures is shown.

Temperature (K)	Equilibrium constant, K_c (mol L^{-1})
298	9.77×10^{25}
500	8.61×10^{11}

a) Deduce if the forward reaction is exothermic or endothermic. Explain your reasoning. [2 marks]

Sample Response	The response
Exothermic Increasing temperature decreases K_c, indicating that the equilibrium shifts towards the reactants (endothermic) direction.	• determines forward reaction is exothermic [1 mark] • explain that the decrease in K_c as temperature increases indicates endothermic direction is towards the reactants [1 mark]

b) Calculate the equilibrium concentration of SO3 at 500 K given the equilibrium concentrations. [2 marks]

$[SO_2] = 0.860$ M; $[O_2] = 0.330$ M

Sample Response	The response
$8.61\times10^{11} = \frac{[SO_3]^2}{(0.860)^2(0.330)}$ $[SO_3]^2 = (0.7396)(0.330)(8.61\times10^{11}) = 2.10\times10^{11}$ Concentration = 4.58×10^5 M	• provides appropriate working [1 mark] • calculates $[SO_3] = 4.58 \times 10^5$ [1 mark]

c) Apply Le Châtelier's principle to explain whether halving the reaction vessel's volume at 500 K would affect the position of the equilibrium or the value of the equilibrium constant. [4 marks]

Sample Response	The response
Halving the volume would double the pressure. To reduce the pressure, the equilibrium would shift toward the product to reduce the number of molecules present. However, due to the reactant decreasing the equilibrium constant remains unchanged.	• indicates that halving the volume doubles the pressure [1 mark] • explains that equilibrium will shift to reduce the number of molecules present to reduce pressure [1 mark] • explains that equilibrium will shift toward the product [1 mark] • explains why the equilibrium constant would not change [1 mark]

2022 Paper 2 Section 1 Question 3

Chemical equilibrium systems

A 50.0 mL solution of ethanoic acid (CH_3COOH) was titrated with 15.0 mL of 0.10 M sodium hydroxide (NaOH) solution to reach the equivalence point (pK_a ethanoic acid = 4.76).

a) Write a balanced chemical equation to indicate how ethanoic acid acts as a Brønsted-Lowry acid during the titration and identify its conjugate base. [2 marks]

Sample Response	The response
$CH_3COOH(aq) + OH^-(aq) \rightleftharpoons CH_3COO^-(aq) + H_2O(l)$ The conjugate base formed is CH_3COO^-.	• provides correct balanced chemical equation [1 mark] • identifies CH_3OO^- as conjugate base [1 mark]

b) Determine the Kb of the conjugate base of ethanoic acid. [1 mark]

Sample Response	The response
$K_b = \frac{1.00 \times 10^{-14}}{10^{-4.76}} = 10^{-9.24} = 5.75 \times 10^{-10}$	• determines K_b is 5.75×10^{-10}

c) Calculate the concentration of the conjugate base at the equivalence point. Show your working. [2 marks]

Sample Response	The response
At equivalence point, moles OH^- = moles H^+ = moles CH_3COO^- moles CH_3COO^- = n × V = 0.10 × 0.015 = 1.50×10^{-3}	• determines moles CH_3COO^- is 1.50×10^{-3} **[1 mark]** • calculates $[CH_3COO^-]$ is 2.31×10^{-2} mol L^{-1} **[1 mark]**

d) Calculate the pH at the equivalence point. Show your working. [4 marks]

Sample Response	The response
$[CH_3COOH] = [OH^-] = x$ $K_b = \frac{[OH^-][CH_3COOH]}{[CH_3COO^-]}$ $K_b = 5.75 \times 10^{-10} = \frac{x^2}{[2.31 \times 10^{-2}]}$ $x^2 = 1.33 \times 10^{-11}$ $x = 3.64 \times 10^{-6} = [OH^-]$ $pOH = -\log(3.64 \times 10^{-6}) = 5.44 \sim 5.4$ $pH = 14 - 5.4 = 8.6$	• provides correct substitution [1 mark] • calculates $[OH^-]$ is 3.64×10^{-6} M [1 mark] • determines pOH is 5.4 [1 mark] • calculates pH is 8.6 [1 mark]

2021 Paper 2 Section 1 Question 1

Chemical equilibrium systems

Phosphoric acid (H_3PO_4) is a common triprotic acid that dissociates fully in three stages. The dissociation equations are shown in the table.

Stage	Dissociation equation	K_a
1	$H_3PO_4(aq) + H_2O(l) \rightleftharpoons H_2PO_4^-(aq) + H_3O^+(aq)$	7.1×10^{-3}
2	$H_2PO_4^-(aq) + H_2O(l) \rightleftharpoons HPO_4^{2-}(aq) + H_3O^+(aq)$	6.5×10^{-8}
3	$HPO_4^{2-}(aq) + H_2O(l) \rightleftharpoons PO_4^{3-}(aq) + H_3O^+(aq)$	4.5×10^{-13}

a) Use the information to determine the strongest Brønsted-Lowry acid and its conjugate base. Explain your reasoning. [3 marks]

Sample Response	The response	Notes
Acid: $H_3PO_4(aq)$ Conjugate base: $H_2PO_4^-(aq)$ Reasoning: H_3PO_4 is the strongest Brønsted-Lowry acid because it has the largest K_a value. $H_3PO_4(aq)$ donates a proton and $H_2PO_4^-(aq)$ accepts a proton.	• identifies H_3PO_4 as the acid and $H_2PO_4^-$ as the conjugate base **[1 mark]** • identifies H_3PO_4 as the strongest acid due to having the largest K_a **[1 mark]** • identifies acid as the H^+ donor and base as the H^+ acceptor **[1 mark]**	For H^+, accept proton. Do not accept hydrogen donor or acceptor.

b) Identify an amphiprotic species from the dissociation reactions. Explain your reasoning. [2 marks]

Sample Response	The response	Notes
$H_2PO_4^-$ (aq) is amphiprotic, because it can donate or accept a proton and therefore act as a Brønsted-Lowry acid or a base.	• identifies an amphiprotic species [1 mark] • identifies that this species can accept or donate protons [1 mark]	Acceptable amphiprotic species are: - $H_2PO_4^-$ - HPO_4^{2-}

c) Determine the K_b value for the strongest conjugate base formed when H_3PO_4 has fully dissociated. Show your working. [2 marks]

Sample Response	The response	Notes
$K_w = K_a \times K_b$ $K_b = \frac{K_w}{K_a} = \frac{10^{-14}}{4.5 \times 10^{-13}} = 2.2 \times 10^{-2}$	• correctly substitutes into formula [1 mark] • determines $K_b = 2.2 \times 10^{-2}$ [1 mark]	Allow FT error from substitution. Do not penalise for incorrect decimal places/significant figures.

d) Calculate the pH of a 0.05 M solution of dihydrogen phosphate ($H_2PO_4^-$). Show your working and state any assumptions made. [4 marks]

Sample Response	The response	Notes
As K_a is very small, the dissociation of $H_2PO_4^- \rightarrow HPO_4^{2-}$ is very very small. Assume $0.05 >> x$, therefore $0.05 - x \approx 0.05$ At equilibrium $[H_2PO_4^-] = 0.05 - x = 0.05$ Let $x = [H^+] = [HPO_4^{2-}]$ $6.5 \times 10^{-8} = \frac{[x][x]}{[0.05-x]} \approx \frac{x^2}{0.05}$ $x^2 = 0.05 \times 6.5 \times 10^{-8}$ $x = \sqrt{3.25 \times 10^{-9}}$ $x = 5.70 \times 10^{-5}$ mol $L^{-1} = [H^+]$ pH = –log 5.70×10^{-5} pH = **4.2** (to one decimal place)	• indicates assumption $0.05 - x \approx 0.05$ [1 mark] • shows substitution correctly performed [1 mark] • correctly determines $[H^+] = 5.70 \times 10^{-5}$ [1 mark] • determines pH = 4.2 [1 mark]	Allow FT error from incorrect substitution of K_a. Accept ICE table or other valid working. Allow FT error from $[H^+]$. Do not penalise for incorrect decimal places/significant figures.

2021 Paper 2 Section 1 Question 4

Chemical equilibrium systems

5.00×10^{-4} moles of hydrogen gas is mixed with 1.00×10^{-3} moles of iodine vapour in a sealed 1.00 L vessel at 455.0 °C. The concentration of hydrogen iodide gas formed at equilibrium is 9.30×10^{-4} M.

The balanced equation for the reaction is shown.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

a) Write the equilibrium law expression for the reaction. [1 mark]

Sample Response	The response	Notes
$K_c = \frac{[HI]^2}{[H_2] \times [I_2]}$	• provides $K_c = \frac{[HI]^2}{[H_2] \times [I_2]}$ **[1 mark]**	

b) Calculate the equilibrium constant (Kc) for the reaction at 455.0 °C.
Show your working. [5 marks]

Sample Response	The response	Notes
Change in $[H_2] = [I_2] = \frac{9.30 \times 10^{-4}\ \text{mol}}{\text{L}} \times \frac{1\ \text{mol}\ H^2}{2\ \text{mol}\ HI} = 4.65 \times 10^{-4}$ M $[H_2]_{eq} = 5.00 \times 10^{-4} - 4.65 \times 10^{-4} = 3.50 \times 10^{-5}$ M $[I_2]_{eq} = 1.0 \times 10^{-3} - 4.65 \times 10^{-4} = 5.35 \times 10^{-4}$ M $K_c = \frac{(9.30 \times 10^{-4})^2}{3.50 \times 10^{-5} \times 5.35 \times 10^{-4}} = 46.2$ $K_c = 46.2$ (to three significant figures)	• correctly determines change in $[H_2] = [I_2] = 4.65 \times 10^{-4}$ **[1 mark]** • determines $[H_2]_{eq} = 3.50 \times 10^{-5}$ **[1 mark]** • determines $[I_2]_{eq} = 5.35 \times 10^{-4}$ **[1 mark]** • shows substitution correctly performed **[1 mark]** • determines $K_c = 46.2$ **[1 mark]**	Allow FT error for $[H_2]_{eq}$. Allow FT error for $[I_2]_{eq}$. Allow FT error from Question 1a). Do not penalise for incorrect decimal places/significant figures.

c) Predict the effect that adding a catalyst would have on the reaction rates, position of the equilibrium and value of K_c. [3 marks]

Sample Response	The response	Notes
A catalyst will speed up both the forward and the reverse reactions. Therefore, the position of the equilibrium will not change. Therefore, there will be no change in the value of the equilibrium constant, K_c.	• identifies that a catalyst speeds up both the forward and reverse reactions [1 mark] • identifies that a catalyst has no effect on the position of the equilibrium [1 mark] • determines that a catalyst has no effect on the Kc value [1 mark]	

2020 Paper 2 Section 1 Question 2

Chemical equilibrium systems

Salicylic acid reacts with ethanoic anhydride in an aqueous solution to produce acetylsalicylic acid, as shown in the equation. Acetylsalicylic acid is commonly known as aspirin.

a) Identify the type of chemical reaction used to produce aspirin. [1 mark]

Sample Response	The response
Esterification	• identifies the reaction as esterification [1 mark]

b) Write the equilibrium expression, K_c, for the reaction. [1 mark]

Sample Response	The response
$K_c = \frac{[C_9H_8O_4][C_2H_4O_2]}{[C_7H_6O_3][C_4H_6O_3]}$	• provides $\frac{[C_9H_8O_4][C_2H_4O_2]}{[C_7H_6O_3][C_4H_6O_3]}$ [1 mark]

c) At 20 °C, the equilibrium constant (K_c) for the reaction is 2×10^{-3} . Determine whether the concentration of the reactants or products is greater at equilibrium at this temperature. [2 marks]

Sample Response	The response
$K_c < 1$ The equilibrium lies towards the reactants, therefore, the concentration of the reactants is greater than the concentration of the products.	• identifies that equilibrium lies towards the reactants [1 mark] • identifies that reactants > products [1 mark]

d) Calculate the minimum mass of salicylic acid required to produce 500.0 mg of aspirin if the yield of aspirin is 45.0%. Show your working. [4 marks]

Sample Response	The response	Notes
Molar mass of aspirin = (12.01 x 9) + (16.00 x 4) + 8.08 = 180.17 g Moles of aspirin produced = 0.5 g / 180.17 g = 2.78×10^{-3} mol Ratio 1:1 45.0% efficient Moles of salicylic acid = $\frac{2.78 \times 10^{-3}}{0.45} = 6.17 \times 10^{-3}$ mol Mass of salicylic acid = $6.17 \times 10^{-3} \times 138.13 = 0.852$ g = Mass = 852 mg (to three significant figures)	• determines molar mass of aspirin is 180 g [1 mark] • determines $n_{aspirin} = 2.78 \times 10{-}3$ [1 mark • determines n_{acid} [1 mark] • determines mass [1 mark]	Allow FT error from $n_{aspirin}$. Do not penalise for incorrect decimal places/ significant figures.

e) When the reaction is heated to 40 °C and equilibrium is re-established, the concentration of acetylsalicylic acid and ethanoic acid increases. Apply Le Châtelier's principle to predict if the forward reaction is exothermic or endothermic. Explain your reasoning. [4 marks]

Sample Response	The response	Notes
An increase in K_c means that equilibrium has shifted towards the products. An increase in temperature shifts equilibrium in the endothermic direction. Le Châtelier's principle means that when a system at equilibrium experiences an increase in temperature, the equilibrium shifts in the endothermic direction to decrease the temperature. As the forward reaction increases, the system as written must be endothermic.	• identifies that increased temperature means increased products [1 mark] • identifies that equilibrium has shifted in the endothermic direction [1 mark] • uses Le Châtelier's principle to explain a shift in equilibrium for an increase in temperature [1 mark] • identifies the forward reaction as endothermic [1 mark]	Allow FT error from an increase in temperature shifting equilibrium towards reactants.

2020 Paper 2 Section 1 Question 5

Chemical equilibrium systems

Compound A reacts with water to produce compound B and hydroxide ions.

$$\underset{\text{A}}{CH_3CH_2NH_2(aq)} + H_2O(l) \rightleftharpoons \underset{\text{B}}{C_2H_5NH_3^+(aq)} + OH^-(aq)$$

a) Apply IUPAC rules to name compound A. [1 mark]

Sample Response	The response
ethanamine	• provides ethanamine [1 mark]

b) Identify the Brønsted-Lowry acids in the equation. [2 marks]

Sample Response	The response
$H_2O(l)$ $C_2H_5NH_3^+(aq)$	• provides $H_2O(l)$ **[1 mark]** • provides $C_2H_5NH_3^+(aq)$ **[1 mark]**

c) A small amount of hydrochloric acid is added to the equilibrium mixture. Predict the effect of this on the concentration of compound A in the mixture. Explain your reasoning. [3 marks]

Sample Response	The response
The hydrochloric acid (H^+) reacts with the OH^- ions and decreases their concentration. According to Le Châtelier's principle, this will make the equilibrium position shift to the right to counteract decrease in OH^- (products). Therefore, the concentration of A will decrease.	• indicates that $[OH^-]$ will decrease **[1 mark]** • indicates that the equilibrium will shift right **[1 mark]** • indicates that A will decrease **[1 mark]**

d) Calculate the pH of a 2.0 M solution of compound A. State any assumptions. Show your working. ($K_b = 5.6 \times 10^{-4}$) [6 marks]

Sample Response	The response	Notes
$[CH_3CH_2NH_2] = 2.0 - x \approx 2.0$ as $2.0 \gg K_b$ Let $x = [C_2H_5NH_3^+] = [OH^-]$ $K_b = \frac{[C_2H_5NH_3^+][OH^-]}{[CH_3CH_2NH_2]}$ $5.6 \times 10^{-4} = \frac{[x][x]}{[2.0]} = \frac{x^2}{2.0}$ $x^2 = 1.12 \times 10^{-3}$ $x = 0.033466 = [OH^-]$ $pOH = -\log [OH^-] = 1.475 \approx 1.5$ $pH = 14 - 1.5 = 12.5$ pH = 12.5 (to 1 decimal place)	• indicates assumption to support $[CH_3CH_2NH_2] \approx 2.0$ **[1 mark]** • indicates $[C_2H_5NH_3^+] = [OH^-]$ **[1 mark]** • shows substitution correctly performed **[1 mark]** • determines $[OH^-] = 3.35 \times 10^{-2}$ **[1 mark]** • determines pOH **[1 mark]** • determines pH **[1 mark]**	Accept ICE table. Allow FT error from $[OH^-]$. Do not penalise for incorrect decimal places/significant figures.

e) Describe, using a balanced chemical equation, how Compound A could be made from bromomethane. Include relevant conditions and reagents in your response. [5 marks]

Sample Response	The response	Notes
Heat CH_3Br with KCN under reflux to produce CH_3CN and KBr $CH_3CN(aq) + 2H_2(g) \xrightarrow{\text{heat with Ni catalyst}} CH_3CH_2NH_2(aq)$	• indicates CH_3Br reacts with KCN to produce KH_3CN and KBr **[1 mark]** • identifies reaction is heated under reflux in ethanol **[1 mark]** • indicates CH_3CN reacts with $H_2(g)$ to produce $CH_3CH_2NH_2$ **[1 mark]** • indicates heat and Ni/Pt/Pd catalyst required **[1 mark]** • represents one of the reactions as a balanced chemical equation **[1 mark]**	Also accept as balanced equation: $CH_3Br(aq) \xrightarrow{\text{heat under reflux with KCN (ethanol)}} CH_3CN(aq) + KBr(aq)$

Unit 3 – Topic 2: Oxidation and reduction

Paper 1 Section 1

2024 Paper 1 Section 1 Question 1-2 Oxidation and reduction	Questions 1–2 refer to hydrated copper sulfate and its decomposition when heated. Hydrated copper sulfate ($CuSO_4 \cdot H_2O$) decomposes to form copper sulfate ($CuSO_4$) and water when heated. $$\text{heat} + CuSO_4 \cdot H_2O(s) \rightleftharpoons CuSO_4(s) + H_2O(g)$$ Which of the following is exchanged with the surrounding environment when $CuSO_4 \cdot H_2O(s)$ is heated in a closed system to establish dynamic equilibrium? (A) heat (B) $H_2O(g)$ (C) $CuSO_4(s) + H_2O(g)$ (D) $\text{heat} + CuSO_4 \cdot H_2O(s)$ Determine the oxidation number of sulfur (S) in $CuSO_4 \cdot H_2O$. (A) +8 (B) +6 (C) −2 (D) −4

2024 Paper 1 Section 1 Question 3 Oxidation and reduction	Identify which of the following is an essential component of an electrolytic cell. (A) voltmeter (B) salt bridge (C) power supply (D) standard hydrogen electrode (SHE)

2024 Paper 1 Section 1 Question 13-14

Oxidation and reduction

Questions 13–14 refer to the reactions below.

Reaction 1: $CH_3CH_2OH \xrightarrow[\text{(heat/reflux)}]{H^+/Cr_2O_7^{2-}}$ compound X

Reaction 2: compound X + $CH_3NH_2 \xrightarrow[\text{(heat >100 °C)}]{TiCl_4}$ compound Y

Determine the type of reaction that produced compound X.

(A) addition

(B) oxidation

(C) substitution

(D) esterification

Identify compound Y.

(A) CH_3CH_2CN

(B) $CH_3CONHCH_3$

(C) $CH_3CH_2CH_2NH_2$

(D) $H_2NCH(CH_3)COOH$

2024 Paper 1 Section 1 Question 15

Oxidation and reduction

Identify the single displacement reaction.

(A) $2Cu(s) + O_2(g) \rightarrow 2CuO(s)$

(B) $CuCl_2(aq) \rightarrow Cu^{2+}(aq) + 2Cl^-(aq)$

(C) $Cu(s) + 2AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2Ag(s)$

(D) $2AgNO_3(aq) + CuCl_2(aq) \rightarrow Cu(NO_3)_2(aq) + 2AgCl(s)$

2024 Paper 1 Section 1 Question 17

Oxidation and reduction

Identify the product produced at the cathode when a concentrated aqueous solution of NaCl undergoes electrolysis.

(A) $Cl_2(g)$

(B) Na(l)

(C) $O_2(g)$

(D) $H_2(g)$

2024 Paper 1 Section 1 Question 18

Oxidation and reduction

The electrode and electrolyte solutions of four half-cells are shown.

Half-cell	Electrode	Electrolyte solution (1.0 M)
1	Cu	$CuNO_3(aq)$
2	Fe	$Fe(NO_3)_2(aq)$
3	Al	$Al(NO_3)_3(aq)$
4	Pt	$Fe(NO_3)_3(aq)$

Determine which two half-cells would produce the largest potential difference (V) under standard conditions when combined to construct a voltaic cell.

(A) 4 and 1
(B) 1 and 2
(C) 2 and 3
(D) 3 and 4

2023 Paper 1 Section 1 Question 7

Oxidation and reduction

Determine which half-cell produces the largest potential difference when joined with a $Zn(s) \mid Zn^{2+}(aq)$ half-cell to form a galvanic cell.

(A) $Mg(s) \mid Mg^{2+}(aq)$

(B) $Cu^{2+}(aq) \mid Cu(s)$

(C) $H^{+}(aq) \mid H_2(g)$

(D) $F_2(g) \mid F^{-}(aq)$

2023 Paper 1 Section 1 Question 8

Oxidation and reduction

Identify the species being reduced in the equation.

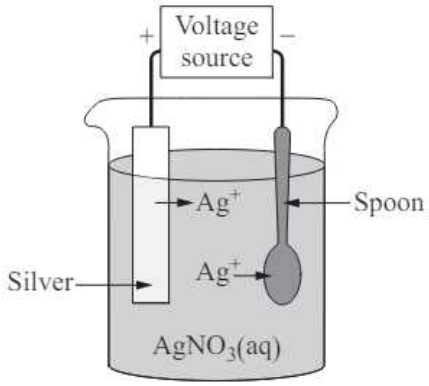
$$Br_2(l) + Sn^{2+}(aq) \rightarrow Sn^{4+}(aq) + 2Br^{-}(aq)$$

(A) $Br_2(l)$

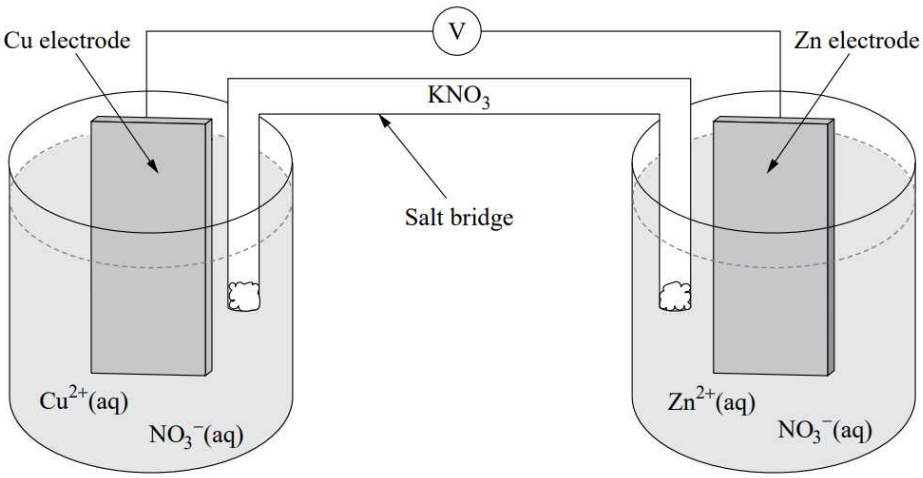
(B) $Br^{-}(aq)$

(C) $Sn^{2+}(aq)$

(D) $Sn^{4+}(aq)$

2023 Paper 1 Section 1 Question 11 Oxidation and reduction	The plating of silver is conducted during the operation of the electrochemical cell shown.  Determine which statement is true for this electrochemical cell. (A) The spoon acts as the cathode. (B) The silver electrode has a negative charge. (C) The silver ions in the solution are oxidised at the spoon. (D) The electrons flow from the spoon to the silver electrode.

2022 Paper 1 Section 1 Question 3 Oxidation and reduction	Which option is true for the redox equation? $Fe(s) + CuCl_2(aq) \rightarrow FeCl_2(aq) + Cu(s)$ (A) Fe is oxidised and Cu is the oxidising agent (B) Fe is oxidised and Cu_2+ is the oxidising agent (C) Fe_2+ is oxidised and Cu is the oxidising agent (D) Fe_2+ is oxidised and Cu_2+ is the oxidising agent

2022 Paper 1 Section 1 Questions 11-12 Oxidation and reduction	These questions refer to the diagram shown.  Determine the species that travels through the salt bridge towards the reduction half-cell in the electrochemical cell at standard conditions. (A) zinc ions (B) nitrate ions (C) copper ions (D) potassium ions The zinc electrode (A) gains electrons and acts as the anode. (B) acts as the cathode and has a positive charge. (C) undergoes reduction and has a negative charge. (D) is oxidised and donates electrons to the copper ions.

2022 Paper 1 Section 1 Question 16 Oxidation and reduction	Determine the oxidation state of manganese in MnO_4^-. (A) +1 (B) +2 (C) +7 (D) +8

2022 Paper 1 Section 1 Question 17 Oxidation and reduction	Identify the redox reaction. (A) $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$ (B) $CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s)$ (C) $Cl_2(g) + H_2O(l) \rightarrow HCl(aq) + HClO(aq)$ (D) $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$

2022 Paper 1 Section 1 Question 19

Oxidation and reduction

Three voltaic cells are constructed with metal Q as one electrode and metals R, S or T as the other electrode. The potential differences for the cells are shown in the table.

Voltaic cell	Half-cell	Half-cell	Potential difference (V)
1	$Q(s) / Q^{2+}(aq)$	$R^{+}(aq) / R(s)$	1.18
2	$Q(s) / Q^{2+}(aq)$	$S^{2+}(aq) / S(s)$	0.72
3	$T(s) / T^{3+}(aq)$	$Q^{2+}(aq) / Q(s)$	0.95

The relative strength of the reducing agents from strongest to weakest is

(A) T > Q > S > R
(B) S > Q > T > R
(C) R > Q > S > T
(D) Q > R > T > S

2021 Paper 1 Section 1 Question 3

Oxidation and reduction

Predict which product is formed at the positive electrode when a 0.1 M aqueous solution of copper(II) sulfate is electrolysed using carbon electrodes.

(A) Cu(s)
(B) $H_2(g)$
(C) $O_2(g)$
(D) $SO_2(g)$

2021 Paper 1 Section 1 Question 18

Oxidation and reduction

Identify the major product when 2-methylbut-2-ene reacts with water under acidic conditions.

(A) $(CH_3)_2CHCOCH_3$

(B) $(CH_3)_2C(OH)CH_2CH_3$

(C) $(CH_3)_2CHCH(OH)CH_3$

(D) $(CH_3)_2C(OH)CH(OH)CH_3$

2020 Paper 1 Section 1 Question 6

Oxidation and reduction

Calculate the cell potential produced by a $Zn(s) | Zn^{2+}(aq) || Cu^{2+}(aq) | Cu(s)$ galvanic cell under standard conditions.

(A) –1.10 V

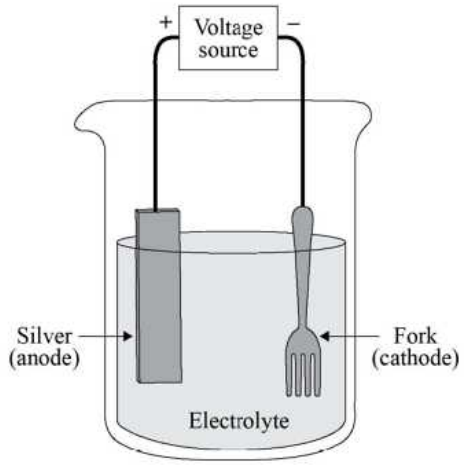
(B) –0.42 V

(C) +0.34 V

(D) +1.10 V

2020 Paper 1 Section 1 Question 10

Oxidation and reduction



Which of the following is true for the electrochemical cell?

	Reaction	Anode	Flow of electrons
(A)	spontaneous	oxidation	From the negative terminal of the power pack, through the wire to the negative electrode.
(B)	spontaneous	positive electrode	From the positive terminal of the power pack, through the wire and the electrolyte to the negative electrode.
(C)	non-spontaneous	negative electrode	From the negative terminal of the power pack, through the wire and the electrolyte to the positive terminal.
(D)	non-spontaneous	oxidation	From the negative terminal of the power pack, through the wire to the negative electrode.

2020 Paper 1 Section 1 Question 16

Oxidation and reduction

$CH_3CN + 2H_2 \xrightarrow{Ni} CH_3CH_2NH_2$

The reaction shows

(A) an addition reaction that converts an amine to a nitrile.
(B) a reduction reaction that converts a nitrile to an amine.
(C) an oxidation reaction that converts an amine to a nitrile.
(D) a substitution reaction that converts a nitrile to an amine.

2020 Paper 1 Section 1 Question 17

Oxidation and reduction

Which of the following represents a spontaneous redox reaction with the correct standard electrode potential?

	Reaction	E^o (V)
(A)	$2Na^+(aq) + 2Br^-(aq) \rightarrow 2Na(s) + Br_2(aq)$	3.79
(B)	$Sn^{2+}(aq) + 2Ag(s) \rightarrow Sn(s) + 2Ag^+(aq)$	−0.94
(C)	$Zn(s) + Cl_2(g) \rightarrow Zn^{2+}(aq) + 2Cl^-(aq)$	2.12
(D)	$2Al(s) + 3Sn^{2+}(aq) \rightarrow 2Al^{3+}(aq) + 3Sn(s)$	1.82

2024 Paper 1 Section 2 Question 26

Oxidation and reduction

Aqueous potassium iodate (KIO_3) reacts with aqueous potassium iodide (KI) in the presence of dilute HCl(aq) to form solid iodine (I_2). The overall balanced equation is shown.

$$KIO_3(aq) + 5KI(aq) + 6HCl(aq) \rightarrow 6KCl(aq) + 3I_2(s) + 3H_2O(l)$$

a) Identify the reducing agent. Explain your reasoning. [2 marks]

b) Determine the reduction half-equation. [3 marks]

2023 Paper 1 Section 2 Question 24

Oxidation and reduction

R and Q are unknown transition metals from period 4 of the periodic table. Pieces of R and Q were placed separately into four 0.1 M aqueous solutions. The results are shown.

Unknown metal	0.1 M aqueous solution			
	$Zn(NO_3)_2$	$Mg(NO_3)_2$	$Cu(NO_3)_2$	$AgNO_3$
R	Coating	No coating	Coating	Coating
Q	No coating	No coating	Coating	Coating

A second experiment was conducted to determine the potential difference produced by electrochemical cells constructed using metals R and Q as the electrodes.

Electrochemical cell	Cathode	Anode	Voltage (V)
1	Q	R	+0.94
2	R	Q	−0.94

Determine the identity of metals R and Q. Explain your reasoning. [5 marks]

2023 **Paper 1** **Section 2** **Question 25** **Oxidation and reduction**	During the contact process for manufacturing sulfuric acid, sulfur dioxide (SO_2) and oxygen (O_2) are passed over a vanadium oxide catalyst to produce sulfur trioxide (SO_3). In the process, the vanadium oxide undergoes the following reactions. Reaction 1: $SO_2(g) + V_2O_5(s) \rightarrow SO_3(g) + V_2O_4(s)$ Reaction 2: $2V_2O_4(s) + O_2(g) \rightarrow 2V_2O_5(s)$ Overall reaction: $2SO_2(g) + O_2(g) \xrightarrow{V_2O_5(s)} 2SO_3(g)$ (a) Determine the oxidation state of vanadium in $V_2O_4(s)$. *[1 mark]* (b) Determine if vanadium in $V_2O_5(s)$ in reaction 1 is acting as an oxidising or reducing agent. Explain your reasoning. *[2 marks]*

(c) Use the reactions provided to explain why $V_2O_5(s)$ is a catalyst for the overall reaction. *[4 marks]*

2022 Paper 1 Section 2 Question 24

Oxidation and reduction

This electrochemical cell was constructed using copper and platinum electrodes.

$$Cu(s) \mid Cu^{2+}(aq)\ (1M) \parallel Fe^{3+}(aq)\ (1M),\ Fe^{2+}(aq)\ (1M) \mid Pt(s)$$

a) Compare the standard electrode potential (E°) of the two half-cells. [3 marks]

Similarity:

Difference:

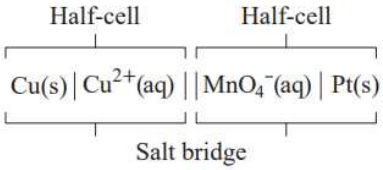
Significance:

b) Write a balanced redox equation for the electrochemical cell. [1 mark]

c) Determine the cell potential (in volts) for the electrochemical cell. [1 mark]

Cell potential = _____ V (to two significant figures)

	d) Determine the oxidising agent. Explain your reasoning. [2 marks]

2021 Paper 1 Section 2 Question 24 **Oxidation and reduction**	The cell diagram represents a voltaic cell at standard conditions. The copper solution is blue because of the presence of $Cu^{2+}(aq)$ ions. The acidified permanganate solution is purple because of the presence of $MnO_4^-(aq)$ ions.  a) Predict which direction the electrons will flow in the voltaic cell by comparing the relative strength of the oxidising agents. Explain your reasoning. [3 marks] b) Determine the standard reduction potential, E°, for the cell. [1 mark] c) Predict two qualitative observations associated with the flow of electrons and the movement of ions in the voltaic cell. [2 marks]

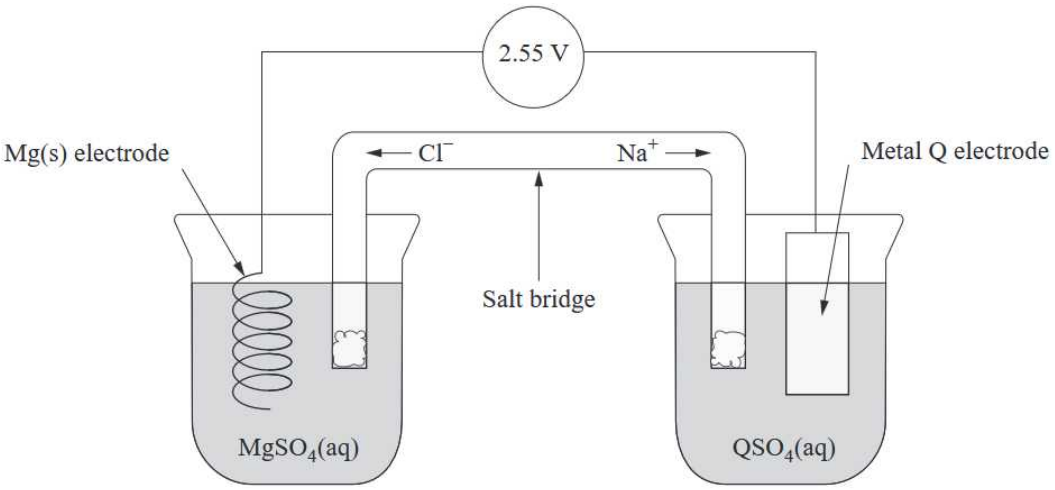
2021 Paper 1 Section 2 Question 27 **Oxidation and reduction**	Arsenous acid, H_3AsO_3, reacts with nitrate ions to form arsenic acid, H_3AsO_4, and nitrogen dioxide. a) Determine the oxidation number of arsenic in arsenous acid. [1 mark] b) Use half-equations to balance the reaction. [4 marks] c) Determine which species is reduced in this reaction. [1 mark]

2020 Paper 1 Section 2 Question 23 Oxidation and reduction	a) Identify the products of the electrolysis of i) molten sodium chloride: [1 mark] ii) dilute aqueous sodium chloride solution: [1 mark] b) Explain how the nature of the electrolyte affects the products generated when a dilute aqueous solution of sodium chloride undergoes electrolysis. [4 marks]

2024 Paper 2 Section 1 Question 5

Oxidation and reduction

The diagram shows a galvanic cell with a cell potential of 2.55 V under standard conditions.



a) Describe the movement of electrons in the galvanic cell. [3 marks]

b) Determine the half-equation and standard electrode potential for the half-cell that contains metal Q. Include states in your half-equation. [2 marks]

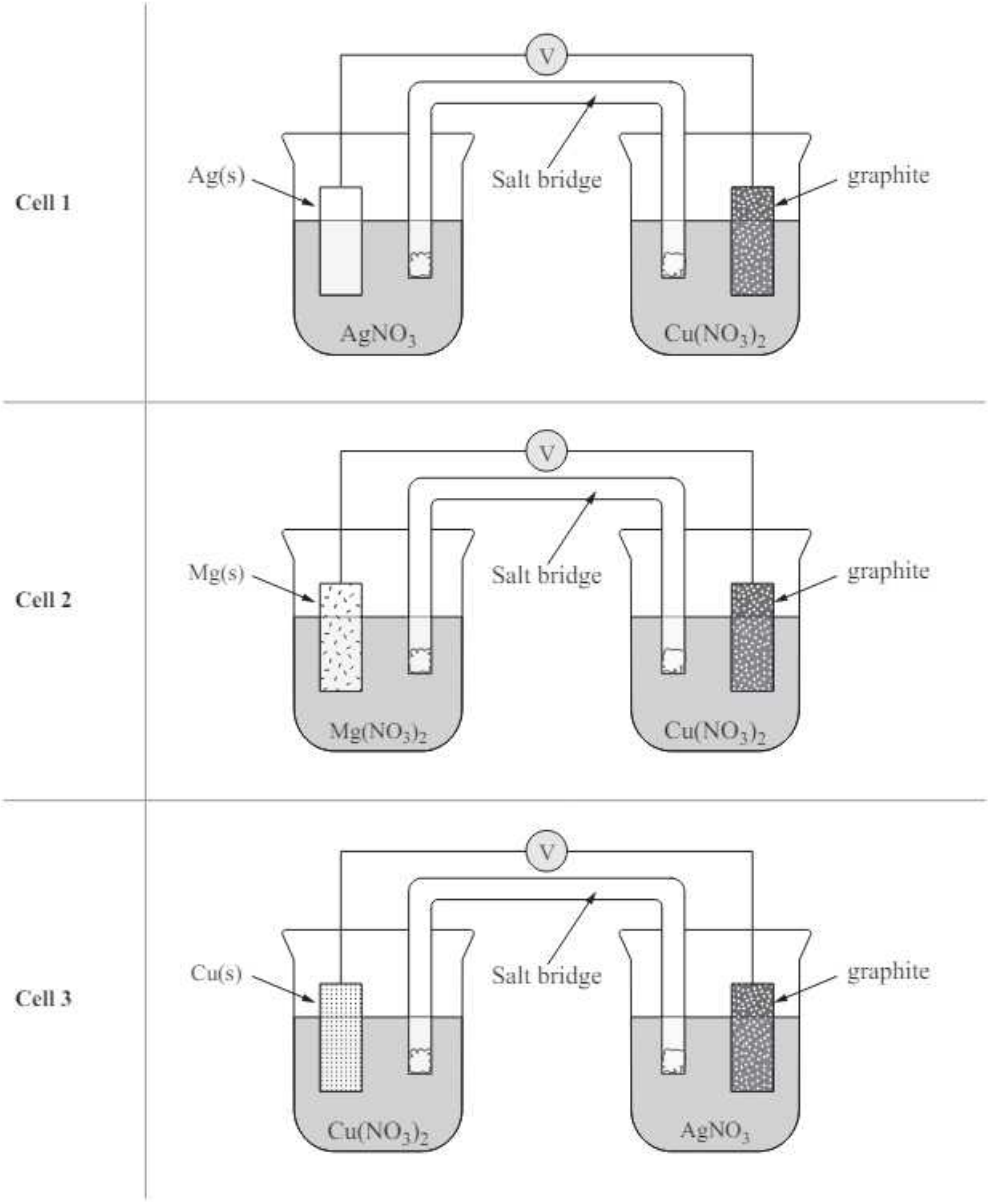
c) Identify one limitation associated with standard reduction potentials. [1 mark]

d) Determine whether metal Q is a stronger reducing agent than metallic copper (Cu).
Explain your reasoning. [2 marks]

2023
Paper 2
Section 1
Question 3

Oxidation and reduction

An experiment was conducted at standard state conditions to investigate the potential difference (V) produced by different galvanic cells. The three cells used in the experiment are shown. [7 marks]



a) Predict which cell produced the highest voltage. Explain your reasoning. [3 marks]

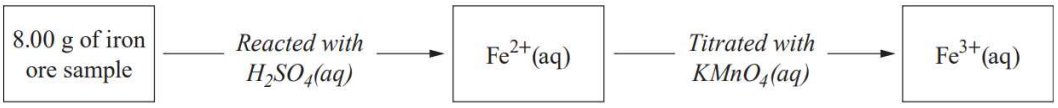
(b) Determine the maximum voltage that could be produced by a fourth galvanic cell constructed from any of the components used in the first three cells. Use oxidation and reduction half-equations to justify your answer. [4 marks]

2022 Paper 2 Section 1 Question 5 **Oxidation and reduction**	One step in the electrolytic refining of copper uses impure copper anodes and high purity copper cathodes in an electrolyte solution of copper(II) sulfate. a) Predict whether the concentration of the copper(II) sulfate solution will change during the purification process. Provide appropriate half-equations to support your reasoning. [4 marks] b) If the copper anodes contain silver and zinc impurities, determine whether either metal could be produced as a by-product of the electrolytic refining of copper. Explain your reasoning. [4 marks]

2021 Paper 2 Section 1 Question 5

Oxidation and reduction

A sample of iron ore was tested for its iron content using the experimental procedure outlined.



All the iron (Fe) in the sample was converted to Fe^{2+} (aq) by reacting it with $H_2SO_4(aq)$, forming hydrogen gas. The solution made up to a final volume of 500.0 mL. A 25.00 mL aliquot of the Fe2+ aqueous solution was titrated with a standardised solution of 0.0500 M $KMnO_4$. An average titre of 16.40 mL was obtained.

a) Write a balanced chemical equation for the reaction between the iron (Fe) in the ore sample and sulfuric acid. [1 mark]

b) Identify the species oxidised in the reaction in Question 5a). Explain your reasoning. [2 marks]

c) Apply your understanding of half-equations to balance the redox equation. [2 marks]

$$\_\_\_\_\ MnO_4^-(aq) + \_\_\_\_\ H^+(aq) + \_\_\_\_\ Fe^{2+}(aq) \rightarrow \_\_\_\_\ Mn^{2+}(aq) + \_\_\_\_\ H_2O(l) + \_\_\_\_\ Fe^{3+}(aq)$$

d) Calculate the percentage of iron (Fe) in the ore sample. Show your working. [5 marks]

Percentage iron (Fe) in ore sample = _____ % (to one decimal place)

2020 Paper 2 Section 1 Question 1 **Oxidation and reduction**	When zinc metal was placed into a blue solution of copper(II) nitrate, the solution became colourless and a red-brown deposit of copper formed on the bottom of the beaker. a) Identify if the reaction that occurred can be classified as a redox reaction. Explain your reasoning. [3 marks] b) When the copper deposited in the reaction was collected and reacted with concentrated nitric acid, copper(II) nitrate solution and nitrogen dioxide gas formed. i) Determine the reduction half-equation for this reaction. [2 marks] ii) Determine the standard reduction potential, E°, for the reduction half-equation. [1 mark] c) Apply your understanding of standard reduction potentials to explain why: i) copper can dissolve in concentrated nitric acid, but does not dissolve in concentrated hydrochloric acid. [3 marks] ii) NO_2 is the gaseous product, rather than H_2, when copper dissolves in nitric acid. [3 marks]

2024 Paper 1 Section 1 Question 1-2

Oxidation and reduction

Questions 1–2 refer to hydrated copper sulfate and its decomposition when heated.

Hydrated copper sulfate ($CuSO_4 \cdot H_2O$) decomposes to form copper sulfate ($CuSO_4$) and water when heated.

$$\text{heat} + CuSO_4 \cdot H_2O(s) \rightleftharpoons CuSO_4(s) + H_2O(g)$$

Which of the following is exchanged with the surrounding environment when $CuSO_4 \cdot H_2O(s)$ is heated in a closed system to establish dynamic equilibrium?

(A) heat

(B) $H_2O(g)$

(C) $CuSO_4(s) + H_2O(g)$

(D) $\text{heat} + CuSO_4 \cdot H_2O(s)$

Answer is A.

Determine the oxidation number of sulfur (S) in $CuSO_4 \cdot H_2O$.

(A) +8

(B) +6

(C) −2

(D) −4

Answer is B.

2024 Paper 1 Section 1 Question 3

Oxidation and reduction

Identify which of the following is an essential component of an electrolytic cell.

(A) voltmeter
(B) salt bridge
(C) power supply – Answer
(D) standard hydrogen electrode (SHE)

2024 Paper 1 Section 1 Question 13-14

Oxidation and reduction

Questions 13–14 refer to the reactions below.

Reaction 1: $CH_3CH_2OH \xrightarrow[\text{(heat/reflux)}]{H^+/Cr_2O_7^{2-}} \text{compound X}$

Reaction 2: $\text{compound X} + CH_3NH_2 \xrightarrow[\text{(heat >100 °C)}]{TiCl_4} \text{compound Y}$

Determine the type of reaction that produced compound X.

(A) addition

(B) oxidation

(C) substitution

(D) esterification

Answer is B.

	Identify compound Y. (A) CH_3CH_2CN (B) $CH_3CONHCH_3$ (C) $CH_3CH_2CH_2NH_2$ (D) $H_2NCH(CH_3)COOH$ **Answer is B.**

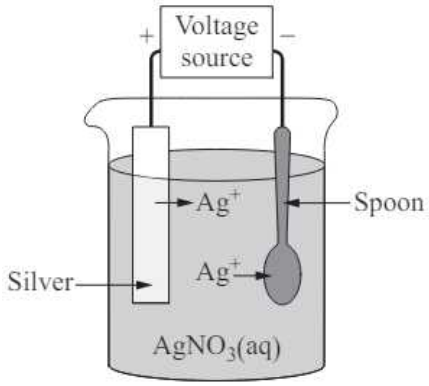
2024 Paper 1 Section 1 Question 15 Oxidation and reduction	Identify the single displacement reaction. (A) $2Cu(s) + O_2(g) \rightarrow 2CuO(s)$ (B) $CuCl_2(aq) \rightarrow Cu^{2+}(aq) + 2Cl^-(aq)$ (C) $Cu(s) + 2AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2Ag(s)$ (D) $2AgNO_3(aq) + CuCl_2(aq) \rightarrow Cu(NO_3)_2(aq) + 2AgCl(s)$ **Answer is C.**

2024 Paper 1 Section 1 Question 17 Oxidation and reduction	Identify the product produced at the cathode when a concentrated aqueous solution of NaCl undergoes electrolysis. (A) $Cl_2(g)$ (B) Na(l) (C) $O_2(g)$ (D) $H_2(g)$ **Answer is D.**

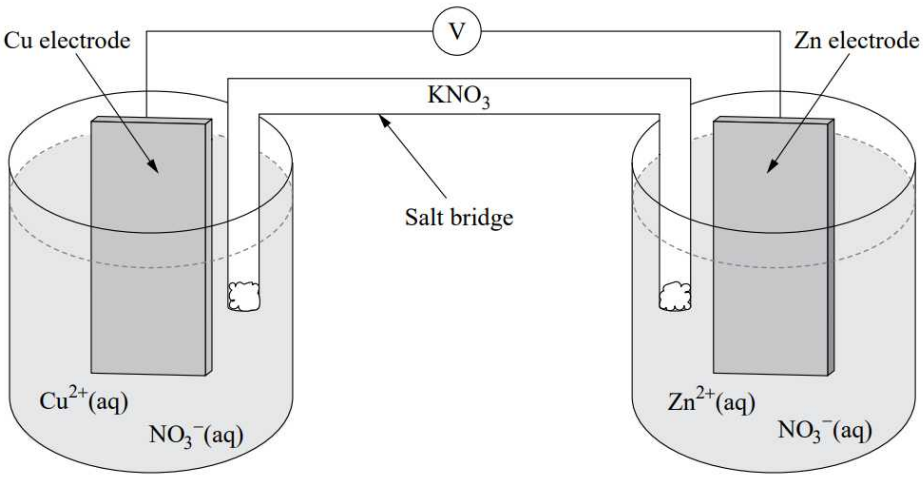
2024 Paper 1 Section 1 Question 18 Oxidation and reduction	The electrode and electrolyte solutions of four half-cells are shown. **Half-cell** | **Electrode** | **Electrolyte solution (1.0 M)** 1 | Cu | $CuNO_3(aq)$ 2 | Fe | $Fe(NO_3)_2(aq)$ 3 | Al | $Al(NO_3)_3(aq)$ 4 | Pt | $Fe(NO_3)_3(aq)$ Determine which two half-cells would produce the largest potential difference (V) under standard conditions when combined to construct a voltaic cell. (A) 4 and 1 (B) 1 and 2 (C) 2 and 3 **(D) 3 and 4 – Answer**

2023 Paper 1 Section 1 Question 7 **Oxidation and reduction**	Determine which half-cell produces the largest potential difference when joined with a $Zn(s) \mid Zn^{2+}(aq)$ half-cell to form a galvanic cell. (A) $Mg(s) \mid Mg^{2+}(aq)$ (B) $Cu^{2+}(aq) \mid Cu(s)$ (C) $H^{+}(aq) \mid H_2(g)$ (D) $F_2(g) \mid F^{-}(aq)$ **Answer is D.**

2023 Paper 1 Section 1 Question 8 **Oxidation and reduction**	Identify the species being reduced in the equation. $$Br_2(l) + Sn^{2+}(aq) \rightarrow Sn^{4+}(aq) + 2Br^{-}(aq)$$ (A) $Br_2(l)$ (B) $Br^{-}(aq)$ (C) $Sn^{2+}(aq)$ (D) $Sn^{4+}(aq)$ **Answer is A.**

2023 Paper 1 Section 1 Question 11 **Oxidation and reduction**	The plating of silver is conducted during the operation of the electrochemical cell shown.  Determine which statement is true for this electrochemical cell. **(A) The spoon acts as the cathode. – Answer** (B) The silver electrode has a negative charge. (C) The silver ions in the solution are oxidised at the spoon. (D) The electrons flow from the spoon to the silver electrode.

2022 Paper 1 Section 1 Question 3 **Oxidation and reduction**	Which option is true for the redox equation? $Fe(s) + CuCl_2(aq) \rightarrow FeCl_2(aq) + Cu(s)$ (A) Fe is oxidised and Cu is the oxidising agent **(B) Fe is oxidised and Cu_2+ is the oxidising agent – Answer** (C) Fe_2+ is oxidised and Cu is the oxidising agent (D) Fe_2+ is oxidised and Cu_2+ is the oxidising agent

2022 Paper 1 Section 1 Questions 11-12 Oxidation and reduction	These questions refer to the diagram shown.  Determine the species that travels through the salt bridge towards the reduction half-cell in the electrochemical cell at standard conditions. (A) zinc ions (B) nitrate ions (C) copper ions **(D) potassium ions – Answer** The zinc electrode (A) gains electrons and acts as the anode. (B) acts as the cathode and has a positive charge. (C) undergoes reduction and has a negative charge. **(D) is oxidised and donates electrons to the copper ions. – Answer**

2022 Paper 1 Section 1 Question 16 Oxidation and reduction	Determine the oxidation state of manganese in MnO_4^-. (A) +1 (B) +2 **(C) +7 – Answer** (D) +8

2022 Paper 1 Section 1 Question 17 Oxidation and reduction	Identify the redox reaction. (A) $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$ (B) $CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s)$ **(C) $Cl_2(g) + H_2O(l) \rightarrow HCl(aq) + HClO(aq)$ – Answer** (D) $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$

2022 Paper 1 Section 1 Question 19

Oxidation and reduction

Three voltaic cells are constructed with metal Q as one electrode and metals R, S or T as the other electrode. The potential differences for the cells are shown in the table.

Voltaic cell	Half-cell	Half-cell	Potential difference (V)
1	$Q(s) / Q^{2+}(aq)$	$R^{+}(aq) / R(s)$	1.18
2	$Q(s) / Q^{2+}(aq)$	$S^{2+}(aq) / S(s)$	0.72
3	$T(s) / T^{3+}(aq)$	$Q^{2+}(aq) / Q(s)$	0.95

The relative strength of the reducing agents from strongest to weakest is

(A) T > Q > S > R – Answer
(B) S > Q > T > R
(C) R > Q > S > T
(D) Q > R > T > S

2021 Paper 1 Section 1 Question 3

Oxidation and reduction

Predict which product is formed at the positive electrode when a 0.1 M aqueous solution of copper(II) sulfate is electrolysed using carbon electrodes.

(A) Cu(s)
(B) $H_2(g)$
(C) $O_2(g)$ – Answer
(D) $SO_2(g)$

2021 Paper 1 Section 1 Question 18

Oxidation and reduction

Identify the major product when 2-methylbut-2-ene reacts with water under acidic conditions.

(A) $(CH_3)_2CHCOCH_3$

(B) $(CH_3)_2C(OH)CH_2CH_3$

(C) $(CH_3)_2CHCH(OH)CH_3$

(D) $(CH_3)_2C(OH)CH(OH)CH_3$

Answer is B.

2020 Paper 1 Section 1 Question 6

Oxidation and reduction

Calculate the cell potential produced by a $Zn(s) | Zn^{2+}(aq) || Cu^{2+}(aq) | Cu(s)$ galvanic cell under standard conditions.

(A) –1.10 V

(B) –0.42 V

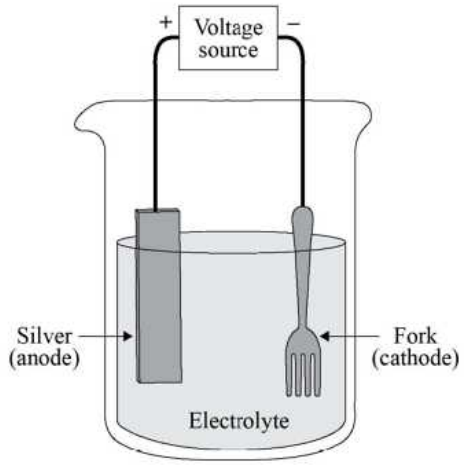
(C) +0.34 V

(D) +1.10 V

Answer is D.

2020 Paper 1 Section 1 Question 10

Oxidation and reduction



Which of the following is true for the electrochemical cell?

	Reaction	Anode	Flow of electrons
(A)	spontaneous	oxidation	From the negative terminal of the power pack, through the wire to the negative electrode.
(B)	spontaneous	positive electrode	From the positive terminal of the power pack, through the wire and the electrolyte to the negative electrode.
(C)	non-spontaneous	negative electrode	From the negative terminal of the power pack, through the wire and the electrolyte to the positive terminal.
(D)	non-spontaneous	oxidation	From the negative terminal of the power pack, through the wire to the negative electrode.

Answer is D.

2020 Paper 1 Section 1 Question 16

Oxidation and reduction

$CH_3CN + 2H_2 \xrightarrow{Ni} CH_3CH_2NH_2$

The reaction shows

(A) an addition reaction that converts an amine to a nitrile.
(B) a reduction reaction that converts a nitrile to an amine. – Answer
(C) an oxidation reaction that converts an amine to a nitrile.
(D) a substitution reaction that converts a nitrile to an amine.

2020 Paper 1 Section 1 Question 17

Oxidation and reduction

Which of the following represents a spontaneous redox reaction with the correct standard electrode potential?

	Reaction	E^o (V)
(A)	$2Na^+(aq) + 2Br^-(aq) \rightarrow 2Na(s) + Br_2(aq)$	3.79
(B)	$Sn^{2+}(aq) + 2Ag(s) \rightarrow Sn(s) + 2Ag^+(aq)$	−0.94
(C)	$Zn(s) + Cl_2(g) \rightarrow Zn^{2+}(aq) + 2Cl^-(aq)$	2.12
(D)	$2Al(s) + 3Sn^{2+}(aq) \rightarrow 2Al^{3+}(aq) + 3Sn(s)$	1.82

Answer is C.

2024 Paper 1 Section 2 Question 26

Oxidation and reduction

Aqueous potassium iodate (KIO_3) reacts with aqueous potassium iodide (KI) in the presence of dilute HCl(aq) to form solid iodine (I_2). The overall balanced equation is shown.

$$KIO_3(aq) + 5KI(aq) + 6HCl(aq) \rightarrow 6KCl(aq) + 3I_2(s) + 3H_2O(l)$$

a) Identify the reducing agent. Explain your reasoning. [2 marks]

Sample response	The response
I^-(aq) in KI is the reducing agent because it loses an electron to be oxidised to I_2(s).	• identifies that the iodide ion (I^-) in KI is the reducing agent **[1 mark]** • explains I^- is oxidised by losing an electron **[1 mark]**

b) Determine the reduction half-equation. [3 marks]

Sample response	The response
Reduction half-equation: $2IO_3^-(aq) + 12H^+(aq) + 10e^- \rightarrow I_2(s) + 6H_2O(l)$	• determines $IO_3^- + H^+ + e^-$ are reactants **[1 mark]** • determines $I_2 + H_2O$ are products **[1 mark]** • determines the balanced reduction half-equation **[1 mark]**

2023 Paper 1 Section 2 Question 24

Oxidation and reduction

R and Q are unknown transition metals from period 4 of the periodic table. Pieces of R and Q were placed separately into four 0.1 M aqueous solutions. The results are shown.

Unknown metal	0.1 M aqueous solution			
	$Zn(NO_3)_2$	$Mg(NO_3)_2$	$Cu(NO_3)_2$	$AgNO_3$
R	Coating	No coating	Coating	Coating
Q	No coating	No coating	Coating	Coating

A second experiment was conducted to determine the potential difference produced by electrochemical cells constructed using metals R and Q as the electrodes.

Electrochemical cell	Cathode	Anode	Voltage (V)
1	Q	R	+0.94
2	R	Q	−0.94

Determine the identity of metals R and Q. Explain your reasoning. [5 marks]

Sample response	The response
Metal R displaces Zn ions from solution but not Mg ions, therefore metal R is more reactive than Zn but less reactive than Mg. Therefore, metal R is manganese. Metal Q displaces Cu ions and Ag ions from solution but not Zn ions, therefore metal Q is more reactive than Cu but less reactive than Zn. $E^o_{cell} = E_{red} - E_{ox}$ $= +0.94 + (-1.18) = -0.24$ V Therefore, metal Q is Ni.	• uses the data to explain that metal R is more reactive than Zn and less reactive than Mg **[1 mark]** • identifies metal R is manganese **[1 mark]** • uses the data to explain that metal Q must be Ni, Co, Fe or Cr **[1 mark]** • uses the electrochemical data to determine $E^o_{metal\ Q} = -0.24$V **[1 mark]** • identifies metal Q is Ni **[1 mark]**

2023 Paper 1 Section 2 Question 25

Oxidation and reduction

During the contact process for manufacturing sulfuric acid, sulfur dioxide (SO_2) and oxygen (O_2) are passed over a vanadium oxide catalyst to produce sulfur trioxide (SO_3). In the process, the vanadium oxide undergoes the following reactions.

Reaction 1: $SO_2(g) + V_2O_5(s) \rightarrow SO_3(g) + V_2O_4(s)$

Reaction 2: $2V_2O_4(s) + O_2(g) \rightarrow 2V_2O_5(s)$

Overall reaction: $2SO_2(g) + O_2(g) \xrightarrow{V_2O_5(s)} 2SO_3(g)$

(a) Determine the oxidation state of vanadium in $V_2O_4(s)$. *[1 mark]*

Sample response	The response
+4	• determines that the oxidation state of vanadium is +4 **[1 mark]**

(b) Determine if vanadium in $V_2O_5(s)$ in reaction 1 is acting as an oxidising or reducing agent. Explain your reasoning. *[2 marks]*

Sample response	The response
Vanadium in $V_2O_5(s)$ is acting as an oxidising agent in reaction 1 as the oxidation state decreased from +5 to +4 in $V_2O_4(s)$.	• determines that vanadium in $V_2O_5(s)$ is an oxidising agent **[1 mark]** • explains that oxidation state of vanadium decreases from +5 to +4 **[1 mark]**

(c) Use the reactions provided to explain why $V_2O_5(s)$ is a catalyst for the overall reaction. *[4 marks]*

Sample response	The response
Reaction 1: $V_2O_5(s)$ is converted to $V_2O_4(s)$ to allow SO_2 to be converted to SO_3. Reaction 2: $V_2O_4(s)$ is converted back to $V_2O_5(s)$ by reacting with O_2. Therefore, $V_2O_5(s)$ acts as a catalyst because it undergoes a temporary chemical change during the reaction but remains chemically unchanged at the end.	• identifies that $V_2O_5(s)$ is involved in the chemical reaction **[1 mark]** • uses data from reaction 1 to support chemical change to $V_2O_4(s)$ **[1 mark]** • uses data from reaction 2 to support chemical change to $V_2O_5(s)$ **[1 mark]** • explains that $V_2O_5(s)$ remains unchanged at the end of the reaction **[1 mark]**

2022 Paper 1 Section 2 Question 24

Oxidation and reduction

This electrochemical cell was constructed using copper and platinum electrodes.

$$Cu(s) \mid Cu^{2+}(aq)\ (1M) \parallel Fe^{3+}(aq)\ (1M), Fe^{2+}(aq)\ (1M) \mid Pt(s)$$

a) Compare the standard electrode potential (E°) of the two half-cells. [3 marks]

Sample Response	The response
Similarity: Both the Pt and Cu half-cells have a positive standard reduction potential compared to SHE. Difference: Pt half-cell is more positive than Cu half-cell. Significance: Cu electrode is oxidised (loses electrons) and the Fe3+(aq) is reduced.	• Similarities: identifies that both half-cells have positive standard reduction potential [1 mark] • Differences: identifies that Pt half-cell is more positive than Cu half-cell [1 mark] • Significance: explains that Cu electrode is oxidised and Fe^{3+} is reduced [1 mark]

b) Write a balanced redox equation for the electrochemical cell. [1 mark]

Sample Response	The response
Balance redox equation: $2Fe^{3+} + Cu \rightarrow Cu^{2+} + 2Fe^{2+}$	• provides correct balanced redox equation [1 mark]

c) Determine the cell potential (in volts) for the electrochemical cell. [1 mark]

Sample Response	The response
Cell potential = 0.77 + (−0.34) = +0.43 V	• determines cell potential is +0.43 [1 mark]

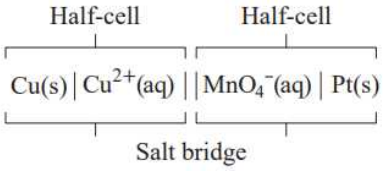
d) Determine the oxidising agent. Explain your reasoning. [2 marks]

Sample Response	The response
Fe^{3+} is the oxidising agent, because ON decreases from +3 to +2.	• identifies Fe^{3+} as the oxidising agent [1 mark] • indicates oxidation number decreases [1 mark]

2021 Paper 1 Section 2 Question 24

Oxidation and reduction

The cell diagram represents a voltaic cell at standard conditions. The copper solution is blue because of the presence of $Cu^{2+}(aq)$ ions. The acidified permanganate solution is purple because of the presence of $MnO_4^-(aq)$ ions.



a) Predict which direction the electrons will flow in the voltaic cell by comparing the relative strength of the oxidising agents. Explain your reasoning. [3 marks]

Sample Response	The response	Notes
$MnO_4^-(aq)$ (+1.51 V) is a stronger oxidising agent than $Cu^{2+}(aq)$ (+0.34 V) because it has a more positive standard potential. $MnO_4^-(aq)$ is preferentially reduced and gains electrons from Cu(s), which is oxidised. Therefore, electrons flow from Cu electrode to Pt electrode.	• correctly identifies MnO_4^- as the stronger oxidising agent [1 mark] • correctly identifies that MnO_4^- gains electrons [1 mark] • determines that electrons flow from Cu to Pt electrode [1 mark]	Acceptable responses are: - MnO_4^- is reduced - Cu is oxidised - Cu loses electrons. Acceptable responses are that electrons flow from: - Cu electrode to Pt electrode - Cu(s) to $MnO_4^-(aq)$.

b) Determine the standard reduction potential, E°, for the cell. [1 mark]

Sample Response	The response	Notes
$E^\circ_{cell} = E^\circ_{red} - E^\circ_{ox} = +1.51 - (+0.34) = 1.17$ V	• determines that the standard reduction potential is 1.17 [1 mark]	Do not penalise for incorrect decimal places/significant figures.

c) Predict two qualitative observations associated with the flow of electrons and the movement of ions in the voltaic cell. [2 marks]

Sample Response	The response	Notes
$Cu^{2+}(aq)$ concentration will increase and the solution will become darker. $MnO_4 -$ (aq) concentration will decrease and the solution will become lighter.	• predicts that the $Cu^{2+}(aq)$ solution will become darker [1 mark] • predicts that the $MnO_4 -$(aq) solution will become lighter [1 mark]	Acceptable responses are: - Cu electrode will become smaller - Cu^{2+} solution will become darker - $MnO_4 -$ solution will become lighter - $MnO_4 -$ solution will become colourless. Allow FT error from 24a).
	•	
	•	

2021 Paper 1 Section 2 Question 27

Oxidation and reduction

Arsenous acid, H_3AsO_3, reacts with nitrate ions to form arsenic acid, H_3AsO_4, and nitrogen dioxide.

a) Determine the oxidation number of arsenic in arsenous acid. [1 mark]

Sample Response	The response	Notes
$3 \times (+1) + As + 3 \times (-2) = 0$ $3 + As - 6 = 0$ $As - 3 = 0$ $As = +3$	• provides +3 [1 mark]	Do not accept 3 or 3+. Do not penalise for incorrect decimal places/significant figures.

b) Use half-equations to balance the reaction. [4 marks]

Sample Response	The response	Notes
Balanced oxidation half-equation: $H_3AsO_3 + H_2O \rightarrow H_3AsO_4 + 2H^+ + 2e^-$ Balanced reduction half-equation: $NO_3^- + 2H^+ + e^- \rightarrow NO_2 + H_2O$ Multiply by 2: $2NO_3^- + 4H^+ + 2e^- \rightarrow 2NO_2 + 2H_2O$ Balanced redox equation: $H_3AsO_3 + 2NO_3^- + 2H^+ \rightarrow H_3AsO_4 + 2NO_2 + H_2O$	• provides balanced oxidation half-equation [1 mark] • provides balanced reduction half-equation [1 mark] • uses multiplication factor to balance electrons [1 mark] • determines balanced redox equation [1 mark]	Allow FT error for multiplication factor and balanced equation. Award full marks for correctly balanced equation without full working.

c) Determine which species is reduced in this reaction. [1 mark]

Sample Response	The response	Notes
NO_3^-	• provides NO_3^- [1 mark]	Acceptable responses are: - nitrogen - N

2020 Paper 1 Section 2 Question 23

Oxidation and reduction

a) Identify the products of the electrolysis of
i) molten sodium chloride: [1 mark]

Sample Response	The response
Na(l) and $Cl_2(g)$	• provides Na(l) and $Cl_2(g)$ [1 mark]

ii) dilute aqueous sodium chloride solution: [1 mark]

Sample Response	The response
$H_2(g)$ and $O_2(g)$	• provides $H_2(g)$ and $O_2(g)$ [1 mark]

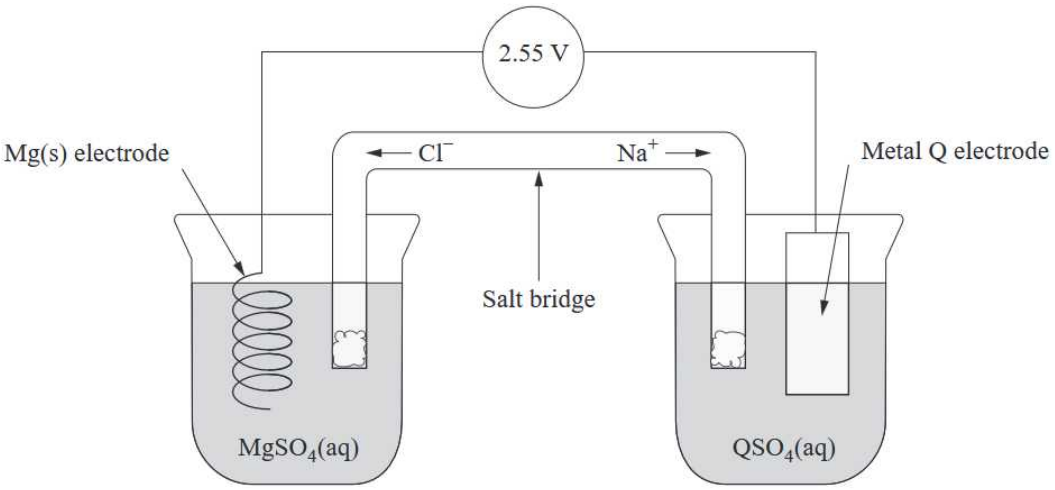
b) Explain how the nature of the electrolyte affects the products generated when a dilute aqueous solution of sodium chloride undergoes electrolysis. [4 marks]

Sample Response	The response	Notes
In a dilute solution of aqueous sodium chloride, sodium ions, chloride ions, hydrogen ions, hydroxide ions and water molecules are present. The concentration and the E^o value of the species create competition at the electrodes and affect the products formed. Na^+ and H^+ compete to be reduced at the cathode. The E0 value for reducing H^+ is more positive; therefore, H+ is preferentially reduced and H_2 gas is formed rather than Na metal. Cl^- and OH^- compete to be oxidised at the anode. As the concentration of Cl− is low in a dilute NaCl solution, OH^- is preferentially oxidised and O_2 gas is produced rather than Cl_2 gas.	• identifes that Na^+, Cl^-, OH^-, H^+, and H_2O are present [1 mark] • identifies that concentration and E^o values of the species affects products [1 mark] • identifies that H^+ is preferentially reduced, producing H_2 gas due to a more positive Eo value [1 mark] • identifies that OH^- is preferentially oxidised, producing O_2 gas due to a higher concentration of ions [1 mark]	For H_2O, accept OH^- and H^+.

2024 Paper 2 Section 1 Question 5

Oxidation and reduction

The diagram shows a galvanic cell with a cell potential of 2.55 V under standard conditions.



a) Describe the movement of electrons in the galvanic cell. [3 marks]

Sample response	The response
Magnesium is the anode and is being oxidised, i.e. it loses electrons. Thus, electrons move from the magnesium electrode through the wire towards metal Q.	• identifies that the magnesium electrode is oxidised **[1 mark]** • describes the movement of electrons through the wire **[1 mark]** • identifies that Q^{2+} ions are reduced **[1 mark]**

b) Determine the half-equation and standard electrode potential for the half-cell that contains metal Q. Include states in your half-equation. [2 marks]

Sample response	The response
Metal Q is reduced. $Q^{2+}(aq) + 2e^- \rightleftharpoons Q(s)$ $E_{cell} = E_{red} - E_{ox}$ $2.55 = Q - (-2.36)$ $Q = 2.55 - 2.36 = 0.19\ V$	• determines the half-equation is $Q^{2+}(aq) + 2e^- \rightleftharpoons Q(s)$ **[1 mark]** • determines standard electrode potential is +0.19 V **[1 mark]**

c) Identify one limitation associated with standard reduction potentials. [1 mark]

Sample response	The response
All solutions must have a concentration of 1.0 M.	• identifies a limitation **[1 mark]**

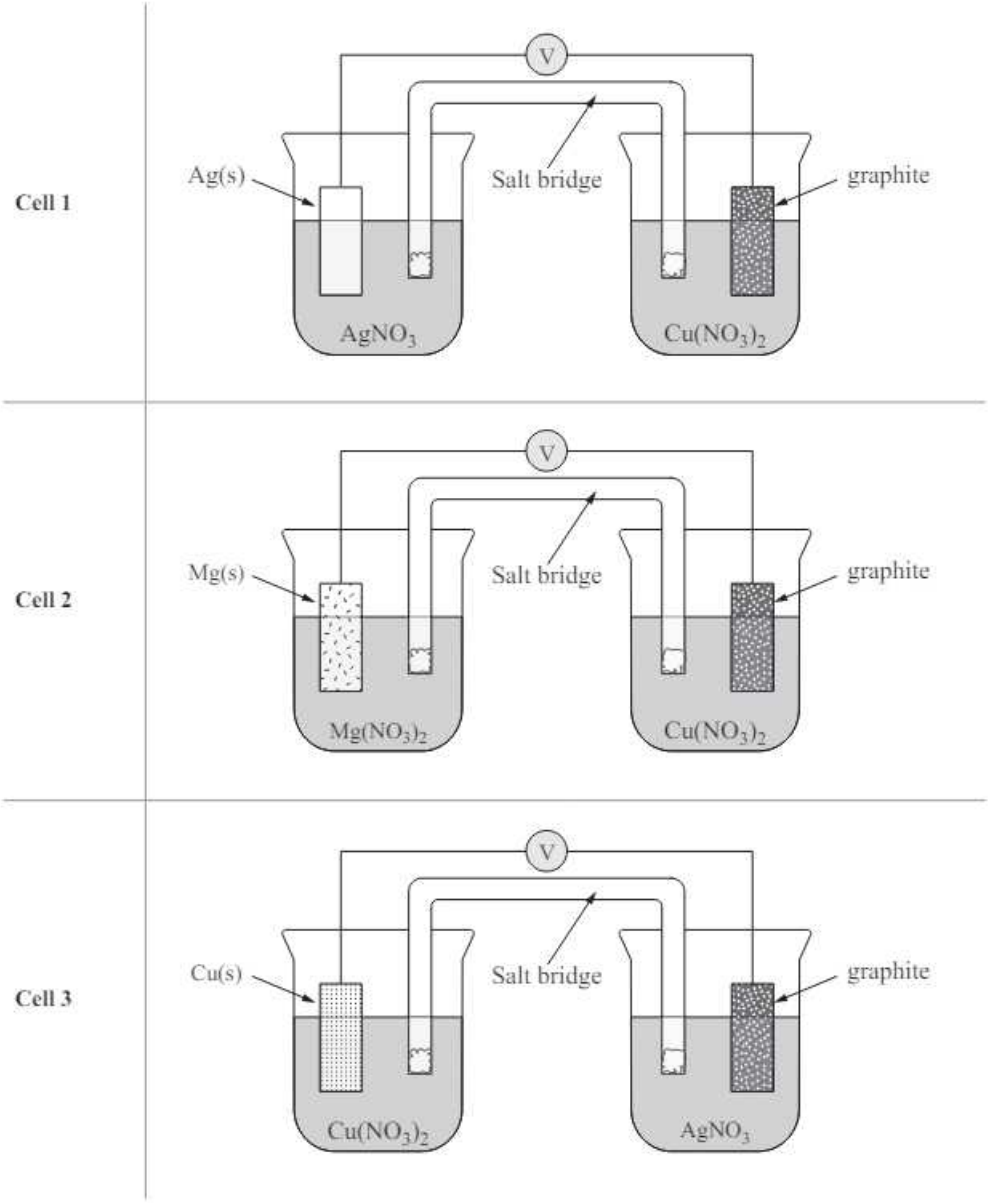
d) Determine whether metal Q is a stronger reducing agent than metallic copper (Cu).
Explain your reasoning. [2 marks]

Sample response	The response
$Q^{2+}(aq) + 2e^- \rightleftharpoons Q(s) = +0.19\ V$ $Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s) = +0.34V$ Q is less positive that Cu, therefore metal Q is a stronger reducing agent than metallic Cu.	• determines metal Q is a stronger reducing agent **[1 mark]** • explains that the lower the standard reduction potential, the stronger the reducing agent **[1 mark]**

2023 Paper 2 Section 1 Question 3

Oxidation and reduction

An experiment was conducted at standard state conditions to investigate the potential difference (V) produced by different galvanic cells. The three cells used in the experiment are shown. [7 marks]



a) Predict which cell produced the highest voltage. Explain your reasoning. [3 marks]

Sample response	The response
Cell 1 is not spontaneous. Cell 2 is spontaneous and would produce voltage of 2.70 V. Cell 3 is spontaneous and would produce 0.46 V. Cell 2 would produce the highest voltage of the three cells.	• determines that cell 1 is not spontaneous **[1 mark]** • determines voltage of cells 2 and 3 **[1 mark]** • predicts which cell produces maximum voltage **[1 mark]**

(b) Determine the maximum voltage that could be produced by a fourth galvanic cell constructed from any of the components used in the first three cells. Use oxidation and reduction half-equations to justify your answer. [4 marks]

Sample response	The response
The new cell would be constructed using Mg as the anode and Ag as the cathode. Anode half-equation: $Mg \rightarrow Mg^{2+} + 2e^-$ (+2.36 V) Cathode half-equation: $Ag^+ + e^- \rightarrow Ag$ (+0.80 V) $E^o_{cell} = 3.16$ V	• determines cell 4 constructed using Mg and Ag **[1 mark]** • identifies oxidation half-equation **[1 mark]** • identifies reduction half-equation **[1 mark]** • determines E^o_{cell} is 3.16 **[1 mark]**

2022 Paper 2 Section 1 Question 5

Oxidation and reduction

One step in the electrolytic refining of copper uses impure copper anodes and high purity copper cathodes in an electrolyte solution of copper(II) sulfate.

a) Predict whether the concentration of the copper(II) sulfate solution will change during the purification process. Provide appropriate half-equations to support your reasoning. [4 marks]

Sample Response	The response
Copper ion is reduced and Cu is plated onto the cathode: Cu^{2+} (aq) + $2e^-$ → Cu(s) Copper anode is oxidised to Cu2+(aq) and is released into solution: Cu(s) → Cu^{2+} (aq) + $2e^-$ Therefore, for every copper ion that is reduced at the cathode, in principle, another one is oxidised at the anode. Therefore, the concentration of the copper(II) sulfate solution should stay the same.	• identifies copper ions are reduced to Cu metal at the cathode and reduction half-equation is Cu^{2+} (aq) + $2e^-$ → Cu(s) **[1 mark]** • identifies copper metal is oxidised to Cu ions at the anode and oxidation half-equation is Cu(s) → Cu^{2+} (aq) + $2e^-$ **[1 mark]** • predicts no change in concentration of copper(II) sulfate solution **[1 mark]** • identifies that copper ions are reduced to copper and copper is oxidised to copper ions at the same rate **[1 mark]**

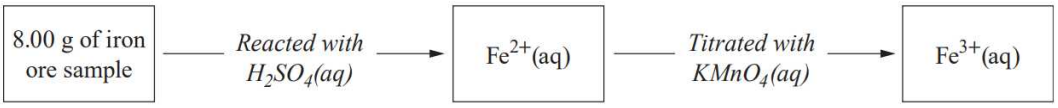
b) If the copper anodes contain silver and zinc impurities, determine whether either metal could be produced as a by-product of the electrolytic refining of copper. Explain your reasoning. [4 marks]

Sample Response	The response
Silver is below copper in the reactivity series and therefore doesn't go into solution, as ions are not oxidised and could be found in the sludge. Zinc impurities are above copper in the electrochemical series and will form ions at the anode and go into solution. However, they won't get discharged at the cathode, provided their concentration doesn't get too high.	• identifies Ag is less reactive than Cu and Zn is more reactive than Cu [1 mark] • deduces Ag metal is not oxidised (or reduced) and remains as metal [1 mark] • deduces Zn metal is oxidised to form ions and found in the solution [1 mark] • explains that Zn^{2+} ions remain in solution at low concentration but are reduced to Zn metal at the cathode if concentration becomes too high [1 mark]

2021 Paper 2 Section 1 Question 5

Oxidation and reduction

A sample of iron ore was tested for its iron content using the experimental procedure outlined.



All the iron (Fe) in the sample was converted to Fe^{2+} (aq) by reacting it with H_2SO_4(aq), forming hydrogen gas. The solution made up to a final volume of 500.0 mL. A 25.00 mL aliquot of the Fe2+ aqueous solution was titrated with a standardised solution of 0.0500 M $KMnO_4$. An average titre of 16.40 mL was obtained.

a) Write a balanced chemical equation for the reaction between the iron (Fe) in the ore sample and sulfuric acid. [1 mark]

Sample Response	The response	Notes
$Fe(s) + H_2SO_4(aq) \rightarrow FeSO_4(aq) + H_2(g)$	• correctly identifies the balanced equation [1 mark]	

b) Identify the species oxidised in the reaction in Question 5a). Explain your reasoning. [2 marks]

Sample Response	The response	Notes
Fe (iron) Fe loses two electrons to form $Fe^{2+}(aq)$.	• correctly identifies that Fe (iron) is oxidised [1 mark] • indicates that Fe loses electrons to form Fe^{2+} [1 mark]	Acceptable responses are: - iron - Fe. Acceptable response is oxidation number of Fe increases from 0 to +2.

c) Apply your understanding of half-equations to balance the redox equation. [2 marks]

Sample Response	The response	Notes
$MnO_4^-(aq) + 8H^+(aq) + 5Fe^{2+}(aq) \rightarrow Mn^{2+}(aq) + 4H_2O(l) + 5Fe^{3+}(aq)$	• correctly balances $8H^+ + 4H_2O$ in equation [1 mark] • correctly balances $5Fe^{2+} + 5Fe^{3+}$ in equation [1 mark]	

d) Calculate the percentage of iron (Fe) in the ore sample. Show your working. [5 marks]

Sample Response	The response	Notes
Moles MnO_4^-(aq) reacted = $0.01640 \times 0.05 = 8.2 \times 10^{-4}$ $MnO_4^- : 5Fe^{2+}$ Moles of Fe^{2+} in 25.00 mL = $5 \times (8.2 \times 10^{-4}) = 4.1 \times 10^{-3}$ mol Moles of Fe^{2+} in 500.0 mL = moles Fe in sample $= 4.1 \times 10^{-3} \times 0.5000 \div 0.025 = 0.082 = 8.2 \times 10^{-2}$ mol Mass Fe dissolved = $0.082 \times 55.85 = 4.6$ g (4.5797) % Fe in iron ore = $4.6 \div 8.00 = 57.2\%$ (57.24625) Percentage Fe in ore sample = 57.2% (to one decimal place)	• correctly determines $n MnO_4 - = 8.2 \times 10^{-4}$ [1 mark] • determines $nFe^{2+} = 4.1 \times 10^{-3}$ [1 mark] • determines $nFe = 8.2 \times 10^{-2}$ [1 mark] • determines mass Fe = 4.6 g [1 mark] • determines Fe = 57.2% [1 mark]	Allow FT error from incorrect mole ratio. Acceptable response is mass Fe = 4.5797 g. Acceptable responses are: - % Fe = 57.2 - % Fe = 57.3

2020 Paper 2 Section 1 Question 1

Oxidation and reduction

When zinc metal was placed into a blue solution of copper(II) nitrate, the solution became colourless and a red-brown deposit of copper formed on the bottom of the beaker.

a) Identify if the reaction that occurred can be classified as a redox reaction.
Explain your reasoning. [3 marks]

Sample Response	The response	Notes
Zinc is oxidised when Zn changes to Zn^{2+}. Copper is reduced when Cu^{2+} changes to Cu. Therefore, the reaction can be classified as redox as Zn is oxidised and Cu^{2+} is reduced.	• identifies that - zinc is oxidised [1 mark] - copper is reduced [1 mark] - reaction is redox [1 mark]	Acceptable responses are: – $Zn(s) \rightarrow Zn^{2+} + 2e^-$ – oxidation number of Zn increases from 0 to +2. Acceptable responses are: – $Cu^{2+} + 2e^- \rightarrow Cu(s)$ – oxidation number of Cu decreases from +2 to 0.

b) When the copper deposited in the reaction was collected and reacted with concentrated nitric acid, copper(II) nitrate solution and nitrogen dioxide gas formed.

i) Determine the reduction half-equation for this reaction. [2 marks]

Sample Response	The response	Notes
i) $4H^+(aq) + 2NO_3^-(aq) + 2e^- \rightarrow 2NO_2(g) + 2H_2O(l)$	• provides $2H^+(aq) + e^- \rightarrow H_2O(l)$ **[1 mark]** • provides $NO_3^-(aq) + e^- \rightarrow NO_2(g)$ **[1 mark]**	Acceptable response is $2H^+(aq) + NO_3^-(aq) + e^- \rightarrow NO_2(g) + H_2O(l)$

ii) Determine the standard reduction potential, E°, for the reduction half-equation. [1 mark]

Sample Response	The response
ii) E°_{red} = 0.46 + 0.34 = +0.80 V	• determines E°_{red} = +0.80 V **[1 mark]**

c) Apply your understanding of standard reduction potentials to explain why:

i) copper can dissolve in concentrated nitric acid, but does not dissolve in concentrated hydrochloric acid. [3 marks]

Sample Response	The response	Notes
i) For hydrochloric acid: $E^\circ_{cell} = E^\circ_{red} - E^\circ_{ox}$ = +0.00 – (+0.34) = –0.34 Reaction is non-spontaneous, therefore HCl cannot dissolve Cu. For nitric acid: E°_{cell} = +0.46 (positive), therefore the reaction is spontaneous. HNO_3 can dissolve Cu.	• determines E° cell for HCl equals –0.34 and E° cell for HNO_3 equals +0.46 V [1 mark] • determines reaction between Cu and HCl is not spontaneous and therefore Cu will not dissolve [1 mark] • indicates reaction between Cu and HNO_3 is spontaneous and therefore Cu will dissolve [1 mark]	Acceptable response is Cl^- is more negative, therefore stronger reducing and will be oxidised in preference to Cu.

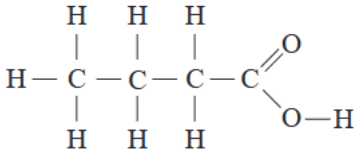
ii) NO2 is the gaseous product, rather than H2, when copper dissolves in nitric acid. [3 marks]

Sample Response	The response	Notes
ii) Reduction: $4H^+(aq) + 2NO_3^-(aq) + 2e^- \rightarrow 2NO_2(g) + 2H_2O(l)$, $E^o = +0.80V$ or $H^+(aq) + 2e^- \rightarrow H_2(g)$, $E^o = 0.00$ V The E^o value for NO_3^- is more positive than $H^+(aq)$, therefore NO_3^- is a stronger oxidising agent. Therefore NO_3^- reduced in preference to H^+ and $NO_2(g)$ formed	• identifies that, in HNO_3, $H^+(aq)$ and NO_3^- compete to be reduced **[1 mark]** • indicates that NO_3^- is stronger oxiding agent **[1 mark]** • determines NO_3^- is preferentially reduced therefore $NO_2(g)$ formed **[1 mark]**	Acceptable response is NO_3^- is more positive than Cu, therefore stronger oxidising agent and can be reduced to oxidise Cu to $Cu^{2+}(aq)$.

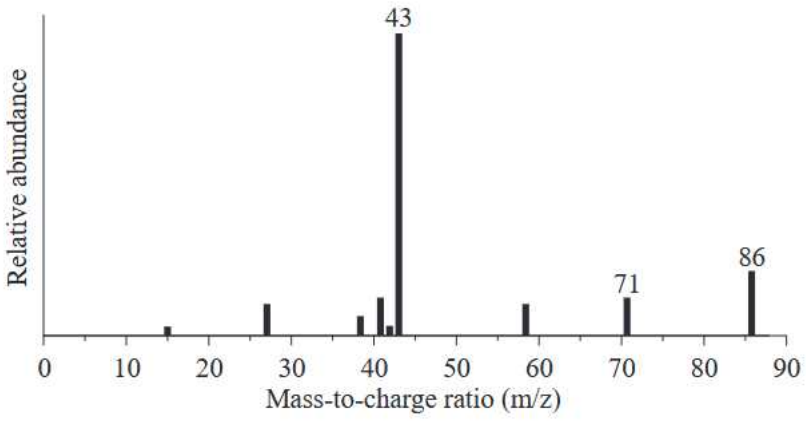
Unit 4 Structure, synthesis and design

Unit 4 – Topic 1: Properties and structure of organic materials

Paper 1 Section 1

2024 Paper 1 Section 1 Question 8 **Properties and structure of organic materials**	 Determine the IUPAC name of the organic compound shown. (A) butanoic acid (B) butanone (C) butanol (D) butanal

2024 Paper 1 Section 1 Question 9 **Properties and structure of organic materials**	Polytetrafluorethene (PTFE) has a higher melting point than polypropene (PP) due to the (A) C– F bonds being non-reactive. (B) fluorine atoms forming stable C– F covalent bonds. (C) dispersion forces between closely packed fluorocarbon chains. (D) dipole–dipole interaction between fluorine and carbon atoms within the fluorocarbon chain

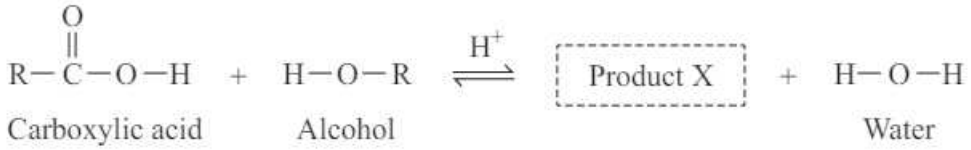
2024 Paper 1 Section 1 Question 16 **Properties and structure of organic materials**	The simplified mass spectrum for an organic compound C_5H_xO is shown.  Determine which compound the mass spectrum belongs to. (A) pentan-2-one (B) pentan-3-one (C) pentan-1-ol (D) pentanal

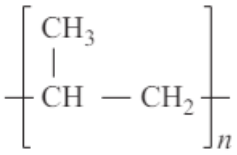
2024 Paper 1 Section 1 Question 19 Properties and structure of organic materials	Esters undergo hydrolysis to form a carboxylic acid and (A) water. (B) an amine. (C) an alcohol. (D) an aldehyde.

2023 Paper 1 Section 1 Question 12 Properties and structure of organic materials	Enzymes are classified as (A) carbohydrates. (B) proteins. (C) starches. (D) lipids.

2023 Paper 1 Section 1 Question 14 Properties and structure of organic materials	Identify which molecule has the lowest boiling point. (A) butanone (B) hexanone (C) pentanone (D) propanone

2023 Paper 1 Section 1 Question 16 Properties and structure of organic materials	Haloalkanes undergo a substitution reaction with cyanide (CN^-) in ethanol to produce (A) alkanes. (B) amines. (C) nitriles. (D) esters.

2023 Paper 1 Section 1 Question 17 **Properties and structure of organic materials**	Questions 17–18 refer to the reaction shown.  **Question 17** Determine the functional group present in Product X. (A) ester (B) ketone (C) alcohol (D) aldehyde **Question 18** Identify the reaction used to produce X. (A) addition (B) hydration (C) condensation (D) hydrogenation

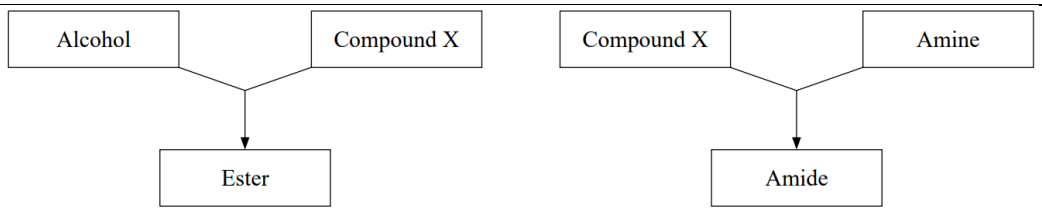
2023 Paper 1 Section 1 Question 19 **Properties and structure of organic materials**	Identify the polymer shown.  (A) polyethene (B) polypeptide (C) polypropene (D) polysaccharide

2022 Paper 1 Section 1 Question 1 **Properties and structure of organic materials**	Identify the type of reaction that occurs when ethene undergoes polymerisation to form polyethene. (A) addition (B) elimination (C) substitution (D) condensation

2022 Paper 1 Section 1 Question 2 **Properties and structure of organic materials**	Structural isomers are compounds with the same molecular formula but a different (A) molar mass. (B) molecular mass. (C) empirical formula. (D) arrangement of atoms.

2022 Paper 1 Section 1 Question 7

Properties and structure of organic materials

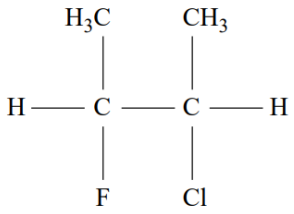


Compound X in these reaction pathways is

(A) a ketone.
(B) an alkene.
(C) an aldehyde.
(D) a carboxylic acid.

2022 Paper 1 Section 1 Question 9

Properties and structure of organic materials



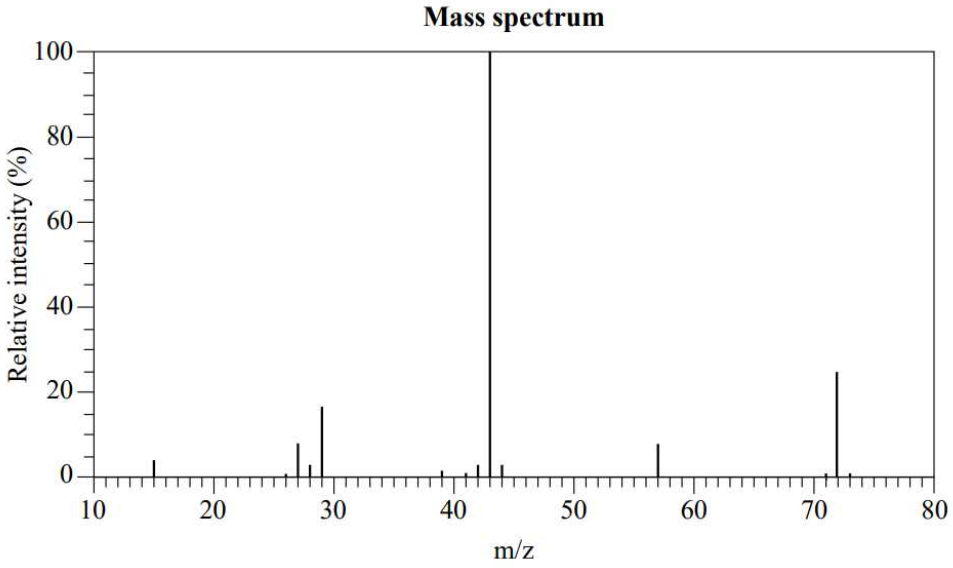
The IUPAC name for this molecule is

(A) 2-chloro-3-fluorobutane.
(B) 2-fluoro-3-chlorobutane.
(C) 2-dimethyl-1-chloro-2-fluoroethane.
(D) 1,2-dimethyl-1-fluoro-2-chloroethane.

2022 Paper 1 Section 1 Question 14

Properties and structure of organic materials

The mass spectrum for Compound X is found to have signals at the following m/z values.

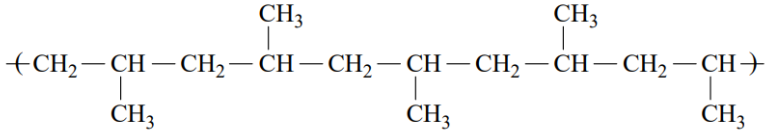
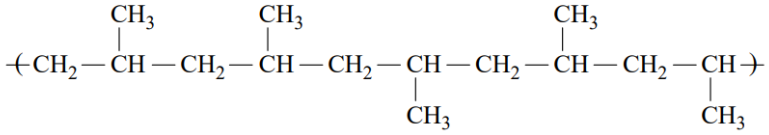


Compound X is

(A) butanal.
(B) butanol.
(C) butanone.
(D) butanoic acid.

2022 Paper 1 Section 1 Question 20

Properties and structure of organic materials

1	
2	

The two forms of polypropene shown are

	1	2
(A)	syntactic	atactic
(B)	isotactic	atactic
(C)	isotactic	syntactic
(D)	atactic	syntactic

2021 Paper 1 Section 1 Question 1

Properties and structure of organic materials

Melting is a

(A) physical change that is reversible.
(B) chemical change that is reversible.
(C) physical change that is irreversible.
(D) chemical change that is irreversible.

2021 Paper 1 Section 1 Question 2

Properties and structure of organic materials

Intra-chain hydrogen bonding between peptide groups occurs in

(A) primary protein structures.
(B) secondary protein structures.
(C) tertiary protein structures.
(D) quaternary protein structures.

2021 Paper 1 Section 1 Question 6

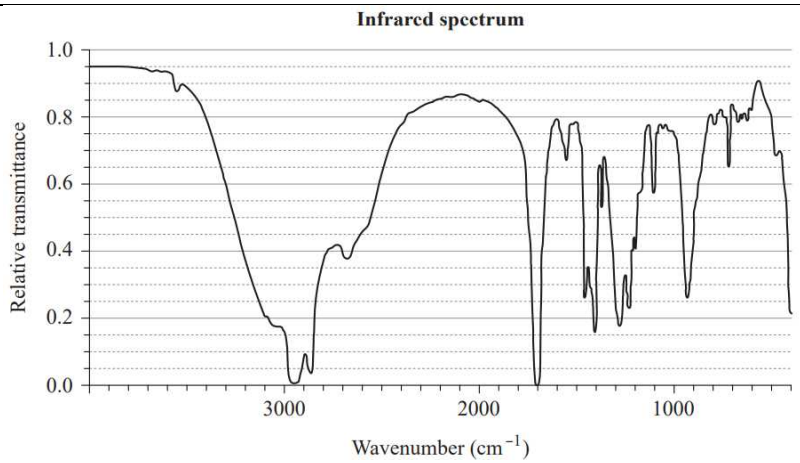
Properties and structure of organic materials

Which type of atoms would be more likely to gain electrons based on its position in the periodic table?

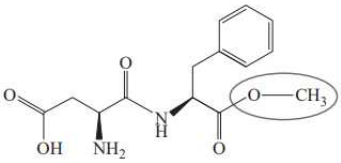
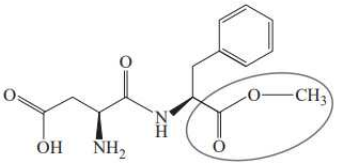
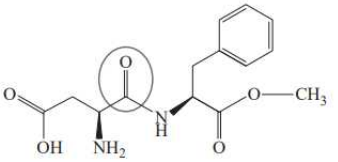
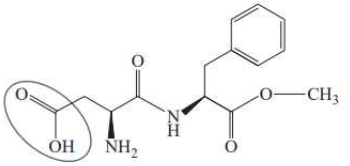
(A) halogens
(B) noble gases
(C) alkali metals
(D) alkaline earth metals

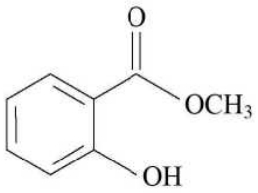
2021 Paper 1 Section 1 Question 7 **Properties and structure of organic materials**	Identify which molecule is an amide. (A) CH_3CH_2CN (B) $CH_3CH_2NH_2$ (C) NH_4CH_3COO (D) $CH_3CONHCH_3$

2021 Paper 1 Section 1 Question 9 **Properties and structure of organic materials**	The boiling points of methane, ethane and propane increase as the lengths of the carbon chains increase because more energy is required to overcome the (A) intramolecular hydrogen bonds. (B) intermolecular hydrogen bonds. (C) intramolecular dispersion forces. (D) intermolecular dispersion forces.

2021 Paper 1 Section 1 Question 13 **Properties and structure of organic materials**	 Determine the functional group present in the infrared spectrum. (A) ester (B) ketone (C) alcohol (D) carboxylic acid

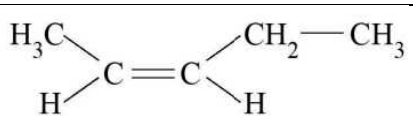
2021 Paper 1 Section 1 Question 15 **Properties and structure of organic materials**	Which organic compound has the highest boiling point? (A) $CH_3(CH_2)_3CH_3$ (B) $CH_3(CH_2)_3CHO$ (C) $CH_2CH(CH_2)_2CH_3$ (D) $CH_3(CH_2)_3CH_2OH$

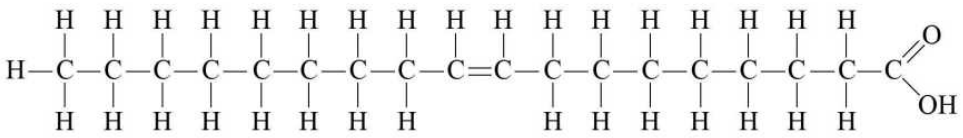
2021 Paper 1 Section 1 Question 20 Properties and structure of organic materials	Identify the ester linkage in aspartame. (A)  (B)  (C)  (D) 

2020 Paper 1 Section 1 Question 4 Properties and structure of organic materials	Oil of wintergreen is a chemical compound with the following chemical structure.  Identify the functional groups present in oil of wintergreen. (A) alcohol and ester (B) alcohol and ketone (C) alcohol and aldehyde (D) alcohol and carboxylic acid

2020 Paper 1 Section 1 Question 8 Properties and structure of organic materials	An organic compound, X, reacts with sodium hydrogen carbonate to form carbon dioxide gas. Compound X is (A) an amine. (B) a haloalkane. (C) a carboxylic acid. (D) a primary alcohol.

2020 Paper 1 Section 1 Question 11 Properties and structure of organic materials	Determine the colour of a solution with a pH of 9.6 containing bromocresol green indicator. (A) pink (B) blue (C) green (D) yellow

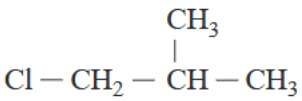
2020 Paper 1 Section 1 Question 12 Properties and structure of organic materials	 Apply IUPAC rules to name the molecule. (A) *cis*–2–pentene (B) *trans*–2–pentene (C) *cis*–1–ethyl–2–methylethene (D) *trans*–1–ethyl–2–methylethene

2020 Paper 1 Section 1 Question 15 Properties and structure of organic materials	 This compound is an unsaturated fatty acid because it contains a (A) double bond and a carboxylic acid group. (B) long carbon chain and a carboxylic acid group. (C) double bond, an aldehyde group and a hydroxyl group. (D) long carbon chain, an aldehyde group and a hydroxyl group.

2020 Paper 1 Section 1 Question 19 Properties and structure of organic materials	Dispersion forces, hydrogen bonding, disulphide bridges and ionic bonding all contribute to the (A) primary structure of proteins. (B) secondary structure of proteins. (C) tertiary structure of proteins. (D) quaternary structure of proteins.

Paper 1 Section 2

2024 Paper 1 Section 2 Question 25 **Properties and structure of organic materials**	Maltose is a disaccharide formed when two monomers of α-glucose are joined. a) Identify whether α-glucose is an aldose or ketose monosaccharide. [1 mark] b) Distinguish between α-glucose and β-glucose. [2 marks]

2024 Paper 1 Section 2 Question 28 **Properties and structure of organic materials**	One structural isomer of C_4H_9Cl is shown.  a) Explain why the isomer is a saturated compound. [1 mark] b) Identify whether the isomer is a primary or secondary haloalkane. [1 mark]

c) Determine the structural formula of another isomer of C_4H_9Cl that is a tertiary haloalkane, and apply IUPAC rules to name this isomer. [2 marks]

IUPAC name:

2023 Paper 1 Section 2 Question 22

Properties and structure of organic materials

(a) Write a balanced chemical equation to describe how polytetrafluorethene (PTFE) is produced from its monomer. [2 marks]

(b) Determine whether polytetrafluorethene is an addition or condensation polymer. Explain your reasoning. [2 marks]

2023 Paper 1 Section 2 Question 26

Properties and structure of organic materials

The table shows a series of reactions that were performed to produce organic compounds A, B and C.

Reaction	Reactant	Reagents/conditions	Products
1	propanol	conc. $H_2SO_4(aq)$ / heat	compound A and water
2	compound A	$H_2O(g)$ / heat	compound B and propanol
3	compound B	$H^+(aq)$ / $KMnO_4(aq)$ / heat	compound C

(a) Determine the IUPAC name for compound A. [1 mark]

IUPAC name:

	(b) Explain one structural difference between compound B and propanol. [2 marks] c) Deduce the structural formula of compound C. [1 mark] (d) Describe one qualitative observation that would be expected for reaction 3. [1 mark]
2022 Paper 1 Section 2 Question 21 Properties and structure of organic materials	a) Identify whether 2-bromopropane is a saturated or unsaturated compound. Explain your reasoning. [2 marks] b) Determine whether 2-bromopropane is a primary, secondary or tertiary halogenoalkane. Explain your reasoning. [2 marks]

2022 Paper 1 Section 2 Question 22

Properties and structure of organic materials

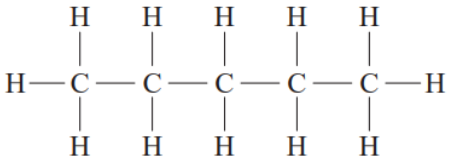
Calculate the concentration of HF (hydrogen fluoride) in an aqueous solution with a pH of 4.00 ($K_a = 7.2 \times 10^{-4}$). Show your working. [2 marks]

Concentration = _____ mol L^{-1} (to two significant figures)

2021 Paper 1 Section 2 Question 22

Properties and structure of organic materials

The structural formula for pentane (C_5H_{12}) is shown.



Draw the structural formulas for two structural isomers of pentane. Name each isomer.

a) Isomer 1 [2 marks]

Note: If you make a mistake in the drawing, cancel it by ruling a single diagonal line through your work and use the additional response space on page 16 of this question and response book.

IUPAC name:

b) Isomer 2 [2 marks]

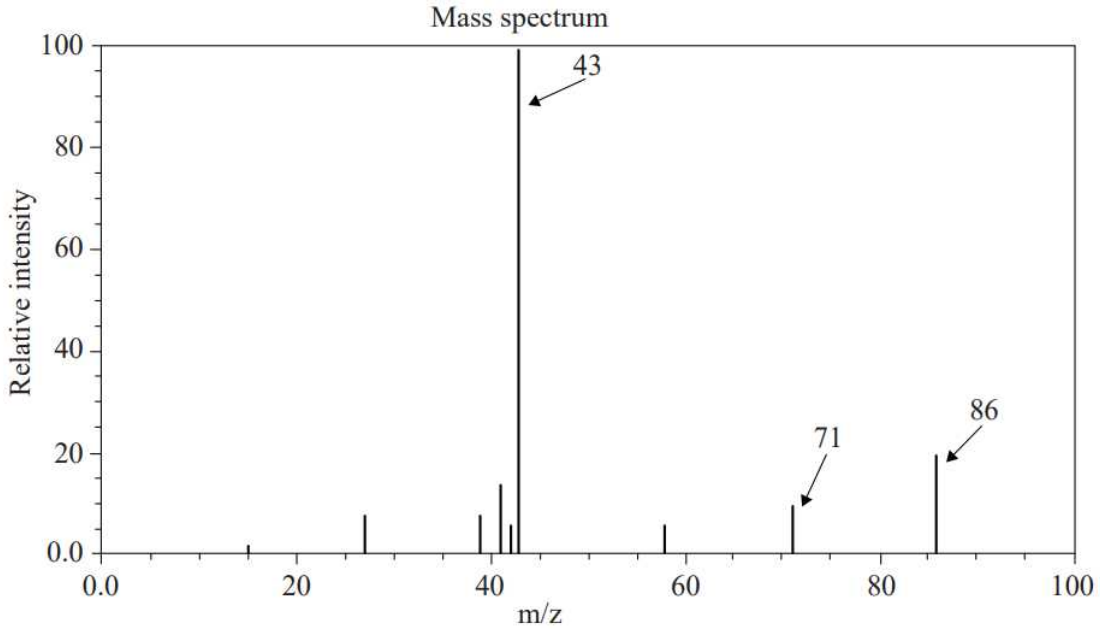
Note: If you make a mistake in the drawing, cancel it by ruling a single diagonal line through your work and use the additional response space on page 16 of this question and response book.

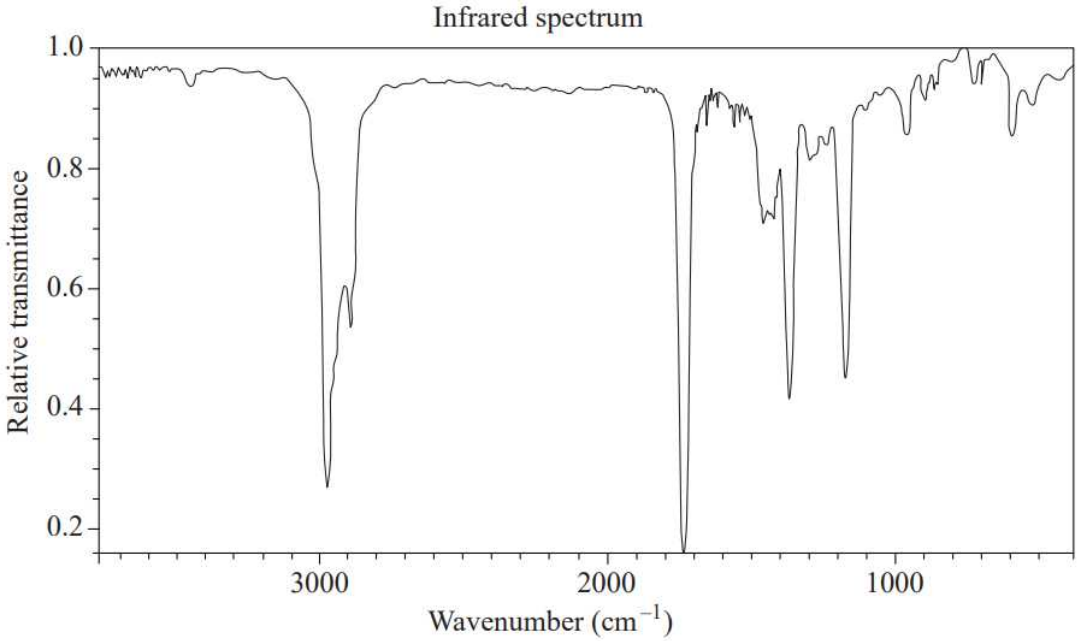
IUPAC name:

2020 Paper 1 Section 2 Question 26

Properties and structure of organic materials

The mass and infrared spectra for an organic compound, X, with the empirical formula $C_5H_{10}O$, are shown.



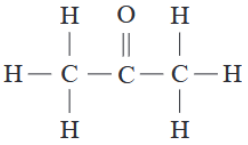


Analyse the spectra to deduce the structural formula of X. Explain your reasoning. [5 marks]

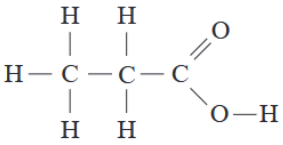
2024 Paper 2 Section 1 Question 6

Properties and structure of organic materials

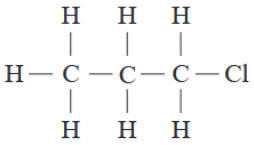
Six molecules were selected to investigate functional groups and the arrangement of atoms.



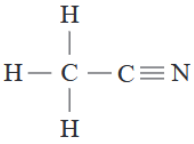
Molecule 1



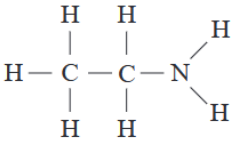
Molecule 2



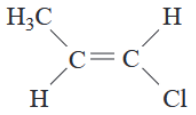
Molecule 3



Molecule 4



Molecule 5



Molecule 6

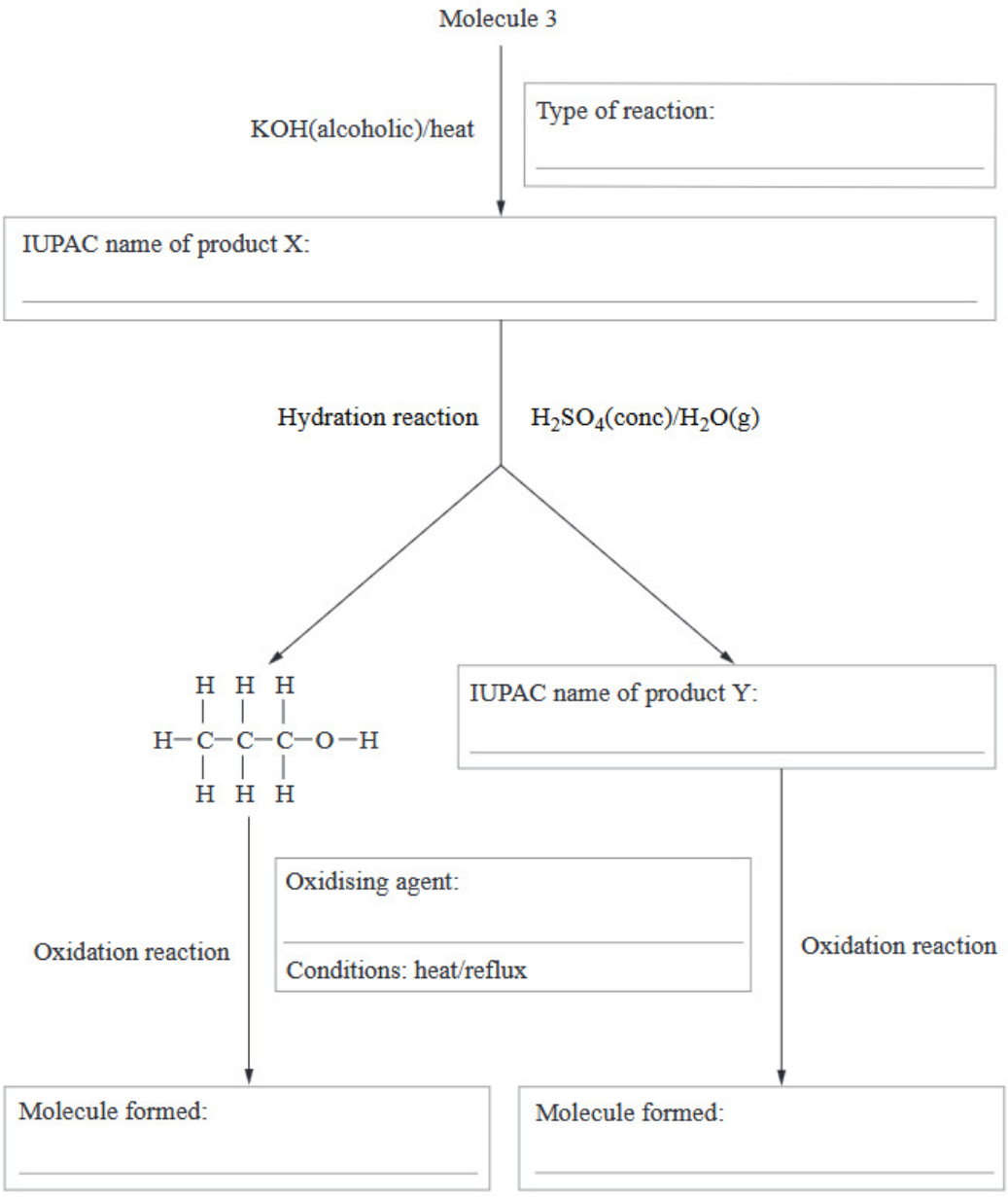
a) Identify a molecule that contains a carbonyl functional group. [1 mark]

b) Identify a geometric isomer of molecule 6 and apply IUPAC rules to name the geometric isomer. [1 mark]

IUPAC name:

c) Describe, using a balanced chemical equation, how molecule 4 can be converted to molecule 5. Include all relevant reagents. [2 marks]

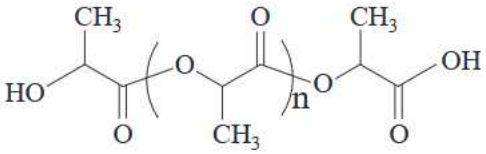
d) Complete the diagram to explain how molecule 3 can be converted into molecule 1 and molecule 2. [5 marks]



2024 Paper 2 Section 1 Question 7

Properties and structure of organic materials

Polylactic acid (PLA) is a biodegradable plastic that can be decomposed by microorganisms into carbon dioxide (CO_2), water and biomass.



Polylactic acid

a) Explain how the biodegradability of polylactic acid is related to its structure. [2 marks]

b) Describe, using a diagram, the structural formula of lactic acid. [2 marks]

2024 Paper 2 Section 1 Question 8

Properties and structure of organic materials

In the aqueous solution of a chromate salt, an equilibrium exists between the yellow chromate $\left(CrO_4^{2-}\right)$ ions and the orange dichromate $\left(Cr_2O_7^{2-}\right)$ ions. This equilibrium can be represented by the equation shown.

$$2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(l)$$
(yellow) (orange)

Explain, at an atomic level, why no colour change occurs once the chromate–dichromate solution has established equilibrium.

2023 Paper 2 Section 1 Question 1

Properties and structure of organic materials

Polylactic acid (PLA) and low-density polyethylene (LDPE) are both used to produce plastic wrapping film.

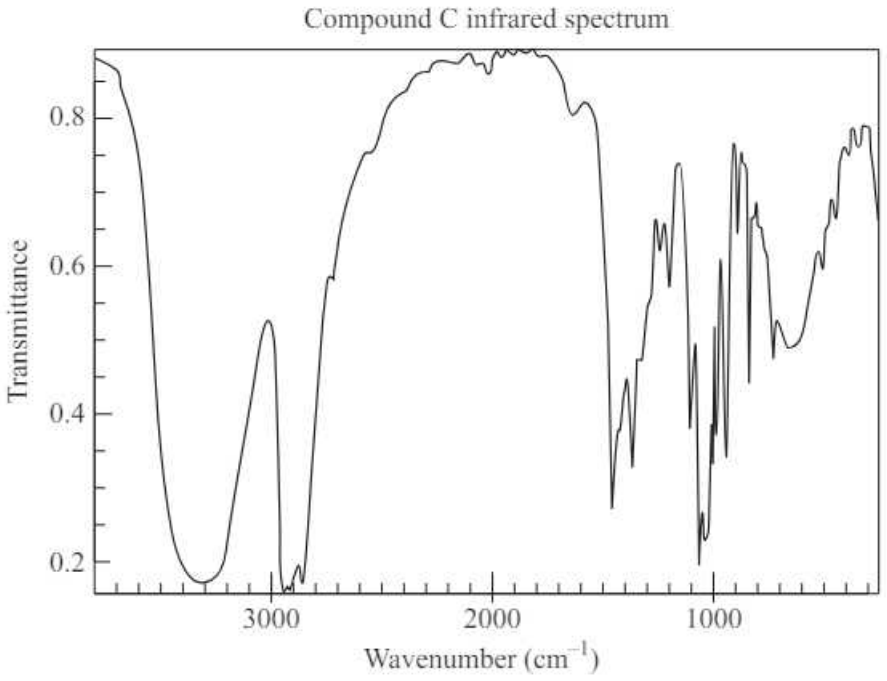
Plastic	Composition	Density (g/cm^3)	Tensile stress (MPa)	Elongation (%)	Degradation rate
PLA	plant-based	1.24	60	6	slow
LDPE	petrochemical-based	0.92	12	148	none

Analyse the data to discuss one advantage and one disadvantage of using PLA rather than LDPE to produce plastic wrapping film. [2 marks]

Advantage:

Disadvantage:

2023 Paper 2 Section 1 Question 2 Properties and structure of organic materials	Compare the structure of α-helix and β-pleated sheets in the secondary structure of proteins. [3 marks] Similarity: Difference: Significance:

2023 Paper 2 Section 1 Question 4 Properties and structure of organic materials	Compound C has the molecular formula $C_4H_{10}O$ and is either an alcohol, an aldehyde or a carboxylic acid.  (a) Deduce the class of compound C. Explain your reasoning. [4 marks]

(b) Deduce the structural formula and IUPAC name of two isomers of compound C. [2 marks]

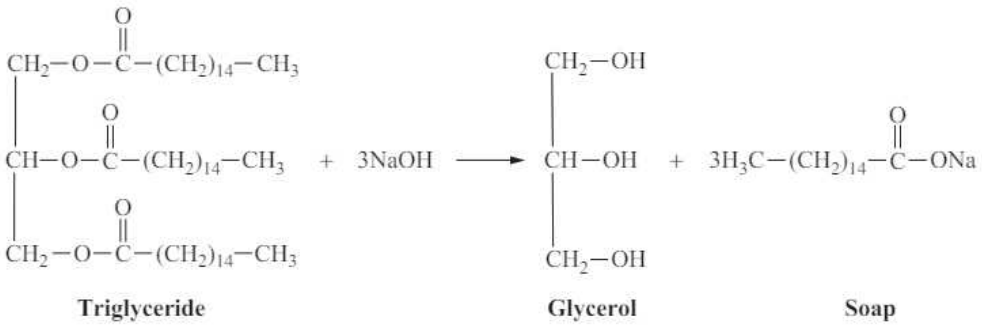
Isomer 1:

IUPAC name:

Isomer 2:

IUPAC name:

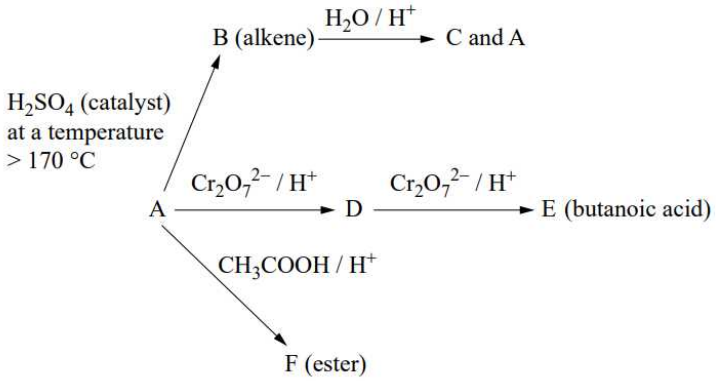
(c) Distinguish between structural and geometric isomers. [2 marks]

2023 Paper 2 Section 1 Question 6 Properties and structure of organic materials	The reaction shows the base hydrolysis (saponification) of a triglyceride to produce glycerol and a soap.  (a) Identify which compound in the reaction is an ester. [1 mark] (b) Contrast the structure of saturated and unsaturated fatty acids. [1 mark] (c) Explain how the cleaning action of soap is related to its structure. [4 marks]

2022 Paper 2 Section 1 Question 1

Properties and structure of organic materials

The diagram shows a series of different reactions starting with compound A, which has the empirical formula $C_4H_{10}O$.



a) Identify the class of organic compounds that compound A belongs to. [1 mark]

b) Compound C is an isomer of compound A. Deduce the structural formulas and IUPAC names of compounds A and C. [4 marks]

i) Compound A

Note: If you make a mistake in the drawing, cancel it by ruling a single diagonal line through your work and use the additional response space at the back of this question and response book.

IUPAC name:

ii) Compound C

Note: If you make a mistake in the drawing, cancel it by ruling a single diagonal line through your work and use the additional response at the back of this question and response book.

IUPAC name:

---

c) Identify whether compounds A and C are structural or geometric isomers. [1 mark]

---

d) Deduce the structural formula and IUPAC name for compound F. [2 marks]

Compound F

Note: If you make a mistake in the drawing, cancel it by ruling a single diagonal line through your work and use the additional response space at the back of this question and response book.

IUPAC name:

2022 Paper 2 Section 1 Question 6 **Properties and structure of organic materials**	Polypeptides and proteins are formed by condensation reactions of amino acids. a) Identify the type of bond formed when three amino acids are joined to form a tripeptide and state any other product/s formed. [2 marks] b) Determine the total number of tripeptides that can be formed containing histidine, lysine and glycine and use the three-letter symbols for the amino acids to describe two of the tripeptides formed. [3 marks] c) Explain how the pH of the buffer solution can be used to separate histidine, lysine and glycine through electrophoresis. [3 marks]

2021 Paper 2 Section 1 Question 3

Properties and structure of organic materials

Four colourless liquids, A, B, C and D, are known to be butane, 1-butene, 2-butanol and 1-propanol. Reactions are carried out to identify the liquids. The results are shown.

Test 1	A	B	C	D
Bromine (Br_2) water	No reaction	No reaction	No reaction	Decolourised

Test 2	A	B	C
Excess acidified potassium manganate(VII) ($KMnO_4$) solution, heated gently	Decolourised, Compound X formed	Decolourised, Compound Y formed	No reaction

Test 3	Compound X	Compound Y
Ethanol and concentrated sulfuric acid solution, heated gently and refluxed	Fruity smell produced, Compound Z formed	No apparent reaction

a) Identify Compound D. Explain your reasoning. [2 marks]

b) Write a balanced equation to describe the decolourisation of bromine (Br2) water by Compound D. Apply IUPAC rules to name the product formed. [2 marks]

IUPAC name:

c) Identify Compound C. Explain your reasoning. [3 marks]

d) Draw the structural formula of Compound Y. [1 mark]

Note: If you make a mistake in the drawing, cancel it by ruling a single diagonal line through your work and use the additional response space on page 17 of this question and response book.

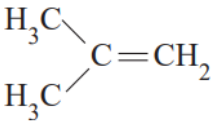
e) Identify Compound B. [1 mark]

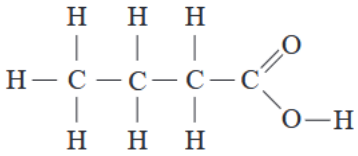
f) Draw the structural formula of Compound Z. [1 mark]

Note: If you make a mistake in the drawing, cancel it by ruling a single diagonal line through your work and use the additional response space on page 17 of this question and response book.

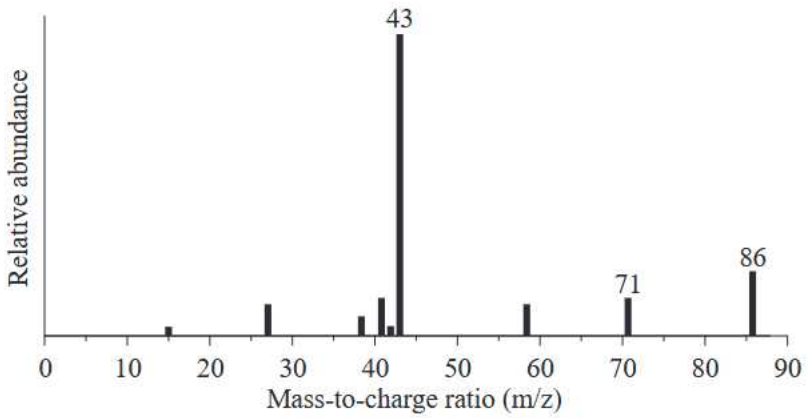
g) Apply IUPAC rules to name Compound Z. [1 mark]

IUPAC name:

2020 Paper 2 Section 1 Question 4 **Properties and structure of organic materials**	Consider the organic molecule shown.  a) Identify the molecule as saturated or unsaturated. [1 mark] b) Apply IUPAC rules to name this molecule. [1 mark] c) Write an equation to show the products formed by the hydration of this molecule. [2 marks] d) Predict which is the major product formed in c). [1 mark] e) Identify a physical property and experimental technique that could be used to separate products formed by hydration in c). Explain your reasoning. [5 marks]

2024 Paper 1 Section 1 Question 8 **Properties and structure of organic materials**	 Determine the IUPAC name of the organic compound shown. **(A) butanoic acid – Answer** (B) butanone (C) butanol (D) butanal

2024 Paper 1 Section 1 Question 9 **Properties and structure of organic materials**	Polytetrafluorethene (PTFE) has a higher melting point than polypropene (PP) due to the (A) C– F bonds being non-reactive. (B) fluorine atoms forming stable C– F covalent bonds. **(C) dispersion forces between closely packed fluorocarbon chains. – Answer** (D) dipole–dipole interaction between fluorine and carbon atoms within the fluorocarbon chain

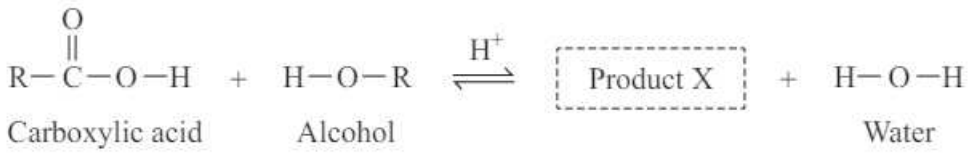
2024 Paper 1 Section 1 Question 16 **Properties and structure of organic materials**	The simplified mass spectrum for an organic compound C_5H_xO is shown.  Determine which compound the mass spectrum belongs to. **(A) pentan-2-one – Answer** (B) pentan-3-one (C) pentan-1-ol (D) pentanal

2024 Paper 1 Section 1 Question 19 **Properties and structure of organic materials**	Esters undergo hydrolysis to form a carboxylic acid and (A) water. (B) an amine. **(C) an alcohol. – Answer** (D) an aldehyde.

2023 Paper 1 Section 1 Question 12 Properties and structure of organic materials	Enzymes are classified as (A) carbohydrates. **(B) proteins. – Answer** (C) starches. (D) lipids.

2023 Paper 1 Section 1 Question 14 Properties and structure of organic materials	Identify which molecule has the lowest boiling point. (A) butanone (B) hexanone (C) pentanone **(D) propanone – Answer**

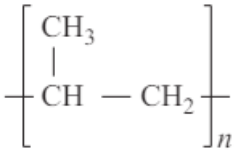
2023 Paper 1 Section 1 Question 16 Properties and structure of organic materials	Haloalkanes undergo a substitution reaction with cyanide (CN^-) in ethanol to produce (A) alkanes. (B) amines. (C) nitriles. (D) esters. **Answer is C.**

2023 Paper 1 Section 1 Question 17 Properties and structure of organic materials	Questions 17–18 refer to the reaction shown.  **Question 17** Determine the functional group present in Product X. **(A) ester - Answer** (B) ketone (C) alcohol (D) aldehyde **Question 18** Identify the reaction used to produce X. (A) addition (B) hydration **(C) condensation - Answer** (D) hydrogenation

2023 Paper 1 Section 1 Question 19

Properties and structure of organic materials

Identify the polymer shown.



(A) polyethene
(B) polypeptide
(C) polypropene – Answer
(D) polysaccharide

2023 Paper 1 Section 2 Question 22

Properties and structure of organic materials

(a) Write a balanced chemical equation to describe how polytetrafluorethene (PTFE) is produced from its monomer. [2 marks]

Sample response	The response
$n\,F_2C=CF_2 \rightarrow \left[F_2C-CF_2\right]_n$	• describes formulas for tetrafluorethene monomer and polytetrafluorethene polymer **[1 mark]** • provides a balanced equation **[1 mark]**

(b) Determine whether polytetrafluorethene is an addition or condensation polymer. Explain your reasoning. [2 marks]

Sample response	The response
Addition polymer The double bond in tetrafluorethene is broken to allow the monomers to join.	• identifies addition polymer **[1 mark]** • explains double bond in monomer is broken to allow the formation of polymer **[1 mark]**

2023 Paper 1 Section 2 Question 26

Properties and structure of organic materials

The table shows a series of reactions that were performed to produce organic compounds A, B and C.

Reaction	Reactant	Reagents/conditions	Products
1	propanol	conc. $H_2SO_4(aq)$ / heat	compound A and water
2	compound A	$H_2O(g)$ / heat	compound B and propanol
3	compound B	$H^+(aq)$ / $KMnO_4(aq)$ / heat	compound C

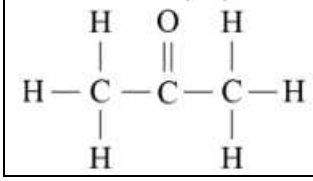
(a) Determine the IUPAC name for compound A. [1 mark]

Sample response	The response
IUPAC name: **propene**	• determines compound A is propene **[1 mark]**

(b) Explain one structural difference between compound B and propanol. [2 marks]

Sample response	The response
Compound B (2-propanol) is a secondary alcohol. Propanol is a primary alcohol. The OH group is attached to the second carbon atom in compound B and the terminal carbon atom in propanol.	• identifies compound B is a secondary alcohol and propanol is a primary alcohol **[1 mark]** • explains that the OH group in propanol is attached to a terminal carbon while the OH group in compound B is attached to the second C in the parent chain **[1 mark]**

c) Deduce the structural formula of compound C. [1 mark]

Sample response	The response
IUPAC name: propanone 	• deduces the structural formula for propanone **[1 mark]**

(d) Describe one qualitative observation that would be expected for reaction 3. [1 mark]

Sample response	The response
The purple colour of $KMnO_4$ would become lighter.	• describes a qualitative observation **[1 mark]**

2022 Paper 1 Section 1 Question 1

Properties and structure of organic materials

Identify the type of reaction that occurs when ethene undergoes polymerisation to form polyethene.

(A) addition – Answer
(B) elimination
(C) substitution
(D) condensation

2022 Paper 1 Section 1 Question 2

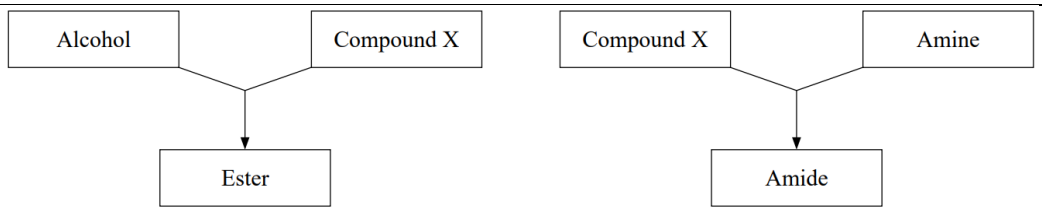
Properties and structure of organic materials

Structural isomers are compounds with the same molecular formula but a different

(A) molar mass.
(B) molecular mass.
(C) empirical formula.
(D) arrangement of atoms. – Answer

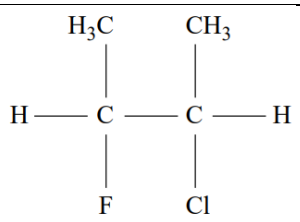
2022 Paper 1 Section 1 Question 7

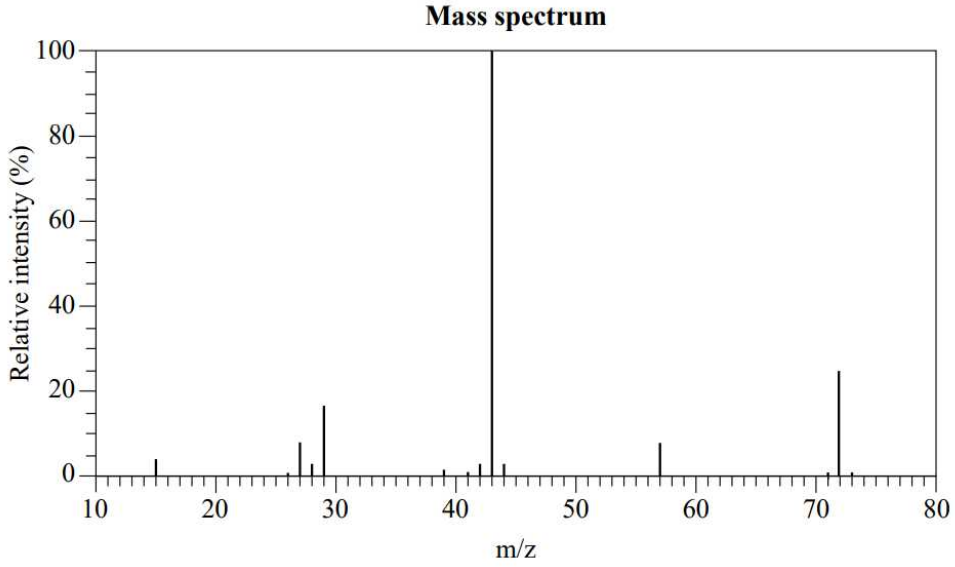
Properties and structure of organic materials



Compound X in these reaction pathways is

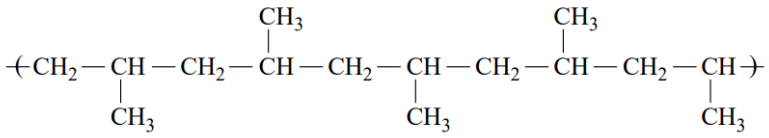
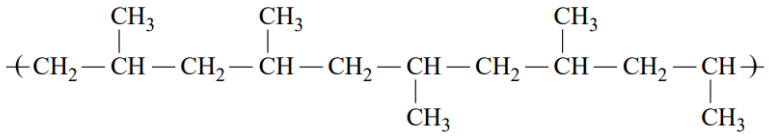
(A) a ketone.
(B) an alkene.
(C) an aldehyde.
(D) a carboxylic acid. – Answer

2022 Paper 1 Section 1 Question 9 Properties and structure of organic materials	 The IUPAC name for this molecule is **(A) 2-chloro-3-fluorobutane. – Answer** (B) 2-fluoro-3-chlorobutane. (C) 2-dimethyl-1-chloro-2-fluoroethane. (D) 1,2-dimethyl-1-fluoro-2-chloroethane.

2022 Paper 1 Section 1 Question 14 Properties and structure of organic materials	The mass spectrum for Compound X is found to have signals at the following m/z values.  Compound X is (A) butanal. (B) butanol. **(C) butanone. – Answer** (D) butanoic acid.

2022 Paper 1 Section 1 Question 20

Properties and structure of organic materials

1	
2	

The two forms of polypropene shown are

	1	2
(A)	syntactic	atactic
(B)	isotactic	atactic
(C)	isotactic	syntactic
(D)	atactic	syntactic

Answer is A.

2021 Paper 1 Section 1 Question 1

Properties and structure of organic materials

Melting is a

(A) physical change that is reversible. – Answer
(B) chemical change that is reversible.
(C) physical change that is irreversible.
(D) chemical change that is irreversible.

2021 Paper 1 Section 1 Question 2

Properties and structure of organic materials

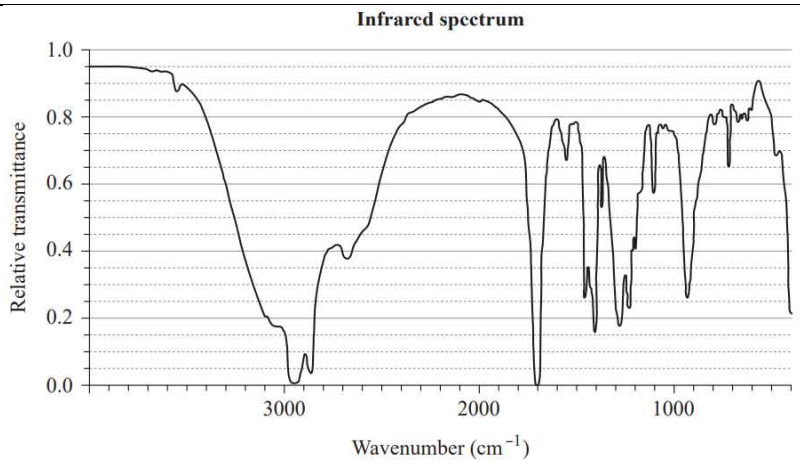
Intra-chain hydrogen bonding between peptide groups occurs in

(A) primary protein structures.
(B) secondary protein structures. – Answer
(C) tertiary protein structures.
(D) quaternary protein structures.

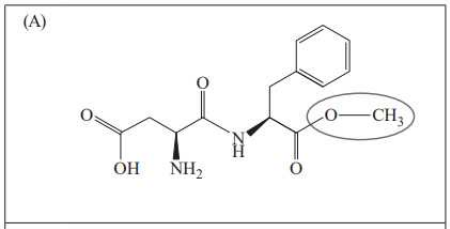
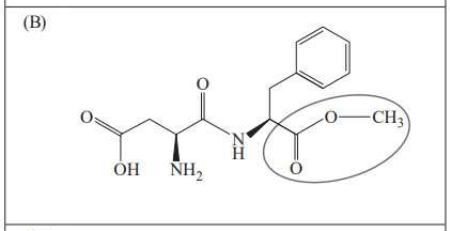
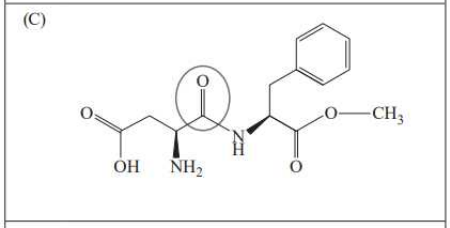
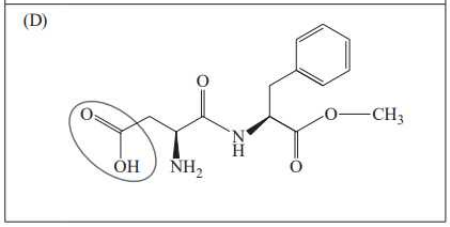
2021 Paper 1 Section 1 Question 6 Properties and structure of organic materials	Which type of atoms would be more likely to gain electrons based on its position in the periodic table? **(A) halogens – Answer** (B) noble gases (C) alkali metals (D) alkaline earth metals

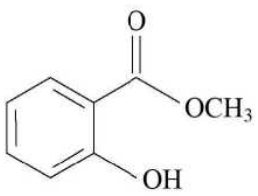
2021 Paper 1 Section 1 Question 7 Properties and structure of organic materials	Identify which molecule is an amide. (A) CH_3CH_2CN (B) $CH_3CH_2NH_2$ (C) NH_4CH_3COO (D) $CH_3CONHCH_3$ **Answer is D.**

2021 Paper 1 Section 1 Question 9 Properties and structure of organic materials	The boiling points of methane, ethane and propane increase as the lengths of the carbon chains increase because more energy is required to overcome the (A) intramolecular hydrogen bonds. (B) intermolecular hydrogen bonds. (C) intramolecular dispersion forces. **(D) intermolecular dispersion forces. – Answer**

2021 Paper 1 Section 1 Question 13 Properties and structure of organic materials	 Determine the functional group present in the infrared spectrum. (A) ester (B) ketone (C) alcohol **(D) carboxylic acid – Answer**

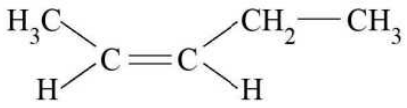
2021 Paper 1 Section 1 Question 15 Properties and structure of organic materials	Which organic compound has the highest boiling point? (A) $CH_3(CH_2)_3CH_3$ (B) $CH_3(CH_2)_3CHO$ (C) $CH_2CH(CH_2)_2CH_3$ (D) $CH_3(CH_2)_3CH_2OH$ **Answer is D.**

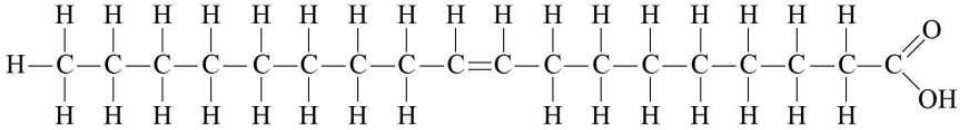
2021 Paper 1 Section 1 Question 20 Properties and structure of organic materials	Identify the ester linkage in aspartame. (A)  (B)  (C)  (D)  **Answer is B.**

2020 Paper 1 Section 1 Question 4 Properties and structure of organic materials	Oil of wintergreen is a chemical compound with the following chemical structure.  Identify the functional groups present in oil of wintergreen. **(A) alcohol and ester – Answer** (B) alcohol and ketone (C) alcohol and aldehyde (D) alcohol and carboxylic acid

2020 Paper 1 Section 1 Question 8 Properties and structure of organic materials	An organic compound, X, reacts with sodium hydrogen carbonate to form carbon dioxide gas. Compound X is (A) an amine. (B) a haloalkane. **(C) a carboxylic acid. – Answer** (D) a primary alcohol.

2020 Paper 1 Section 1 Question 11 Properties and structure of organic materials	Determine the colour of a solution with a pH of 9.6 containing bromocresol green indicator. (A) pink **(B) blue – Answer** (C) green (D) yellow

2020 Paper 1 Section 1 Question 12 Properties and structure of organic materials	 Apply IUPAC rules to name the molecule. (A) *cis*–2–pentene (B) *trans*–2–pentene (C) *cis*–1–ethyl–2–methylethene (D) *trans*–1–ethyl–2–methylethene **Answer is A.**

2020 Paper 1 Section 1 Question 15 Properties and structure of organic materials	 This compound is an unsaturated fatty acid because it contains a **(A) double bond and a carboxylic acid group. – Answer** (B) long carbon chain and a carboxylic acid group. (C) double bond, an aldehyde group and a hydroxyl group. (D) long carbon chain, an aldehyde group and a hydroxyl group.

2020 Paper 1 Section 1 Question 19 Properties and structure of organic materials	Dispersion forces, hydrogen bonding, disulphide bridges and ionic bonding all contribute to the (A) primary structure of proteins. (B) secondary structure of proteins. **(C) tertiary structure of proteins. – Answer** (D) quaternary structure of proteins.

2024 Paper 1 Section 2 Question 25

Properties and structure of organic materials

Maltose is a disaccharide formed when two monomers of α-glucose are joined.

a) Identify whether α-glucose is an aldose or ketose monosaccharide. [1 mark]

Sample response	The response
Glucose is an aldose monosaccharide.	• identifies that glucose is an aldose monosaccharide **[1 mark]**

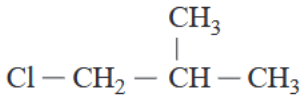
b) Distinguish between α-glucose and β-glucose. [2 marks]

Sample response	The response
α-glucose has its OH group attached on the opposite side of the carbon ring (*trans*) to the CH_2OH group, while β-glucose has its OH group attached on the same side of the ring (*cis*) as the CH_2OH group.	• identifies that α-glucose has its OH group and CH_2OH group attached to opposite sides of ring (*trans*) for **[1 mark]** • identifies that β-glucose has its OH group and CH_2OH group attached on the same side of the ring (*cis*) **[1 mark]**

2024 Paper 1 Section 2 Question 28

Properties and structure of organic materials

One structural isomer of C_4H_9Cl is shown.



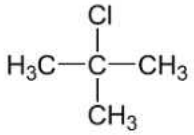
a) Explain why the isomer is a saturated compound. [1 mark]

Sample response	The response
The isomer is a saturated compound because it contains only single bonds.	• identifies that the compound is saturated because it contains only single bonds **[1 mark]**

b) Identify whether the isomer is a primary or secondary haloalkane. [1 mark]

Sample response	The response
Primary haloalkane	• identifies compound is a primary haloalkane **[1 mark]**

c) Determine the structural formula of another isomer of C_4H_9Cl that is a tertiary haloalkane, and apply IUPAC rules to name this isomer. [2 marks]

Sample response	The response
 IUPAC name: 2-chloro-2-methylpropane	• determines structural formula **[1 mark]** • determines IUPAC name **[1 mark]**

2022 Paper 1 Section 2 Question 21

Properties and structure of organic materials

a) Identify whether 2-bromopropane is a saturated or unsaturated compound. Explain your reasoning. [2 marks]

Sample Response	The response
2-bromopropane is saturated because it contains only single bonds.	• identifies 2-bromopropane is satured [1 mark] • indicates 2-bromopropane contains only single bonds [1 mark]

b) Determine whether 2-bromopropane is a primary, secondary or tertiary halogenoalkane. Explain your reasoning. [2 marks]

Sample Response	The response
2-bromopropane is a secondary halogenoalkane, because the carbon that the bromine is attached to two carbon atoms.	• determines 2-bromopropane is a secondary halogenoalkane [1 mark] • explains that the bromine (halogen) is bonded to a carbon that is attached to two other carbon atoms [1 mark]

2022 Paper 1 Section 2 Question 22

Properties and structure of organic materials

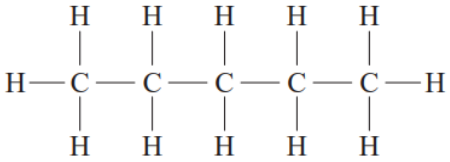
Calculate the concentration of HF (hydrogen fluoride) in an aqueous solution with a pH of 4.00 ($K_a = 7.2 \times 10^{-4}$). Show your working. [2 marks]

Sample Response	The response
$[H_3O^+] = 10^{-4}$ and $[F^-] = 10^{-4}$ $[HF] = \frac{[H_3O^+][F^-]}{K_a}$ $[HF] = \frac{10^{-4} \times 10^{-4}}{7.2 \times 10^{-4}}$ $[HF] = 1.4 \times 10^{-5}$ mol L^{-1}	• uses correct substitution [1 mark] • calculates [HF] = 1.4 x 10^{-5} [1 mark]

2021 Paper 1 Section 2 Question 22

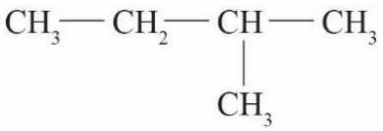
Properties and structure of organic materials

The structural formula for pentane (C_5H_{12}) is shown.

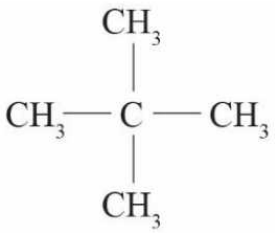


Draw the structural formulas for two structural isomers of pentane. Name each isomer.

a) Isomer 1 [2 marks]

Sample Response	The response	Notes
 IUPAC name: 2-methylbutane	• correctly determines structural formula for 2-methylbutane [1 mark] • determines name [1 mark]	Allow FT error for name. Isomers can be given in either order.

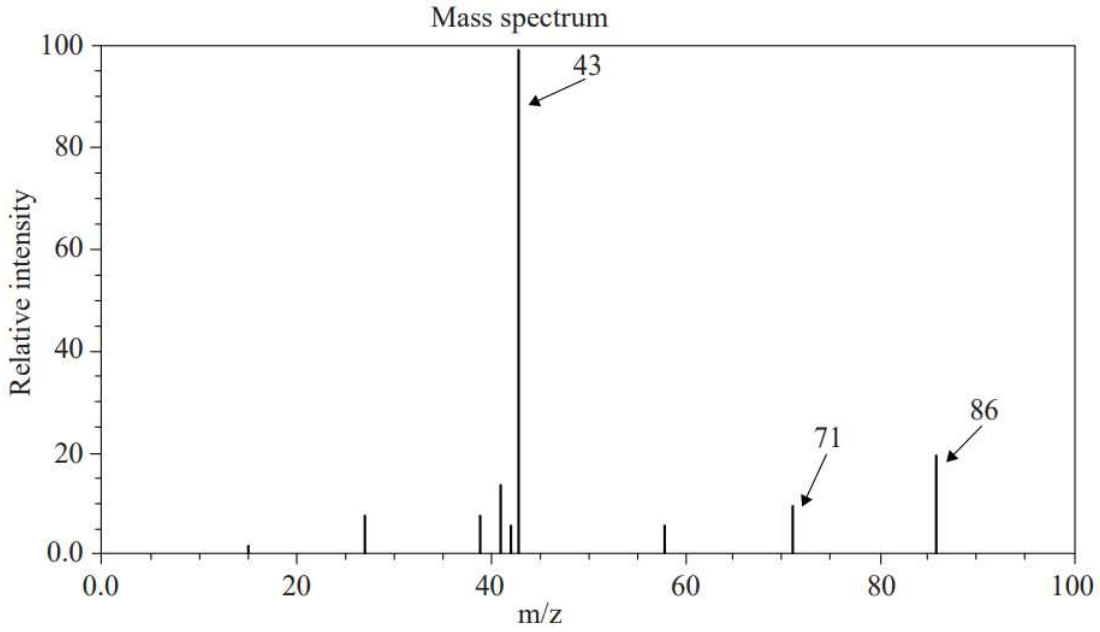
b) Isomer 2 [2 marks]

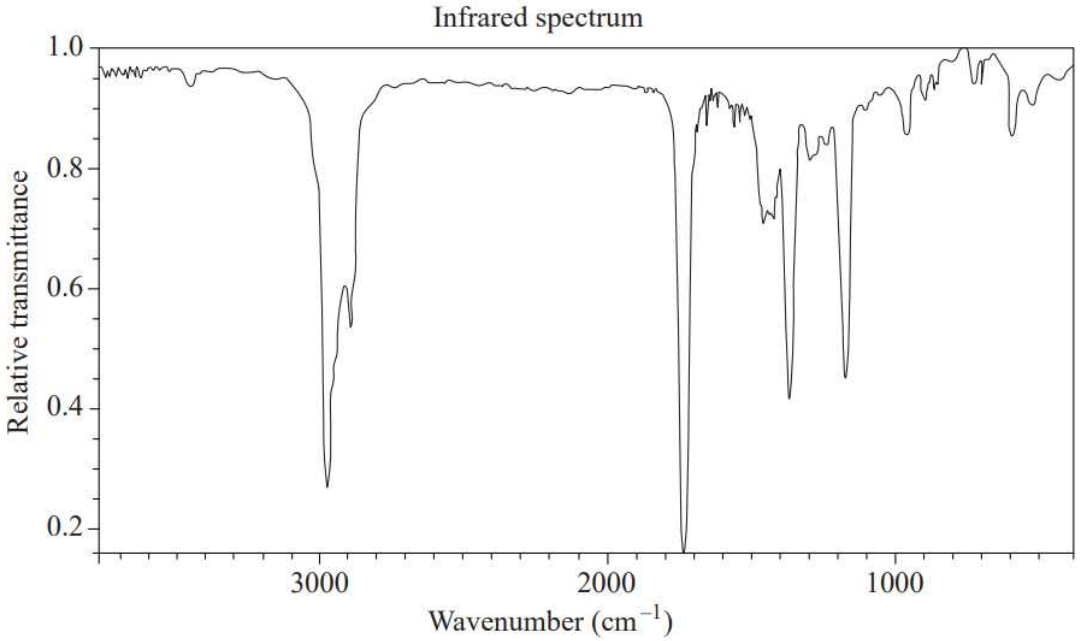
Sample Response	The response	Notes
 IUPAC name: 2,2-dimethylpropane	• correctly determines structural formula for 2,2-dimethylpropane [1 mark] • determines name [1 mark]	Allow FT error for name.

2020 Paper 1 Section 2 Question 26

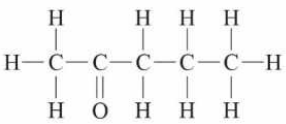
Properties and structure of organic materials

The mass and infrared spectra for an organic compound, X, with the empirical formula $C_5H_{10}O$, are shown.





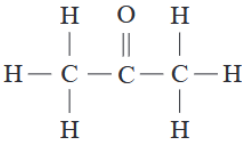
Analyse the spectra to deduce the structural formula of X. Explain your reasoning. [5 marks]

Sample Response	The response
The peak in the IR spectrum at 1700–1750 corresponds to a C=O bond in either an aldehyde or a ketone. There is no stretch in the IR peak at 2720–3100, therefore, the molecule is not an aldehyde and must be a ketone Fragment at m/z = 43 is $CH_3CH_2CH_2^+$ and $COCH_3^+$ Fragment at m/z = 71 is $CH_3CH_2CH_2CO^+$ Empirical formula = 86. This corresponds to the molecular mass shown on the mass spectrum. Therefore, the molecular formula is $C_5H_{10}O$. 	• identifies IR peak at 1700–1750 corresponds to a C=O bond in aldehyde or ketone **[1 mark]** • indicates that X is a ketone **[1 mark]** • identifies mass fragment at – 43 m/z as $CH_3CH_2CH_2^+$ and $COCH_3^+$ **OR** – 71 m/z as $CH_3CH_2CH_2CO^+$ **[1 mark]** • uses mass spectrum data to show that the molecular formula for X is $C_5H_{10}O$ **[1 mark]** • provides correct structural formula for pentan-2-one **[1 mark]**

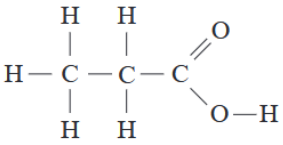
2024 Paper 2 Section 1 Question 6

Properties and structure of organic materials

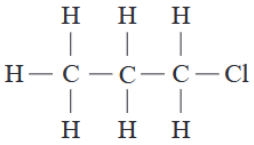
Six molecules were selected to investigate functional groups and the arrangement of atoms.



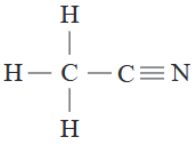
Molecule 1



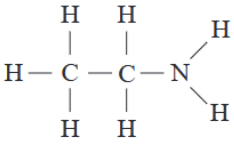
Molecule 2



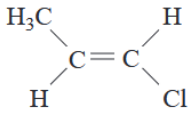
Molecule 3



Molecule 4



Molecule 5



Molecule 6

a) Identify a molecule that contains a carbonyl functional group. [1 mark]

Sample response	The response
Molecule 1	• identifies molecule 1 or molecule 2 **[1 mark]**

b) Identify a geometric isomer of molecule 6 and apply IUPAC rules to name the geometric isomer. [1 mark]

Sample response	The response
cis-1-chloropropene	• determines the IUPAC name of a geometric isomer **[1 mark]**

c) Describe, using a balanced chemical equation, how molecule 4 can be converted to molecule 5. Include all relevant reagents. [2 marks]

Sample response	The response
$CH_3CN(l) + 2H_2(g) \xrightarrow{Pt} CH_3CH_2NH_2(g)$	• determines balanced chemical equation **[1 mark]** • identifies appropriate catalyst **[1 mark]**

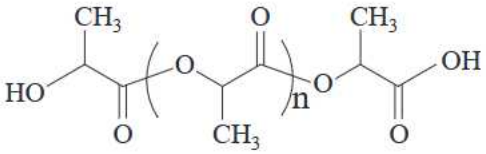
d) Complete the diagram to explain how molecule 3 can be converted into molecule 1 and molecule 2. [5 marks]

Sample response	The response
Type of reaction: elimination IUPAC name of product X: propene IUPAC name of product Y: propan-2-ol Oxidising agent: $K_2Cr_2O_7/H^+$ Propanol forms molecule 2 and propan-2-ol forms molecule 1.	• identifies type of reaction is elimination **[1 mark]** • determines product X is propene **[1 mark]** • determines product Y is propan-2-ol **[1 mark]** • identifies oxidising agent **[1 mark]** • determines that propanol forms molecule 2 **and** propan-2-ol forms molecule 1 **[1 mark]**

2024 Paper 2 Section 1 Question 7

Properties and structure of organic materials

Polylactic acid (PLA) is a biodegradable plastic that can be decomposed by microorganisms into carbon dioxide (CO_2), water and biomass.

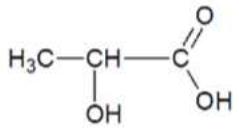


Polylactic acid

a) Explain how the biodegradability of polylactic acid is related to its structure. [2 marks]

Sample response	The response
Polylactic acid contains an ester linkage. Microorganisms produce enzymes that can hydrolyse the ester linkage to decompose PLA into CO_2 and water.	• explains that polylactic acid contains an ester linkage **[1 mark]** • explains that the ester linkage can be hydrolysed **[1 mark]**

b) Describe, using a diagram, the structural formula of lactic acid. [2 marks]

Sample response	The response
	• describes the location of COOH group **[1 mark]** • describes the location of the OH group **[1 mark]**

2024 Paper 2 Section 1 Question 8

Properties and structure of organic materials

In the aqueous solution of a chromate salt, an equilibrium exists between the yellow chromate $\left(CrO_4^{2-}\right)$ ions and the orange dichromate $\left(Cr_2O_7^{2-}\right)$ ions. This equilibrium can be represented by the equation shown.

$$2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(l)$$
(yellow) (orange)

Explain, at an atomic level, why no colour change occurs once the chromate–dichromate solution has established equilibrium.

Sample response	The response
At equilibrium, the forward reaction rate equals the reverse reaction rate. Therefore, yellow chromate ions and orange dichromate ions are re-formed at the same rate at which they are broken down, so the colour remains constant because the $[CrO_4^{2-}]$ and $[Cr_2O_7^{2-}]$ remain constant.	• identifies that the forward reaction rate equals the reverse reaction rate at equilibrium **[1 mark]** • explains that the colour remains constant because the $[CrO_4^{2-}]$ and $[Cr_2O_7^{2-}]$ remain constant **[1 mark]**

2023 Paper 2 Section 1 Question 1

Properties and structure of organic materials

Polylactic acid (PLA) and low-density polyethylene (LDPE) are both used to produce plastic wrapping film.

Plastic	Composition	Density (g/cm^3)	Tensile stress (MPa)	Elongation (%)	Degradation rate
PLA	plant-based	1.24	60	6	slow
LDPE	petrochemical-based	0.92	12	148	none

Analyse the data to discuss one advantage and one disadvantage of using PLA rather than LDPE to produce plastic wrapping film. [2 marks]

Sample response	The response
Advantage: An advantage is that PLA is plant based, therefore it uses (renewable) natural resources while LDPE is produced from non-renewable fossil fuels. Disadvantage: PLA has less % elongation than LDPE, therefore PLA would stretch less.	• identifies an advantage of using PLA using data **[1 mark]** • identifies a disadvantage of using PLA using data **[1 mark]**

2023 Paper 2 Section 1 Question 2

Properties and structure of organic materials

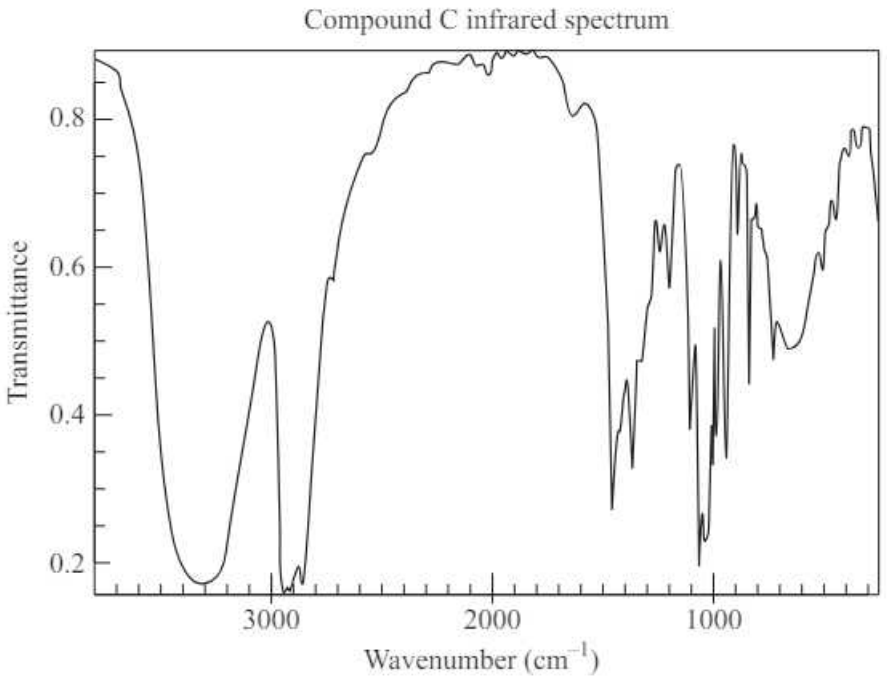
Compare the structure of α-helix and β-pleated sheets in the secondary structure of proteins. [3 marks]

Sample response	The response
Similarity: α-helix structure and β-pleated sheets both form H-bonds between two peptide bonds on polypeptide chains. Difference: α-helix structure contains intra-chain H-bonds while β-pleated sheets contain inter-chain H-bonds. Significance: α-helix structure produces a regular coiled configuration, whereas β-pleated structure produces a sheet.	• identifies both contain H-bonds between peptide bonds in the polypeptide chain **[1 mark]** • identifies α-helix structure contains intra-chain H-bonds while β-pleated sheets contain inter-chain H-bonds **[1 mark]** • explains α-helix is coiled and β-pleated forms sheets **[1 mark]**

2023 Paper 2 Section 1 Question 4

Properties and structure of organic materials

Compound C has the molecular formula $C_4H_{10}O$ and is either an alcohol, an aldehyde or a carboxylic acid.



(a) Deduce the class of compound C. Explain your reasoning. [4 marks]

Sample response	The response
Compound C is an alcohol which can be inferred from the broad peak between 3200–3600 cm^{-1} on infrared spectrum which indicates the presence of an OH functional group. Compound C cannot be an aldehyde as there is no peak at 1700–1750 cm^{-1} on infrared spectrum, therefore the compound does not contain a C=O functional group. Compound C cannot be a carboxylic acid since the molecular formula only contains one oxygen atom, therefore the compound does not contain a COOH functional group.	• determines that compound C is an alcohol **[1 mark]** • explains that the peak at 3200–3600 indicates OH functional group **[1 mark]** • explains that no peak at 2500–3000 indicates that compound C is not a carboxylic acid **[1 mark]** • explains that no peak at 1700–1750 indicates that compound C is not an aldehyde **[1 mark]**

(b) Deduce the structural formula and IUPAC name of two isomers of compound C. [2 marks]

Sample response	The response
Isomer 1: $CH_2(OH)-CH_2-CH_2-CH_3$ IUPAC name: 1-butanol Isomer 2: $CH_3-CH(OH)-CH_2-CH_3$ IUPAC name: 2-butanol	• deduces the structural formula and IUPAC name for – an isomer **[1 mark]** – a second isomer **[1 mark]**

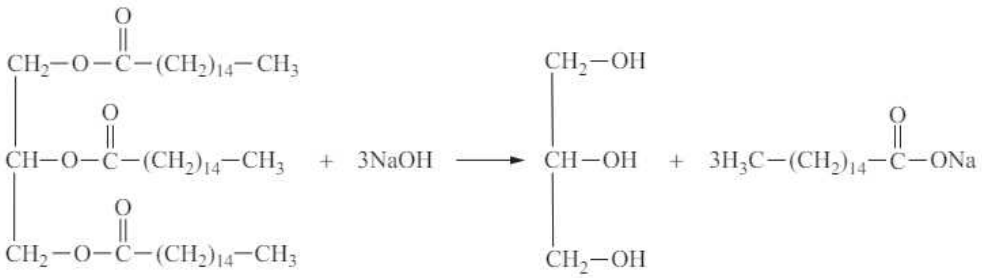
(c) Distinguish between structural and geometric isomers. [2 marks]

Sample response	The response
Structural isomers have the same molecular formula but different structures. Geometric isomers have the same order of atom bonding but the atoms are arranged differently in space.	• explains structural isomers have the same molecular formula but different structure **[1 mark]** • explains geometric isomers have the same bonding of atoms, but the atoms are arranged differently in space **[1 mark]**

2023 Paper 2 Section 1 Question 6

Properties and structure of organic materials

The reaction shows the base hydrolysis (saponification) of a triglyceride to produce glycerol and a soap.



(a) Identify which compound in the reaction is an ester. [1 mark]

Sample response	The response
The triglyceride is an ester.	• identifies the triglyceride is an ester **[1 mark]**

(b) Contrast the structure of saturated and unsaturated fatty acids. [1 mark]

Sample response	The response
Unsaturated fatty acids contain at least one double bond while saturated fatty acids contain only single bonds.	• identifies saturated fatty acids contain only single bonds and unsaturated fatty acids contain at least one double bond **[1 mark]**

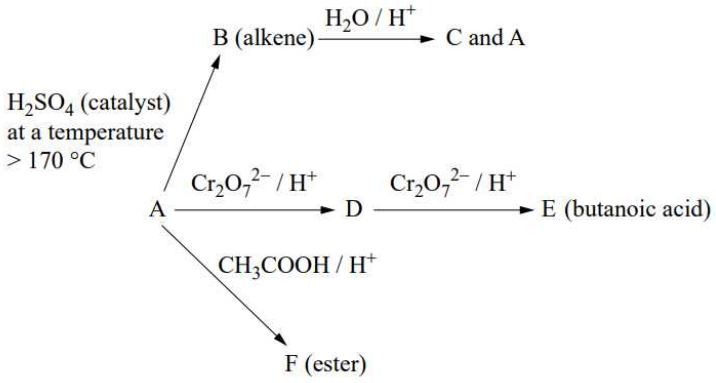
(c) Explain how the cleaning action of soap is related to its structure. [4 marks]

Sample response	The response
Soap contains a non-polar, hydrophobic group and a polar, hydrophilic group. The ionic salt is attracted to the polar water, allowing the soap to dissolve in water while the non-polar fatty acid chain is attracted to non-polar oils allowing the soap to dissolve in the oils. Thus, soap can form a bridge between polar water and non-polar oils that water can't dissolve.	• identifies soap contains a polar and non-polar region **[1 mark]** • explains that fatty acid group is non-polar and dissolves in oil **[1 mark]** • explains ionic salt group is polar and dissolves in water **[1 mark]** • explains how soap acts as a bridge to remove oils from water **[1 mark]**

2022 Paper 2 Section 1 Question 1

Properties and structure of organic materials

The diagram shows a series of different reactions starting with compound A, which has the empirical formula $C_4H_{10}O$.

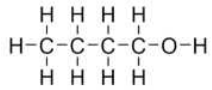


a) Identify the class of organic compounds that compound A belongs to. [1 mark]

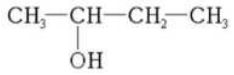
Sample Response	The response
Compound A is an alcohol.	• identifies the class as alcohol [1 mark]

b) Compound C is an isomer of compound A. Deduce the structural formulas and IUPAC names of compounds A and C. [4 marks]

i) Compound A

Sample Response	The response
 Compound A is butanol.	• deduces structural formula for butanol [1 mark] • provides IUPAC name [1 mark]

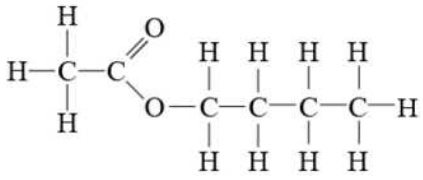
ii) Compound C

Sample Response	The response
 Compound C is 2-butanol.	• deduces structural formula for 2-butanol [1 mark] • provides IUPAC name [1 mark]

c) Identify whether compounds A and C are structural or geometric isomers. [1 mark]

Sample Response	The response
Butanol and 2-butanol are structural isomers.	• identifies structural isomers [1 mark]

d) Deduce the structural formula and IUPAC name for compound F. [2 marks]

Sample Response	The response
 Compound F is butyl ethanoate.	• provides structural formula for butyl ethanoate [1 mark] • provides IUPAC name as butyl ethanoate [1 mark]

2022 Paper 2 Section 1 Question 6

Properties and structure of organic materials

Polypeptides and proteins are formed by condensation reactions of amino acids.

a) Identify the type of bond formed when three amino acids are joined to form a tripeptide and state any other product/s formed. [2 marks]

Sample Response	The response
Peptide bond Water is formed	• identifies peptide bond [1 mark] • identifies water is formed [1 mark]

b) Determine the total number of tripeptides that can be formed containing histidine, lysine and glycine and use the three-letter symbols for the amino acids to describe two of the tripeptides formed. [3 marks]

Sample Response	The response
6 tripeptides can be formed: Gly-His-Lys and Gly-Lys-His	• determines 6 tripeptides can be formed [1 mark] • describes one tripeptide [1 mark] • describes a second tripeptide [1 mark]

c) Explain how the pH of the buffer solution can be used to separate histidine, lysine and glycine through electrophoresis. [3 marks]

Sample Response	The response
The isoelectric point of His is 7.6. If the pH of the buffer solution is 7.6 histidine will not migrate towards either the anode or cathode because it remains neutral. The isoelectric point Gly is 6, which is less than 7.6. Therefore, in a buffer solution of 7.6 Gly will form a negative ion and migrate towards the anode. Similarly, the isoelectric point for Lys is 9.7, therefore, Lys will form a positive ion and migrate towards the cathode.	• explains when buffer solution is pH 7.6 - histidine is neutral and will not migrate [1 mark] - Gly forms a negative ion and migrates towards anode (positive terminal) [1 mark] - Lys forms a positive ion and migrates towards the cathode (negative terminal) [1 mark]

2021 Paper 2 Section 1 Question 3

Properties and structure of organic materials

Four colourless liquids, A, B, C and D, are known to be butane, 1-butene, 2-butanol and 1-propanol. Reactions are carried out to identify the liquids. The results are shown.

Test 1	A	B	C	D
Bromine (Br_2) water	No reaction	No reaction	No reaction	Decolourised

Test 2	A	B	C
Excess acidified potassium manganate(VII) ($KMnO_4$) solution, heated gently	Decolourised, Compound X formed	Decolourised, Compound Y formed	No reaction

Test 3	Compound X	Compound Y
Ethanol and concentrated sulfuric acid solution, heated gently and refluxed	Fruity smell produced, Compound Z formed	No apparent reaction

a) Identify Compound D. Explain your reasoning. [2 marks]

Sample Response	The response	Notes
Compound D is 1-butene. Undergoes addition reaction with Br_2(aq).	• identifies Compound D as 1-butene [1 mark] • indicates that Compound D undergoes addition [1 mark]	For 1-butene, accept but-1-ene.

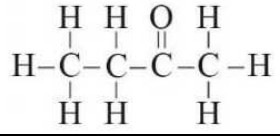
b) Write a balanced equation to describe the decolourisation of bromine (Br2) water by Compound D. Apply IUPAC rules to name the product formed. [2 marks]

Sample Response	The response	Notes
$CH_2CHCH_2CH_3 + Br_2 \rightarrow CH_2(Br)CH(Br)CH_2CH_3$ IUPAC name: 1,2-dibromobutane	• indicates balanced equation with the correct structural formula for reactants and products [1 mark] • correctly names 1,2-dibromobutane [1 mark]	Allow FT error from equation.

c) Identify Compound C. Explain your reasoning. [3 marks]

Sample Response	The response	Notes
Compound C is butane. It can't be oxidised by potassium manganate(VII) or undergo an addition reaction with bromine water. Therefore, Compound C is unreactive because it's saturated.	• identifies Compound C as butane [1 mark] • identifies that Compound C cannot be oxidised [1 mark] • concludes that Compound C is unreactive and saturated [1 mark]	For saturated, accept contains only single bonds. Acceptable response is to identify that Compound C cannot undergo an addition reaction.

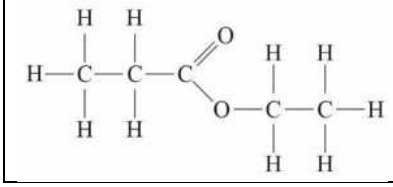
d) Draw the structural formula of Compound Y. [1 mark]

Sample Response	The response	Notes
	• provides correct structural formula for butanone for Compound Y [1 mark]	Acceptable response is Compound Y = $CH_3COCH_2CH_3$

e) Identify Compound B. [1 mark]

Sample Response	The response	Notes
2-butanol	• identifies Compound B as 2-butanol [1 mark]	For 2-butanol, accept butan-2-ol.

f) Draw the structural formula of Compound Z. [1 mark]

Sample Response	The response	Notes
	• provides correct structural formula for ethyl propanoate for Compound Z [1 mark]	Acceptable response is Compound Z = $CH_3CH_2COOCH_2CH_3$

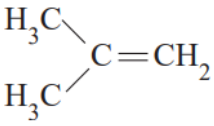
g) Apply IUPAC rules to name Compound Z. [1 mark]

Sample Response	The response	Notes
IUPAC name: ethyl propanoate	• correctly names ethyl propanoate [1 mark]	

2020 Paper 2 Section 1 Question 4

Properties and structure of organic materials

Consider the organic molecule shown.



a) Identify the molecule as saturated or unsaturated. [1 mark]

Sample Response	The response
unsaturated	• provides unsaturated [1 mark]

b) Apply IUPAC rules to name this molecule. [1 mark]

Sample Response	The response
2–methylpropene	• provides 2- methylpropene [1 mark]

c) Write an equation to show the products formed by the hydration of this molecule. [2 marks]

Sample Response	The response	Notes
$2(CH_3)_2C = CH_2 + 2H_2O \xrightarrow{H^+} (CH_3)_3C(OH) + (CH_3)_2CHCH_2OH$	• identifies $(CH_3)_3C(OH)$ as a product **[1 mark]** • identifies $(CH_3)_2CHCH_2OH$ as a product **[1 mark]**	Accept condensed or expanded structural formula.

d) Predict which is the major product formed in c). [1 mark]

Sample Response	The response
Major product (Markovnikov's rule) $(CH_3)_3C(OH)$	• identifies tertiary alcohol as the major product produced [1 mark]

e) Identify a physical property and experimental technique that could be used to separate products formed by hydration in c). Explain your reasoning. [5 marks]

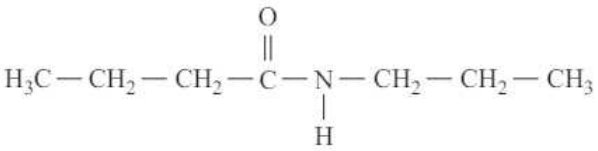
Sample Response	The response
$(CH_3)_2CHCH_2OH$ is a primary alcohol and $(CH_3)_3C(OH)$ is a tertiary alcohol. Therefore, they have different boiling points. Experimental technique: distillation The hydroxyl group of a primary alcohol is more exposed than it is in a tertiary alcohol, therefore is easier for the primary alcohol to form more hydrogen bonds. Therefore, the intermolecular forces are stronger and the boiling point higher for $(CH_3)_2CHCH_2OH$.	• identifies the products are primary and tertiary alcohols [1 mark] • identifies boiling point as physical property that can be used to separate the alcohols [1 mark] • identifies distillation as a suitable experimental technique [1 mark] • links the position of the hydroxyl group in the primary alcohol to increased hydrogen bonding [1 mark] • indicates that stronger intermolecular forces result in a higher boiling point for the primary alcohol [1 mark]

Unit 4 – Topic 2: Chemical synthesis and design

Paper 1 Section 1

2024 Paper 1 Section 1 Question 4 Chemical synthesis and design	Identify which polymer contains a carbonyl (C= O) group. (A) polyester (B) polyethene (C) polypropene (D) polytetrafluorethene

2024 Paper 1 Section 1 Question 7 Chemical synthesis and design	Which option is a principle of green chemistry? (A) avoid chemical derivatives (B) decrease energy efficiency (C) prevent catalytic reactions (D) minimise atom economy

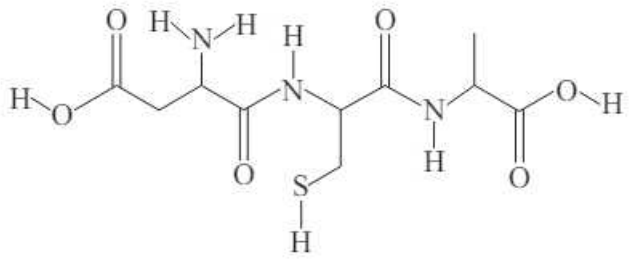
2023 Paper 1 Section 1 Question 6 Chemical synthesis and design	Identify the reactants that undergo a condensation reaction to produce the molecule shown.  (A) 1-butanol and propanamine (B) 1-propanol and butanamine (C) butanoic acid and propanamine (D) propanoic acid and butanamine

2023 Paper 1 Section 1 Question 13 Chemical synthesis and design	Identify the reaction used to produce methanol and triglycerides. (A) oxidation (B) substitution (C) saponification (D) transesterification

2023 Paper 1 Section 1 Question 20

Chemical synthesis and design

The structural formula for a polypeptide is shown.



Identify the three amino acids present from left to right.

(A) Arg, Cys, Met
(B) Asp, Cys, Ala
(C) Glu, Cys, Asp
(D) Ile, Cys, Gly

2022 Paper 1 Section 1 Question 4

Chemical synthesis and design

Which pair of reagents would react to form a glycosidic bond?

(A) lysine and aniline
(B) glucose and galactose
(C) methanol and butanoic acid
(D) glycerol and sodium hydroxide

2022 Paper 2 Section 1 Question 4

Chemical synthesis and design

Bioethanol is a renewable energy source made from biomasses such as starch and cellulosic materials. The two-step process for the conversion of starch and cellulose to bioethanol is shown.

Process	Step 1	Step 2	Conversion to glucose	Production process
Starch	Enzymatic hydrolysis (α–amylase) of starch biomass to form glucose	Fermentation of glucose to form bioethanol (yeast)	Easier	Faster
Cellulose	Acid hydrolysis (H_2SO_4(aq) at 320 °C and 25 MPa) of cellulose biomass to form glucose	Fermentation of glucose to form bioethanol (yeast)	Harder	Slower

a) Identify why it is important to control the temperature during the fermentation process to produce bioethanol. [2 marks]

b) Explain why cellulose is harder to convert to glucose than starch. [3 marks]

c) After 48 hours of fermentation, a 15% w/v glucose solution produces 37.5 g L^{-1} of ethanol. Calculate the percentage yield of ethanol. Show your working. [3 marks]

Ethanol yield = _____ % (to one decimal place)

2022 Paper 1 Section 1 Question 5

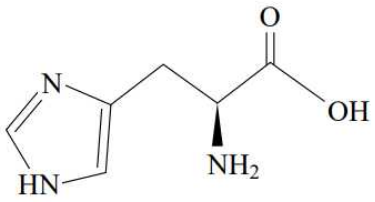
Chemical synthesis and design

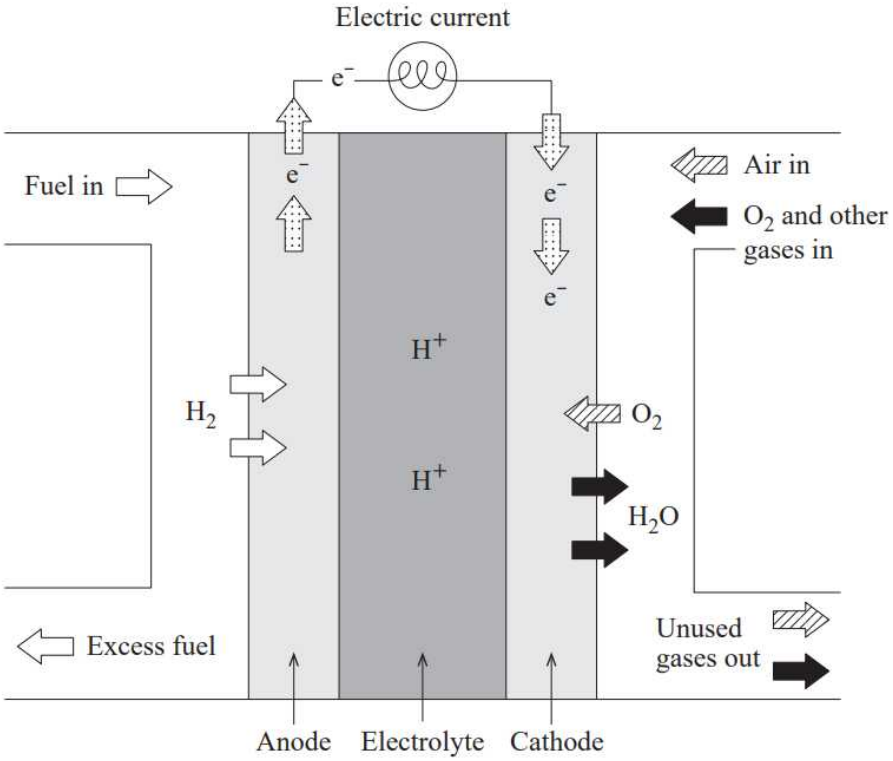
Phosphorus pentoxide is prepared by burning phosphorus in oxygen.

$P_4(s) + 5O_2(g) \rightarrow P_4O_{10}(s)$

Calculate the percentage yield if 10.0 g of P_4O_{10} is produced when 0.200 mol of P_4 and 0.200 mol of O_2 are reacted.

(A) 2.0%
(B) 3.5%
(C) 17.6%
(D) 88.0%

2022 Paper 1 Section 1 Question 15 Chemical synthesis and design	The structure of an amino acid is shown.  This molecule contains an amine group and a (A) carboxyl group. (B) hydroxy group. (C) methyl group. (D) ketone group.

2021 Paper 1 Section 1 Question 8 Chemical synthesis and design	 Identify the operating conditions for the hydrogen fuel cell. (A) acidic conditions with hydrogen given off as an unused gas (B) alkaline conditions with hydrogen given off as an unused gas (C) acidic conditions with hydrogen ions present in the electrolyte (D) alkaline conditions with hydrogen ions present in the electrolyte

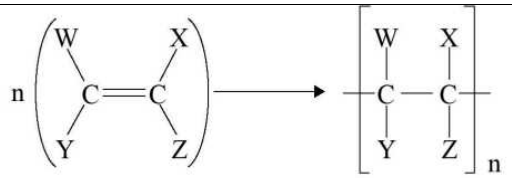
2021 Paper 1 Section 1 Question 12 Chemical synthesis and design	Green chemistry principles include the design of chemical synthesis processes that (A) use renewable raw materials and minimise unwanted products. (B) use renewable raw materials and minimise unwanted reactants. (C) use non-renewable raw materials and minimise unwanted products. (D) use non-renewable raw materials and minimise unwanted reactants.

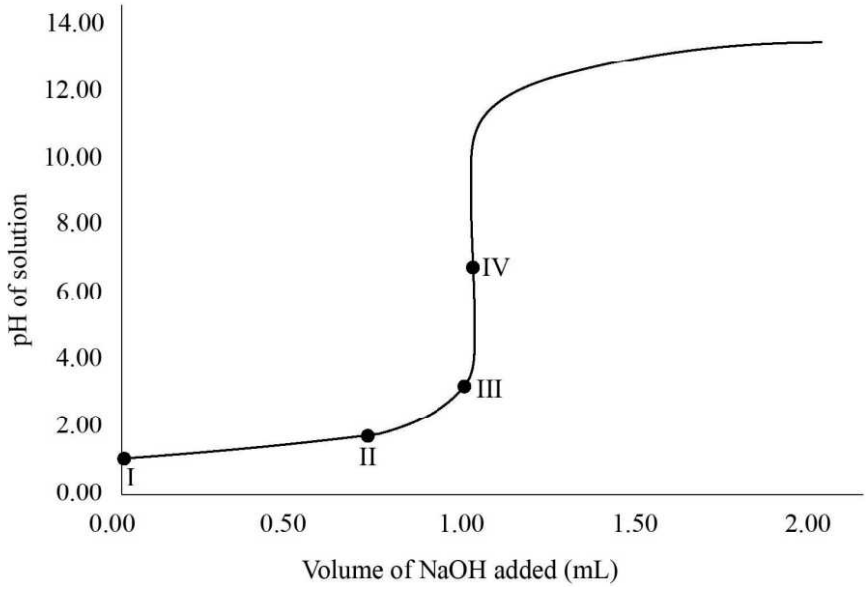
2021 Paper 1 Section 1 Question 16 Chemical synthesis and design	Calculate the percentage yield of magnesium ethanoate when 8.0 moles of ethanoic acid reacts with 6.0 moles of magnesium carbonate, producing 3.5 moles of magnesium ethanoate as shown in the equation. $2CH_3COOH(aq) + MgCO_3(s) \rightarrow (CH_3COO)_2Mg(aq) + CO_2(g) + H_2O(l)$ (A) 44% (B) 58% (C) 88% (D) 100%

2021 Paper 1 Section 1 Question 19 Chemical synthesis and design	To form ethanol biofuel in the fermentation of glucose, a catalyst is used because (A) less energy is required and the rate of reaction is increased. (B) less energy is required and the rate of reaction is decreased. (C) more energy is required and the rate of reaction is increased. (D) more energy is required and the rate of reaction is decreased.

2020 Paper 1 Section 1 Question 1 Chemical synthesis and design	A partly filled water bottle is sealed and left on a bench in a room with a constant temperature. After several minutes, it is noted that the water level in the bottle remains constant. In the water bottle, the rate of evaporation is (A) less than the rate of condensation. (B) greater than the rate of condensation. (C) equal to the rate of condensation and equal to zero. (D) equal to the rate of condensation but not equal to zero.

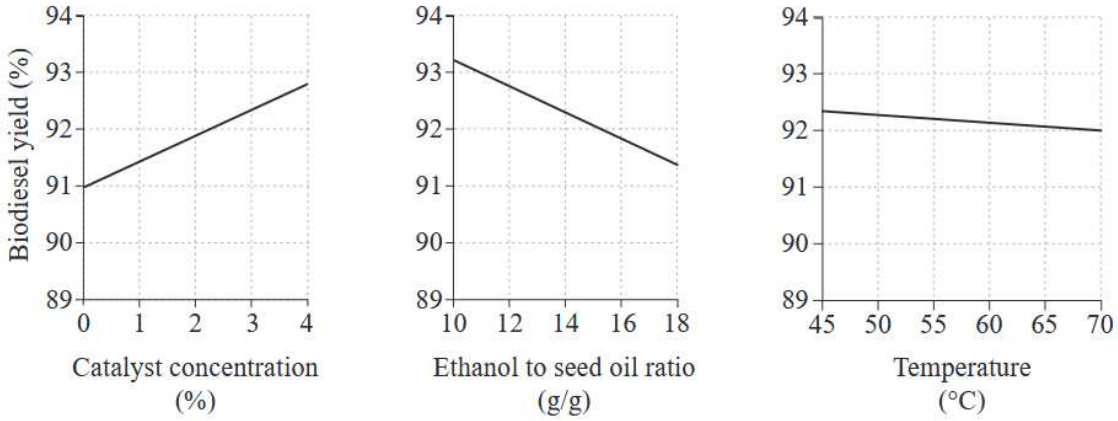
2020 Paper 1 Section 1 Question 2 Chemical synthesis and design	$Mg(s) + 2Ag^+(aq) \rightarrow 2Ag(s) + Mg^{2+}(aq)$ Determine which of the following statements is true for the chemical reaction. (A) less than the rate of condensation. (B) greater than the rate of condensation. (C) equal to the rate of condensation and equal to zero. (D) equal to the rate of condensation but not equal to zero.

2020 Paper 1 Section 1 Question 3 Chemical synthesis and design	 This general chemical equation represents the following type of reaction. (A) addition (B) hydrolysis (C) esterification (D) condensation

2020 Paper 1 Section 1 Question 13 Chemical synthesis and design	 Identify the equivalence point on the titration curve. (A) I (B) II (C) III (D) IV

Paper 1 Section 2

2024 Paper 1 Section 2 Question 22 **Chemical synthesis and design**	a) Describe the type of reaction that occurs when amino acid monomers are joined to form polypeptides. [2 marks] b) Identify the bond formed when amino acid monomers join to form a dipeptide. [1 mark]

2024 Paper 1 Section 2 Question 27 **Chemical synthesis and design**	A series of experiments was performed to investigate the optimum reaction conditions to produce biodiesel from seed oils using a two-step process. Step 1: acid esterification using an acid catalyst (H_2SO_4) Step 2: transesterification using ethanol as a solvent and magnesium oxide as a nanocatalyst The experiments measured the effect of the catalyst concentration, ethanol to seed oil ratio and temperature on biodiesel yield. Temperature was held constant when investigating the effect of catalyst concentration and ethanol to seed oil ratio. The results are shown.  a) Identify the optimal reaction conditions to maximise biodiesel production. [1 mark] Catalyst concentration (%): Ethanol to seed oil ratio (g/g): Temperature (°C):

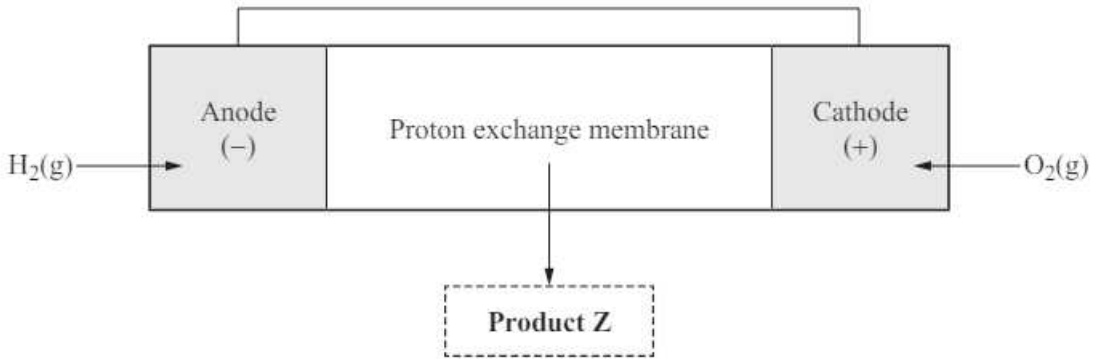
b) Explain why both esterification and transesterification reactions are used to optimise biodiesel production. [3 marks]

c) Determine the effect that catalyst concentration, ethanol to seed oil ratio and temperature have on biodiesel production. Use data to support your reasoning. [4 marks]

2023
Paper 1
Section 2
Question 23

Chemical synthesis and design

The diagram represents a hydrogen fuel cell with an acid electrolyte.



(a) Determine the redox half-equation occurring at the anode and cathode. [2 marks]

Anode half-equation:

Cathode half-equation:

(b) Identify product Z. [1 mark]

(c) Compare the movement of electrons and hydrogen ions in the fuel cell. [3 marks]

Similarity:

Difference:

Significance:

2022 Paper 1 Section 2 Question 23

Chemical synthesis and design

Ibuprofen is manufactured using two different processes.

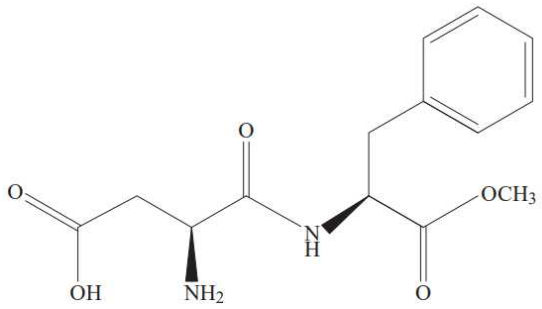
Process	Number of reagents used	Reagents		Ibuprofen		Waste products	
		Atoms	M_r	Atoms	M_r	Atoms	M_r
1	7	$C_{20}H_{42}NO_{10}ClNa$	514.5	$C_{13}H_{18}O_2$	206.0	$C_7H_{24}NO_8ClNa$	308.5
2	4	$C_{15}H_{22}O_4$	266.0	$C_{13}H_{18}O_2$	206.0	$C_2H_4O_2$	60.0

Calculate the atom economy for each process and draw conclusions about the economic and environmental impact of each process. [4 marks]

2021 Paper 1 Section 2 Question 23

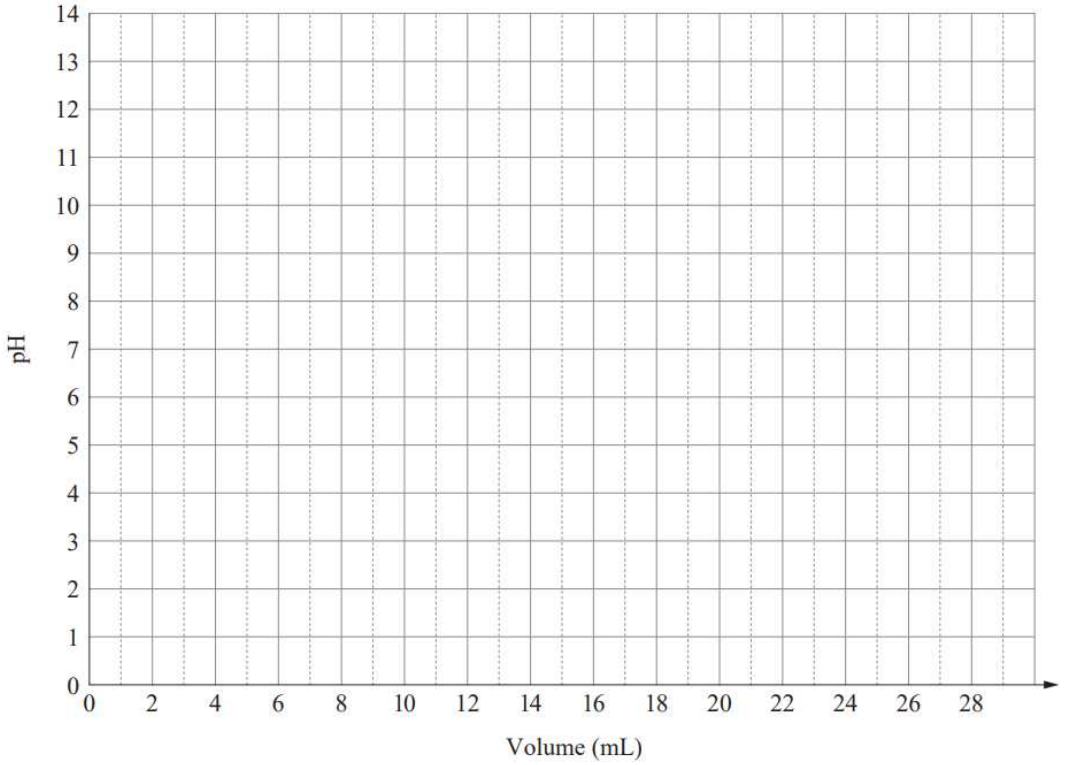
Chemical synthesis and design

Aspartame is a methyl ester of a dipeptide that hydrolyses to form methanol and two amino acids. The structure of aspartame is shown.



a) Identify the two amino acids that form aspartame. [1 mark]

	A hydrolysed sample of aspartame was analysed with silica thin layer chromatography (TLC), using a mixture of butanol and ethanoic acid as the solvent. The TLC plate was then reacted with ninhydrin to produce spots. b) Determine which amino acid in aspartame corresponds to Spot A. Explain your reasoning. [3 marks] c) Explain why the reference amino acids are included on the TLC plate. [1 mark]

2021 Paper 1 Section 2 Question 28 Chemical synthesis and design	Sketch the titration curve formed when 20 mL of 0.1 M butylamine ($pK_a = 10.0$) is titrated with 0.1 M hydrochloric acid.  Note: If you make a mistake in the sketch, cancel it by ruling a single diagonal line through your work and use the additional response space on page 17 of this question and response book.

2020 Paper 1 Section 2 Question 21 Chemical synthesis and design	a) Glucose is an example of which type of carbohydrate? [1 mark] b) Starch and cellulose are both polymers of glucose. Compare the structure of starch and cellulose in terms of their glycosidic links. [4 marks]

2024 Paper 2 Section 1 Question 4

Chemical synthesis and design

Bioethanol can be synthesised from plants rich in starch. Amylose and amylopectin in the starch are converted to glucose, which then undergoes fermentation to produce ethanol.

$$\underset{\text{(starch)}}{(C_6H_{10}O_5)_x} \xrightarrow{\text{enzymes}} \underset{\text{(glucose)}}{C_6H_{12}O_6} \xrightarrow{\text{yeast}} \underset{\text{(bioethanol)}}{2(C_2H_5OH) + 2CO_2}$$

a) Explain the role of enzymes in converting the amylose and amylopectin in starch to glucose. [2 marks]

b) Describe the structure of amylose and amylopectin by completing the table. [4 marks]

	Amylose	Amylopectin
Monomer		
Glycosidic linkage		
Chain structure		
Shape		

c) Determine whether the fermentation of glucose to bioethanol is a redox reaction.
Explain your reasoning. [3 marks]

d) Calculate the atom economy for the fermentation of glucose to bioethanol.
Show your working. [2 marks]

2023 Paper 2 Section 1 Question 9

Chemical synthesis and design

Aspirin ($C_9H_8O_4$) can be produced from a reaction between salicylic acid ($C_7H_6O_3$) and acetic anhydride ($C_4H_6O_3$) with ethanoic acid being a minor product.

$$C_7H_6O_3(s) + C_4H_6O_3(aq) \rightarrow C_9H_8O_4(s) + C_2H_4O_2(aq)$$

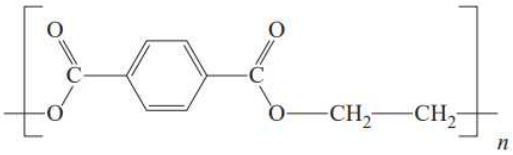
Calculate the mass of salicylic acid required to produce 8.25 g of aspirin if the percentage yield of the reaction is 60%. Show your working.

[4 marks]

2021 Paper 2 Section 1 Question 2

Chemical synthesis and design

Polypropene (PP) is a polymer formed from propene. Polyethylene terephthalate (PET) is a polymer formed from monomers of carboxylic acid and alcohol. A section of the PET polymer is shown.



a) Draw the structural formulas of the monomers used to form PET. [2 marks]

i) Carboxylic acid monomer

ii) Alcohol monomer

Note: If you make a mistake in the drawing, cancel it by ruling a single diagonal line through your work and use the additional response space on page 16 of this question and response book.

b) Determine the type of polymerisation used to form PET. [1 mark]

c) Identify the functional group formed by the reaction of the monomers in PET. [1 mark]

d) Determine the type of polymerisation used to form PP. [1 mark]

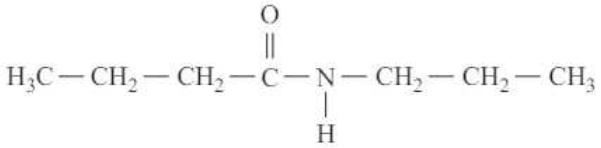
e) Explain how the position of the methyl group on the polymer chain affects the strength of isotactic PP, relative to syntactic PP. [5 marks]

2020 Paper 2 Section 1 Question 3 **Chemical synthesis and design**	Ethanol can be produced by the fermentation of glucose or the hydration of ethene. a) Describe the production of ethanol by fermentation of glucose by writing a balanced equation and indicating if a catalyst is required. [3 marks] b) Calculate the atom economy for the production of ethanol by fermentation of glucose. [2 marks] Atom economy = _____ % c) In terms of atom economy, determine which process for the production of ethanol (i.e. hydration of ethene or fermentation of glucose) is greener. [2 marks] d) Identify two principles of green chemistry, other than atom economy, that make the production of ethanol by fermentation greener than by hydration. [2 marks]

Marking Guide – Paper 1 Section 1

2024 Paper 1 Section 1 Question 4 Chemical synthesis and design	Identify which polymer contains a carbonyl (C= O) group. **(A) polyester – Answer** (B) polyethene (C) polypropene (D) polytetrafluorethene

2024 Paper 1 Section 1 Question 7 Chemical synthesis and design	Which option is a principle of green chemistry? **(A) avoid chemical derivatives – Answer** (B) decrease energy efficiency (C) prevent catalytic reactions (D) minimise atom economy

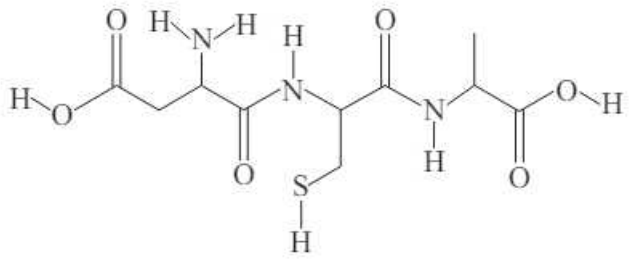
2023 Paper 1 Section 1 Question 6 Chemical synthesis and design	Identify the reactants that undergo a condensation reaction to produce the molecule shown.  (A) 1-butanol and propanamine (B) 1-propanol and butanamine (C) butanoic acid and propanamine (D) propanoic acid and butanamine **Answer is C.**

2023 Paper 1 Section 1 Question 13 Chemical synthesis and design	Identify the reaction used to produce methanol and triglycerides. (A) oxidation (B) substitution (C) saponification **(D) transesterification – Answer**

2023 Paper 1 Section 1 Question 20

Chemical synthesis and design

The structural formula for a polypeptide is shown.



Identify the three amino acids present from left to right.

(A) Arg, Cys, Met
(B) Asp, Cys, Ala
(C) Glu, Cys, Asp
(D) Ile, Cys, Gly – Answer

2022 Paper 1 Section 1 Question 4

Chemical synthesis and design

Which pair of reagents would react to form a glycosidic bond?

(A) lysine and aniline
(B) glucose and galactose – Answer
(C) methanol and butanoic acid
(D) glycerol and sodium hydroxide

2022 Paper 2 Section 1 Question 4

Chemical synthesis and design

Bioethanol is a renewable energy source made from biomasses such as starch and cellulosic materials. The two-step process for the conversion of starch and cellulose to bioethanol is shown.

Process	Step 1	Step 2	Conversion to glucose	Production process
Starch	Enzymatic hydrolysis (α–amylase) of starch biomass to form glucose	Fermentation of glucose to form bioethanol (yeast)	Easier	Faster
Cellulose	Acid hydrolysis (H_2SO_4(aq) at 320 °C and 25 MPa) of cellulose biomass to form glucose	Fermentation of glucose to form bioethanol (yeast)	Harder	Slower

a) Identify why it is important to control the temperature during the fermentation process to produce bioethanol. [2 marks]

Sample Response	The response
The fermentation process requires yeast as a catalyst. Yeast is temperature sensitive	• identifies fermentation requires yeast as a catalyst [1 mark] • identifies that yeast is temperature-sensitive [1 mark]

b) Explain why cellulose is harder to convert to glucose than starch. [3 marks]

Sample Response	The response
Cellulose is a linear polymer. The β-glucose monomers in cellulose can pack closely together. This increases hydrogen bonding between adjacent chains, which reduces interactions with water (solvents) and makes hydrolysis of cellulose more difficult than starch.	• identifies cellulose is a linear polymer [1 mark] • identifies monomers can pack closely together [1 mark] • explains increased H-bonding between adjacent chains makes hydrolysis of cellulose more difficult [1 mark]

c) After 48 hours of fermentation, a 15% w/v glucose solution produces 37.5 g L^{-1} of ethanol. Calculate the percentage yield of ethanol. Show your working. [3 marks]

Sample Response	The response
Moles $C_6H_{12}O_6 = \frac{150}{180.18} = 0.833$ Moles $CH_3CH_2OH = 0.83 \times 2 = 1.67$ Mass $CH_3CH_2OH = 1.67 \times 46.08 = 76.72$ g Ethanol yield $= \frac{37.5}{\text{theoretical yield}} = \frac{37.5}{76.72} = 48.9\%$	• determines 150 g glucose can produce 1.67 M of ethanol [1 mark] • calculates theoretical mass of ethanol as 76.72 g [1 mark] • calculates % yield of ethanol is 48.9% [1 mark]

2022 Paper 1 Section 1 Question 5

Chemical synthesis and design

Phosphorus pentoxide is prepared by burning phosphorus in oxygen.

$P_4(s) + 5O_2(g) \rightarrow P_4O_{10}(s)$

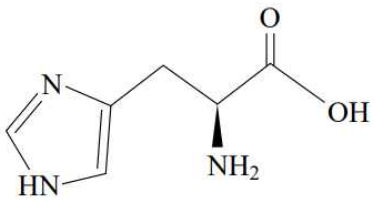
Calculate the percentage yield if 10.0 g of P_4O_{10} is produced when 0.200 mol of P_4 and 0.200 mol of O_2 are reacted.

(A) 2.0%
(B) 3.5%
(C) 17.6%
(D) 88.0% – Answer

2022 Paper 1 Section 1 Question 15

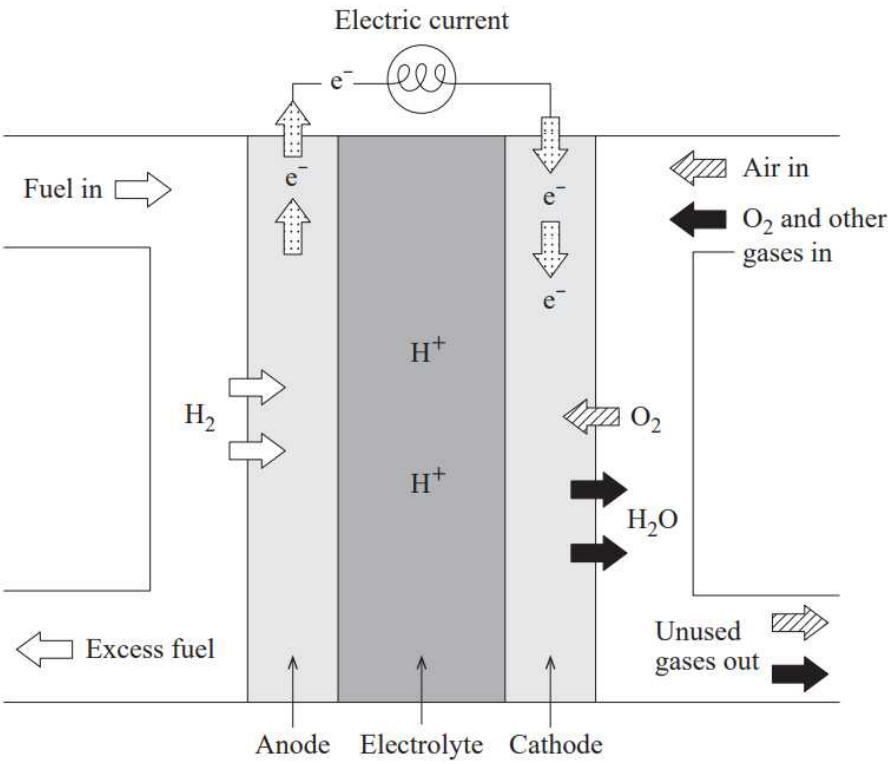
Chemical synthesis and design

The structure of an amino acid is shown.



This molecule contains an amine group and a

(A) carboxyl group. – Answer
(B) hydroxy group.
(C) methyl group.
(D) ketone group.

2021 Paper 1 Section 1 Question 8 Chemical synthesis and design	 Identify the operating conditions for the hydrogen fuel cell. (A) acidic conditions with hydrogen given off as an unused gas (B) alkaline conditions with hydrogen given off as an unused gas **(C) acidic conditions with hydrogen ions present in the electrolyte – Answer** (D) alkaline conditions with hydrogen ions present in the electrolyte

2021 Paper 1 Section 1 Question 12 Chemical synthesis and design	Green chemistry principles include the design of chemical synthesis processes that **(A) use renewable raw materials and minimise unwanted products. – Answer** (B) use renewable raw materials and minimise unwanted reactants. (C) use non-renewable raw materials and minimise unwanted products. (D) use non-renewable raw materials and minimise unwanted reactants.

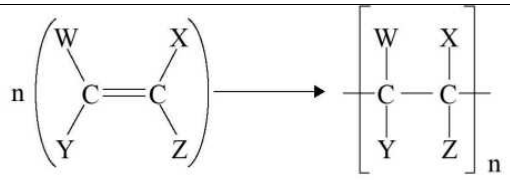
2021 Paper 1 Section 1 Question 16 Chemical synthesis and design	Calculate the percentage yield of magnesium ethanoate when 8.0 moles of ethanoic acid reacts with 6.0 moles of magnesium carbonate, producing 3.5 moles of magnesium ethanoate as shown in the equation. $$2CH_3COOH(aq) + MgCO_3(s) \rightarrow (CH_3COO)_2Mg(aq) + CO_2(g) + H_2O(l)$$ (A) 44% (B) 58% **(C) 88% – Answer** (D) 100%

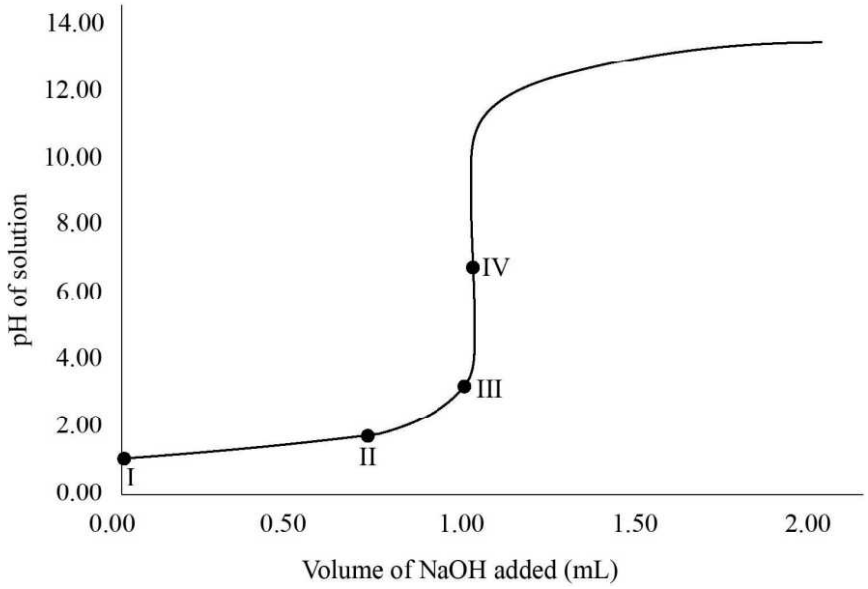
2021 Paper 1 Section 1 Question 19 Chemical synthesis and design	To form ethanol biofuel in the fermentation of glucose, a catalyst is used because **(A) less energy is required and the rate of reaction is increased. – Answer** (B) less energy is required and the rate of reaction is decreased. (C) more energy is required and the rate of reaction is increased. (D) more energy is required and the rate of reaction is decreased.

2020 Paper 1 Section 1 Question 1 Chemical synthesis and design	A partly filled water bottle is sealed and left on a bench in a room with a constant temperature. After several minutes, it is noted that the water level in the bottle remains constant. In the water bottle, the rate of evaporation is (A) less than the rate of condensation. (B) greater than the rate of condensation. (C) equal to the rate of condensation and equal to zero. **(D) equal to the rate of condensation but not equal to zero. – Answer**

2020 Paper 1 Section 1 Question 1 Chemical synthesis and design	A partly filled water bottle is sealed and left on a bench in a room with a constant temperature. After several minutes, it is noted that the water level in the bottle remains constant. In the water bottle, the rate of evaporation is (A) less than the rate of condensation. (B) greater than the rate of condensation. (C) equal to the rate of condensation and equal to zero. **(D) equal to the rate of condensation but not equal to zero. – Answer**

2020 Paper 1 Section 1 Question 2 Chemical synthesis and design	$Mg(s) + 2Ag^{+}(aq) \rightarrow 2Ag(s) + Mg^{2+}(aq)$ Determine which of the following statements is true for the chemical reaction. (A) less than the rate of condensation. (B) greater than the rate of condensation. (C) equal to the rate of condensation and equal to zero. **(D) equal to the rate of condensation but not equal to zero. – Answer**

2020 Paper 1 Section 1 Question 3 Chemical synthesis and design	 This general chemical equation represents the following type of reaction. **(A) addition – Answer** (B) hydrolysis (C) esterification (D) condensation

2020 Paper 1 Section 1 Question 13 Chemical synthesis and design	 Identify the equivalence point on the titration curve. (A) I (B) II (C) III **(D) IV – Answer**

2024 Paper 1 Section 2 Question 22

Chemical synthesis and design

a) Describe the type of reaction that occurs when amino acid monomers are joined to form polypeptides. [2 marks]

Sample response	The response
A condensation reaction occurs when amino acid monomers are joined to form a peptide bond and water is removed.	• identifies condensation reaction **[1 mark]** • describes that water is removed when the amino acids are joined to form polypeptides **[1 mark]**

b) Identify the bond formed when amino acid monomers join to form a dipeptide. [1 mark]

Sample response	The response
A peptide bond is formed.	• identifies peptide bond **[1 mark]**

2024 Paper 1 Section 2 Question 27

Chemical synthesis and design

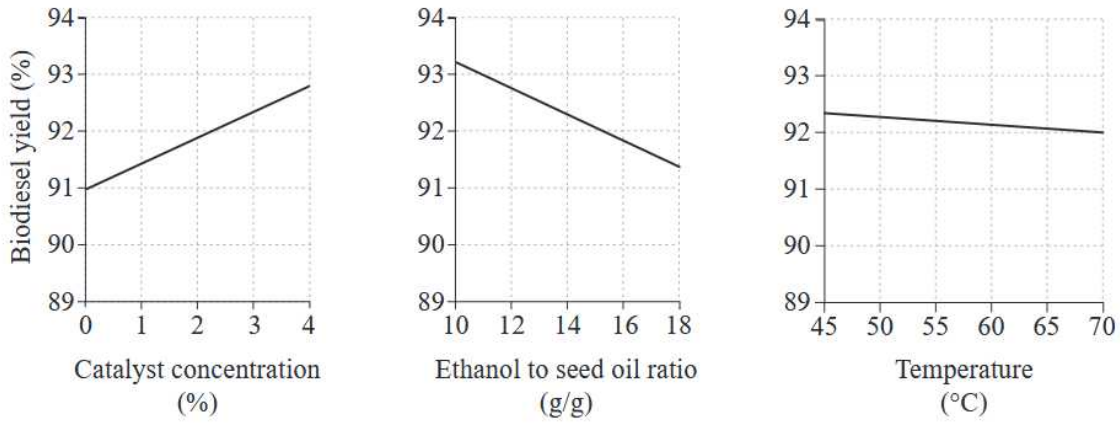
A series of experiments was performed to investigate the optimum reaction conditions to produce biodiesel from seed oils using a two-step process.

Step 1: acid esterification using an acid catalyst (H_2SO_4)

Step 2: transesterification using ethanol as a solvent and magnesium oxide as a nanocatalyst

The experiments measured the effect of the catalyst concentration, ethanol to seed oil ratio and temperature on biodiesel yield. Temperature was held constant when investigating the effect of catalyst concentration and ethanol to seed oil ratio.

The results are shown.



a) Identify the optimal reaction conditions to maximise biodiesel production. [1 mark]

Sample response	The response
Catalyst concentration (%): 4 Ethanol to seed oil ratio (g/g): 10:1 Temperature (°C): 45	• identifies optimal reaction conditions are 4% catalyst concentration, 10:1 ethanol to seed oil ratio and 45 °C **[1 mark]**

b) Explain why both esterification and transesterification reactions are used to optimise biodiesel production. [3 marks]

Sample response	The response
In esterification, free fatty acids (FFAs) react with an alcohol to produce esters and water. In transesterification, esters react with an alcohol to produce fatty acid alkyl esters (FAAEs) (biodiesel) and glycerol. A two-step process maximises the conversion of FFAs to biodiesel (FAAE).	• explains that esterification converts free fatty acids to esters **[1 mark]** • explains that transesterification converts esters to fatty acid alkyl esters **[1 mark]** • explains that a two-step process maximises the production of biodiesel **[1 mark]**

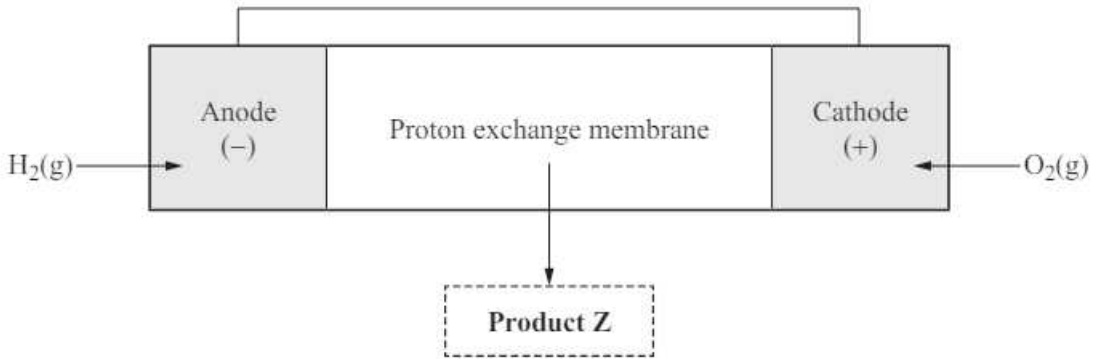
c) Determine the effect that catalyst concentration, ethanol to seed oil ratio and temperature have on biodiesel production. Use data to support your reasoning. [4 marks]

Sample response	The response
Increasing the catalyst concentration from 0% to 4% resulted in ~1.8% increase in biodiesel yield from ~91.0% to ~92.8%. Increasing the ethanol–oil ratio from 10:1 g/g to 18:1 g/g resulted in a ~1.9% decrease in biodiesel yield from ~93.2% to ~91.3%. Increasing temperature from 45 °C to 75 °C has minimal effect, decreasing biodiesel yield by ~0.4% from ~92.3% to ~92.0%.	• determines that increasing catalyst concentration increases biodiesel yield **[1 mark]** • determines that increasing ethanol to seed oil ratio decreases biodiesel yield **[1 mark]** • determines that increasing temperature results in a slight decrease in biodiesel yield **[1 mark]** • identifies data from the graphs to support reasoning **[1 mark]**

2023 Paper 1 Section 2 Question 23

Chemical synthesis and design

The diagram represents a hydrogen fuel cell with an acid electrolyte.



(a) Determine the redox half-equation occurring at the anode and cathode. [2 marks]

Sample response	The response
Anode half-equation: $2H_2(g) \rightarrow 4H^+(aq) + 4e^-$ Cathode half-equation: $O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$	• identifies anode half-equation **[1 mark]** • identifies cathode half-equation **[1 mark]**

(b) Identify product Z. [1 mark]

Sample response	The response
Product Z is water.	• identifies product Z is water **[1 mark]**

(c) Compare the movement of electrons and hydrogen ions in the fuel cell. [3 marks]

Sample response	The response
Similarity: Electrons and hydrogen ions move from the anode towards the cathode. Difference: Hydrogen ions move through the proton exchange membrane while electrons move through the wire. Significance: Flow of electrons creates the potential difference.	• identifies electrons and hydrogen ions move from the anode to the cathode **[1 mark]** • identifies hydrogen ions move through the proton exchange membrane while electrons flow through the wire **[1 mark]** • identifies that movement of electrons creates potential difference **[1 mark]**

2022 Paper 1 Section 2 Question 23

Chemical synthesis and design

Ibuprofen is manufactured using two different processes.

Process	Number of reagents used	Reagents		Ibuprofen		Waste products	
		Atoms	M_r	Atoms	M_r	Atoms	M_r
1	7	$C_{20}H_{42}NO_{10}ClNa$	514.5	$C_{13}H_{18}O_2$	206.0	$C_7H_{24}NO_8ClNa$	308.5
2	4	$C_{15}H_{22}O_4$	266.0	$C_{13}H_{18}O_2$	206.0	$C_2H_4O_2$	60.0

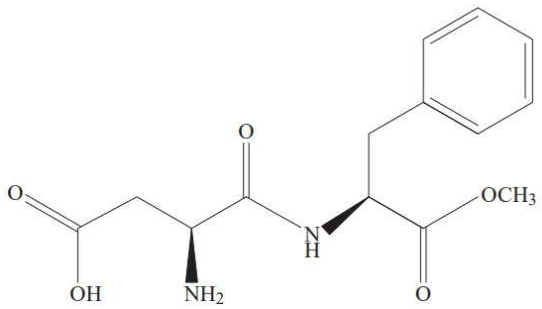
Calculate the atom economy for each process and draw conclusions about the economic and environmental impact of each process. [4 marks]

Sample Response	The response
Process 1: atom economy = 206.0/514.5 x 100 = 40.04% Process 2: atom economy = 206.0/266.0 x 100 = 77.44% Process 2 has 37.4% better atom economy than process 1 Economic impact: Process 2 has a better atom economy than process 1 (fewer reagents are required). Environmental impact: Process 2 is greener than process 1 because fewer waste products (atoms) are produced.	• calculates atom economy for - Process 1 as 40% [1 mark] - Process 2 as 77% [1 mark] • concludes process 2 is - cheaper as fewer reagent atoms are required [1 mark] - greener as fewer waste atoms are produced [1 mark]

2021 Paper 1 Section 2 Question 23

Chemical synthesis and design

Aspartame is a methyl ester of a dipeptide that hydrolyses to form methanol and two amino acids. The structure of aspartame is shown.



a) Identify the two amino acids that form aspartame. [1 mark]

Sample Response	The response	Notes
aspartic acid and phenylalanine	• correctly identifies aspartic acid and phenylalanine [1 mark]	For aspartic acid, accept Asp. For phenylalanine, accept Phe. Accept correctly drawn diagrams.

A hydrolysed sample of aspartame was analysed with silica thin layer chromatography (TLC), using a mixture of butanol and ethanoic acid as the solvent. The TLC plate was then reacted with ninhydrin to produce spots.

b) Determine which amino acid in aspartame corresponds to Spot A. Explain your reasoning. [3 marks]

Sample Response	The response	Notes
Isoleucine is a non-polar amino acid. The distance travelled by Spot A is similar to the distance travelled by isoleucine; therefore, Spot A is also non-polar. Spot A is phenylalanine because it is a non-polar amino acid.	• indicates that isoleucine is non-polar [1 mark] • indicates that Spot A is non-polar and travels a similar distance to isoleucine [1 mark] • determines that Spot A is phenylalanine [1 mark]	Acceptable response indicates Spot A has a similar R_f value (distance travelled) as isoleucine and is therefore non-polar.

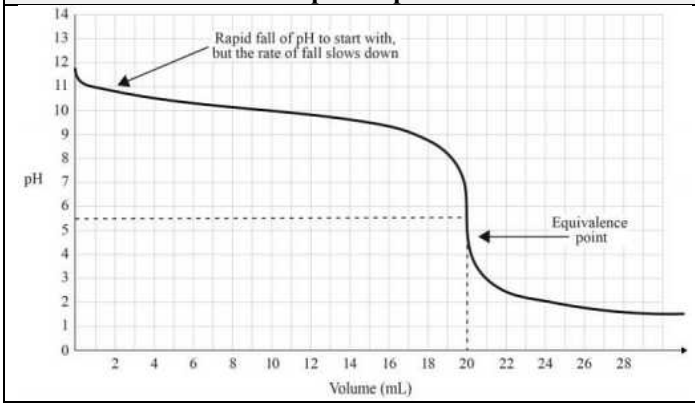
c) Explain why the reference amino acids are included on the TLC plate. [1 mark]

Sample Response	The response	Notes
To allow the distance travelled by the separated amino acids to be compared to control amino acids.	• indicates that separated amino acids can be compared to control amino acids [1 mark]	Acceptable response indicates R_f value for separated amino acids can be compared to R_f values for control amino acids.

2021 Paper 1 Section 2 Question 28

Chemical synthesis and design

Sketch the titration curve formed when 20 mL of 0.1 M butylamine ($pK_a = 10.0$) is titrated with 0.1 M hydrochloric acid.

Sample Response	The response	Notes
	• sketches an S-shaped curve with - the half equivalence point at pH 10 and 10 mL [1 mark] - the equivalence point < pH 7 at 20 mL [1 mark] - initial pH between 10 and 12, and the final pH between 3 and 1 (but not below 1) [1 mark]	

2020 Paper 1 Section 2 Question 21

Chemical synthesis and design

a) Glucose is an example of which type of carbohydrate? [1 mark]

Sample Response	The response	Notes
Monosaccharide	• provides monosaccharide [1 mark]	Accept aldose.

b) Starch and cellulose are both polymers of glucose. Compare the structure of starch and cellulose in terms of their glycosidic links. [4 marks]

Sample Response	The response
Both starch and cellulose form 1-4 glycosidic links. However, starch is a polymer of α–glucose and cellulose is a polymer of β–glucose. Starch forms a linear polymer due to 1-4 α–glycosidic links (amylose) and a branched polymer due to 1-4 and 1-6 α–glycosidic links (amylopectin). Cellulose only exists as a linear polymer with 1-4, β–glycosidic links.	• identifies that both contain 1-4 links [1 mark] • identifies that starch is a polymer of α–glucose and cellolose is a polymer of β–glucose [1 mark] • indicates that starch can be linear due to 1-4 α–glycosidic links (amylose) and branched due to 1-4 and 1-6 α–glycosidic links [1 mark] • indicates that cellulose only exists as a linear polymer with 1-4, β–glycosidic links [1 mark]

2024 Paper 2 Section 1 Question 4

Chemical synthesis and design

Bioethanol can be synthesised from plants rich in starch. Amylose and amylopectin in the starch are converted to glucose, which then undergoes fermentation to produce ethanol.

$$\underset{\text{(starch)}}{(C_6H_{10}O_5)_x} \xrightarrow{\text{enzymes}} \underset{\text{(glucose)}}{C_6H_{12}O_6} \xrightarrow{\text{yeast}} \underset{\text{(bioethanol)}}{2(C_2H_5OH) + 2CO_2}$$

a) Explain the role of enzymes in converting the amylose and amylopectin in starch to glucose. [2 marks]

Sample response	The response
Enzymes convert starch into glucose via hydrolysis that breaks the glycosidic bond.	• identifies that enzymes break glycosidic bonds in starch to form glucose **[1 mark]** • explains that enzymes convert starch to glucose via hydrolysis **[1 mark]**

b) Describe the structure of amylose and amylopectin by completing the table. [4 marks]

Sample response			The response
	Amylose	**Amylopectin**	• describes that the monomer for amylose and amylopectin is α-glucose **[1 mark]** • describes that amylose contains 1,4-glycosidic bonds and amylopectin contains 1,4 and 1,6-glycosidic bonds **[1 mark]** • describes that amylose has a straight chain structure and that amylopectin has a branched chain structure **[1 mark]** • describes that amylose is helical in shape and that amylopectin forms spheres **[1 mark]**
Monomer	α-glucose	α-glucose	
Glycosidic bonds	1,4-glycosidic bonds	both 1,4 and 1,6-glycosidic bonds	
Chain structure	Linear	Branched	
Shape	Helix	Spherical	

c) Determine whether the fermentation of glucose to bioethanol is a redox reaction.
Explain your reasoning. [3 marks]

Sample response	The response
$\overset{0}{C_6}\overset{+1}{H_{12}}\overset{-2}{O_6} \rightarrow 2(\overset{-2}{C_2}\overset{+1}{H_5}\overset{-2}{O}\overset{+1}{H}) + 2\overset{+4}{C}\overset{-2}{O_2}$ Carbon in glucose is oxidised to CO_2. Oxidation number increases from 0 to +4. Carbon in glucose is reduced to C_2H_5OH. Oxidation number decreases from 0 to –2.	• determines fermentation is a redox reaction **[1 mark]** • explains carbon in glucose is oxidised to CO_2; oxidation number increases from 0 to +4 **[1 mark]** • explains carbon in glucose is reduced to C_2H_5OH; oxidation number decreases from 0 to –2 **[1 mark]**

d) Calculate the atom economy for the fermentation of glucose to bioethanol.
Show your working. [2 marks]

Sample response	The response
Molar mass glucose = 180 Molar mass ethanol = 2(46) (C = 12, H = 1, O = 16) =92 $\text{atom economy} = \frac{92}{180} \times \frac{100}{1} = 51\%$	• determines the molar mass of glucose is 180 and molar mass of ethanol is 92 **[1 mark]** • calculates atom economy **[1 mark]**

2023 Paper 2 Section 1 Question 9

Chemical synthesis and design

Aspirin ($C_9H_8O_4$) can be produced from a reaction between salicylic acid ($C_7H_6O_3$) and acetic anhydride ($C_4H_6O_3$) with ethanoic acid being a minor product.

$$C_7H_6O_3(s) + C_4H_6O_3(aq) \rightarrow C_9H_8O_4(s) + C_2H_4O_2(aq)$$

Calculate the mass of salicylic acid required to produce 8.25 g of aspirin if the percentage yield of the reaction is 60%. Show your working.

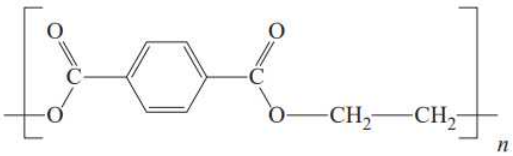
[4 marks]

Sample response	The response
1:1 Aspirin : salicylic acid (SA) $n(\text{aspirin}) = \frac{8.25}{(9\times12.01)+(8\times1.01)+(4\times16.00)} = \frac{8.25}{180.17} = 0.0458 \text{ mol}$ $n(\text{SA}) = \frac{0.0458}{0.60} = 0.0763 \text{ mol}$ $m(\text{SA}) = 0.0763\times138.13 = 10.5\text{g}$	• determines molar mass aspirin is 180.17 **[1 mark]** • determines moles aspirin **[1 mark]** • determines moles salicylic acid **[1 mark]** • calculates mass salicylic acid **[1 mark]**

2021 Paper 2 Section 1 Question 2

Chemical synthesis and design

Polypropene (PP) is a polymer formed from propene. Polyethylene terephthalate (PET) is a polymer formed from monomers of carboxylic acid and alcohol. A section of the PET polymer is shown.



a) Draw the structural formulas of the monomers used to form PET. [2 marks]
i) Carboxylic acid monomer
ii) Alcohol monomer

Sample Response	The response
i) carboxylic acid monomer  ii) alcohol monomer $HO-CH_2-CH_2-OH$	• provides the correct structural formula for - benzene-1,4-dicarboxylic acid (terephthalic acid) [1 mark] - ethane-1,2-diol (ethylene glycol) [1 mark]

b) Determine the type of polymerisation used to form PET. [1 mark]

Sample Response	The response	Notes
condensation	• determines polymerisation as condensation [1 mark]	For condensation, accept: - elimination - esterification.

c) Identify the functional group formed by the reaction of the monomers in PET. [1 mark]

Sample Response	The response	Notes
Ester	• identifies ester as the functional group [1 mark]	Also accept: - RCOOR[1] - carboalkoxy.

d) Determine the type of polymerisation used to form PP. [1 mark]

Sample Response	The response	Notes
addition	• determines polymerisation as addition [1 mark]	

e) Explain how the position of the methyl group on the polymer chain affects the strength of isotactic PP, relative to syntactic PP. [5 marks]

Sample Response	The response	Notes
Structural features Isotactic and syntactic — both have regular arrangement methyl groups. Syntactic has methyl groups on the opposite side of the polymer chain, while isotactic has methyl groups on the same side of the chain. Properties Isotactic — chains can pack closer together, resulting in greater intermolecular forces. Isotactic PP is therefore stronger than syntactic PP.	• identifies regular arrangement methyl groups [1 mark] • identifies methyl groups on the opposite side of the chain for syntactic and same side of the chain for isotactic PP [1 mark] • indicates that isotactic chains can pack closer together [1 mark] • indicates increased intermolecular forces for isotactic PP [1 mark] • indicates increased strength for isotactic PP [1 mark]	For intermolecular forces, accept dispersion forces.

2020 Paper 2 Section 1 Question 3

Chemical synthesis and design

Ethanol can be produced by the fermentation of glucose or the hydration of ethene.

a) Describe the production of ethanol by fermentation of glucose by writing a balanced equation and indicating if a catalyst is required. [3 marks]

Sample Response	The response
$C_2H_{12}O_6(aq) \xrightarrow{\text{yeast}} 2CH_3CH_2OH(aq) + 2CO_2(g)$	• provides correct reactants and products [1 mark] • correctly balances the equation [1 mark] • indicates that yeast is required as a catalyst [1 mark]

b) Calculate the atom economy for the production of ethanol by fermentation of glucose. [2 marks]

Sample Response	The response	Notes
Molar mass (ethanol) = 46.08 g Molar mass (glucose) = 180.18 g atom economy = $\frac{2\times46.08}{180.18} \times 100$ atom economy = $\frac{2\times46.08}{180.18} \times 100 = 51.148\,\% \approx 51\%$ Atom economy = 51%	• shows substitution correctly performed [1 mark] • determines atom economy [1 mark]	Allow FT error from incorrect molar masses. Do not penalise for incorrect decimal places/significant figures.

c) In terms of atom economy, determine which process for the production of ethanol (i.e. hydration of ethene or fermentation of glucose) is greener. [2 marks]

Sample Response	The response
Hydration atom economy = 100% Fermentation atom economy = 51% Therefore, production of ethene by hydration is greener.	• determines atom economy for hydration reaction is 100% [1 mark] • identifies that hydration reaction is greener [1 mark]

d) Identify two principles of green chemistry, other than atom economy, that make the production of ethanol by fermentation greener than by hydration. [2 marks]

Sample Response	The response
Use of renewable feedstocks Design for energy efficiency	• provides use of renewable feedstocks [1 mark] • provides design for energy efficiency [1 mark]