

# Apex Exam Guide

## Chemistry

Year 12 QCE

Queensland Curriculum

2025 Edition

Frederick Wong

# Apex Exam Guide

## Chemistry

### Year 12 QCE

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#### Acknowledgements

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## Unit 3 – Equilibrium, acid and redox

### Unit 3 – Topic 1: Chemical equilibrium systems

#### Paper 1 Section 1

<b>2023 Paper 1 Section 1 Question 1</b>  <b>Chemical equilibrium systems</b>	<p>In a chemical equation at equilibrium, a reversible arrow (<math>\rightleftharpoons</math>) symbolises that</p> <p>(A) the forward reaction has stopped but can be reversed.</p> <p>(B) the moles of reactants and products present are equal.</p> <p>(C) half of the reactants have been converted into products.</p> <p>(D) the concentration of reactants and products remains constant.</p>
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<b>2023 Paper 1 Section 1 Question 2</b>  <b>Chemical equilibrium systems</b>	<p>Determine which expression represents the hydrogen ion (<math>\text{H}^+</math>) concentration at a pH of 8.4.</p> <p>(A) <math>1 \times 10^{-8.4}</math></p> <p>(B) <math>1 \times 10^{-5.6}</math></p> <p>(C) <math>1 \times 10^{-0.9}</math></p> <p>(D) <math>1 \times 10^{-0.8}</math></p>
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<b>2023 Paper 1 Section 1 Question 3</b>  <b>Chemical equilibrium systems</b>	<p>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.</p> <table border="1"><thead><tr><th></th><th>Solution X</th><th>Solution Y</th></tr></thead><tbody><tr><td>(A)</td><td>HCl</td><td><math>\text{CH}_3\text{COOH}</math></td></tr><tr><td>(B)</td><td><math>\text{HNO}_3</math></td><td><math>\text{H}_2\text{SO}_4</math></td></tr><tr><td>(C)</td><td><math>\text{H}_3\text{PO}_4</math></td><td><math>\text{HNO}_3</math></td></tr><tr><td>(D)</td><td><math>\text{H}_2\text{SO}_4</math></td><td>HCl</td></tr></tbody></table>		Solution X	Solution Y	(A)	HCl	$\text{CH}_3\text{COOH}$	(B)	$\text{HNO}_3$	$\text{H}_2\text{SO}_4$	(C)	$\text{H}_3\text{PO}_4$	$\text{HNO}_3$	(D)	$\text{H}_2\text{SO}_4$	HCl
	Solution X	Solution Y														
(A)	HCl	$\text{CH}_3\text{COOH}$														
(B)	$\text{HNO}_3$	$\text{H}_2\text{SO}_4$														
(C)	$\text{H}_3\text{PO}_4$	$\text{HNO}_3$														
(D)	$\text{H}_2\text{SO}_4$	HCl														

<b>2023 Paper 1 Section 1 Questions 4-5</b>  <b>Chemical equilibrium systems</b>	<p>Questions 4–5 refer to the decomposition of hydrogen iodide gas (HI) to produce hydrogen gas (<math>\text{H}_2</math>) and iodine gas (<math>\text{I}_2</math>) in a sealed 1-litre container.</p> $2\text{HI}(\text{g}) \rightleftharpoons \text{H}_2(\text{g}) + \text{I}_2(\text{g}) \quad \Delta H = +53.6 \text{ kJ mol}^{-1}$ <p style="text-align: center;">Colourless      Colourless      Purple</p> <p>Question 4 Identify which change would shift the system from light purple to dark purple.</p> <p>(A) adding HI(g)</p> <p>(B) adding a catalyst</p> <p>(C) decreasing the temperature</p> <p>(D) increasing the concentration of <math>\text{H}_2(\text{g})</math></p>
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**Question 5**  
Determine the equilibrium expression ( $K_c$ ) for the reaction.

(A)  $K_c = \frac{[\text{H}_2][\text{I}_2]}{2[\text{HI}]}$

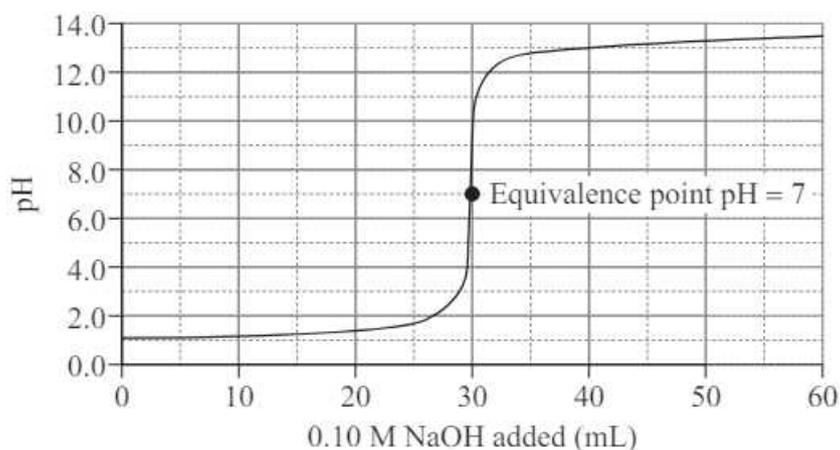
(B)  $K_c = \frac{[\text{H}_2][\text{I}_2]}{[\text{HI}]^2}$

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

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

**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

<p><b>2023</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 15</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Predict how a buffer solution, consisting of carbonic acid (<math>\text{H}_2\text{CO}_3</math>) and hydrogen carbonate ions (<math>\text{HCO}_3^-</math>), would react to resist a change in pH when a small amount of hydrochloric acid is added.</p> $\text{H}_2\text{CO}_3(\text{aq}) \rightleftharpoons \text{HCO}_3^-(\text{aq}) + \text{H}^+(\text{aq}) \rightleftharpoons \text{CO}_3^{2-}(\text{aq}) + 2\text{H}^+(\text{aq})$ <p>(A) Equilibrium shifts to the right and the <math>[\text{H}^+](\text{aq})</math> increases.</p> <p>(B) Equilibrium shifts to the left and the <math>[\text{CO}_3^{2-}](\text{aq})</math> increases.</p> <p>(C) Equilibrium shifts to the left and the <math>[\text{H}_2\text{CO}_3](\text{aq})</math> increases.</p> <p>(D) Equilibrium shifts to the right and the <math>[\text{HCO}_3^-](\text{aq})</math> increases.</p>
<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 6</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>The equilibrium concentration of A is <math>2.8 \times 10^{-4}</math> M and B is <math>1.2 \times 10^{-4}</math> M.</p> $\text{A}(\text{g}) \rightleftharpoons \text{B}(\text{g}) \quad \Delta H > 0$ <p>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?</p> <p>(A) 8 molecules of A and 2 molecules of B</p> <p>(B) 5 molecules of A and 5 molecules of B</p> <p>(C) 3 molecules of A and 7 molecules of B</p> <p>(D) 2 molecules of A and 8 molecules of B</p>
<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 8</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Predict how the system shown will respond when a small amount of aqueous sodium hydroxide is added.</p> $\text{CH}_3\text{COOH}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{CH}_3\text{COO}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$ <p>(A) Equilibrium shifts to the left and the pH decreases.</p> <p>(B) Equilibrium shifts to the right and the pH increases.</p> <p>(C) Equilibrium shifts to the left and the pH remains the same.</p> <p>(D) Equilibrium shifts to the right and the pH remains the same.</p>
<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 10</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>The midpoint of the colour change of a weak acid indicator occurs when</p> <p>(A) <math>[\text{In}^-] = [\text{H}^+]</math></p> <p>(B) <math>[\text{In}^-] = [\text{HIn}]</math></p> <p>(C) <math>[\text{H}^+] = [\text{OH}^-]</math></p> <p>(D) <math>[\text{HIn}] = [\text{OH}^-]</math></p>
<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 13</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Determine the <math>K_a</math> of an unknown weak acid (HA) with an aqueous concentration of 0.12 M and a pH of 3.2.</p> <p>(A) <math>5.2 \times 10^{-3}</math></p> <p>(B) <math>6.3 \times 10^{-4}</math></p> <p>(C) <math>3.3 \times 10^{-6}</math></p> <p>(D) <math>4.0 \times 10^{-7}</math></p>

<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 18</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Determine the <math>K_b</math> expression for the weak base shown in the equilibrium equation.</p> $\text{NH}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq})$ <p>(A) <math>K_b = \frac{[\text{NH}_3][\text{H}_2\text{O}]}{[\text{NH}_4^+]}</math></p> <p>(B) <math>K_b = \frac{[\text{NH}_3][\text{H}_2\text{O}]}{[\text{OH}^-]}</math></p> <p>(C) <math>K_b = \frac{[\text{NH}_4^+][\text{OH}^-]}{[\text{NH}_3]}</math></p> <p>(D) <math>K_b = \frac{[\text{NH}_4^+][\text{OH}^-]}{[\text{H}_2\text{O}]}</math></p>
<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 4</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>The cleaning action of soap is impaired in hard water because the</p> <p>(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.</p>
<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 5</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>A 10.0 M solution of ethanoic acid is best described as a</p> <p>(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.</p>
<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 10</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Determine which system at equilibrium will shift to the right (products) if the total pressure on the system is increased.</p> <p>(A) <math>\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})</math>            (B) <math>2\text{H}_2\text{O}(\text{g}) \rightleftharpoons 2\text{H}_2(\text{g}) + \text{O}_2(\text{g})</math>            (C) <math>2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})</math>            (D) <math>\text{CO}(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}_2(\text{g}) + \text{H}_2(\text{g})</math></p>
<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 11</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Enzymes can act as biological catalysts because they</p> <p>(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.</p>

<b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 14</b>  <b>Chemical equilibrium systems</b>	<table border="1"> <thead> <tr> <th>Acid</th> <th><math>K_a</math> value</th> </tr> </thead> <tbody> <tr> <td>Nitrous acid</td> <td><math>K_a = 4.00 \times 10^{-4}</math></td> </tr> <tr> <td>Ethanoic acid</td> <td><math>K_a = 1.76 \times 10^{-5}</math></td> </tr> <tr> <td>Hydrofluoric acid</td> <td><math>K_a = 7.20 \times 10^{-4}</math></td> </tr> <tr> <td>Chloroethanoic acid</td> <td><math>K_a = 1.40 \times 10^{-3}</math></td> </tr> </tbody> </table>	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	$K_a = 1.40 \times 10^{-3}$
	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	$K_a = 1.40 \times 10^{-3}$										
<p>Analyse the data to determine the relative strengths of acids from strongest to weakest.</p> <p>(A) chloroethanoic, ethanoic, nitrous, hydrofluoric            (B) chloroethanoic, hydrofluoric, nitrous, ethanoic            (C) ethanoic, nitrous, hydrofluoric, chloroethanoic            (D) ethanoic, hydrofluoric, nitrous, chloroethanoic</p>											

<b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 17</b>  <b>Chemical equilibrium systems</b>	<p>Determine the concentration of hydrogen ions (<math>H^+</math>) in an aqueous solution containing <math>1.2 \times 10^{-3}</math> M hydroxide ions (<math>OH^-</math>).</p> <p>(A) <math>1.2 \times 10^{11}</math>            (B) <math>8.3 \times 10^{-12}</math>            (C) <math>8.3 \times 10^{-17}</math>            (D) <math>1.2 \times 10^{-17}</math></p>
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<b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 5</b>  <b>Chemical equilibrium systems</b>	<p>The equilibrium constants of four different reactions are given.</p> <p>In which reaction does the equilibrium lie furthest to the left?</p> <table border="1"> <thead> <tr> <th></th> <th>Reaction</th> <th><math>K_c</math></th> </tr> </thead> <tbody> <tr> <td>(A)</td> <td><math>PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)</math></td> <td><math>2.4 \times 10^1</math></td> </tr> <tr> <td>(B)</td> <td><math>AgIO_3(s) \rightleftharpoons Ag^+(aq) + IO_3^-(aq)</math></td> <td><math>3.0 \times 10^{-8}</math></td> </tr> <tr> <td>(C)</td> <td><math>Cl_2(g) + H_2O(l) \rightleftharpoons HOCl(aq) + Cl^-(aq) + H^+(aq)</math></td> <td><math>4.0 \times 10^{-4}</math></td> </tr> <tr> <td>(D)</td> <td><math>HSO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + SO_3^{2-}(aq)</math></td> <td><math>6.3 \times 10^{-8}</math></td> </tr> </tbody> </table>		Reaction	$K_c$	(A)	$PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$	$2.4 \times 10^1$	(B)	$AgIO_3(s) \rightleftharpoons Ag^+(aq) + IO_3^-(aq)$	$3.0 \times 10^{-8}$	(C)	$Cl_2(g) + H_2O(l) \rightleftharpoons HOCl(aq) + Cl^-(aq) + H^+(aq)$	$4.0 \times 10^{-4}$	(D)	$HSO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + SO_3^{2-}(aq)$	$6.3 \times 10^{-8}$
	Reaction	$K_c$														
(A)	$PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$	$2.4 \times 10^1$														
(B)	$AgIO_3(s) \rightleftharpoons Ag^+(aq) + IO_3^-(aq)$	$3.0 \times 10^{-8}$														
(C)	$Cl_2(g) + H_2O(l) \rightleftharpoons HOCl(aq) + Cl^-(aq) + H^+(aq)$	$4.0 \times 10^{-4}$														
(D)	$HSO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + SO_3^{2-}(aq)$	$6.3 \times 10^{-8}$														

<b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 7</b>  <b>Chemical equilibrium systems</b>	<table border="1"> <thead> <tr> <th>Acid</th> <th>Concentration (M)</th> <th>pH</th> </tr> </thead> <tbody> <tr> <td><math>H_3PO_4</math></td> <td><math>2.0 \times 10^{-2}</math></td> <td>1.9</td> </tr> <tr> <td>HCN</td> <td><math>1.5 \times 10^{-1}</math></td> <td>5.0</td> </tr> <tr> <td><math>H_2SO_4</math></td> <td><math>9.0 \times 10^{-2}</math></td> <td>1.0</td> </tr> <tr> <td><math>CH_3COOH</math></td> <td><math>1.0 \times 10^{-1}</math></td> <td>2.8</td> </tr> </tbody> </table> <p>Analyse the experimental data to determine the relative strength of the acids from strongest to weakest.</p> <p>(A) <math>H_2SO_4 &gt; H_3PO_4 &gt; HCN &gt; CH_3COOH</math>            (B) <math>H_2SO_4 &gt; H_3PO_4 &gt; CH_3COOH &gt; HCN</math>            (C) <math>HCN &gt; CH_3COOH &gt; H_2SO_4 &gt; H_3PO_4</math>            (D) <math>HCN &gt; CH_3COOH &gt; H_3PO_4 &gt; H_2SO_4</math></p>	Acid	Concentration (M)	pH	$H_3PO_4$	$2.0 \times 10^{-2}$	1.9	HCN	$1.5 \times 10^{-1}$	5.0	$H_2SO_4$	$9.0 \times 10^{-2}$	1.0	$CH_3COOH$	$1.0 \times 10^{-1}$	2.8
Acid	Concentration (M)	pH														
$H_3PO_4$	$2.0 \times 10^{-2}$	1.9														
HCN	$1.5 \times 10^{-1}$	5.0														
$H_2SO_4$	$9.0 \times 10^{-2}$	1.0														
$CH_3COOH$	$1.0 \times 10^{-1}$	2.8														

<p><b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 9</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Phosgene gas (<math>\text{COCl}_2</math>) is formed by the following reaction.</p> $\text{CO}(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons \text{COCl}_2(\text{g}) \quad \Delta H = -110 \text{ kJ mol}^{-1}$ <p>Which of the following statements is true for the system at equilibrium?</p> <p>(A) Removing <math>\text{Cl}_2(\text{g})</math> will increase the yield of phosgene and keep the <math>K_c</math> value constant.</p> <p>(B) Adding a catalyst will increase the yield of phosgene and keep the <math>K_c</math> value constant.</p> <p>(C) Increasing the pressure will increase the yield of phosgene and keep the <math>K_c</math> value constant.</p> <p>(D) Decreasing the temperature will decrease the yield of phosgene and keep the <math>K_c</math> value constant.</p>
<p><b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 14</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Ammonia gas reacts with oxygen gas in the following equilibrium reaction.</p> $4\text{NH}_3(\text{g}) + 3\text{O}_2(\text{g}) \rightleftharpoons 2\text{N}_2(\text{g}) + 6\text{H}_2\text{O}(\text{g})$ <p>The equilibrium expression for the reaction is</p> <p>(A) <math>\frac{[\text{NH}_3][\text{O}_2]}{[\text{N}_2][\text{H}_2\text{O}]}</math></p> <p>(B) <math>\frac{[\text{N}_2][\text{H}_2\text{O}]}{[\text{NH}_3][\text{O}_2]}</math></p> <p>(C) <math>\frac{[\text{NH}_3]^4[\text{O}_2]^3}{[\text{N}_2]^2[\text{H}_2\text{O}]^6}</math></p> <p>(D) <math>\frac{[\text{N}_2]^2[\text{H}_2\text{O}]^6}{[\text{NH}_3]^4[\text{O}_2]^3}</math></p>
<p><b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 18</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Solution A has a pH of 3 and solution B has a pH of 6. This indicates that solution A is</p> <p>(A) less acidic and has 0.5 times the concentration of hydrogen ions in solution B.</p> <p>(B) more acidic and has 2 times the concentration of hydrogen ions in solution B.</p> <p>(C) less acidic and has 0.001 times the concentration of hydrogen ions in solution B.</p> <p>(D) more acidic and has 1000 times the concentration of hydrogen ions in solution B.</p>

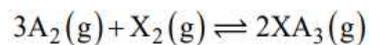




**2022  
Paper 1  
Section 2  
Question 25**

**Chemical  
equilibrium  
systems**

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



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

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

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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 <sup>-1</sup> )	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<sup>-1</sup> (to two significant figures)

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

pOH = \_\_\_\_\_ (to one decimal place)



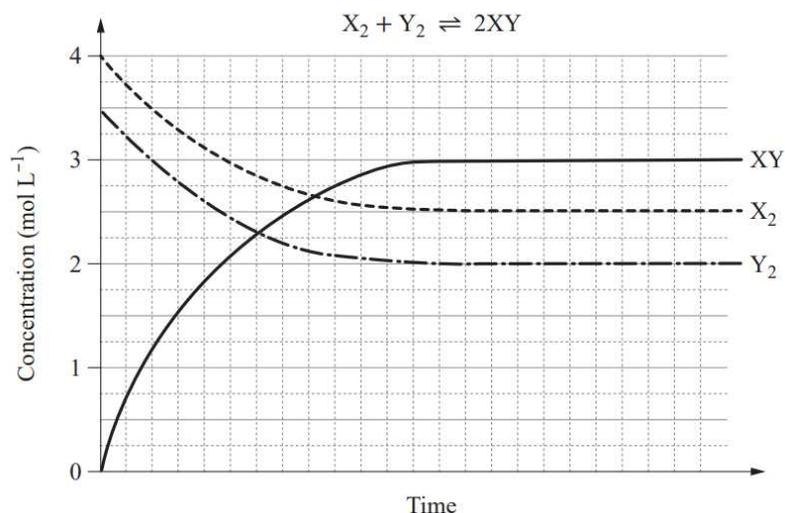
<b>2021</b> <b>Paper 1</b> <b>Section 2</b> <b>Question 21</b>  <b>Chemical equilibrium systems</b>	Calculate the pH of a 0.1M aqueous solution of Ba(OH) <sub>2</sub> , assuming complete dissociation. Show your working.
	<div style="border: 1px solid black; padding: 5px; display: inline-block;">           pH = _____ (to one decimal place)         </div>

<b>2021</b> <b>Paper 1</b> <b>Section 2</b> <b>Question 25</b>  <b>Chemical equilibrium systems</b>	An equilibrium is formed between two differently coloured cobalt species, Co(H <sub>2</sub> O) <sub>6</sub> <sup>2+</sup> (aq), which is pink, and CoCl <sub>4</sub> <sup>2-</sup> (aq), which is blue. The equation for this equilibrium is shown.
	$\text{Co(H}_2\text{O)}_6^{2+}(\text{aq}) + 4\text{Cl}^-(\text{aq}) \rightleftharpoons \text{CoCl}_4^{2-}(\text{aq}) + 6\text{H}_2\text{O(l)}$
	Apply Le Châtelier's principle to predict the visible effect of adding AgNO <sub>3</sub> to an aqueous, blue-coloured solution containing Co(H <sub>2</sub> O) <sub>6</sub> <sup>2+</sup> and CoCl <sub>4</sub> <sup>2-</sup> 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  
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]

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

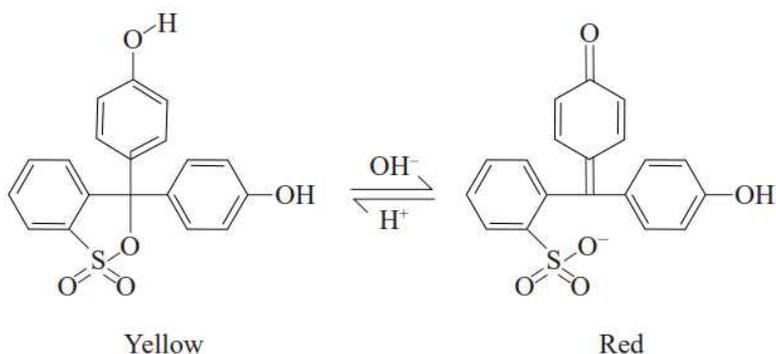
$K_c =$  \_\_\_\_\_ (to two significant figures)

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

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]

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  $2.0 \times 10^{-4}$  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]

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$pK_a =$  \_\_\_\_\_ (to two significant figures)

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

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**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]

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

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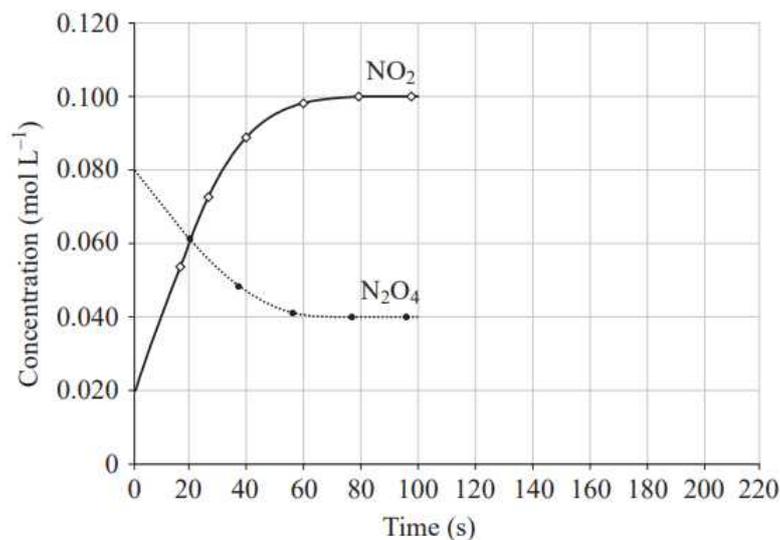
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$K_w =$  \_\_\_\_\_ (to three significant figures)

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 <sub>3</sub> ) <sub>2</sub> solution	X(NO <sub>3</sub> ) <sub>2</sub> solution	Z(NO <sub>3</sub> ) <sub>2</sub> solution	A(NO <sub>3</sub> ) <sub>2</sub> 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<sub>3</sub>)<sub>2</sub>. [1 mark]

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b) Identify the oxidising agent in the reaction between Z and Q(NO<sub>3</sub>)<sub>2</sub>. [1 mark]

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c) Determine the products formed from the reaction between Z and A(NO<sub>3</sub>)<sub>2</sub>. [1 mark]

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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]

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2023  
Paper 2  
Section 1  
Question 5Chemical  
equilibrium  
systems

The table gives the properties of four monoprotic acids.

Acid	Concentration (mol L <sup>-1</sup> )	[H <sup>+</sup> ] (mol L <sup>-1</sup> )	pH	K <sub>a</sub>
1	0.200	$7.90 \times 10^{-5}$		
2	0.100	$4.20 \times 10^{-3}$	2.34	$1.80 \times 10^{-4}$
CH <sub>3</sub> COOH(aq)	0.100			$1.78 \times 10^{-5}$
HCl(aq)	0.010	$1.00 \times 10^{-2}$	2.00	>1

(a) Determine the relative strength of acids 1 and 2 by contrasting their K<sub>a</sub> values. [3 marks]

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b) Write a balanced chemical equation for the dissociation of ethanoic acid (CH<sub>3</sub>COOH) in water. [2 marks]

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(c) Identify whether the conjugate base of ethanoic acid (CH<sub>3</sub>COO<sup>-</sup>) is amphiprotic. Explain your reasoning. [2 marks]

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(d) Calculate the pH of the aqueous solution of ethanoic acid CH<sub>3</sub>COOH. Show your working. [3 marks]

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	(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]

<b>2023 Paper 2 Section 1 Question 7</b>  <b>Chemical equilibrium systems</b>	When heated in a sealed container, solid mercury(II) oxide (HgO) decomposed to form metallic mercury (Hg) and oxygen gas (O <sub>2</sub> ).
	$\begin{array}{ccccc} 2\text{HgO(s)} & \rightleftharpoons & 2\text{Hg(l)} & + & \text{O}_2\text{(g)} \\ \text{Orange} & & \text{Silver} & & \text{Colourless} \end{array}$
	(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).



Experiment	Initial concentration (mol L <sup>-1</sup> )			Equilibrium concentration (mol L <sup>-1</sup> )			$K_c$
	[HI]	[H <sub>2</sub> ]	[I <sub>2</sub> ]	[HI]	[H <sub>2</sub> ]	[I <sub>2</sub> ]	
1	0.08	0.00	0.00		0.01		$2.78 \times 10^{-2}$
2	0.00	0.06	0.06	0.06	0.03	0.03	

(a) Determine the concentration of HI(g) and I<sub>2</sub>(g) at equilibrium for experiment 1. [2 marks]

[HI]:

[I<sub>2</sub>]:

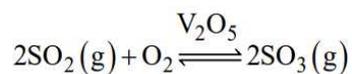
(b) Calculate the equilibrium constant ( $K_c$ ) for experiment 2. Show your working. [2 marks]

(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.



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

Temperature (K)	Equilibrium constant, $K_c$ (mol L <sup>-1</sup> )
298	$9.77 \times 10^{25}$
500	$8.61 \times 10^{11}$

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

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b) Calculate the equilibrium concentration of SO<sub>3</sub> at 500 K given the equilibrium concentrations. [2 marks]

$$[\text{SO}_2] = 0.860 \text{ M}; [\text{O}_2] = 0.330 \text{ M}$$

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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]

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**2022**  
**Paper 2**  
**Section 1**  
**Question 3**  
  
**Chemical**  
**equilibrium**  
**systems**

A 50.0 mL solution of ethanoic acid ( $\text{CH}_3\text{COOH}$ ) was titrated with 15.0 mL of 0.10 M sodium hydroxide (NaOH) solution to reach the equivalence point ( $\text{p}K_{\text{a}}$  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  $K_{\text{b}}$  of the conjugate base of ethanoic acid. [1 mark]

$K_{\text{b}} = \text{_____}$  (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]

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pH = \_\_\_\_\_ (to one decimal place)

**2021  
Paper 2  
Section 1  
Question 1**

**Chemical  
equilibrium  
systems**

Phosphoric acid ( $\text{H}_3\text{PO}_4$ ) 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	$\text{H}_3\text{PO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_2\text{PO}_4^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$	$7.1 \times 10^{-3}$
2	$\text{H}_2\text{PO}_4^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HPO}_4^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$	$6.5 \times 10^{-8}$
3	$\text{HPO}_4^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{PO}_4^{3-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$	$4.5 \times 10^{-13}$

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

Acid:

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Conjugate base:

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Reasoning:

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**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]

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

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

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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]

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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]

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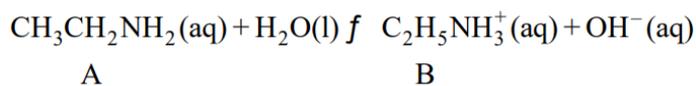
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2020  
Paper 2  
Section 1  
Question 5

Chemical  
equilibrium  
systems

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



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]

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## Marking Guide – Paper 1 Section 1

<b>2023 Paper 1 Section 1 Question 1</b>  <b>Chemical equilibrium systems</b>	<p>In a chemical equation at equilibrium, a reversible arrow (<math>\rightleftharpoons</math>) symbolises that</p> <p>(A) the forward reaction has stopped but can be reversed.</p> <p>(B) the moles of reactants and products present are equal.</p> <p>(C) half of the reactants have been converted into products.</p> <p>(D) the concentration of reactants and products remains constant.</p> <p><b>Answer is D.</b></p>
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<b>2023 Paper 1 Section 1 Question 2</b>  <b>Chemical equilibrium systems</b>	<p>Determine which expression represents the hydrogen ion (<math>\text{H}^+</math>) concentration at a pH of 8.4.</p> <p>(A) <math>1 \times 10^{-8.4}</math></p> <p>(B) <math>1 \times 10^{-5.6}</math></p> <p>(C) <math>1 \times 10^{-0.9}</math></p> <p>(D) <math>1 \times 10^{-0.8}</math></p> <p><b>Answer is A.</b></p>
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<b>2023 Paper 1 Section 1 Question 3</b>  <b>Chemical equilibrium systems</b>	<p>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.</p> <table border="1"><thead><tr><th></th><th>Solution X</th><th>Solution Y</th></tr></thead><tbody><tr><td>(A)</td><td>HCl</td><td><math>\text{CH}_3\text{COOH}</math></td></tr><tr><td>(B)</td><td><math>\text{HNO}_3</math></td><td><math>\text{H}_2\text{SO}_4</math></td></tr><tr><td>(C)</td><td><math>\text{H}_3\text{PO}_4</math></td><td><math>\text{HNO}_3</math></td></tr><tr><td>(D)</td><td><math>\text{H}_2\text{SO}_4</math></td><td>HCl</td></tr></tbody></table> <p><b>Answer is D.</b></p>		Solution X	Solution Y	(A)	HCl	$\text{CH}_3\text{COOH}$	(B)	$\text{HNO}_3$	$\text{H}_2\text{SO}_4$	(C)	$\text{H}_3\text{PO}_4$	$\text{HNO}_3$	(D)	$\text{H}_2\text{SO}_4$	HCl
	Solution X	Solution Y														
(A)	HCl	$\text{CH}_3\text{COOH}$														
(B)	$\text{HNO}_3$	$\text{H}_2\text{SO}_4$														
(C)	$\text{H}_3\text{PO}_4$	$\text{HNO}_3$														
(D)	$\text{H}_2\text{SO}_4$	HCl														

<b>2023 Paper 1 Section 1 Questions 4-5</b>  <b>Chemical equilibrium systems</b>	<p>Questions 4–5 refer to the decomposition of hydrogen iodide gas (HI) to produce hydrogen gas (<math>\text{H}_2</math>) and iodine gas (<math>\text{I}_2</math>) in a sealed 1-litre container.</p> $2\text{HI}(\text{g}) \rightleftharpoons \text{H}_2(\text{g}) + \text{I}_2(\text{g}) \quad \Delta H = +53.6 \text{ kJ mol}^{-1}$ <p style="text-align: center;">Colourless      Colourless      Purple</p> <p><b>Question 4</b> Identify which change would shift the system from light purple to dark purple.</p> <p>(A) adding HI(g)</p> <p>(B) adding a catalyst</p> <p>(C) decreasing the temperature</p> <p>(D) increasing the concentration of <math>\text{H}_2(\text{g})</math></p> <p><b>Question 4 Answer is A.</b></p>
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**Question 5**

Determine the equilibrium expression ( $K_c$ ) for the reaction.

(A)  $K_c = \frac{[\text{H}_2][\text{I}_2]}{2[\text{HI}]}$

(B)  $K_c = \frac{[\text{H}_2][\text{I}_2]}{[\text{HI}]^2}$

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

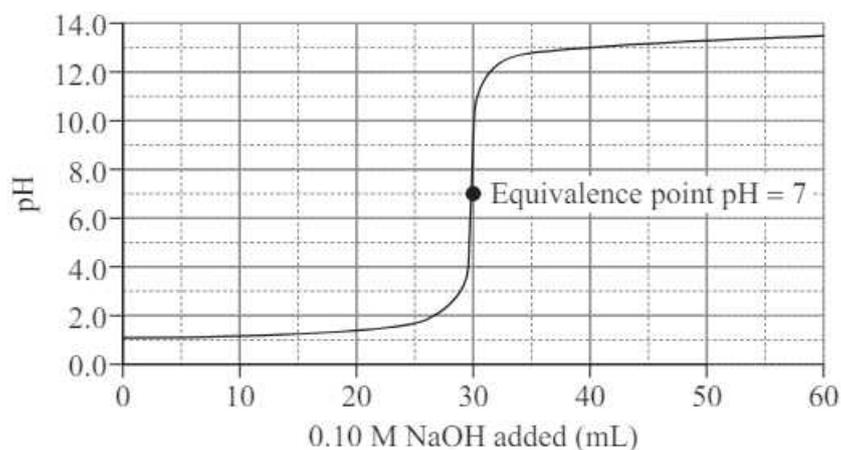
(D)  $K_c = \frac{2[\text{H}]2[\text{I}]}{[\text{HI}]^2}$

**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.**

<p><b>2023</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 15</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Predict how a buffer solution, consisting of carbonic acid (<math>\text{H}_2\text{CO}_3</math>) and hydrogen carbonate ions (<math>\text{HCO}_3^-</math>), would react to resist a change in pH when a small amount of hydrochloric acid is added.</p> $\text{H}_2\text{CO}_3(\text{aq}) \rightleftharpoons \text{HCO}_3^-(\text{aq}) + \text{H}^+(\text{aq}) \rightleftharpoons \text{CO}_3^{2-}(\text{aq}) + 2\text{H}^+(\text{aq})$ <p>(A) Equilibrium shifts to the right and the <math>[\text{H}^+](\text{aq})</math> increases.</p> <p>(B) Equilibrium shifts to the left and the <math>[\text{CO}_3^{2-}](\text{aq})</math> increases.</p> <p>(C) Equilibrium shifts to the left and the <math>[\text{H}_2\text{CO}_3](\text{aq})</math> increases.</p> <p>(D) Equilibrium shifts to the right and the <math>[\text{HCO}_3^-](\text{aq})</math> increases.</p> <p><b>Answer is C.</b></p>
<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 6</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>The equilibrium concentration of A is <math>2.8 \times 10^{-4}</math> M and B is <math>1.2 \times 10^{-4}</math> M.</p> $\text{A}(\text{g}) \rightleftharpoons \text{B}(\text{g}) \quad \Delta H > 0$ <p>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?</p> <p><b>(A) 8 molecules of A and 2 molecules of B – Answer</b></p> <p>(B) 5 molecules of A and 5 molecules of B</p> <p>(C) 3 molecules of A and 7 molecules of B</p> <p>(D) 2 molecules of A and 8 molecules of B</p>
<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 8</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Predict how the system shown will respond when a small amount of aqueous sodium hydroxide is added.</p> $\text{CH}_3\text{COOH}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{CH}_3\text{COO}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$ <p>(A) Equilibrium shifts to the left and the pH decreases.</p> <p>(B) Equilibrium shifts to the right and the pH increases.</p> <p>(C) Equilibrium shifts to the left and the pH remains the same.</p> <p><b>(D) Equilibrium shifts to the right and the pH remains the same. – Answer</b></p>
<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 10</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>The midpoint of the colour change of a weak acid indicator occurs when</p> <p>(A) <math>[\text{In}^-] = [\text{H}^+]</math></p> <p>(B) <math>[\text{In}^-] = [\text{HIn}]</math></p> <p>(C) <math>[\text{H}^+] = [\text{OH}^-]</math></p> <p>(D) <math>[\text{HIn}] = [\text{OH}^-]</math></p> <p><b>Answer is B.</b></p>
<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 13</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Determine the <math>K_a</math> of an unknown weak acid (HA) with an aqueous concentration of 0.12 M and a pH of 3.2.</p> <p>(A) <math>5.2 \times 10^{-3}</math></p> <p>(B) <math>6.3 \times 10^{-4}</math></p> <p><b>(C) <math>3.3 \times 10^{-6}</math> – Answer</b></p> <p>(D) <math>4.0 \times 10^{-7}</math></p>

<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 18</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Determine the <math>K_b</math> expression for the weak base shown in the equilibrium equation.</p> $\text{NH}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq})$ <p>(A) <math>K_b = \frac{[\text{NH}_3][\text{H}_2\text{O}]}{[\text{NH}_4^+]}</math></p> <p>(B) <math>K_b = \frac{[\text{NH}_3][\text{H}_2\text{O}]}{[\text{OH}^-]}</math></p> <p>(C) <math>K_b = \frac{[\text{NH}_4^+][\text{OH}^-]}{[\text{NH}_3]}</math></p> <p>(D) <math>K_b = \frac{[\text{NH}_4^+][\text{OH}^-]}{[\text{H}_2\text{O}]}</math></p> <p><b>Answer is C.</b></p>
<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 4</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>The cleaning action of soap is impaired in hard water because the</p> <p><b>(A) hydrophilic end reacts with calcium ions to form insoluble salts. – Answer</b> (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.</p>
<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 5</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>A 10.0 M solution of ethanoic acid is best described as a</p> <p>(A) dilute solution of a weak acid. (B) dilute solution of a strong acid. <b>(C) concentrated solution of a weak acid. – Answer</b> (D) concentrated solution of a strong acid.</p>
<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 10</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Determine which system at equilibrium will shift to the right (products) if the total pressure on the system is increased.</p> <p>(A) <math>\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})</math></p> <p>(B) <math>2\text{H}_2\text{O}(\text{g}) \rightleftharpoons 2\text{H}_2(\text{g}) + \text{O}_2(\text{g})</math></p> <p>(C) <math>2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})</math></p> <p>(D) <math>\text{CO}(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}_2(\text{g}) + \text{H}_2(\text{g})</math></p> <p><b>Answer is C.</b></p>
<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 11</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Enzymes can act as biological catalysts because they</p> <p>(A) can be denatured. <b>(B) lower the activation energy. – Answer</b> (C) are sensitive to pH and temperature changes. (D) increase the equilibrium constant for the reaction.</p>

<b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 14</b>  <b>Chemical equilibrium systems</b>	<table border="1"> <thead> <tr> <th>Acid</th> <th><math>K_a</math> value</th> </tr> </thead> <tbody> <tr> <td>Nitrous acid</td> <td><math>K_a = 4.00 \times 10^{-4}</math></td> </tr> <tr> <td>Ethanoic acid</td> <td><math>K_a = 1.76 \times 10^{-5}</math></td> </tr> <tr> <td>Hydrofluoric acid</td> <td><math>K_a = 7.20 \times 10^{-4}</math></td> </tr> <tr> <td>Chloroethanoic acid</td> <td><math>K_a = 1.40 \times 10^{-3}</math></td> </tr> </tbody> </table>	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	$K_a = 1.40 \times 10^{-3}$
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Analyse the data to determine the relative strengths of acids from strongest to weakest.											
(A) chloroethanoic, ethanoic, nitrous, hydrofluoric											
<b>(B) chloroethanoic, hydrofluoric, nitrous, ethanoic – Answer</b>											
(C) ethanoic, nitrous, hydrofluoric, chloroethanoic											
(D) ethanoic, hydrofluoric, nitrous, chloroethanoic											

<b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 17</b>  <b>Chemical equilibrium systems</b>	Determine the concentration of hydrogen ions ( $H^+$ ) in an aqueous solution containing $1.2 \times 10^{-3}$ M hydroxide ions ( $OH^-$ ).
	(A) $1.2 \times 10^{11}$ <b>(B) <math>8.3 \times 10^{-12}</math> – Answer</b> (C) $8.3 \times 10^{-17}$ (D) $1.2 \times 10^{-17}$

<b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 5</b>  <b>Chemical equilibrium systems</b>	The equilibrium constants of four different reactions are given.															
	In which reaction does the equilibrium lie furthest to the left?															
	<table border="1"> <thead> <tr> <th></th> <th>Reaction</th> <th><math>K_c</math></th> </tr> </thead> <tbody> <tr> <td>(A)</td> <td><math>PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)</math></td> <td><math>2.4 \times 10^1</math></td> </tr> <tr> <td>(B)</td> <td><math>AgIO_3(s) \rightleftharpoons Ag^+(aq) + IO_3^-(aq)</math></td> <td><math>3.0 \times 10^{-8}</math></td> </tr> <tr> <td>(C)</td> <td><math>Cl_2(g) + H_2O(l) \rightleftharpoons HOCl(aq) + Cl^-(aq) + H^+(aq)</math></td> <td><math>4.0 \times 10^{-4}</math></td> </tr> <tr> <td>(D)</td> <td><math>HSO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + SO_3^{2-}(aq)</math></td> <td><math>6.3 \times 10^{-8}</math></td> </tr> </tbody> </table>		Reaction	$K_c$	(A)	$PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g)$	$2.4 \times 10^1$	(B)	$AgIO_3(s) \rightleftharpoons Ag^+(aq) + IO_3^-(aq)$	$3.0 \times 10^{-8}$	(C)	$Cl_2(g) + H_2O(l) \rightleftharpoons HOCl(aq) + Cl^-(aq) + H^+(aq)$	$4.0 \times 10^{-4}$	(D)	$HSO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + SO_3^{2-}(aq)$	$6.3 \times 10^{-8}$
		Reaction	$K_c$													
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(B)	$AgIO_3(s) \rightleftharpoons Ag^+(aq) + IO_3^-(aq)$	$3.0 \times 10^{-8}$														
(C)	$Cl_2(g) + H_2O(l) \rightleftharpoons HOCl(aq) + Cl^-(aq) + H^+(aq)$	$4.0 \times 10^{-4}$														
(D)	$HSO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + SO_3^{2-}(aq)$	$6.3 \times 10^{-8}$														
<b>Answer is B.</b>																

<b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 7</b>  <b>Chemical equilibrium systems</b>	<table border="1"> <thead> <tr> <th>Acid</th> <th>Concentration (M)</th> <th>pH</th> </tr> </thead> <tbody> <tr> <td><math>H_3PO_4</math></td> <td><math>2.0 \times 10^{-2}</math></td> <td>1.9</td> </tr> <tr> <td>HCN</td> <td><math>1.5 \times 10^{-1}</math></td> <td>5.0</td> </tr> <tr> <td><math>H_2SO_4</math></td> <td><math>9.0 \times 10^{-2}</math></td> <td>1.0</td> </tr> <tr> <td><math>CH_3COOH</math></td> <td><math>1.0 \times 10^{-1}</math></td> <td>2.8</td> </tr> </tbody> </table>	Acid	Concentration (M)	pH	$H_3PO_4$	$2.0 \times 10^{-2}$	1.9	HCN	$1.5 \times 10^{-1}$	5.0	$H_2SO_4$	$9.0 \times 10^{-2}$	1.0	$CH_3COOH$	$1.0 \times 10^{-1}$	2.8
	Acid	Concentration (M)	pH													
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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) $HCN > CH_3COOH > H_3PO_4 > H_2SO_4$																
<b>Answer is B.</b>																

<p><b>2020 Paper 1 Section 1 Question 9</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Phosgene gas (<math>\text{COCl}_2</math>) is formed by the following reaction.</p> $\text{CO}(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons \text{COCl}_2(\text{g}) \quad \Delta H = -110 \text{ kJ mol}^{-1}$ <p>Which of the following statements is true for the system at equilibrium?</p> <p>(A) Removing <math>\text{Cl}_2(\text{g})</math> will increase the yield of phosgene and keep the <math>K_c</math> value constant.</p> <p>(B) Adding a catalyst will increase the yield of phosgene and keep the <math>K_c</math> value constant.</p> <p>(C) Increasing the pressure will increase the yield of phosgene and keep the <math>K_c</math> value constant.</p> <p>(D) Decreasing the temperature will decrease the yield of phosgene and keep the <math>K_c</math> value constant.</p> <p><b>Answer is C.</b></p>
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<p><b>2020 Paper 1 Section 1 Question 14</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Ammonia gas reacts with oxygen gas in the following equilibrium reaction.</p> $4\text{NH}_3(\text{g}) + 3\text{O}_2(\text{g}) \rightleftharpoons 2\text{N}_2(\text{g}) + 6\text{H}_2\text{O}(\text{g})$ <p>The equilibrium expression for the reaction is</p> <p>(A) <math>\frac{[\text{NH}_3][\text{O}_2]}{[\text{N}_2][\text{H}_2\text{O}]}</math></p> <p>(B) <math>\frac{[\text{N}_2][\text{H}_2\text{O}]}{[\text{NH}_3][\text{O}_2]}</math></p> <p>(C) <math>\frac{[\text{NH}_3]^4[\text{O}_2]^3}{[\text{N}_2]^2[\text{H}_2\text{O}]^6}</math></p> <p>(D) <math>\frac{[\text{N}_2]^2[\text{H}_2\text{O}]^6}{[\text{NH}_3]^4[\text{O}_2]^3}</math></p> <p><b>Answer is D.</b></p>
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<p><b>2020 Paper 1 Section 1 Question 18</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Solution A has a pH of 3 and solution B has a pH of 6. This indicates that solution A is</p> <p>(A) less acidic and has 0.5 times the concentration of hydrogen ions in solution B.</p> <p>(B) more acidic and has 2 times the concentration of hydrogen ions in solution B.</p> <p>(C) less acidic and has 0.001 times the concentration of hydrogen ions in solution B.</p> <p><b>(D) more acidic and has 1000 times the concentration of hydrogen ions in solution B. – Answer</b></p>
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<p>2023 Paper 1 Section 2 Question 21</p> <p>Chemical equilibrium systems</p>	<p>CO(g) reacts with O<sub>2</sub>(g) in a sealed container producing CO<sub>2</sub>(g) to reach equilibrium.</p> $2\text{CO(g)} + \text{O}_2\text{(g)} \rightleftharpoons 2\text{CO}_2\text{(g)}$ <p>Apply collision theory to explain how increasing the concentration of O<sub>2</sub> at equilibrium will affect the concentration of CO<sub>2</sub> if the temperature and volume are held constant.</p> <p style="text-align: right;">[4 marks]</p> <table border="1" style="width: 100%;"> <thead> <tr> <th style="text-align: center;">Sample response</th> <th style="text-align: center;">The response</th> </tr> </thead> <tbody> <tr> <td style="vertical-align: top;"> <p>Increasing the concentration of O<sub>2</sub> increases the number of O<sub>2</sub> molecules.</p> <p>This increases the frequency of collisions between O<sub>2</sub> and CO.</p> <p>Therefore, the rate of the forward reaction increases and equilibrium shifts to the right (products) to increase the concentration of CO<sub>2</sub>.</p> </td> <td style="vertical-align: top;"> <ul style="list-style-type: none"> <li>• identifies that increasing concentration of O<sub>2</sub> increases the number of O<sub>2</sub> molecules [1 mark]</li> <li>• explains that an increase in [O<sub>2</sub>] increases collisions between O<sub>2</sub> and CO [1 mark]</li> <li>• explains that the rate of forward reaction increases [1 mark]</li> <li>• identifies that equilibrium shifts to the right and concentration of CO<sub>2</sub> increases [1 mark]</li> </ul> </td> </tr> </tbody> </table>	Sample response	The response	<p>Increasing the concentration of O<sub>2</sub> increases the number of O<sub>2</sub> molecules.</p> <p>This increases the frequency of collisions between O<sub>2</sub> and CO.</p> <p>Therefore, the rate of the forward reaction increases and equilibrium shifts to the right (products) to increase the concentration of CO<sub>2</sub>.</p>	<ul style="list-style-type: none"> <li>• identifies that increasing concentration of O<sub>2</sub> increases the number of O<sub>2</sub> molecules [1 mark]</li> <li>• explains that an increase in [O<sub>2</sub>] increases collisions between O<sub>2</sub> and CO [1 mark]</li> <li>• explains that the rate of forward reaction increases [1 mark]</li> <li>• identifies that equilibrium shifts to the right and concentration of CO<sub>2</sub> increases [1 mark]</li> </ul>
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<p>Increasing the concentration of O<sub>2</sub> increases the number of O<sub>2</sub> molecules.</p> <p>This increases the frequency of collisions between O<sub>2</sub> and CO.</p> <p>Therefore, the rate of the forward reaction increases and equilibrium shifts to the right (products) to increase the concentration of CO<sub>2</sub>.</p>	<ul style="list-style-type: none"> <li>• identifies that increasing concentration of O<sub>2</sub> increases the number of O<sub>2</sub> molecules [1 mark]</li> <li>• explains that an increase in [O<sub>2</sub>] increases collisions between O<sub>2</sub> and CO [1 mark]</li> <li>• explains that the rate of forward reaction increases [1 mark]</li> <li>• identifies that equilibrium shifts to the right and concentration of CO<sub>2</sub> increases [1 mark]</li> </ul>				

<p>2023 Paper 1 Section 2 Question 27</p> <p>Chemical equilibrium systems</p>	<p>An unknown monoprotic acid solution was titrated with 0.1 M NaOH(aq).</p> <div style="text-align: center;"> </div> <p>(a) Use Le Châtelier's principle to explain why phenolphthalein is a suitable indicator for this titration. [4 marks]</p> <table border="1" style="width: 100%;"> <thead> <tr> <th style="text-align: center;">Sample response</th> <th style="text-align: center;">The response</th> </tr> </thead> <tbody> <tr> <td style="vertical-align: top;"> <p><math>\text{HIn(aq)} \rightleftharpoons \text{In}^-\text{(aq)} + \text{H}^+\text{(aq)}</math></p> <p>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.</p> <p>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.</p> </td> <td style="vertical-align: top;"> <ul style="list-style-type: none"> <li>• explains phenolphthalein is colourless in its acidic form [1 mark]</li> <li>• explains adding OH<sup>-</sup>(aq) removes H<sup>+</sup>(aq) [1 mark]</li> <li>• explains equilibrium shifts toward the coloured anion [1 mark]</li> <li>• explains pH equivalence point lies within the pH range of the colour change [1 mark]</li> </ul> </td> </tr> </tbody> </table>	Sample response	The response	<p><math>\text{HIn(aq)} \rightleftharpoons \text{In}^-\text{(aq)} + \text{H}^+\text{(aq)}</math></p> <p>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.</p> <p>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.</p>	<ul style="list-style-type: none"> <li>• explains phenolphthalein is colourless in its acidic form [1 mark]</li> <li>• explains adding OH<sup>-</sup>(aq) removes H<sup>+</sup>(aq) [1 mark]</li> <li>• explains equilibrium shifts toward the coloured anion [1 mark]</li> <li>• explains pH equivalence point lies within the pH range of the colour change [1 mark]</li> </ul>
Sample response	The response				
<p><math>\text{HIn(aq)} \rightleftharpoons \text{In}^-\text{(aq)} + \text{H}^+\text{(aq)}</math></p> <p>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.</p> <p>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.</p>	<ul style="list-style-type: none"> <li>• explains phenolphthalein is colourless in its acidic form [1 mark]</li> <li>• explains adding OH<sup>-</sup>(aq) removes H<sup>+</sup>(aq) [1 mark]</li> <li>• explains equilibrium shifts toward the coloured anion [1 mark]</li> <li>• explains pH equivalence point lies within the pH range of the colour change [1 mark]</li> </ul>				

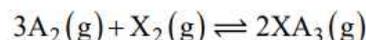
(b) Predict whether the pH of the equivalence point and the volume of NaOH required to neutralise the acid would change if the concentration of NaOH was doubled to 0.2 M. [2 marks]

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 $[\text{OH}^-]$ has doubled.	<ul style="list-style-type: none"> <li>determines the pH of the equivalence point would remain the same [1 mark]</li> <li>determines the volume of NaOH required to reach the equivalence would be halved [1 mark]</li> </ul>

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.



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.	<ul style="list-style-type: none"> <li>identifies gases reach dynamic equilibrium [1 mark]</li> <li>explains matter is not exchanged with surrounds [1 mark]</li> <li>explains rate of forward reaction is equal to rate of reverse reaction [1 mark]</li> </ul>

b) Determine if the relative position of equilibrium lies towards the products or reactants, if the molar concentrations at equilibrium are  $3.4 \text{ mol L}^{-1}$  for  $\text{A}_2$ ,  $1.8 \text{ mol L}^{-1}$  for  $\text{X}_2$  and  $4.2 \text{ mol L}^{-1}$  for  $\text{XA}_3$ . Explain your reasoning. [2 marks]

Sample Response	The response
$K_c = \frac{[\text{XA}_3]^2}{[\text{A}_2]^3 [\text{X}_2]}$ $K_c = \frac{[4.2]^2}{[3.4]^3 [1.8]}$ $K_c = \frac{17.64}{70.7472} = 0.25$ $K_c < 1$ therefore equilibrium lies to the left	<ul style="list-style-type: none"> <li>determines <math>K_c = 0.25</math> [1 mark]</li> <li>indicates that since <math>K_c &lt; 1</math>, equilibrium lies towards the reactants [1 mark]</li> </ul>

<b>2022</b> <b>Paper 1</b> <b>Section 2</b> <b>Question 26</b>  <b>Chemical equilibrium systems</b>	Three unknown 0.1 M solutions, A, B and C, are found to have the following properties.																
	<table border="1"> <thead> <tr> <th>Solution</th> <th>[H<sup>+</sup>] (mol L<sup>-1</sup>)</th> <th>pH</th> <th>pOH</th> </tr> </thead> <tbody> <tr> <td>A</td> <td>0.0001</td> <td></td> <td>10.0</td> </tr> <tr> <td>B</td> <td></td> <td>2.0</td> <td></td> </tr> <tr> <td>C</td> <td>0.063</td> <td></td> <td></td> </tr> </tbody> </table>	Solution	[H <sup>+</sup> ] (mol L <sup>-1</sup> )	pH	pOH	A	0.0001		10.0	B		2.0		C	0.063		
	Solution	[H <sup>+</sup> ] (mol L <sup>-1</sup> )	pH	pOH													
	A	0.0001		10.0													
B		2.0															
C	0.063																
a) Determine the pH of solution A. [1 mark]																	
<table border="1"> <thead> <tr> <th>Sample Response</th> <th>The response</th> </tr> </thead> <tbody> <tr> <td>pH = 4.0</td> <td>• determines pH for solution A is 4.0 [1 mark]</td> </tr> </tbody> </table>	Sample Response	The response	pH = 4.0	• determines pH for solution A is 4.0 [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<sup>+</sup>] in solution B. [1 mark]

Sample Response	The response
[H <sup>+</sup> ] in Solution B = 0.010 mol L <sup>-1</sup>	• determines [H <sup>+</sup> ] 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]

<b>2022</b> <b>Paper 1</b> <b>Section 2</b> <b>Question 27</b>  <b>Chemical equilibrium systems</b>	Five colourless 0.1 M solutions of NH <sub>3</sub> , HCl, KOH, H <sub>2</sub> SO <sub>4</sub> and CH <sub>3</sub> CH <sub>2</sub> COOH 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.																		
	<table border="1"> <thead> <tr> <th>Solution</th> <th>Conductivity (S/m)</th> <th>Colour with phenol red</th> </tr> </thead> <tbody> <tr> <td>A</td> <td>4.1</td> <td>yellow</td> </tr> <tr> <td>B</td> <td>0.14</td> <td>red</td> </tr> <tr> <td>C</td> <td>0.08</td> <td>yellow</td> </tr> <tr> <td>D</td> <td>6.7</td> <td>yellow</td> </tr> <tr> <td>E</td> <td>4.9</td> <td>red</td> </tr> </tbody> </table>	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
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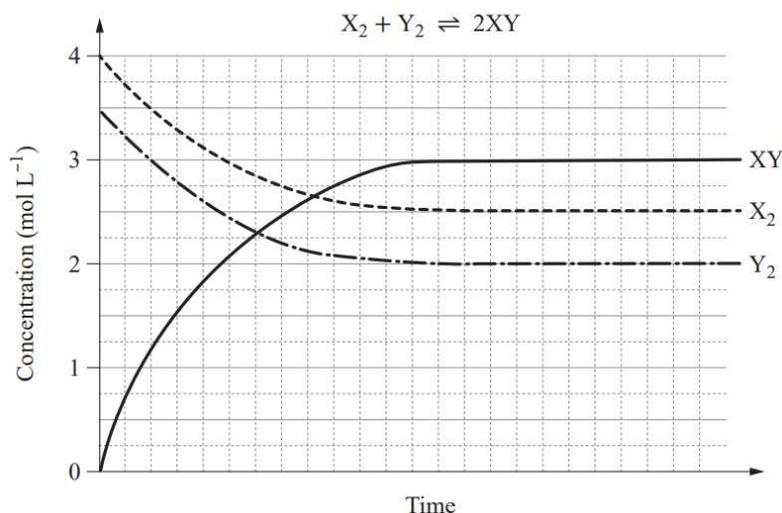
<b>2021</b> <b>Paper 1</b> <b>Section 2</b> <b>Question 21</b>  <b>Chemical equilibrium systems</b>	Calculate the pH of a 0.1M aqueous solution of Ba(OH) <sub>2</sub> , assuming complete dissociation. Show your working.							
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<b>2021</b> <b>Paper 1</b> <b>Section 2</b> <b>Question 25</b>  <b>Chemical equilibrium systems</b>	An equilibrium is formed between two differently coloured cobalt species, $\text{Co}(\text{H}_2\text{O})_6^{2+}(\text{aq})$ , which is pink, and $\text{CoCl}_4^{2-}(\text{aq})$ , which is blue. The equation for this equilibrium is shown.								
	$\text{Co}(\text{H}_2\text{O})_6^{2+}(\text{aq}) + 4\text{Cl}^-(\text{aq}) \rightleftharpoons \text{CoCl}_4^{2-}(\text{aq}) + 6\text{H}_2\text{O}(\text{l})$								
Apply Le Châtelier's principle to predict the visible effect of adding AgNO <sub>3</sub> to an aqueous, blue-coloured solution containing $\text{Co}(\text{H}_2\text{O})_6^{2+}$ and $\text{CoCl}_4^{2-}$ ions. Explain your reasoning. [3 marks]									
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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]									
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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.	<ul style="list-style-type: none"> <li>identifies <math>XY</math> as the product [1 mark]</li> </ul>	

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

Sample Response	The response	Notes
$K_c = \frac{[XY]^2}{[X][Y]} = \frac{3^2}{2 \times 2.5} = 1.8 \text{ (to two significant figures)}$	<ul style="list-style-type: none"> <li>indicates correct substitution [1 mark]</li> <li>determines <math>K_c = 1.8</math> [1 mark]</li> </ul>	<p>Allow FT error for <math>K_c</math>.</p> <p>Do not penalise for incorrect decimal places/significant figures.</p>

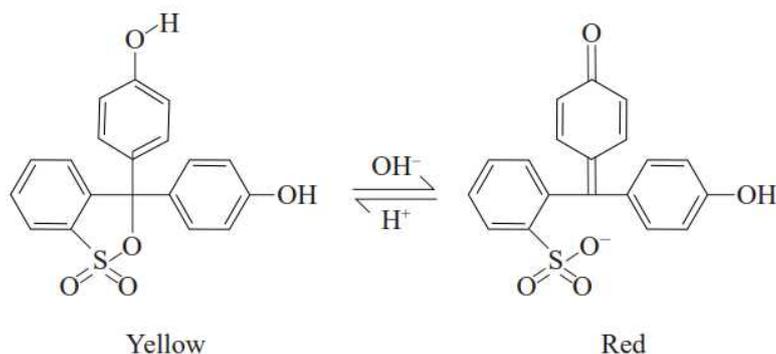
c) Determine whether the position of equilibrium favours the reactants or products. Explain your reasoning. [2 marks]

Sample Response	The response	Notes
$K_c > 1$ . Therefore, equilibrium favours the products.	<ul style="list-style-type: none"> <li>identifies <math>K_c &gt; 1</math> [1 mark]</li> <li>concludes that equilibrium favours products [1 mark]</li> </ul>	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
<p style="text-align: center;">Yellow <span style="margin-left: 200px;">Red</span></p>	<ul style="list-style-type: none"> <li>circles the red species [1 mark]</li> </ul>

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  $2.0 \times 10^{-4}$  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
$K_a = \frac{[2.0 \times 10^{-4}][2.0 \times 10^{-4}]}{0.034}$ $= 1.18 \times 10^{-6}$ $pK_a = -\log [1.18 \times 10^{-6}] = 5.9$ $pK_a = 5.9 \text{ (to two significant figures)}$	<ul style="list-style-type: none"> <li>demonstrates substitution correctly performed [1 mark]</li> <li>determines <math>K_a = 1.2 \times 10^{-6}</math> [1 mark]</li> <li>determine <math>pK_a = 5.9</math> [1 mark]</li> </ul>	<p>Allow FT error for <math>K_a</math>.</p> <p>Do not penalise for incorrect decimal places/significant figures.</p>

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

Sample Response	The response
<p>Phenol red changes colour over a pH range because the molecular form (<math>HIn(aq)</math>) and ionic form (<math>In^-(aq)</math>) are different colours.</p> <p>When <math>[HIn(aq)] = [In^-(aq)]</math>, the <math>pH = pK_a</math> and phenol red changes colour.</p> <p>When <math>pH &lt; pK_a</math>, the <math>[HIn(aq)] &gt; [In^-(aq)]</math> and phenol red turns yellow.</p> <p>When <math>pH &gt; pK_a</math>, the <math>[HIn(aq)] &lt; [In^-(aq)]</math> and phenol red turns red.</p>	<ul style="list-style-type: none"> <li>indicates pH colour range is due to molecular form and ionic form being different colours [1 mark]</li> <li>identifies phenol red changes colour when <math>pH = pK_a</math> [1 mark]</li> <li>indicates when <math>pH &lt; pK_a</math> equilibrium favours the molecular form (<math>HIn</math>), the solution is yellow. When <math>pH &gt; pK_a</math> equilibrium favours the ionic form (<math>In^-</math>), the solution is red [1 mark]</li> </ul>

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
<p>As the temperature increases, the <math>[\text{H}_3\text{O}^+]</math> increases.</p> $2\text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{OH}^-(\text{aq})$ <p>Therefore, the equilibrium shifts towards the products. Increasing temperature shifts equilibrium in the endothermic direction, therefore the self-ionisation of water is endothermic.</p>	<ul style="list-style-type: none"> <li>identifies <math>[\text{H}_3\text{O}^+]</math> increases as temperature increases [1 mark]</li> <li>identifies equilibrium shifts towards the products and the endothermic direction [1 mark]</li> <li>determines self-ionisation of water is endothermic [1 mark]</li> </ul>	<p>Allow FT error for:</p> <ul style="list-style-type: none"> <li>equilibrium shifts to the reactants</li> <li>self-ionisation of water decreases.</li> </ul>

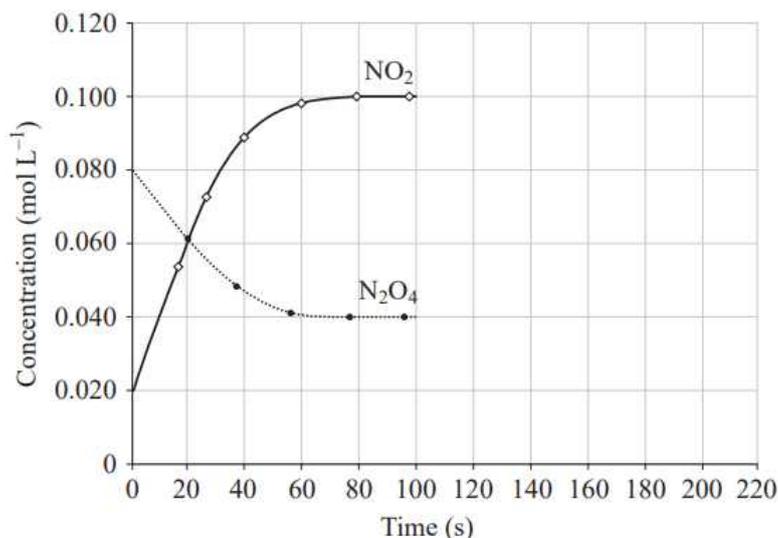
b) Calculate the  $K_w$  of pure water at 50 °C. Show your working. [2 marks]

Sample Response	The response	Notes
<p><math>\text{pH} = -\log [\text{H}^+] = 6.63</math>  <math>[\text{H}^+] = 10^{-6.63}</math>  <math>= 2.34 \times 10^{-7}</math>  <math>K_w = [\text{H}^+][\text{OH}^-]</math>  <math>= (2.34 \times 10^{-7})^2</math>  <math>K_w = 5.48 \times 10^{-14}</math> (to 3 significant figures)</p>	<ul style="list-style-type: none"> <li>determines <math>[\text{H}^+] = 2.34 \times 10^{-7}</math> [1 mark]</li> <li>determines consequentially correct <math>K_w</math> [1 mark]</li> </ul>	<p>Allow FT error from <math>[\text{H}^+]</math>.</p> <p>Do not penalise for incorrect decimal places/significant figures.</p>

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
$\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$	• provides $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$ [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
	<ul style="list-style-type: none"> <li>• indicates that at 100 s concentration of N<sub>2</sub>O<sub>4</sub> and NO<sub>2</sub> would halve [1 mark]</li> <li>• indicates that after 100 s concentration of N<sub>2</sub>O<sub>4</sub> would decrease to a new equilibrium at a lower concentration [1 mark]</li> <li>• indicates that after 100 s concentration of NO<sub>2</sub> would increase to a new equilibrium at a higher concentration [1 mark]</li> </ul>

**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 <sub>3</sub> ) <sub>2</sub> solution	X(NO <sub>3</sub> ) <sub>2</sub> solution	Z(NO <sub>3</sub> ) <sub>2</sub> solution	A(NO <sub>3</sub> ) <sub>2</sub> 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<sub>3</sub>)<sub>2</sub>. [1 mark]

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

b) Identify the oxidising agent in the reaction between Z and Q(NO<sub>3</sub>)<sub>2</sub>. [1 mark]

Sample Response	The response	Notes
Q <sup>2+</sup>	• provides Q <sup>2+</sup> [1 mark]	For Q <sup>2+</sup> accept Q in Q(NO <sub>3</sub> ) <sub>2</sub>

c) Determine the products formed from the reaction between Z and A(NO<sub>3</sub>)<sub>2</sub>. [1 mark]

Sample Response	The response
Z(NO <sub>3</sub> ) <sub>2</sub> (aq) and A(s)	• provides Z(NO <sub>3</sub> ) <sub>2</sub> (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 <sup>2+</sup> , Q <sup>2+</sup> and A <sup>2+</sup> , therefore it is the strongest reducing agent. X can only reduce Q <sup>2+</sup> 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]

2023  
 Paper 2  
 Section 1  
 Question 5

 Chemical  
 equilibrium  
 systems

The table gives the properties of four monoprotic acids.

Acid	Concentration (mol L <sup>-1</sup> )	[H <sup>+</sup> ] (mol L <sup>-1</sup> )	pH	K <sub>a</sub>
1	0.200	7.90 × 10 <sup>-5</sup>		
2	0.100	4.20 × 10 <sup>-3</sup>	2.34	1.80 × 10 <sup>-4</sup>
CH <sub>3</sub> COOH(aq)	0.100			1.78 × 10 <sup>-5</sup>
HCl(aq)	0.010	1.00 × 10 <sup>-2</sup>	2.00	>1

(a) Determine the relative strength of acids 1 and 2 by contrasting their K<sub>a</sub> values. [3 marks]

Sample response	The response
Acid 1: $K_a = \frac{[H^+][A^-]}{[HA]} = \frac{(7.90 \times 10^{-5})^2}{0.200} = 3.12 \times 10^{-8}$ Acid 2 has a larger K <sub>a</sub> than acid 1. Therefore, acid 2 is a stronger acid.	<ul style="list-style-type: none"> <li>calculates K<sub>a</sub> for acid 1 as 3.12 × 10<sup>-8</sup> [1 mark]</li> <li>identifies the K<sub>a</sub> for acid 2 is greater than acid 1 [1 mark]</li> <li>determines acid 2 is stronger [1 mark]</li> </ul>

(b) Write a balanced chemical equation for the dissociation of ethanoic acid (CH<sub>3</sub>COOH) in water. [2 marks]

Sample response	The response
$CH_3COOH(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CH_3COO^-(aq)$	<ul style="list-style-type: none"> <li>states balanced equation [1 mark]</li> <li>uses an equilibrium arrow [1 mark]</li> </ul>

(c) Identify whether the conjugate base of ethanoic acid (CH<sub>3</sub>COOH(aq)) is amphiprotic. Explain your reasoning. [2 marks]

Sample response	The response
Conjugate base of ethanoic acid, CH <sub>3</sub> COO <sup>-</sup> , is not amphiprotic as it can accept a H <sup>+</sup> ion but cannot donate one.	<ul style="list-style-type: none"> <li>identifies the conjugate base, CH<sub>3</sub>COO<sup>-</sup>, is not amphiprotic [1 mark]</li> <li>explains that CH<sub>3</sub>COO<sup>-</sup> can accept but not donate a H<sup>+</sup> ion [1 mark]</li> </ul>

(d) Calculate the pH of the aqueous solution of ethanoic acid (CH<sub>3</sub>COOH). Show your working. [3 marks]

Sample response	The response
$1.78 \times 10^{-5} = \frac{[H^+][A^-]}{[HA]} = \frac{x^2}{0.100}$ $x = [H^+] = \sqrt{(1.78 \times 10^{-5}) \times 0.1} = 1.33 \times 10^{-3} \text{ M}$ $\text{pH} = -\log(1.33 \times 10^{-3}) = 2.87$	<ul style="list-style-type: none"> <li>identifies [CH<sub>3</sub>COO<sup>-</sup>] equals [H<sup>+</sup>] [1 mark]</li> <li>determines [H<sup>+</sup>] is 1.33 × 10<sup>-3</sup> [1 mark]</li> <li>calculates pH [1 mark]</li> </ul>

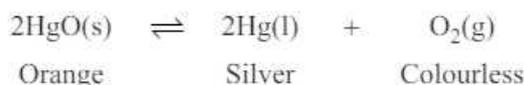
(e) Determine the volume of water that would need to be added to 100.0 mL of HCl(aq) to change the pH from 2.00 to 3.00. Explain your reasoning. [3 marks]

Sample response	The response
[H <sup>+</sup> ] is 10x greater at pH 2.0 than at pH 3.0. Therefore, final volume needs to be 1 L (0.1000 L × 10 = 1.000 L). Therefore, 1.000 – 0.1000 = 0.900 L of water is needed.	<ul style="list-style-type: none"> <li>identifies [H<sup>+</sup>] at pH 2.0 is 10 times greater than pH 3.0 [1 mark]</li> <li>determines final volume would be 1 L [1 mark]</li> <li>determines 0.900 L of water needs to be added [1 mark]</li> </ul>

2023  
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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<sub>2</sub>).



(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.	<ul style="list-style-type: none"> <li>• identifies the concentration of the reactants and products remain constant at equilibrium [1 mark]</li> <li>• explains that the forward and reverse reactions are occurring simultaneously [1 mark]</li> <li>• explains forward reaction is equal to reverse reaction and therefore there is no colour change [1 mark]</li> </ul>

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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).



Experiment	Initial concentration (mol L <sup>-1</sup> )			Equilibrium concentration (mol L <sup>-1</sup> )			K <sub>c</sub>
	[HI]	[H <sub>2</sub> ]	[I <sub>2</sub> ]	[HI]	[H <sub>2</sub> ]	[I <sub>2</sub> ]	
1	0.08	0.00	0.00		0.01		2.78 × 10 <sup>-2</sup>
2	0.00	0.06	0.06	0.06	0.03	0.03	

(a) Determine the concentration of HI(g) and I<sub>2</sub>(g) at equilibrium for experiment 1. [2 marks]

Sample response	The response
[HI]: 0.06 mol L <sup>-1</sup> [I <sub>2</sub> ]: 0.01 mol L <sup>-1</sup>	<ul style="list-style-type: none"> <li>• determines [HI] is 0.06 [1 mark]</li> <li>• determines [I<sub>2</sub>] is 0.01 [1 mark]</li> </ul>

(b) Calculate the equilibrium constant (K<sub>c</sub>) for experiment 2. Show your working. [2 marks]

Sample response	The response
$K_c = \frac{[\text{H}_2][\text{I}_2]}{[\text{HI}]^2}$ $K_c = \frac{(0.03)^2}{(0.06)^2} = 0.25$	<ul style="list-style-type: none"> <li>• uses appropriate substitution [1 mark]</li> <li>• calculates K<sub>c</sub> is 0.25 [1 mark]</li> </ul>

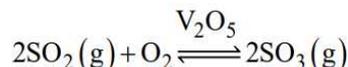
(c) Determine which experiment was conducted at a higher temperature. Explain your reasoning. [3 marks]

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.	<ul style="list-style-type: none"> <li>determines experiment 2 was conducted at a higher temperature [1 mark]</li> <li>explains that <math>K_c</math> value for experiment 2 is larger [1 mark]</li> <li>explains higher <math>K_c</math> value indicates equilibrium shifts to the right [1 mark]</li> </ul>

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Question 2

Chemical  
equilibrium  
systems

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



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

Temperature (K)	Equilibrium constant, $K_c$ (mol L <sup>-1</sup> )
298	$9.77 \times 10^{25}$
500	$8.61 \times 10^{11}$

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.	<ul style="list-style-type: none"> <li>determines forward reaction is exothermic [1 mark]</li> <li>explain that the decrease in <math>K_c</math> as temperature increases indicates endothermic direction is towards the reactants [1 mark]</li> </ul>

b) Calculate the equilibrium concentration of  $\text{SO}_3$  at 500 K given the equilibrium concentrations. [2 marks]

$$[\text{SO}_2] = 0.860 \text{ M}; [\text{O}_2] = 0.330 \text{ M}$$

Sample Response	The response
$8.61 \times 10^{11} = \frac{[\text{SO}_3]^2}{(0.860)^2(0.330)}$ $[\text{SO}_3]^2 = (0.7396)(0.330)(8.61 \times 10^{11}) = 2.10 \times 10^{11}$ Concentration = $4.58 \times 10^5 \text{ M}$	<ul style="list-style-type: none"> <li>provides appropriate working [1 mark]</li> <li>calculates <math>[\text{SO}_3] = 4.58 \times 10^5</math> [1 mark]</li> </ul>

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.	<ul style="list-style-type: none"> <li>indicates that halving the volume doubles the pressure [1 mark]</li> <li>explains that equilibrium will shift to reduce the number of molecules present to reduce pressure [1 mark]</li> <li>explains that equilibrium will shift toward the product [1 mark]</li> <li>explains why the equilibrium constant would not change [1 mark]</li> </ul>

**2022**  
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**Question 3**

**Chemical equilibrium systems**

A 50.0 mL solution of ethanoic acid ( $\text{CH}_3\text{COOH}$ ) was titrated with 15.0 mL of 0.10 M sodium hydroxide ( $\text{NaOH}$ ) solution to reach the equivalence point ( $\text{p}K_a$  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
$\text{CH}_3\text{COOH}(\text{aq}) + \text{OH}^-(\text{aq}) \rightleftharpoons \text{CH}_3\text{COO}^-(\text{aq}) + \text{H}_2\text{O}(\text{l})$ The conjugate base formed is $\text{CH}_3\text{COO}^-$ .	<ul style="list-style-type: none"> <li>provides correct balanced chemical equation [1 mark]</li> <li>identifies <math>\text{CH}_3\text{COO}^-</math> as conjugate base [1 mark]</li> </ul>

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

Sample Response	The response
$K_b = \frac{1.00 \times 10^{-14}}{10^{-4.76}} = 10^{-9.24} = 5.75 \times 10^{-10}$	<ul style="list-style-type: none"> <li>determines <math>K_b</math> is <math>5.75 \times 10^{-10}</math></li> </ul>

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 $\text{OH}^-$ = moles $\text{H}^+$ = moles $\text{CH}_3\text{COO}^-$ moles $\text{CH}_3\text{COO}^-$ = $n \times V = 0.10 \times 0.015 = 1.50 \times 10^{-3}$	<ul style="list-style-type: none"> <li>determines moles <math>\text{CH}_3\text{COO}^-</math> is <math>1.50 \times 10^{-3}</math> [1 mark]</li> <li>calculates <math>[\text{CH}_3\text{COO}^-]</math> is <math>2.31 \times 10^{-2} \text{ mol L}^{-1}</math> [1 mark]</li> </ul>

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

Sample Response	The response
$[\text{CH}_3\text{COOH}] = [\text{OH}^-] = x$ $K_b = \frac{[\text{OH}^-][\text{CH}_3\text{COOH}]}{[\text{CH}_3\text{COO}^-]}$ $K_b = 5.75 \times 10^{-10} = \frac{x^2}{[2.31 \times 10^{-2}]}$ $x^2 = 1.33 \times 10^{-11}$ $x = 3.64 \times 10^{-6} = [\text{OH}^-]$ $\text{pOH} = -\log(3.64 \times 10^{-6}) = 5.44 \sim 5.4$ $\text{pH} = 14 - 5.4 = 8.6$	<ul style="list-style-type: none"> <li>provides correct substitution [1 mark]</li> <li>calculates <math>[\text{OH}^-]</math> is <math>3.64 \times 10^{-6} \text{ M}</math> [1 mark]</li> <li>determines pOH is 5.4 [1 mark]</li> <li>calculates pH is 8.6 [1 mark]</li> </ul>

2021  
Paper 2  
Section 1  
Question 1

Chemical  
equilibrium  
systems

Phosphoric acid ( $\text{H}_3\text{PO}_4$ ) 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	$\text{H}_3\text{PO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_2\text{PO}_4^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$	$7.1 \times 10^{-3}$
2	$\text{H}_2\text{PO}_4^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HPO}_4^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$	$6.5 \times 10^{-8}$
3	$\text{HPO}_4^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{PO}_4^{3-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$	$4.5 \times 10^{-13}$

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: $\text{H}_3\text{PO}_4(\text{aq})$ Conjugate base: $\text{H}_2\text{PO}_4^-(\text{aq})$  Reasoning: $\text{H}_3\text{PO}_4$ is the strongest Brønsted-Lowry acid because it has the largest $K_a$ value. $\text{H}_3\text{PO}_4(\text{aq})$ donates a proton and $\text{H}_2\text{PO}_4^-(\text{aq})$ accepts a proton.	<ul style="list-style-type: none"> <li>identifies <math>\text{H}_3\text{PO}_4</math> as the acid and <math>\text{H}_2\text{PO}_4^-</math> as the conjugate base [1 mark]</li> <li>identifies <math>\text{H}_3\text{PO}_4</math> as the strongest acid due to having the largest <math>K_a</math> [1 mark]</li> <li>identifies acid as the <math>\text{H}^+</math> donor and base as the <math>\text{H}^+</math> acceptor [1 mark]</li> </ul>	For $\text{H}^+$ , 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
$\text{H}_2\text{PO}_4^-(\text{aq})$ is amphiprotic, because it can donate or accept a proton and therefore act as a Brønsted-Lowry acid or a base.	<ul style="list-style-type: none"> <li>identifies an amphiprotic species [1 mark]</li> <li>identifies that this species can accept or donate protons [1 mark]</li> </ul>	Acceptable amphiprotic species are: - $\text{H}_2\text{PO}_4^-$ - $\text{HPO}_4^{2-}$

c) Determine the  $K_b$  value for the strongest conjugate base formed when  $\text{H}_3\text{PO}_4$  has fully dissociated. Show your working. [2 marks]

Sample Response	The response	Notes
$K_w = K_a \times K_b$ $K_b = \frac{K_w}{K_a} = \frac{10^{-14}}{4.5 \times 10^{-13}} = 2.2 \times 10^{-2}$	<ul style="list-style-type: none"> <li>correctly substitutes into formula [1 mark]</li> <li>determines <math>K_b = 2.2 \times 10^{-2}</math> [1 mark]</li> </ul>	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 ( $\text{H}_2\text{PO}_4^-$ ). Show your working and state any assumptions made. [4 marks]

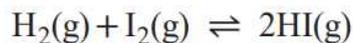
Sample Response	The response	Notes
As $K_a$ is very small, the dissociation of $\text{H}_2\text{PO}_4^- \rightarrow \text{HPO}_4^{2-}$ is very very small. Assume $0.05 \gg x$ , therefore $0.05 - x \approx 0.05$ At equilibrium $[\text{H}_2\text{PO}_4^-] = 0.05 - x = 0.05$ Let $x = [\text{H}^+] = [\text{HPO}_4^{2-}]$ $6.5 \times 10^{-8} = \frac{[x][x]}{[0.05-x]} \approx \frac{x^2}{0.05}$ $x^2 = 0.05 \times 6.5 \times 10^{-8}$ $x = \sqrt{3.25 \times 10^{-9}}$ $x = 5.70 \times 10^{-5} \text{ mol L}^{-1} = [\text{H}^+]$ $\text{pH} = -\log 5.70 \times 10^{-5}$ $\text{pH} = 4.2 \text{ (to one decimal place)}$	<ul style="list-style-type: none"> <li>indicates assumption <math>0.05 - x \approx 0.05</math> [1 mark]</li> <li>shows substitution correctly performed [1 mark]</li> <li>correctly determines <math>[\text{H}^+] = 5.70 \times 10^{-5}</math> [1 mark]</li> <li>determines <math>\text{pH} = 4.2</math> [1 mark]</li> </ul>	Allow FT error from incorrect substitution of $K_a$ .  Accept ICE table or other valid working. Allow FT error from $[\text{H}^+]$ .  Do not penalise for incorrect decimal places/significant figures.

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Paper 2  
Section 1  
Question 4

Chemical  
equilibrium  
systems

$5.00 \times 10^{-4}$  moles of hydrogen gas is mixed with  $1.00 \times 10^{-3}$  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  $9.30 \times 10^{-4}$  M.

The balanced equation for the reaction is shown.



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

Sample Response	The response	Notes
$K_c = \frac{[\text{HI}]^2}{[\text{H}_2] \times [\text{I}_2]}$	<ul style="list-style-type: none"> <li>provides <math>K_c = \frac{[\text{HI}]^2}{[\text{H}_2] \times [\text{I}_2]}</math> [1 mark]</li> </ul>	

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

Sample Response	The response	Notes
Change in $[\text{H}_2] = [\text{I}_2] = \frac{9.30 \times 10^{-4} \text{ mol}}{\text{L}} \times \frac{1 \text{ mol H}_2}{2 \text{ mol HI}} = 4.65 \times 10^{-4} \text{ M}$ $[\text{H}_2]_{\text{eq}} = 5.00 \times 10^{-4} - 4.65 \times 10^{-4} = 3.50 \times 10^{-5} \text{ M}$ $[\text{I}_2]_{\text{eq}} = 1.0 \times 10^{-3} - 4.65 \times 10^{-4} = 5.35 \times 10^{-4} \text{ M}$ $K_c = \frac{(9.30 \times 10^{-4})^2}{3.50 \times 10^{-5} \times 5.35 \times 10^{-4}} = 46.2$ $K_c = 46.2$ (to three significant figures)	<ul style="list-style-type: none"> <li>correctly determines change in <math>[\text{H}_2] = [\text{I}_2] = 4.65 \times 10^{-4}</math> [1 mark]</li> <li>determines <math>[\text{H}_2]_{\text{eq}} = 3.50 \times 10^{-5}</math> [1 mark]</li> <li>determines <math>[\text{I}_2]_{\text{eq}} = 5.35 \times 10^{-4}</math> [1 mark]</li> <li>shows substitution correctly performed [1 mark]</li> <li>determines <math>K_c = 46.2</math> [1 mark]</li> </ul>	Allow FT error for $[\text{H}_2]_{\text{eq}}$ . Allow FT error for $[\text{I}_2]_{\text{eq}}$ . 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, $K_c$ .	<ul style="list-style-type: none"> <li>identifies that a catalyst speeds up both the forward and reverse reactions [1 mark]</li> <li>identifies that a catalyst has no effect on the position of the equilibrium [1 mark]</li> <li>determines that a catalyst has no effect on the <math>K_c</math> value [1 mark]</li> </ul>	

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  $2 \times 10^{-3}$ . 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 = $(12.01 \times 9) + (16.00 \times 4) + 8.08 = 180.17 \text{ g}$  Moles of aspirin produced = $0.5 \text{ g} / 180.17 \text{ g} = 2.78 \times 10^{-3} \text{ mol}$  Ratio 1:1 45.0% efficient Moles of salicylic acid = $\frac{2.78 \times 10^{-3}}{0.45} = 6.17 \times 10^{-3} \text{ mol}$  Mass of salicylic acid = $6.17 \times 10^{-3} \times 138.13 = 0.852 \text{ g} = \text{Mass} = 852 \text{ mg}$ (to three significant figures)	• determines molar mass of aspirin is 180 g [1 mark] • determines $n_{\text{aspirin}} = 2.78 \times 10^{-3}$ [1 mark] • determines $n_{\text{acid}}$ [1 mark] • determines mass [1 mark]	Allow FT error from $n_{\text{aspirin}}$ .  Do not penalise for incorrect decimal places/significant figures.

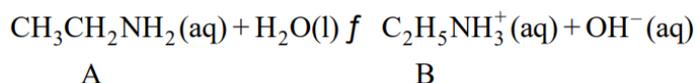
e) When the reaction is heated to 40 °C and equilibrium is re-established, the concentration of acetylsalicylic acid and ethanoic acid increases. Apply Le Châtelier's principle to predict if the forward reaction is exothermic or endothermic. Explain your reasoning. [4 marks]

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.



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 <sub>2</sub> O(l) C <sub>2</sub> H <sub>5</sub> NH <sub>3</sub> <sup>+</sup> (aq)	• provides H <sub>2</sub> O(l) [1 mark] • provides C <sub>2</sub> H <sub>5</sub> NH <sub>3</sub> <sup>+</sup> (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 <sup>+</sup> ) reacts with the OH <sup>-</sup> 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 <sup>-</sup> (products). Therefore, the concentration of A will decrease.	• indicates that [OH <sup>-</sup> ] 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*<sub>b</sub> = 5.6 × 10<sup>-4</sup>) [6 marks]

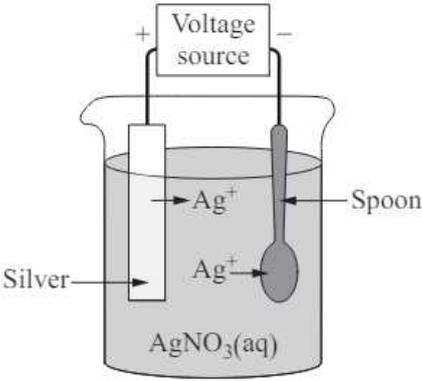
Sample Response	The response	Notes
$[\text{CH}_3\text{CH}_2\text{NH}_2] = 2.0 - x \approx 2.0 \text{ as } 2.0 \gg K_b$  Let $x = [\text{C}_2\text{H}_5\text{NH}_3^+] = [\text{OH}^-]$  $K_b = \frac{[\text{C}_2\text{H}_5\text{NH}_3^+][\text{OH}^-]}{[\text{CH}_3\text{CH}_2\text{NH}_2]}$ $5.6 \times 10^{-4} = \frac{[x][x]}{[2.0]} = \frac{x^2}{2.0}$ $x^2 = 1.12 \times 10^{-3}$  $x = 0.033466 = [\text{OH}^-]$  $\text{pOH} = -\log [\text{OH}^-] = 1.475 \approx 1.5$  $\text{pH} = 14 - 1.5 = 12.5$ $\text{pH} = 12.5 \text{ (to 1 decimal place)}$	<ul style="list-style-type: none"> <li>• indicates assumption to support <math>[\text{CH}_3\text{CH}_2\text{NH}_2] \approx 2.0</math> [1 mark]</li> <li>• indicates <math>[\text{C}_2\text{H}_5\text{NH}_3^+] = [\text{OH}^-]</math> [1 mark]</li> <li>• shows substitution correctly performed [1 mark]</li> <li>• determines <math>[\text{OH}^-] = 3.35 \times 10^{-2}</math> [1 mark]</li> <li>• determines pOH [1 mark]</li> <li>• determines pH [1 mark]</li> </ul>	Accept ICE table.  Allow FT error from [OH <sup>-</sup> ].  Do not penalise for incorrect decimal places/significant figures.

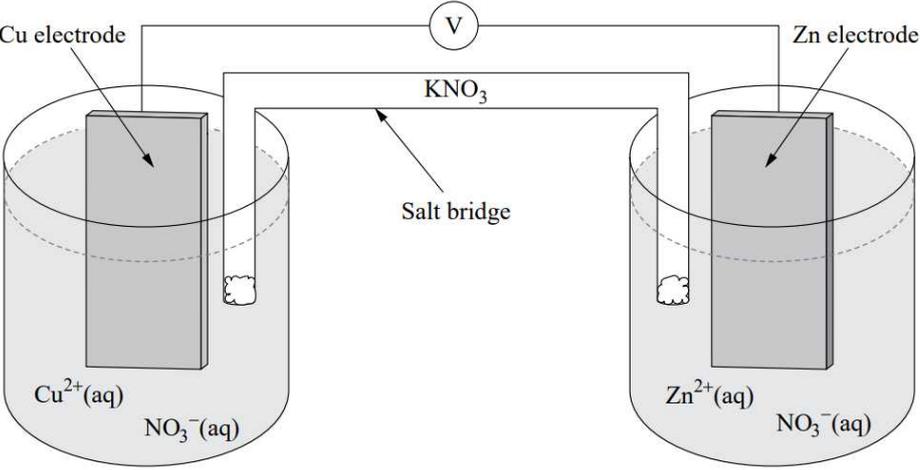
e) Describe, using a balanced chemical equation, how Compound A could be made from bromomethane. Include relevant conditions and reagents in your response. [5 marks]

Sample Response	The response	Notes
Heat $\text{CH}_3\text{Br}$ with KCN under reflux to produce $\text{CH}_3\text{CN}$ and KBr $\text{CH}_3\text{CN}(\text{aq}) + 2\text{H}_2(\text{g}) \xrightarrow{\text{heat with Ni catalyst}} \text{CH}_3\text{CH}_2\text{NH}_2(\text{aq})$	<ul style="list-style-type: none"> <li>• indicates <math>\text{CH}_3\text{Br}</math> reacts with KCN to produce <math>\text{KH}_3\text{CN}</math> and KBr [1 mark]</li> <li>• identifies reaction is heated under reflux in ethanol [1 mark]</li> <li>• indicates <math>\text{CH}_3\text{CN}</math> reacts with <math>\text{H}_2(\text{g})</math> to produce <math>\text{CH}_3\text{CH}_2\text{NH}_2</math> [1 mark]</li> <li>• indicates heat and Ni/Pt/Pd catalyst required [1 mark]</li> <li>• represents one of the reactions as a balanced chemical equation [1 mark]</li> </ul>	Also accept as balanced equation: $\text{CH}_3\text{Br}(\text{aq}) \xrightarrow{\text{heat under reflux with KCN (ethanol)}} \text{CH}_3\text{CN}(\text{aq}) + \text{KBr}(\text{aq})$

## Unit 3 – Topic 2: Oxidation and reduction

### Paper 1 Section 1

<p>2023 Paper 1 Section 1 Question 7</p> <p>Oxidation and reduction</p>	<p>Determine which half-cell produces the largest potential difference when joined with a <math>\text{Zn(s)} \mid \text{Zn}^{2+}(\text{aq})</math> half-cell to form a galvanic cell.</p> <p>(A) <math>\text{Mg(s)} \mid \text{Mg}^{2+}(\text{aq})</math></p> <p>(B) <math>\text{Cu}^{2+}(\text{aq}) \mid \text{Cu(s)}</math></p> <p>(C) <math>\text{H}^+(\text{aq}) \mid \text{H}_2(\text{g})</math></p> <p>(D) <math>\text{F}_2(\text{g}) \mid \text{F}^-(\text{aq})</math></p>
<p>2023 Paper 1 Section 1 Question 8</p> <p>Oxidation and reduction</p>	<p>Identify the species being reduced in the equation.</p> $\text{Br}_2(\text{l}) + \text{Sn}^{2+}(\text{aq}) \rightarrow \text{Sn}^{4+}(\text{aq}) + 2\text{Br}^-(\text{aq})$ <p>(A) <math>\text{Br}_2(\text{l})</math></p> <p>(B) <math>\text{Br}^-(\text{aq})</math></p> <p>(C) <math>\text{Sn}^{2+}(\text{aq})</math></p> <p>(D) <math>\text{Sn}^{4+}(\text{aq})</math></p>
<p>2023 Paper 1 Section 1 Question 11</p> <p>Oxidation and reduction</p>	<p>The plating of silver is conducted during the operation of the electrochemical cell shown.</p>  <p>Determine which statement is true for this electrochemical cell.</p> <p>(A) The spoon acts as the cathode.</p> <p>(B) The silver electrode has a negative charge.</p> <p>(C) The silver ions in the solution are oxidised at the spoon.</p> <p>(D) The electrons flow from the spoon to the silver electrode.</p>
<p>2022 Paper 1 Section 1 Question 3</p> <p>Oxidation and reduction</p>	<p>Which option is true for the redox equation?</p> $\text{Fe(s)} + \text{CuCl}_2(\text{aq}) \rightarrow \text{FeCl}_2(\text{aq}) + \text{Cu(s)}$ <p>(A) Fe is oxidised and Cu is the oxidising agent</p> <p>(B) Fe is oxidised and <math>\text{Cu}_2^+</math> is the oxidising agent</p> <p>(C) <math>\text{Fe}_2^+</math> is oxidised and Cu is the oxidising agent</p> <p>(D) <math>\text{Fe}_2^+</math> is oxidised and <math>\text{Cu}_2^+</math> is the oxidising agent</p>

<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Questions</b> <b>11-12</b></p> <p><b>Oxidation</b> <b>and</b> <b>reduction</b></p>	<p>These questions refer to the diagram shown.</p>  <p>Determine the species that travels through the salt bridge towards the reduction half-cell in the electrochemical cell at standard conditions.</p> <p>(A) zinc ions (B) nitrate ions (C) copper ions (D) potassium ions</p> <p>The zinc electrode</p> <p>(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.</p>
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<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 16</b></p> <p><b>Oxidation</b> <b>and</b> <b>reduction</b></p>	<p>Determine the oxidation state of manganese in <math>\text{MnO}_4^-</math>.</p> <p>(A) +1 (B) +2 (C) +7 (D) +8</p>
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<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 17</b></p> <p><b>Oxidation</b> <b>and</b> <b>reduction</b></p>	<p>Identify the redox reaction.</p> <p>(A) <math>\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})</math> (B) <math>\text{CaO}(\text{s}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{Ca}(\text{OH})_2(\text{s})</math> (C) <math>\text{Cl}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{HCl}(\text{aq}) + \text{HClO}(\text{aq})</math> (D) <math>\text{NaOH}(\text{aq}) + \text{HCl}(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})</math></p>
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<b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 19</b>  <b>Oxidation and reduction</b>	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.															
	<table border="1"> <thead> <tr> <th>Voltaic cell</th> <th>Half-cell</th> <th>Half-cell</th> <th>Potential difference (V)</th> </tr> </thead> <tbody> <tr> <td>1</td> <td><math>\text{Q(s)} / \text{Q}^{2+}(\text{aq})</math></td> <td><math>\text{R}^{+}(\text{aq}) / \text{R(s)}</math></td> <td>1.18</td> </tr> <tr> <td>2</td> <td><math>\text{Q(s)} / \text{Q}^{2+}(\text{aq})</math></td> <td><math>\text{S}^{2+}(\text{aq}) / \text{S(s)}</math></td> <td>0.72</td> </tr> <tr> <td>3</td> <td><math>\text{T(s)} / \text{T}^{3+}(\text{aq})</math></td> <td><math>\text{Q}^{2+}(\text{aq}) / \text{Q(s)}</math></td> <td>0.95</td> </tr> </tbody> </table> <p>The relative strength of the reducing agents from strongest to weakest is</p> <p>(A) <math>\text{T} &gt; \text{Q} &gt; \text{S} &gt; \text{R}</math>          (B) <math>\text{S} &gt; \text{Q} &gt; \text{T} &gt; \text{R}</math>          (C) <math>\text{R} &gt; \text{Q} &gt; \text{S} &gt; \text{T}</math>          (D) <math>\text{Q} &gt; \text{R} &gt; \text{T} &gt; \text{S}</math></p>	Voltaic cell	Half-cell	Half-cell	Potential difference (V)	1	$\text{Q(s)} / \text{Q}^{2+}(\text{aq})$	$\text{R}^{+}(\text{aq}) / \text{R(s)}$	1.18	2	$\text{Q(s)} / \text{Q}^{2+}(\text{aq})$	$\text{S}^{2+}(\text{aq}) / \text{S(s)}$	0.72	3	$\text{T(s)} / \text{T}^{3+}(\text{aq})$	$\text{Q}^{2+}(\text{aq}) / \text{Q(s)}$
Voltaic cell	Half-cell	Half-cell	Potential difference (V)													
1	$\text{Q(s)} / \text{Q}^{2+}(\text{aq})$	$\text{R}^{+}(\text{aq}) / \text{R(s)}$	1.18													
2	$\text{Q(s)} / \text{Q}^{2+}(\text{aq})$	$\text{S}^{2+}(\text{aq}) / \text{S(s)}$	0.72													
3	$\text{T(s)} / \text{T}^{3+}(\text{aq})$	$\text{Q}^{2+}(\text{aq}) / \text{Q(s)}$	0.95													

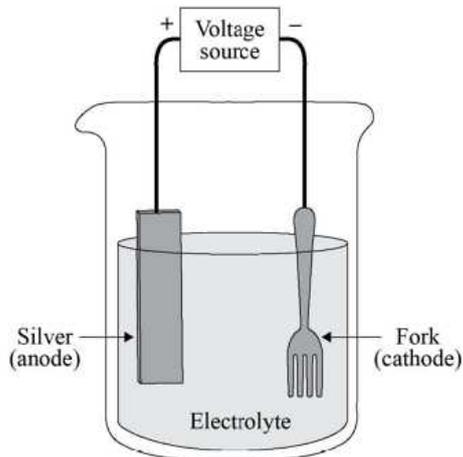
<b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 3</b>  <b>Oxidation and reduction</b>	Predict which product is formed at the positive electrode when a 0.1 M aqueous solution of copper(II) sulfate is electrolysed using carbon electrodes.
	<p>(A) <math>\text{Cu(s)}</math>          (B) <math>\text{H}_2(\text{g})</math>          (C) <math>\text{O}_2(\text{g})</math>          (D) <math>\text{SO}_2(\text{g})</math></p>

<b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 18</b>  <b>Oxidation and reduction</b>	Identify the major product when 2-methylbut-2-ene reacts with water under acidic conditions.
	<p>(A) <math>(\text{CH}_3)_2\text{CHCOCH}_3</math>          (B) <math>(\text{CH}_3)_2\text{C(OH)CH}_2\text{CH}_3</math>          (C) <math>(\text{CH}_3)_2\text{CHCH(OH)CH}_3</math>          (D) <math>(\text{CH}_3)_2\text{C(OH)CH(OH)CH}_3</math></p>

<b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 6</b>  <b>Oxidation and reduction</b>	Calculate the cell potential produced by a $\text{Zn(s)}   \text{Zn}^{2+}(\text{aq})    \text{Cu}^{2+}(\text{aq})   \text{Cu(s)}$ galvanic cell under standard conditions.
	<p>(A) <math>-1.10 \text{ V}</math>          (B) <math>-0.42 \text{ V}</math>          (C) <math>+0.34 \text{ V}</math>          (D) <math>+1.10 \text{ V}</math></p>

2020  
Paper 1  
Section 1  
Question 10

Oxidation  
and  
reduction

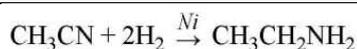


Which of the following is true for the electrochemical cell?

	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



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?

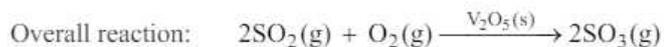
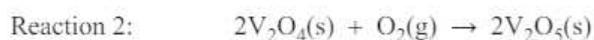
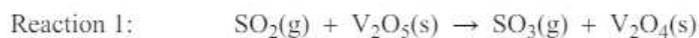
	Reaction	$E^\circ$ (V)
(A)	$2\text{Na}^+(\text{aq}) + 2\text{Br}^-(\text{aq}) \rightarrow 2\text{Na}(\text{s}) + \text{Br}_2(\text{aq})$	3.79
(B)	$\text{Sn}^{2+}(\text{aq}) + 2\text{Ag}(\text{s}) \rightarrow \text{Sn}(\text{s}) + 2\text{Ag}^+(\text{aq})$	-0.94
(C)	$\text{Zn}(\text{s}) + \text{Cl}_2(\text{g}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2\text{Cl}^-(\text{aq})$	2.12
(D)	$2\text{Al}(\text{s}) + 3\text{Sn}^{2+}(\text{aq}) \rightarrow 2\text{Al}^{3+}(\text{aq}) + 3\text{Sn}(\text{s})$	1.82



**2023  
Paper 1  
Section 2  
Question 25**

**Oxidation  
and  
reduction**

During the contact process for manufacturing sulfuric acid, sulfur dioxide (SO<sub>2</sub>) and oxygen (O<sub>2</sub>) are passed over a vanadium oxide catalyst to produce sulfur trioxide (SO<sub>3</sub>). In the process, the vanadium oxide undergoes the following reactions.



(a) Determine the oxidation state of vanadium in V<sub>2</sub>O<sub>4</sub>(s). [1 mark]

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(b) Determine if vanadium in V<sub>2</sub>O<sub>5</sub>(s) in reaction 1 is acting as an oxidising or reducing agent. Explain your reasoning. [2 marks]

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(c) Use the reactions provided to explain why V<sub>2</sub>O<sub>5</sub>(s) is a catalyst for the overall reaction. [4 marks]

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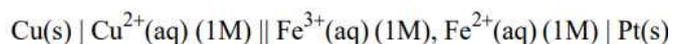
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**2022  
Paper 1  
Section 2  
Question 24**

**Oxidation  
and  
reduction**

This electrochemical cell was constructed using copper and platinum electrodes.



a) Compare the standard electrode potential ( $E^\ominus$ ) of the two half-cells. [3 marks]

Similarity:

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Difference:

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Significance:

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

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

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Cell potential = \_\_\_\_\_ V (to two significant figures)

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

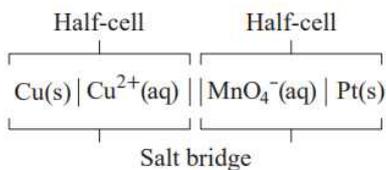
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**2021  
Paper 1  
Section 2  
Question 24**

**Oxidation  
and  
reduction**

The cell diagram represents a voltaic cell at standard conditions. The copper solution is blue because of the presence of  $\text{Cu}^{2+}(\text{aq})$  ions. The acidified permanganate solution is purple because of the presence of  $\text{MnO}_4^-$  (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]

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b) Determine the standard reduction potential,  $E^\circ$ , for the cell. [1 mark]

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

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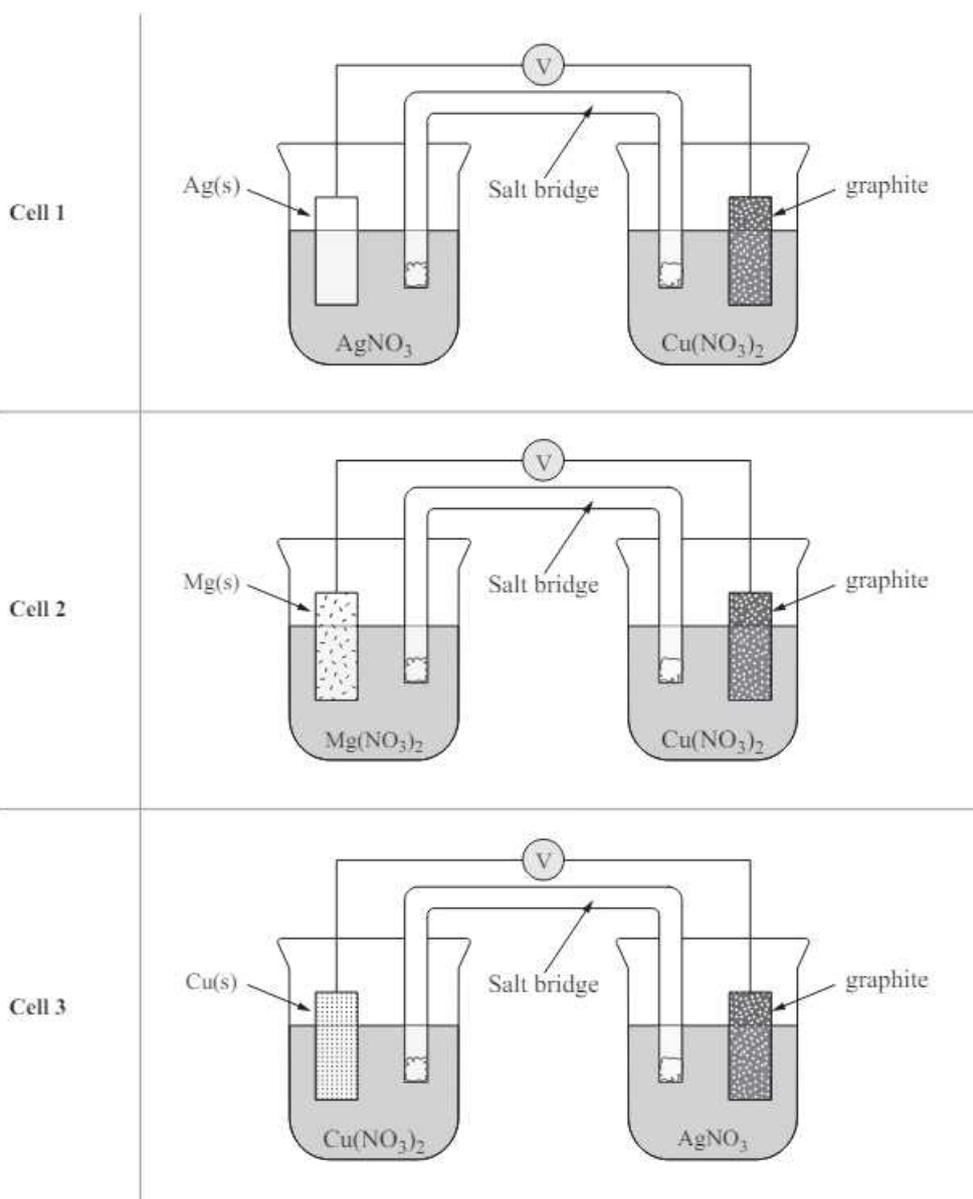
<b>2021 Paper 1 Section 2 Question 27</b>  <b>Oxidation and reduction</b>	Arsenous acid, $\text{H}_3\text{AsO}_3$ , reacts with nitrate ions to form arsenic acid, $\text{H}_3\text{AsO}_4$ , and nitrogen dioxide.
	a) Determine the oxidation number of arsenic in arsenous acid. [1 mark]
	b) Use half-equations to balance the reaction. [4 marks]
c) Determine which species is reduced in this reaction. [1 mark]	

<b>2020 Paper 1 Section 2 Question 23</b>	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]

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]

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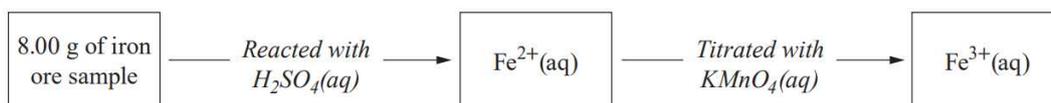




2021  
Paper 2  
Section 1  
Question 5

Oxidation  
and  
reduction

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

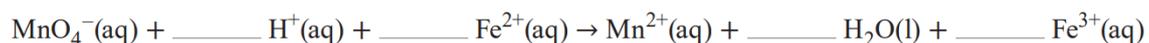


All the iron (Fe) in the sample was converted to  $Fe^{2+}(aq)$  by reacting it with  $H_2SO_4(aq)$ , forming hydrogen gas. The solution made up to a final volume of 500.0 mL. A 25.00 mL aliquot of the  $Fe^{2+}$  aqueous solution was titrated with a standardised solution of 0.0500 M  $KMnO_4$ . An average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



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]

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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]

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ii) Determine the standard reduction potential,  $E^\circ$ , for the reduction half-equation. [1 mark]

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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]

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ii)  $\text{NO}_2$  is the gaseous product, rather than  $\text{H}_2$ , when copper dissolves in nitric acid. [3 marks]

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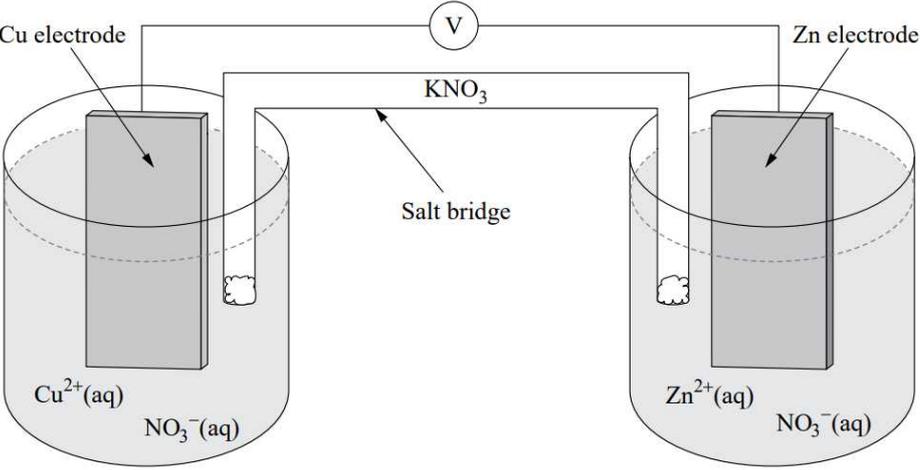
**Marking Guide – Paper 1 Section 1**

<p><b>2023</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 7</b></p> <p><b>Oxidation and reduction</b></p>	<p>Determine which half-cell produces the largest potential difference when joined with a <math>\text{Zn(s)} \mid \text{Zn}^{2+}(\text{aq})</math> half-cell to form a galvanic cell.</p> <p>(A) <math>\text{Mg(s)} \mid \text{Mg}^{2+}(\text{aq})</math></p> <p>(B) <math>\text{Cu}^{2+}(\text{aq}) \mid \text{Cu(s)}</math></p> <p>(C) <math>\text{H}^+(\text{aq}) \mid \text{H}_2(\text{g})</math></p> <p>(D) <math>\text{F}_2(\text{g}) \mid \text{F}^-(\text{aq})</math></p> <p><b>Answer is D.</b></p>
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<p><b>2023</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 8</b></p> <p><b>Oxidation and reduction</b></p>	<p>Identify the species being reduced in the equation.</p> $\text{Br}_2(\text{l}) + \text{Sn}^{2+}(\text{aq}) \rightarrow \text{Sn}^{4+}(\text{aq}) + 2\text{Br}^-(\text{aq})$ <p>(A) <math>\text{Br}_2(\text{l})</math></p> <p>(B) <math>\text{Br}^-(\text{aq})</math></p> <p>(C) <math>\text{Sn}^{2+}(\text{aq})</math></p> <p>(D) <math>\text{Sn}^{4+}(\text{aq})</math></p> <p><b>Answer is A.</b></p>
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<p><b>2023</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 11</b></p> <p><b>Oxidation and reduction</b></p>	<p>The plating of silver is conducted during the operation of the electrochemical cell shown.</p> <div style="text-align: center;"> </div> <p>Determine which statement is true for this electrochemical cell.</p> <p>(A) <b>The spoon acts as the cathode. – Answer</b></p> <p>(B) The silver electrode has a negative charge.</p> <p>(C) The silver ions in the solution are oxidised at the spoon.</p> <p>(D) The electrons flow from the spoon to the silver electrode.</p>
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<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 3</b></p> <p><b>Oxidation and reduction</b></p>	<p>Which option is true for the redox equation?</p> $\text{Fe(s)} + \text{CuCl}_2(\text{aq}) \rightarrow \text{FeCl}_2(\text{aq}) + \text{Cu(s)}$ <p>(A) Fe is oxidised and Cu is the oxidising agent</p> <p>(B) <b>Fe is oxidised and <math>\text{Cu}_2^+</math> is the oxidising agent – Answer</b></p> <p>(C) <math>\text{Fe}_2^+</math> is oxidised and Cu is the oxidising agent</p> <p>(D) <math>\text{Fe}_2^+</math> is oxidised and <math>\text{Cu}_2^+</math> is the oxidising agent</p>
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<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Questions 11-12</b></p> <p><b>Oxidation and reduction</b></p>	<p>These questions refer to the diagram shown.</p>  <p>Determine the species that travels through the salt bridge towards the reduction half-cell in the electrochemical cell at standard conditions.</p> <p>(A) zinc ions (B) nitrate ions (C) copper ions <b>(D) potassium ions – Answer</b></p> <p>The zinc electrode</p> <p>(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. <b>(D) is oxidised and donates electrons to the copper ions. – Answer</b></p>
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<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 16</b></p> <p><b>Oxidation and reduction</b></p>	<p>Determine the oxidation state of manganese in <math>\text{MnO}_4^-</math>.</p> <p>(A) +1 (B) +2 <b>(C) +7 – Answer</b> (D) +8</p>
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<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 17</b></p> <p><b>Oxidation and reduction</b></p>	<p>Identify the redox reaction.</p> <p>(A) <math>\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})</math> (B) <math>\text{CaO}(\text{s}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{Ca}(\text{OH})_2(\text{s})</math> <b>(C) <math>\text{Cl}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{HCl}(\text{aq}) + \text{HClO}(\text{aq})</math> – Answer</b> (D) <math>\text{NaOH}(\text{aq}) + \text{HCl}(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})</math></p>
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<b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 19</b>  <b>Oxidation and reduction</b>	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.															
	<table border="1"> <thead> <tr> <th>Voltaic cell</th> <th>Half-cell</th> <th>Half-cell</th> <th>Potential difference (V)</th> </tr> </thead> <tbody> <tr> <td>1</td> <td><math>\text{Q(s)} / \text{Q}^{2+}(\text{aq})</math></td> <td><math>\text{R}^{+}(\text{aq}) / \text{R(s)}</math></td> <td>1.18</td> </tr> <tr> <td>2</td> <td><math>\text{Q(s)} / \text{Q}^{2+}(\text{aq})</math></td> <td><math>\text{S}^{2+}(\text{aq}) / \text{S(s)}</math></td> <td>0.72</td> </tr> <tr> <td>3</td> <td><math>\text{T(s)} / \text{T}^{3+}(\text{aq})</math></td> <td><math>\text{Q}^{2+}(\text{aq}) / \text{Q(s)}</math></td> <td>0.95</td> </tr> </tbody> </table> <p>The relative strength of the reducing agents from strongest to weakest is</p> <p>(A) <math>\text{T} &gt; \text{Q} &gt; \text{S} &gt; \text{R}</math> – Answer            (B) <math>\text{S} &gt; \text{Q} &gt; \text{T} &gt; \text{R}</math>            (C) <math>\text{R} &gt; \text{Q} &gt; \text{S} &gt; \text{T}</math>            (D) <math>\text{Q} &gt; \text{R} &gt; \text{T} &gt; \text{S}</math></p>	Voltaic cell	Half-cell	Half-cell	Potential difference (V)	1	$\text{Q(s)} / \text{Q}^{2+}(\text{aq})$	$\text{R}^{+}(\text{aq}) / \text{R(s)}$	1.18	2	$\text{Q(s)} / \text{Q}^{2+}(\text{aq})$	$\text{S}^{2+}(\text{aq}) / \text{S(s)}$	0.72	3	$\text{T(s)} / \text{T}^{3+}(\text{aq})$	$\text{Q}^{2+}(\text{aq}) / \text{Q(s)}$
Voltaic cell	Half-cell	Half-cell	Potential difference (V)													
1	$\text{Q(s)} / \text{Q}^{2+}(\text{aq})$	$\text{R}^{+}(\text{aq}) / \text{R(s)}$	1.18													
2	$\text{Q(s)} / \text{Q}^{2+}(\text{aq})$	$\text{S}^{2+}(\text{aq}) / \text{S(s)}$	0.72													
3	$\text{T(s)} / \text{T}^{3+}(\text{aq})$	$\text{Q}^{2+}(\text{aq}) / \text{Q(s)}$	0.95													

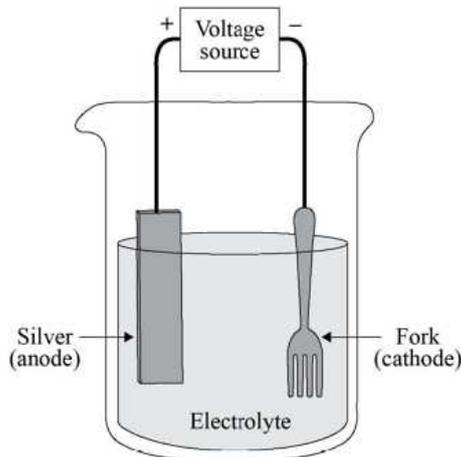
<b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 3</b>  <b>Oxidation and reduction</b>	Predict which product is formed at the positive electrode when a 0.1 M aqueous solution of copper(II) sulfate is electrolysed using carbon electrodes.
	(A) $\text{Cu(s)}$ (B) $\text{H}_2(\text{g})$ (C) $\text{O}_2(\text{g})$ – Answer (D) $\text{SO}_2(\text{g})$

<b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 18</b>  <b>Oxidation and reduction</b>	Identify the major product when 2-methylbut-2-ene reacts with water under acidic conditions.
	(A) $(\text{CH}_3)_2\text{CHCOCH}_3$ (B) $(\text{CH}_3)_2\text{C(OH)CH}_2\text{CH}_3$ (C) $(\text{CH}_3)_2\text{CHCH(OH)CH}_3$ (D) $(\text{CH}_3)_2\text{C(OH)CH(OH)CH}_3$  <b>Answer is B.</b>

<b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 6</b>  <b>Oxidation and reduction</b>	Calculate the cell potential produced by a $\text{Zn(s)}   \text{Zn}^{2+}(\text{aq})    \text{Cu}^{2+}(\text{aq})   \text{Cu(s)}$ galvanic cell under standard conditions.
	(A) $-1.10 \text{ V}$ (B) $-0.42 \text{ V}$ (C) $+0.34 \text{ V}$ (D) $+1.10 \text{ V}$  <b>Answer is D.</b>

2020  
Paper 1  
Section 1  
Question 10

Oxidation  
and  
reduction



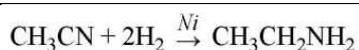
Which of the following is true for the electrochemical cell?

	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



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	$E^\circ$ (V)
(A)	$2\text{Na}^+(\text{aq}) + 2\text{Br}^-(\text{aq}) \rightarrow 2\text{Na}(\text{s}) + \text{Br}_2(\text{aq})$	3.79
(B)	$\text{Sn}^{2+}(\text{aq}) + 2\text{Ag}(\text{s}) \rightarrow \text{Sn}(\text{s}) + 2\text{Ag}^+(\text{aq})$	-0.94
(C)	$\text{Zn}(\text{s}) + \text{Cl}_2(\text{g}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2\text{Cl}^-(\text{aq})$	2.12
(D)	$2\text{Al}(\text{s}) + 3\text{Sn}^{2+}(\text{aq}) \rightarrow 2\text{Al}^{3+}(\text{aq}) + 3\text{Sn}(\text{s})$	1.82

Answer is C.

Marking Guide – Paper 1 Section 2

**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 <sub>3</sub> ) <sub>2</sub>	Mg(NO <sub>3</sub> ) <sub>2</sub>	Cu(NO <sub>3</sub> ) <sub>2</sub>	AgNO <sub>3</sub>
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
<p>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.</p> <p>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.</p> $E_{cell}^{\circ} = E_{red} - E_{ox}$ $= +0.94 + (-1.18) = -0.24 \text{ V}$ <p>Therefore, metal Q is Ni.</p>	<ul style="list-style-type: none"> <li>uses the data to explain that metal R is more reactive than Zn and less reactive than Mg [1 mark]</li> <li>identifies metal R is manganese [1 mark]</li> <li>uses the data to explain that metal Q must be Ni, Co, Fe or Cr [1 mark]</li> <li>uses the electrochemical data to determine <math>E_{metal\ Q}^{\circ} = -0.24\text{V}</math> [1 mark]</li> <li>identifies metal Q is Ni [1 mark]</li> </ul>

**2023 Paper 1 Section 2 Question 25**

**Oxidation and reduction**

During the contact process for manufacturing sulfuric acid, sulfur dioxide (SO<sub>2</sub>) and oxygen (O<sub>2</sub>) are passed over a vanadium oxide catalyst to produce sulfur trioxide (SO<sub>3</sub>). In the process, the vanadium oxide undergoes the following reactions.

Reaction 1:  $\text{SO}_2(\text{g}) + \text{V}_2\text{O}_5(\text{s}) \rightarrow \text{SO}_3(\text{g}) + \text{V}_2\text{O}_4(\text{s})$

Reaction 2:  $2\text{V}_2\text{O}_4(\text{s}) + \text{O}_2(\text{g}) \rightarrow 2\text{V}_2\text{O}_5(\text{s})$

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Overall reaction:  $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \xrightarrow{\text{V}_2\text{O}_5(\text{s})} 2\text{SO}_3(\text{g})$

(a) Determine the oxidation state of vanadium in V<sub>2</sub>O<sub>4</sub>(s). [1 mark]

Sample response	The response
+4	<ul style="list-style-type: none"> <li>determines that the oxidation state of vanadium is +4 [1 mark]</li> </ul>

(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 $V_2O_4(s)$ .	<ul style="list-style-type: none"> <li>determines that vanadium in <math>V_2O_5(s)</math> is an oxidising agent [1 mark]</li> <li>explains that oxidation state of vanadium decreases from +5 to +4 [1 mark]</li> </ul>

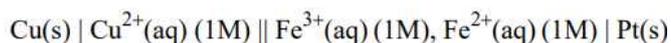
(c) Use the reactions provided to explain why  $V_2O_5(s)$  is a catalyst for the overall reaction. [4 marks]

Sample response	The response
<p>Reaction 1: <math>V_2O_5(s)</math> is converted to <math>V_2O_4(s)</math> to allow <math>SO_2</math> to be converted to <math>SO_3</math>.</p> <p>Reaction 2: <math>V_2O_4(s)</math> is converted back to <math>V_2O_5(s)</math> by reacting with <math>O_2</math>.</p> <p>Therefore, <math>V_2O_5(s)</math> acts as a catalyst because it undergoes a temporary chemical change during the reaction but remains chemically unchanged at the end.</p>	<ul style="list-style-type: none"> <li>identifies that <math>V_2O_5(s)</math> is involved in the chemical reaction [1 mark]</li> <li>uses data from reaction 1 to support chemical change to <math>V_2O_4(s)</math> [1 mark]</li> <li>uses data from reaction 2 to support chemical change to <math>V_2O_5(s)</math> [1 mark]</li> <li>explains that <math>V_2O_5(s)</math> remains unchanged at the end of the reaction [1 mark]</li> </ul>

2022  
Paper 1  
Section 2  
Question 24

Oxidation  
and  
reduction

This electrochemical cell was constructed using copper and platinum electrodes.



a) Compare the standard electrode potential ( $E^\ominus$ ) of the two half-cells. [3 marks]

Sample Response	The response
<p>Similarity: Both the Pt and Cu half-cells have a positive standard reduction potential compared to SHE.</p> <p>Difference: Pt half-cell is more positive than Cu half-cell. Significance: Cu electrode is oxidised (loses electrons) and the <math>Fe^{3+}(aq)</math> is reduced.</p>	<ul style="list-style-type: none"> <li>Similarities: identifies that both half-cells have positive standard reduction potential [1 mark]</li> <li>Differences: identifies that Pt half-cell is more positive than Cu half-cell [1 mark]</li> <li>Significance: explains that Cu electrode is oxidised and <math>Fe^{3+}</math> is reduced [1 mark]</li> </ul>

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

Sample Response	The response
Balance redox equation: $2Fe^{3+} + Cu \rightarrow Cu^{2+} + 2Fe^{2+}$	<ul style="list-style-type: none"> <li>provides correct balanced redox equation [1 mark]</li> </ul>

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	<ul style="list-style-type: none"> <li>determines cell potential is +0.43 [1 mark]</li> </ul>

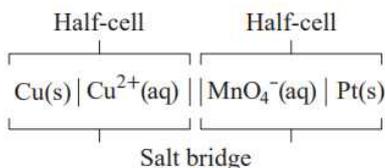
d) Determine the oxidising agent. Explain your reasoning. [2 marks]

Sample Response	The response
$Fe^{3+}$ is the oxidising agent, because ON decreases from +3 to +2.	<ul style="list-style-type: none"> <li>identifies <math>Fe^{3+}</math> as the oxidising agent [1 mark]</li> <li>indicates oxidation number decreases [1 mark]</li> </ul>

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  $\text{Cu}^{2+}(\text{aq})$  ions. The acidified permanganate solution is purple because of the presence of  $\text{MnO}_4^-$  (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
$\text{MnO}_4^-$ (aq) (+1.51 V) is a stronger oxidising agent than $\text{Cu}^{2+}(\text{aq})$ (+0.34 V) because it has a more positive standard potential. $\text{MnO}_4^-$ (aq) is preferentially reduced and gains electrons from $\text{Cu(s)}$ , which is oxidised. Therefore, electrons flow from Cu electrode to Pt electrode.	<ul style="list-style-type: none"> <li>correctly identifies <math>\text{MnO}_4^-</math> as the stronger oxidising agent [1 mark]</li> <li>correctly identifies that <math>\text{MnO}_4^-</math> gains electrons [1 mark]</li> <li>determines that electrons flow from Cu to Pt electrode [1 mark]</li> </ul>	Acceptable responses are: <ul style="list-style-type: none"> <li><math>\text{MnO}_4^-</math> is reduced</li> <li>Cu is oxidised</li> <li>Cu loses electrons.</li> </ul> Acceptable responses are that electrons flow from: <ul style="list-style-type: none"> <li>Cu electrode to Pt electrode</li> <li>Cu(s) to <math>\text{MnO}_4^-</math> (aq).</li> </ul>

b) Determine the standard reduction potential,  $E^\circ$ , for the cell. [1 mark]

Sample Response	The response	Notes
$E^\circ_{\text{cell}} = E^\circ_{\text{red}} - E^\circ_{\text{ox}} = +1.51 - (+0.34) = 1.17 \text{ V}$	<ul style="list-style-type: none"> <li>determines that the standard reduction potential is 1.17 [1 mark]</li> </ul>	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
$\text{Cu}^{2+}(\text{aq})$ concentration will increase and the solution will become darker.  $\text{MnO}_4^-$ (aq) concentration will decrease and the solution will become lighter.	<ul style="list-style-type: none"> <li>predicts that the <math>\text{Cu}^{2+}(\text{aq})</math> solution will become darker [1 mark]</li> <li>predicts that the <math>\text{MnO}_4^-</math> (aq) solution will become lighter [1 mark]</li> </ul>	Acceptable responses are: <ul style="list-style-type: none"> <li>Cu electrode will become smaller</li> <li><math>\text{Cu}^{2+}</math> solution will become darker - <math>\text{MnO}_4^-</math> solution will become lighter</li> <li><math>\text{MnO}_4^-</math> solution will become colourless. Allow FT error from 24a).</li> </ul>
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	•	

**2021  
Paper 1  
Section 2  
Question 27**

**Oxidation  
and  
reduction**

Arsenous acid,  $\text{H}_3\text{AsO}_3$ , reacts with nitrate ions to form arsenic acid,  $\text{H}_3\text{AsO}_4$ , and nitrogen dioxide.

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

Sample Response	The response	Notes
$3 \times (+1) + \text{As} + 3 \times (-2) = 0$ $3 + \text{As} - 6 = 0$ $\text{As} - 3 = 0$ <b>As = +3</b>	<ul style="list-style-type: none"> <li>provides +3 [1 mark]</li> </ul>	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: $\text{H}_3\text{AsO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_3\text{AsO}_4 + 2\text{H}^+ + 2\text{e}^-$  Balanced reduction half-equation: $\text{NO}_3^- + 2\text{H}^+ + \text{e}^- \rightarrow \text{NO}_2 + \text{H}_2\text{O}$  Multiply by 2: $2\text{NO}_3^- + 4\text{H}^+ + 2\text{e}^- \rightarrow 2\text{NO}_2 + 2\text{H}_2\text{O}$  Balanced redox equation: $\text{H}_3\text{AsO}_3 + 2\text{NO}_3^- + 2\text{H}^+ \rightarrow \text{H}_3\text{AsO}_4 + 2\text{NO}_2 + \text{H}_2\text{O}$	<ul style="list-style-type: none"> <li>provides balanced oxidation half-equation [1 mark]</li> <li>provides balanced reduction half-equation [1 mark]</li> <li>uses multiplication factor to balance electrons [1 mark]</li> <li>determines balanced redox equation [1 mark]</li> </ul>	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
$\text{NO}_3^-$	<ul style="list-style-type: none"> <li>provides <math>\text{NO}_3^-</math> [1 mark]</li> </ul>	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 <sub>2</sub> (g)	• provides Na(l) and Cl <sub>2</sub> (g) [1 mark]

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

Sample Response	The response
H <sub>2</sub> (g) and O <sub>2</sub> (g)	• provides H <sub>2</sub> (g) and O <sub>2</sub> (g) [1 mark]

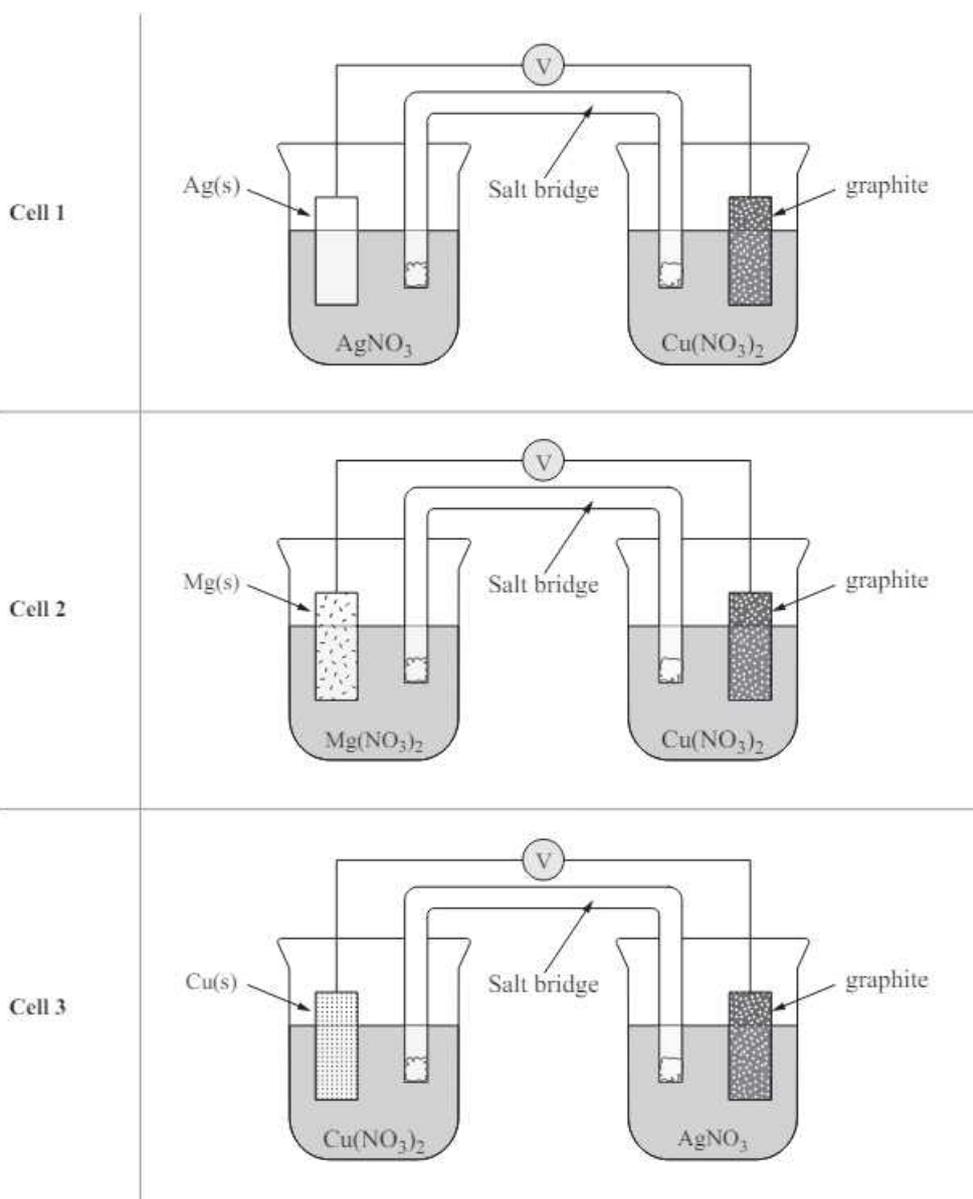
b) Explain how the nature of the electrolyte affects the products generated when a dilute aqueous solution of sodium chloride undergoes electrolysis. [4 marks]

Sample Response	The response	Notes
<p>In a dilute solution of aqueous sodium chloride, sodium ions, chloride ions, hydrogen ions, hydroxide ions and water molecules are present.</p> <p>The concentration and the E<sup>o</sup> value of the species create competition at the electrodes and affect the products formed.</p> <p>Na<sup>+</sup> and H<sup>+</sup> compete to be reduced at the cathode. The E<sub>0</sub> value for reducing H<sup>+</sup> is more positive; therefore, H<sup>+</sup> is preferentially reduced and H<sub>2</sub> gas is formed rather than Na metal.</p> <p>Cl<sup>-</sup> and OH<sup>-</sup> compete to be oxidised at the anode. As the concentration of Cl<sup>-</sup> is low in a dilute NaCl solution, OH<sup>-</sup> is preferentially oxidised and O<sub>2</sub> gas is produced rather than Cl<sub>2</sub> gas.</p>	<ul style="list-style-type: none"> <li>• identifies that Na<sup>+</sup>, Cl<sup>-</sup>, OH<sup>-</sup>, H<sup>+</sup>, and H<sub>2</sub>O are present [1 mark]</li> <li>• identifies that concentration and E<sup>o</sup> values of the species affects products [1 mark]</li> <li>• identifies that H<sup>+</sup> is preferentially reduced, producing H<sub>2</sub> gas due to a more positive E<sub>o</sub> value [1 mark]</li> <li>• identifies that OH<sup>-</sup> is preferentially oxidised, producing O<sub>2</sub> gas due to a higher concentration of ions [1 mark]</li> </ul>	<p>For H<sub>2</sub>O, accept OH<sup>-</sup> and H<sup>+</sup>.</p>

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
<p>Cell 1 is not spontaneous.</p> <p>Cell 2 is spontaneous and would produce voltage of 2.70 V. Cell 3 is spontaneous and would produce 0.46 V.</p> <p>Cell 2 would produce the highest voltage of the three cells.</p>	<ul style="list-style-type: none"> <li>determines that cell 1 is not spontaneous [1 mark]</li> <li>determines voltage of cells 2 and 3 [1 mark]</li> <li>predicts which cell produces maximum voltage [1 mark]</li> </ul>

(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
<p>The new cell would be constructed using Mg as the anode and Ag as the cathode.</p> <p>Anode half-equation: <math>\text{Mg} \rightarrow \text{Mg}^{2+} + 2\text{e}^-</math> (+2.36 V)</p> <p>Cathode half-equation: <math>\text{Ag}^+ + \text{e}^- \rightarrow \text{Ag}</math> (+0.80 V)</p> <p><math>E_{\text{cell}}^{\circ} = 3.16 \text{ V}</math></p>	<ul style="list-style-type: none"> <li>determines cell 4 constructed using Mg and Ag [1 mark]</li> <li>identifies oxidation half-equation [1 mark]</li> <li>identifies reduction half-equation [1 mark]</li> <li>determines <math>E_{\text{cell}}^{\circ}</math> is 3.16 [1 mark]</li> </ul>

**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
<p>Copper ion is reduced and Cu is plated onto the cathode: <math>\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Cu}(\text{s})</math></p> <p>Copper anode is oxidised to <math>\text{Cu}^{2+}(\text{aq})</math> and is released into solution: <math>\text{Cu}(\text{s}) \rightarrow \text{Cu}^{2+}(\text{aq}) + 2\text{e}^-</math></p> <p>Therefore, for every copper ion that is reduced at the cathode, in principle, another one is oxidised at the anode.</p> <p>Therefore, the concentration of the copper(II) sulfate solution should stay the same.</p>	<ul style="list-style-type: none"> <li>identifies copper ions are reduced to Cu metal at the cathode and reduction half-equation is <math>\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Cu}(\text{s})</math> [1 mark]</li> <li>identifies copper metal is oxidised to Cu ions at the anode and oxidation half-equation is <math>\text{Cu}(\text{s}) \rightarrow \text{Cu}^{2+}(\text{aq}) + 2\text{e}^-</math> [1 mark]</li> <li>predicts no change in concentration of copper(II) sulfate solution [1 mark]</li> <li>identifies that copper ions are reduced to copper and copper is oxidised to copper ions at the same rate [1 mark]</li> </ul>

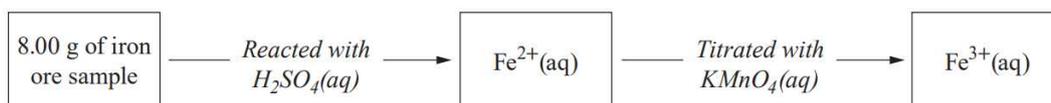
b) If the copper anodes contain silver and zinc impurities, determine whether either metal could be produced as a by-product of the electrolytic refining of copper. Explain your reasoning. [4 marks]

Sample Response	The response
<p>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.</p>	<ul style="list-style-type: none"> <li>identifies Ag is less reactive than Cu and Zn is more reactive than Cu [1 mark]</li> <li>deduces Ag metal is not oxidised (or reduced) and remains as metal [1 mark]</li> <li>deduces Zn metal is oxidised to form ions and found in the solution [1 mark]</li> <li>explains that <math>\text{Zn}^{2+}</math> ions remain in solution at low concentration but are reduced to Zn metal at the cathode if concentration becomes too high [1 mark]</li> </ul>

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  $\text{Fe}^{2+}(\text{aq})$  by reacting it with  $\text{H}_2\text{SO}_4(\text{aq})$ , forming hydrogen gas. The solution made up to a final volume of 500.0 mL. A 25.00 mL aliquot of the  $\text{Fe}^{2+}$  aqueous solution was titrated with a standardised solution of 0.0500 M  $\text{KMnO}_4$ . 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
$\text{Fe}(\text{s}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{FeSO}_4(\text{aq}) + \text{H}_2(\text{g})$	<ul style="list-style-type: none"> <li>correctly identifies the balanced equation [1 mark]</li> </ul>	

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 $\text{Fe}^{2+}(\text{aq})$ .	<ul style="list-style-type: none"> <li>correctly identifies that Fe (iron) is oxidised [1 mark]</li> <li>indicates that Fe loses electrons to form <math>\text{Fe}^{2+}</math> [1 mark]</li> </ul>	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
$\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{Fe}^{2+}(\text{aq}) \rightarrow \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l}) + 5\text{Fe}^{3+}(\text{aq})$	<ul style="list-style-type: none"> <li>correctly balances <math>8\text{H}^+ + 4\text{H}_2\text{O}</math> in equation [1 mark]</li> <li>correctly balances <math>5\text{Fe}^{2+} + 5\text{Fe}^{3+}</math> in equation [1 mark]</li> </ul>	

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

Sample Response	The response	Notes
Moles $\text{MnO}_4^-(\text{aq})$ reacted = $0.01640 \times 0.05 = 8.2 \times 10^{-4}$ $\text{MnO}_4^- : 5\text{Fe}^{2+}$ Moles of $\text{Fe}^{2+}$ in 25.00 mL = $5 \times (8.2 \times 10^{-4}) = 4.1 \times 10^{-3}$ mol Moles of $\text{Fe}^{2+}$ 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)	<ul style="list-style-type: none"> <li>correctly determines <math>n\text{MnO}_4^- = 8.2 \times 10^{-4}</math> [1 mark]</li> <li>determines <math>n\text{Fe}^{2+} = 4.1 \times 10^{-3}</math> [1 mark]</li> <li>determines <math>n\text{Fe} = 8.2 \times 10^{-2}</math> [1 mark]</li> <li>determines mass Fe = 4.6 g [1 mark]</li> <li>determines Fe = 57.2% [1 mark]</li> </ul>	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.	<ul style="list-style-type: none"> <li>identifies that</li> <li>- zinc is oxidised [1 mark]</li> <li>- copper is reduced [1 mark]</li> <li>- reaction is redox [1 mark]</li> </ul>	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) $4H^{+}(aq) + 2NO_3^{-}(aq) + 2e^{-} \rightarrow 2NO_2(g) + 2H_2O(l)$	<ul style="list-style-type: none"> <li>provides <math>2H^{+}(aq) + e^{-} \rightarrow H_2O(l)</math> [1 mark]</li> <li>provides <math>NO_3^{-}(aq) + e^{-} \rightarrow NO_2(g)</math> [1 mark]</li> </ul>	Acceptable response is $2H^{+}(aq) + NO_3^{-}(aq) + e^{-} \rightarrow NO_2(g) + H_2O(l)$

- ii) Determine the standard reduction potential,  $E^{\circ}$ , for the reduction half-equation. [1 mark]

Sample Response	The response
ii) $E^{\circ}_{red} = 0.46 + 0.34 = +0.80 \text{ V}$	<ul style="list-style-type: none"> <li>determines <math>E^{\circ}_{red} = +0.80 \text{ V}</math> [1 mark]</li> </ul>

- 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: $E^{\circ}_{cell} = +0.46$ (positive), therefore the reaction is spontaneous. $HNO_3$ can dissolve Cu.	<ul style="list-style-type: none"> <li>determines <math>E^{\circ}</math> cell for HCl equals <math>-0.34</math> and <math>E^{\circ}</math> cell for <math>HNO_3</math> equals <math>+0.46 \text{ V}</math> [1 mark]</li> <li>determines reaction between Cu and HCl is not spontaneous and therefore Cu will not dissolve [1 mark]</li> <li>indicates reaction between Cu and <math>HNO_3</math> is spontaneous and therefore Cu will dissolve [1 mark]</li> </ul>	Acceptable response is $Cl^{-}$ is more negative, therefore stronger reducing and will be oxidised in preference to Cu.

ii) NO<sub>2</sub> is the gaseous product, rather than H<sub>2</sub>, when copper dissolves in nitric acid. [3 marks]

Sample Response	The response	Notes
<p>ii) Reduction:  <math>4\text{H}^+(\text{aq}) + 2\text{NO}_3^-(\text{aq}) + 2\text{e}^- \rightarrow 2\text{NO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}), E^\ominus = +0.80\text{V}</math> or  <math>\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g}), E^\ominus = 0.00\text{V}</math>                      The <math>E^\ominus</math> value for <math>\text{NO}_3^-</math> is more positive than <math>\text{H}^+(\text{aq})</math>, therefore <math>\text{NO}_3^-</math> is a stronger oxidising agent.</p> <p>Therefore <math>\text{NO}_3^-</math> reduced in preference to <math>\text{H}^+</math> and <math>\text{NO}_2(\text{g})</math> formed</p>	<ul style="list-style-type: none"> <li>• identifies that, in <math>\text{HNO}_3</math>, <math>\text{H}^+(\text{aq})</math> and <math>\text{NO}_3^-</math> compete to be reduced [1 mark]</li> <li>• indicates that <math>\text{NO}_3^-</math> is stronger oxidising agent [1 mark]</li> <li>• determines <math>\text{NO}_3^-</math> is preferentially reduced therefore <math>\text{NO}_2(\text{g})</math> formed [1 mark]</li> </ul>	<p>Acceptable response is <math>\text{NO}_3^-</math> is more positive than Cu, therefore stronger oxidising agent and can be reduced to <math>\text{Cu}^{2+}(\text{aq})</math>.</p>

## Unit 4 Structure, synthesis and design

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

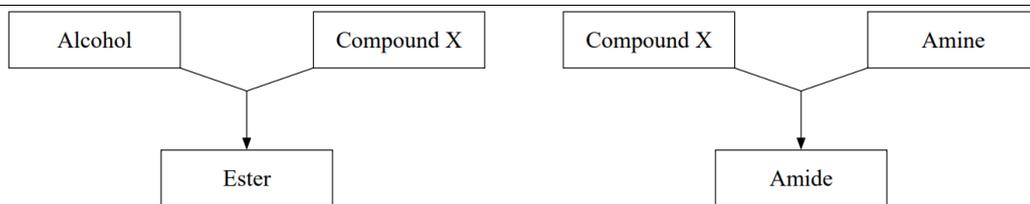
#### Paper 1 Section 1

<b>2023 Paper 1 Section 1 Question 12</b>  <b>Properties and structure of organic materials</b>	Enzymes are classified as  (A) carbohydrates. (B) proteins. (C) starches. (D) lipids.
<b>2023 Paper 1 Section 1 Question 14</b>  <b>Properties and structure of organic materials</b>	Identify which molecule has the lowest boiling point.  (A) butanone (B) hexanone (C) pentanone (D) propanone
<b>2023 Paper 1 Section 1 Question 16</b>  <b>Properties and structure of organic materials</b>	Haloalkanes undergo a substitution reaction with cyanide ( $\text{CN}^-$ ) in ethanol to produce  (A) alkanes. (B) amines. (C) nitriles. (D) esters.

<p><b>2023</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 17</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Questions 17–18 refer to the reaction shown.</p> $  \begin{array}{ccccccc}  \text{R}-\overset{\text{O}}{\parallel}{\text{C}}-\text{O}-\text{H} & + & \text{H}-\text{O}-\text{R} & \xrightleftharpoons{\text{H}^+} & \boxed{\text{Product X}} & + & \text{H}-\text{O}-\text{H} \\  \text{Carboxylic acid} & & \text{Alcohol} & & & & \text{Water}  \end{array}  $ <p><b>Question 17</b> Determine the functional group present in Product X.</p> <p>(A) ester (B) ketone (C) alcohol (D) aldehyde</p> <p><b>Question 18</b> Identify the reaction used to produce X.</p> <p>(A) addition (B) hydration (C) condensation (D) hydrogenation</p>
<p><b>2023</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 19</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Identify the polymer shown.</p> $  \left[ \begin{array}{c} \text{CH}_3 \\   \\ \text{CH} - \text{CH}_2 \end{array} \right]_n  $ <p>(A) polyethene (B) polypeptide (C) polypropene (D) polysaccharide</p>
<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 1</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Identify the type of reaction that occurs when ethene undergoes polymerisation to form polyethene.</p> <p>(A) addition (B) elimination (C) substitution (D) condensation</p>
<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 2</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Structural isomers are compounds with the same molecular formula but a different</p> <p>(A) molar mass. (B) molecular mass. (C) empirical formula. (D) arrangement of atoms.</p>

2022  
Paper 1  
Section 1  
Question 7

Properties  
and  
structure of  
organic  
materials

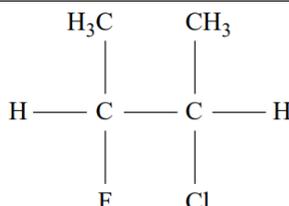


Compound X in these reaction pathways is

- (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



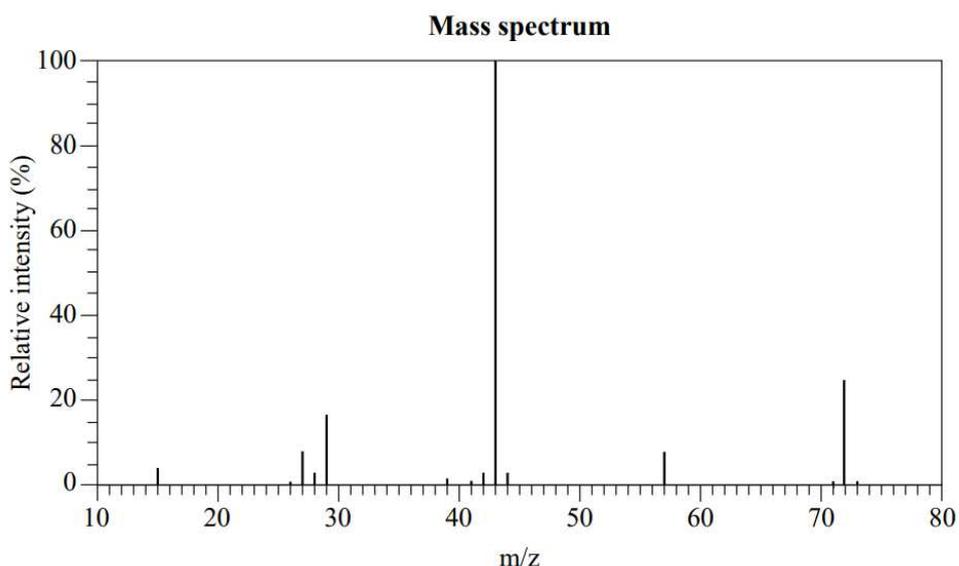
The IUPAC name for this molecule is

- (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.

<b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 20</b>  <b>Properties and structure of organic materials</b>	<b>1</b> $\left( \text{CH}_2 - \underset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \overset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \underset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \overset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \underset{\text{CH}_3}{\text{CH}} \right)$															
	<b>2</b> $\left( \text{CH}_2 - \overset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \overset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \underset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \overset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \underset{\text{CH}_3}{\text{CH}} \right)$															
<p>The two forms of polypropene shown are</p> <table border="1"> <thead> <tr> <th></th> <th><b>1</b></th> <th><b>2</b></th> </tr> </thead> <tbody> <tr> <td>(A)</td> <td>syntactic</td> <td>atactic</td> </tr> <tr> <td>(B)</td> <td>isotactic</td> <td>atactic</td> </tr> <tr> <td>(C)</td> <td>isotactic</td> <td>syntactic</td> </tr> <tr> <td>(D)</td> <td>atactic</td> <td>syntactic</td> </tr> </tbody> </table>			<b>1</b>	<b>2</b>	(A)	syntactic	atactic	(B)	isotactic	atactic	(C)	isotactic	syntactic	(D)	atactic	syntactic
	<b>1</b>	<b>2</b>														
(A)	syntactic	atactic														
(B)	isotactic	atactic														
(C)	isotactic	syntactic														
(D)	atactic	syntactic														

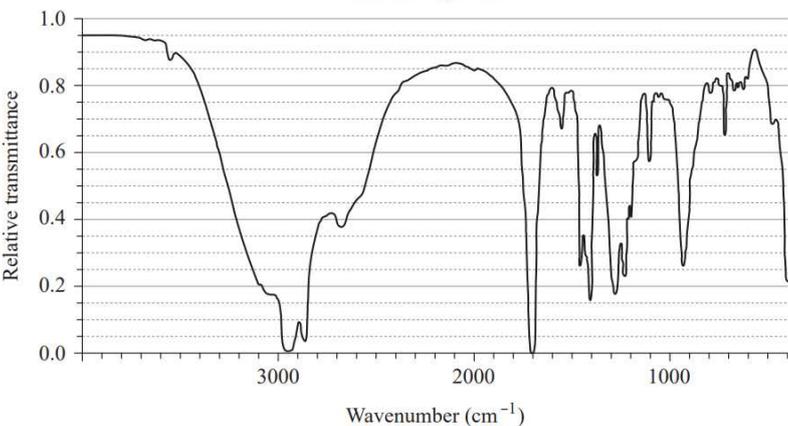
<b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 1</b>  <b>Properties and structure of organic materials</b>	<p>Melting is a</p> <p>(A) physical change that is reversible.          (B) chemical change that is reversible.          (C) physical change that is irreversible.          (D) chemical change that is irreversible.</p>
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<b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 2</b>  <b>Properties and structure of organic materials</b>	<p>Intra-chain hydrogen bonding between peptide groups occurs in</p> <p>(A) primary protein structures.          (B) secondary protein structures.          (C) tertiary protein structures.          (D) quaternary protein structures.</p>
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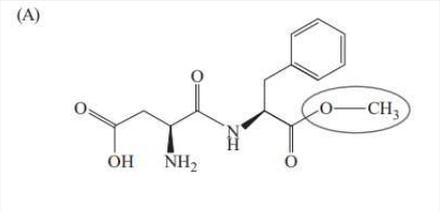
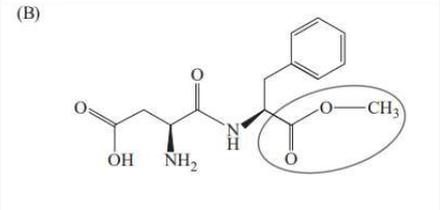
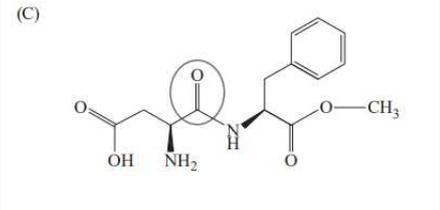
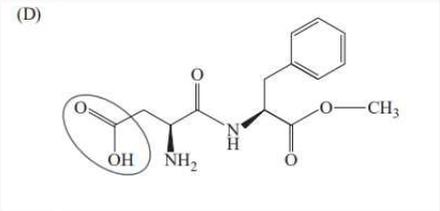
<b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 6</b>  <b>Properties and structure of organic materials</b>	<p>Which type of atoms would be more likely to gain electrons based on its position in the periodic table?</p> <p>(A) halogens          (B) noble gases          (C) alkali metals          (D) alkaline earth metals</p>
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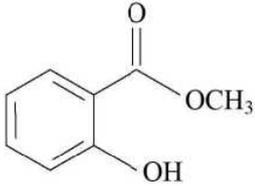
<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 7</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Identify which molecule is an amide.</p> <p>(A) <math>\text{CH}_3\text{CH}_2\text{CN}</math></p> <p>(B) <math>\text{CH}_3\text{CH}_2\text{NH}_2</math></p> <p>(C) <math>\text{NH}_4\text{CH}_3\text{COO}</math></p> <p>(D) <math>\text{CH}_3\text{CONHCH}_3</math></p>
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<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 9</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>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</p> <p>(A) intramolecular hydrogen bonds.</p> <p>(B) intermolecular hydrogen bonds.</p> <p>(C) intramolecular dispersion forces.</p> <p>(D) intermolecular dispersion forces.</p>
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<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 13</b></p> <p><b>Properties and structure of organic materials</b></p>	<p style="text-align: center;"><b>Infrared spectrum</b></p>  <p>Determine the functional group present in the infrared spectrum.</p> <p>(A) ester</p> <p>(B) ketone</p> <p>(C) alcohol</p> <p>(D) carboxylic acid</p>
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<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 15</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which organic compound has the highest boiling point?</p> <p>(A) <math>\text{CH}_3(\text{CH}_2)_3\text{CH}_3</math></p> <p>(B) <math>\text{CH}_3(\text{CH}_2)_3\text{CHO}</math></p> <p>(C) <math>\text{CH}_2\text{CH}(\text{CH}_2)_2\text{CH}_3</math></p> <p>(D) <math>\text{CH}_3(\text{CH}_2)_3\text{CH}_2\text{OH}</math></p>
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<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 20</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Identify the ester linkage in aspartame.</p> <p>(A) </p> <p>(B) </p> <p>(C) </p> <p>(D) </p>
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<p><b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 4</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Oil of wintergreen is a chemical compound with the following chemical structure.</p> <p></p> <p>Identify the functional groups present in oil of wintergreen.</p> <p>(A) alcohol and ester (B) alcohol and ketone (C) alcohol and aldehyde (D) alcohol and carboxylic acid</p>
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<p><b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 8</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>An organic compound, X, reacts with sodium hydrogen carbonate to form carbon dioxide gas. Compound X is</p> <p>(A) an amine. (B) a haloalkane. (C) a carboxylic acid. (D) a primary alcohol.</p>
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<b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 11</b>  <b>Properties and structure of organic materials</b>	Determine the colour of a solution with a pH of 9.6 containing bromocresol green indicator.  (A) pink (B) blue (C) green (D) yellow
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<b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 12</b>  <b>Properties and structure of organic materials</b>	$  \begin{array}{c}  \text{H}_3\text{C} \quad \quad \quad \text{CH}_2 - \text{CH}_3 \\  \quad \quad \quad \diagdown \quad \diagup \\  \quad \quad \quad \text{C} = \text{C} \\  \quad \quad \quad \diagup \quad \diagdown \\  \text{H} \quad \quad \quad \quad \quad \text{H}  \end{array}  $ <p>Apply IUPAC rules to name the molecule.</p> <p>(A) <i>cis</i>-2-pentene          (B) <i>trans</i>-2-pentene          (C) <i>cis</i>-1-ethyl-2-methylethene          (D) <i>trans</i>-1-ethyl-2-methylethene</p>
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<b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 15</b>  <b>Properties and structure of organic materials</b>	$  \begin{array}{cccccccccccccccccccc}  & \text{H} & \text{O} \\  & // \\  \text{H} - & \text{C} = & \text{C} - & \text{C} \\  &   &   &   &   &   &   &   & & &   &   &   &   &   &   &   &   &   &   & \backslash \\  & \text{H} & & & \text{H} & \text{OH}  \end{array}  $ <p>This compound is an unsaturated fatty acid because it contains a</p> <p>(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.</p>
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<b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 19</b>  <b>Properties and structure of organic materials</b>	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.
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Paper 1 Section 2

<b>2023 Paper 1 Section 2 Question 22</b>  <b>Properties and structure of organic materials</b>	(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]

<b>2023 Paper 1 Section 2 Question 26</b>  <b>Properties and structure of organic materials</b>	The table shows a series of reactions that were performed to produce organic compounds A, B and C.																
	<table border="1"><thead><tr><th>Reaction</th><th>Reactant</th><th>Reagents/conditions</th><th>Products</th></tr></thead><tbody><tr><td>1</td><td>propanol</td><td>conc. H<sub>2</sub>SO<sub>4</sub>(aq) / heat</td><td>compound A and water</td></tr><tr><td>2</td><td>compound A</td><td>H<sub>2</sub>O(g) / heat</td><td>compound B and propanol</td></tr><tr><td>3</td><td>compound B</td><td>H<sup>+</sup>(aq) / KMnO<sub>4</sub>(aq) / heat</td><td>compound C</td></tr></tbody></table>	Reaction	Reactant	Reagents/conditions	Products	1	propanol	conc. H <sub>2</sub> SO <sub>4</sub> (aq) / heat	compound A and water	2	compound A	H <sub>2</sub> O(g) / heat	compound B and propanol	3	compound B	H <sup>+</sup> (aq) / KMnO <sub>4</sub> (aq) / heat	compound C
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3	compound B	H <sup>+</sup> (aq) / KMnO <sub>4</sub> (aq) / heat	compound C														
(a) Determine the IUPAC name for compound A. [1 mark]																	
IUPAC name: <hr/> <hr/> <hr/>																	
(b) Explain one structural difference between compound B and propanol. [2 marks]																	
<hr/> <hr/> <hr/>																	
c) Deduce the structural formula of compound C. [1 mark]																	
<div style="border: 1px solid black; height: 100px; width: 100%;"></div>																	

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

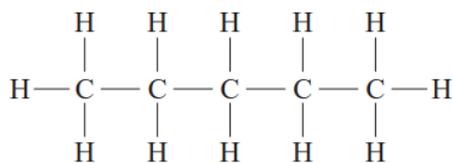
<b>2022 Paper 1 Section 2 Question 21</b>  <b>Properties and structure of organic materials</b>	a) Identify whether 2-bromopropane is a saturated or unsaturated compound. Explain your reasoning. [2 marks]
	<hr/> <hr/> <hr/>
	b) Determine whether 2-bromopropane is a primary, secondary or tertiary halogenoalkane. Explain your reasoning. [2 marks]
	<hr/> <hr/> <hr/> <hr/> <hr/>

<b>2022 Paper 1 Section 2 Question 22</b>  <b>Properties and structure of organic materials</b>	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]
	<hr/> <hr/> <hr/> <hr/>
	<div style="border: 1px solid black; padding: 5px; width: fit-content; margin: 0 auto;">Concentration = _____ mol L<sup>-1</sup> (to two significant figures)</div>

**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:

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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.

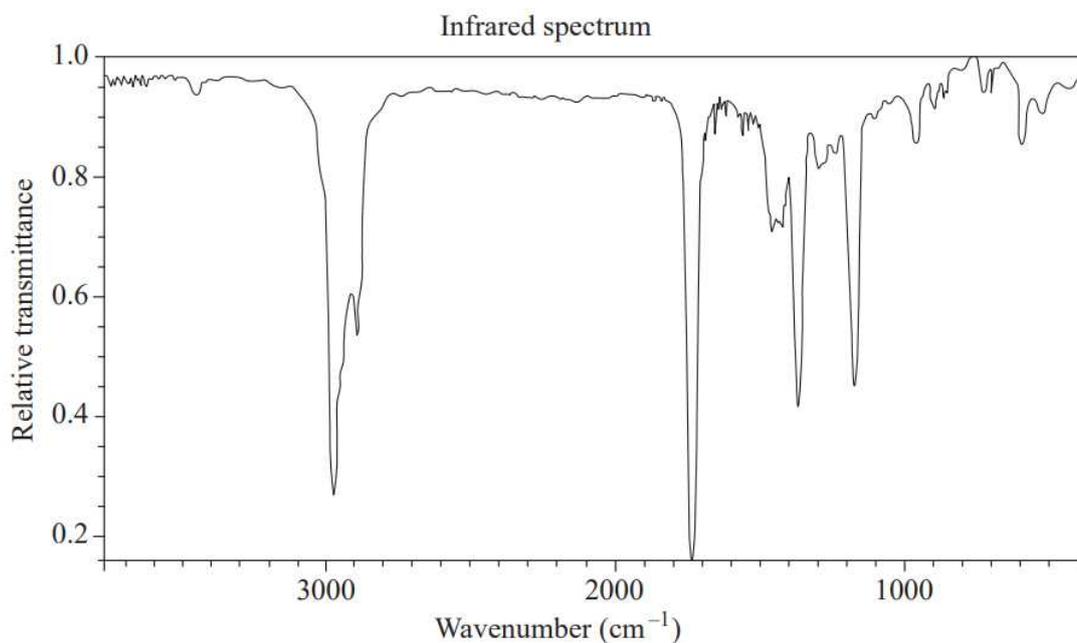
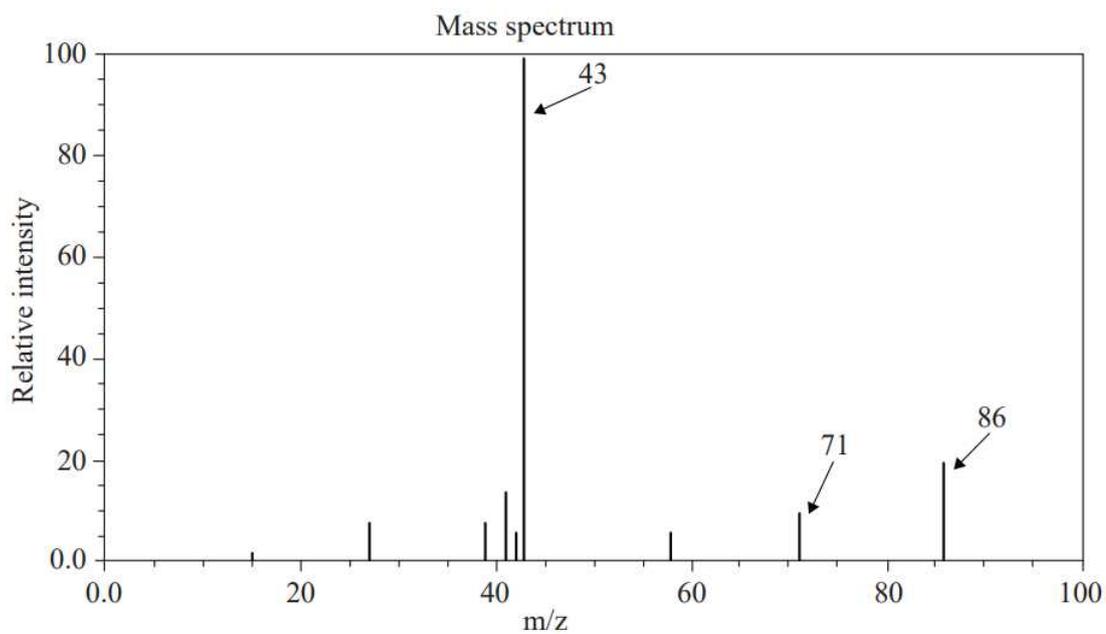
IUPAC name:

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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]

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**Paper 2 Section 1**

<b>2023 Paper 2 Section 1 Question 1</b>  <b>Properties and structure of organic materials</b>	Polylactic acid (PLA) and low-density polyethylene (LDPE) are both used to produce plastic wrapping film.					
	<b>Plastic</b>	<b>Composition</b>	<b>Density (g/cm<sup>3</sup>)</b>	<b>Tensile stress (MPa)</b>	<b>Elongation (%)</b>	<b>Degradation rate</b>
	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:					
	<hr/> <hr/> <hr/>					
	Disadvantage:					
	<hr/> <hr/> <hr/>					

<b>2023 Paper 2 Section 1 Question 2</b>  <b>Properties and structure of organic materials</b>	Compare the structure of $\alpha$ -helix and $\beta$ -pleated sheets in the secondary structure of proteins. [3 marks]					
	Similarity:					
	<hr/> <hr/> <hr/>					
	Difference:					
<hr/> <hr/> <hr/>						
Significance:						
<hr/> <hr/> <hr/>						



(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]

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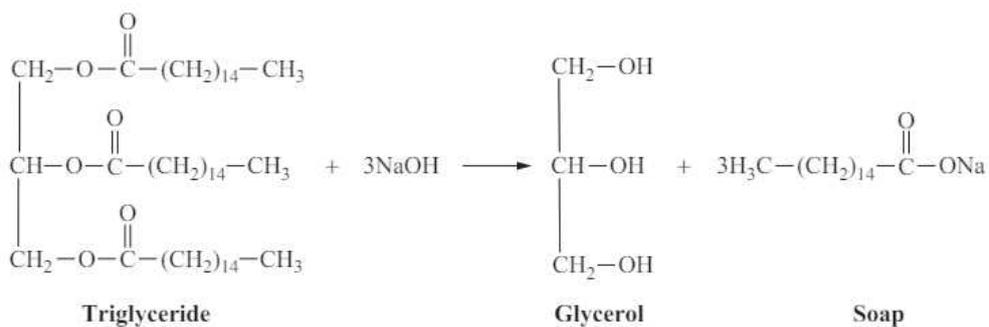
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2023  
Paper 2  
Section 1  
Question 6

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]

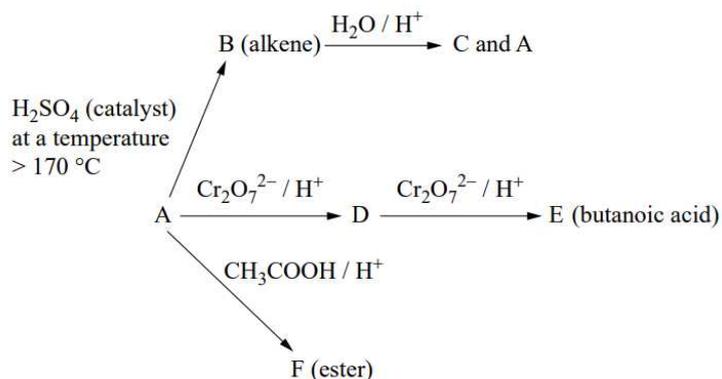
(b) Contrast the structure of saturated and unsaturated fatty acids. [1 mark]

(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:

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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.

<p><b>2022 Paper 2 Section 1 Question 6</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>IUPAC name:</p> <hr/>
	<p>c) Identify whether compounds A and C are structural or geometric isomers. [1 mark]</p> <hr/>
	<p>d) Deduce the structural formula and IUPAC name for compound F. [2 marks]</p> <p>Compound F</p> <div style="border: 1px solid black; height: 150px; width: 100%; margin: 10px 0;"></div>
	<p>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.</p> <p>IUPAC name:</p> <hr/>

<p><b>2022 Paper 2 Section 1 Question 6</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Polypeptides and proteins are formed by condensation reactions of amino acids.</p> <p>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]</p> <hr/> <hr/>
	<p>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]</p> <hr/> <hr/> <hr/> <hr/>



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 <sub>2</sub> ) water	No reaction	No reaction	No reaction	Decolourised

Test 2	A	B	C
Excess acidified potassium manganate(VII) (KMnO <sub>4</sub> ) 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]

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

IUPAC name:

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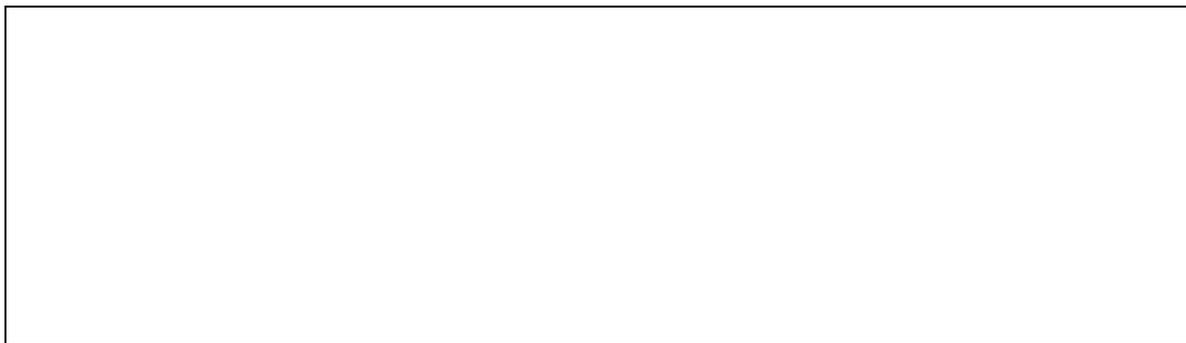
c) Identify Compound C. Explain your reasoning. [3 marks]

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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:

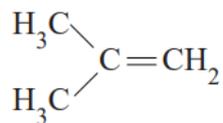
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**2020  
Paper 2  
Section 1  
Question 4**

**Properties  
and  
structure of  
organic  
materials**

Consider the organic molecule shown.



a) Identify the molecule as saturated or unsaturated. [1 mark]

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b) Apply IUPAC rules to name this molecule. [1 mark]

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c) Write an equation to show the products formed by the hydration of this molecule. [2 marks]

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d) Predict which is the major product formed in c). [1 mark]

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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]

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## Marking Guide – Paper 1 Section 1

<p>2023 Paper 1 Section 1 Question 12</p> <p>Properties and structure of organic materials</p>	<p>Enzymes are classified as</p> <p>(A) carbohydrates. <b>(B) proteins. – Answer</b> (C) starches. (D) lipids.</p>
<p>2023 Paper 1 Section 1 Question 14</p> <p>Properties and structure of organic materials</p>	<p>Identify which molecule has the lowest boiling point.</p> <p>(A) butanone (B) hexanone (C) pentanone <b>(D) propanone – Answer</b></p>
<p>2023 Paper 1 Section 1 Question 16</p> <p>Properties and structure of organic materials</p>	<p>Haloalkanes undergo a substitution reaction with cyanide (<math>\text{CN}^-</math>) in ethanol to produce</p> <p>(A) alkanes. (B) amines. (C) nitriles. (D) esters.</p> <p><b>Answer is C.</b></p>
<p>2023 Paper 1 Section 1 Question 17</p> <p>Properties and structure of organic materials</p>	<p>Questions 17–18 refer to the reaction shown.</p> $\begin{array}{c} \text{O} \\ \parallel \\ \text{R}-\text{C}-\text{O}-\text{H} \end{array} + \text{H}-\text{O}-\text{R} \xrightleftharpoons{\text{H}^+} \boxed{\text{Product X}} + \text{H}-\text{O}-\text{H}$ <p>Carboxylic acid      Alcohol      Water</p> <p><b>Question 17</b> Determine the functional group present in Product X.</p> <p>(A) ester - <b>Answer</b> (B) ketone (C) alcohol (D) aldehyde</p> <p><b>Question 18</b> Identify the reaction used to produce X.</p> <p>(A) addition (B) hydration <b>(C) condensation - Answer</b> (D) hydrogenation</p>

<p>2023 Paper 1 Section 1 Question 19</p> <p>Properties and structure of organic materials</p>	<p>Identify the polymer shown.</p> $\left[ \begin{array}{c} \text{CH}_3 \\   \\ \text{CH} - \text{CH}_2 \end{array} \right]_n$ <p>(A) polyethene (B) polypeptide <b>(C) polypropene – Answer</b> (D) polysaccharide</p>
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<p>2023 Paper 1 Section 2 Question 22</p> <p>Properties and structure of organic materials</p>	<p>(a) Write a balanced chemical equation to describe how polytetrafluorethene (PTFE) is produced from its monomer. [2 marks]</p> <table border="1"> <thead> <tr> <th>Sample response</th> <th>The response</th> </tr> </thead> <tbody> <tr> <td><math>n\text{F}_2\text{C}=\text{CF}_2 \rightarrow \left[ \text{F}_2\text{C}-\text{CF}_2 \right]_n</math></td> <td> <ul style="list-style-type: none"> <li>describes formulas for tetrafluorethene monomer and polytetrafluorethene polymer [1 mark]</li> <li>provides a balanced equation [1 mark]</li> </ul> </td> </tr> </tbody> </table> <p>(b) Determine whether polytetrafluorethene is an addition or condensation polymer. Explain your reasoning. [2 marks]</p> <table border="1"> <thead> <tr> <th>Sample response</th> <th>The response</th> </tr> </thead> <tbody> <tr> <td>           Addition polymer            The double bond in tetrafluorethene is broken to allow the monomers to join.         </td> <td> <ul style="list-style-type: none"> <li>identifies addition polymer [1 mark]</li> <li>explains double bond in monomer is broken to allow the formation of polymer [1 mark]</li> </ul> </td> </tr> </tbody> </table>	Sample response	The response	$n\text{F}_2\text{C}=\text{CF}_2 \rightarrow \left[ \text{F}_2\text{C}-\text{CF}_2 \right]_n$	<ul style="list-style-type: none"> <li>describes formulas for tetrafluorethene monomer and polytetrafluorethene polymer [1 mark]</li> <li>provides a balanced equation [1 mark]</li> </ul>	Sample response	The response	Addition polymer The double bond in tetrafluorethene is broken to allow the monomers to join.	<ul style="list-style-type: none"> <li>identifies addition polymer [1 mark]</li> <li>explains double bond in monomer is broken to allow the formation of polymer [1 mark]</li> </ul>
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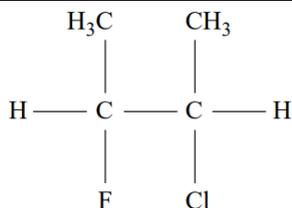
<b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 1</b>  <b>Properties and structure of organic materials</b>	Identify the type of reaction that occurs when ethene undergoes polymerisation to form polyethene.  <b>(A) addition – Answer</b> (B) elimination (C) substitution (D) condensation
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<b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 2</b>  <b>Properties and structure of organic materials</b>	Structural isomers are compounds with the same molecular formula but a different  (A) molar mass. (B) molecular mass. (C) empirical formula. <b>(D) arrangement of atoms. – Answer</b>
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<b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 7</b>  <b>Properties and structure of organic materials</b>	<table style="width: 100%; border: none;"> <tr> <td style="border: 1px solid black; padding: 5px; text-align: center;">Alcohol</td> <td style="border: none; padding: 0 20px;"></td> <td style="border: 1px solid black; padding: 5px; text-align: center;">Compound X</td> <td style="border: none; padding: 0 20px;"></td> <td style="border: 1px solid black; padding: 5px; text-align: center;">Compound X</td> <td style="border: none; padding: 0 20px;"></td> <td style="border: 1px solid black; padding: 5px; text-align: center;">Amine</td> </tr> <tr> <td colspan="2" style="border: none; text-align: center;">\</td> <td colspan="2" style="border: none; text-align: center;">/</td> <td colspan="2" style="border: none; text-align: center;">\</td> <td colspan="2" style="border: none; text-align: center;">/</td> </tr> <tr> <td colspan="4" style="border: none; text-align: center;">↓</td> <td colspan="4" style="border: none; text-align: center;">↓</td> </tr> <tr> <td colspan="4" style="border: 1px solid black; padding: 5px; text-align: center;">Ester</td> <td colspan="4" style="border: 1px solid black; padding: 5px; text-align: center;">Amide</td> </tr> </table> <p>Compound X in these reaction pathways is</p> <p>(A) a ketone.          (B) an alkene.          (C) an aldehyde.  <b>(D) a carboxylic acid. – Answer</b></p>	Alcohol		Compound X		Compound X		Amine	\		/		\		/		↓				↓				Ester				Amide			
Alcohol		Compound X		Compound X		Amine																										
\		/		\		/																										
↓				↓																												
Ester				Amide																												

2022  
Paper 1  
Section 1  
Question 9

Properties  
and  
structure of  
organic  
materials



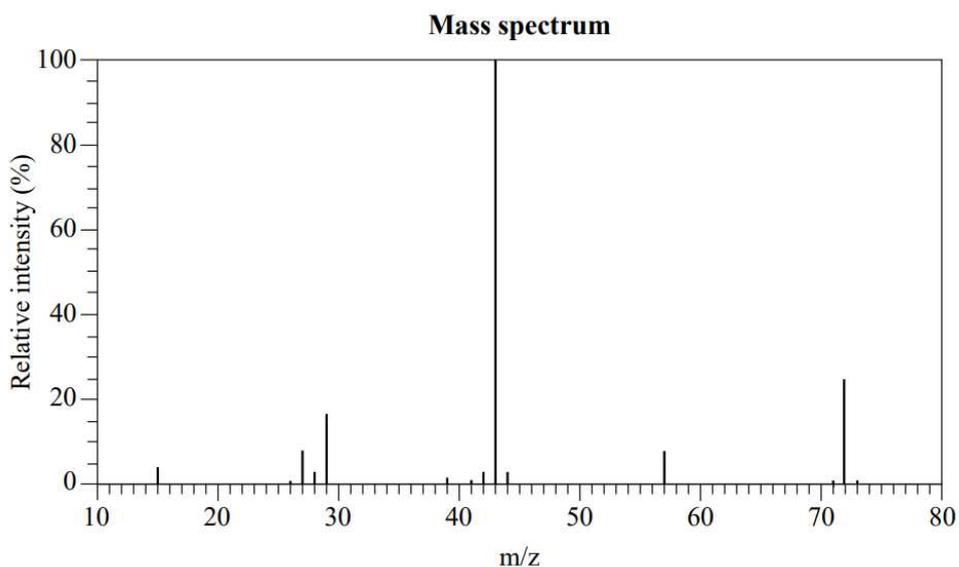
The IUPAC name for this molecule is

- (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.

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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.

<b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 20</b>  <b>Properties and structure of organic materials</b>	<b>1</b> $\left( \text{CH}_2 - \underset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \overset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \underset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \overset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \underset{\text{CH}_3}{\text{CH}} \right)$															
	<b>2</b> $\left( \text{CH}_2 - \overset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \overset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \underset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \overset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \underset{\text{CH}_3}{\text{CH}} \right)$															
<p>The two forms of polypropene shown are</p> <table border="1"> <thead> <tr> <th></th> <th><b>1</b></th> <th><b>2</b></th> </tr> </thead> <tbody> <tr> <td>(A)</td> <td>syntactic</td> <td>atactic</td> </tr> <tr> <td>(B)</td> <td>isotactic</td> <td>atactic</td> </tr> <tr> <td>(C)</td> <td>isotactic</td> <td>syntactic</td> </tr> <tr> <td>(D)</td> <td>atactic</td> <td>syntactic</td> </tr> </tbody> </table> <p><b>Answer is A.</b></p>			<b>1</b>	<b>2</b>	(A)	syntactic	atactic	(B)	isotactic	atactic	(C)	isotactic	syntactic	(D)	atactic	syntactic
	<b>1</b>	<b>2</b>														
(A)	syntactic	atactic														
(B)	isotactic	atactic														
(C)	isotactic	syntactic														
(D)	atactic	syntactic														

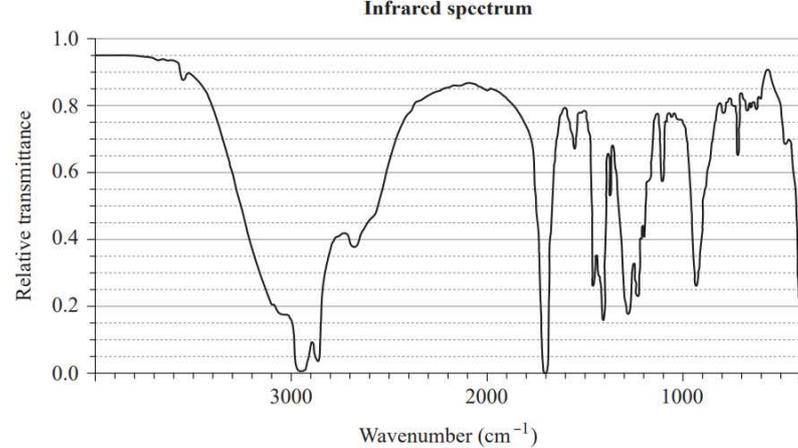
<b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 1</b>  <b>Properties and structure of organic materials</b>	<p>Melting is a</p> <p>(A) <b>physical change that is reversible.</b> – Answer          (B) chemical change that is reversible.          (C) physical change that is irreversible.          (D) chemical change that is irreversible.</p>
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<b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 2</b>  <b>Properties and structure of organic materials</b>	<p>Intra-chain hydrogen bonding between peptide groups occurs in</p> <p>(A) primary protein structures.  <b>(B) secondary protein structures.</b> – Answer          (C) tertiary protein structures.          (D) quaternary protein structures.</p>
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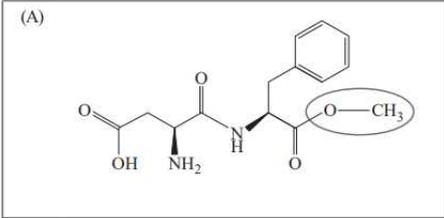
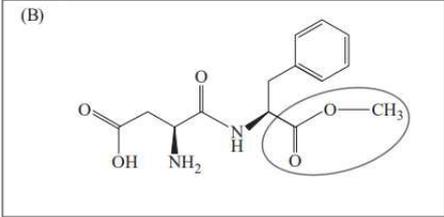
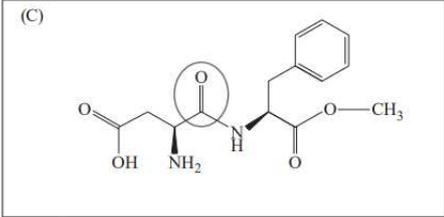
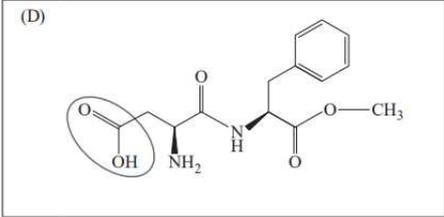
<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 6</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which type of atoms would be more likely to gain electrons based on its position in the periodic table?</p> <p>(A) <b>halogens – Answer</b> (B) noble gases (C) alkali metals (D) alkaline earth metals</p>
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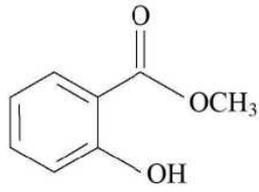
<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 7</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Identify which molecule is an amide.</p> <p>(A) <math>\text{CH}_3\text{CH}_2\text{CN}</math> (B) <math>\text{CH}_3\text{CH}_2\text{NH}_2</math> (C) <math>\text{NH}_4\text{CH}_3\text{COO}</math> (D) <math>\text{CH}_3\text{CONHCH}_3</math></p> <p><b>Answer is D.</b></p>
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<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 9</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>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</p> <p>(A) intramolecular hydrogen bonds. (B) intermolecular hydrogen bonds. (C) intramolecular dispersion forces. (D) <b>intermolecular dispersion forces. – Answer</b></p>
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<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 13</b></p> <p><b>Properties and structure of organic materials</b></p>	<p style="text-align: center;"><b>Infrared spectrum</b></p>  <p>Determine the functional group present in the infrared spectrum.</p> <p>(A) ester (B) ketone (C) alcohol (D) <b>carboxylic acid – Answer</b></p>
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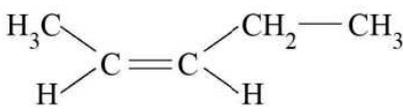
<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 15</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which organic compound has the highest boiling point?</p> <p>(A) <math>\text{CH}_3(\text{CH}_2)_3\text{CH}_3</math></p> <p>(B) <math>\text{CH}_3(\text{CH}_2)_3\text{CHO}</math></p> <p>(C) <math>\text{CH}_2\text{CH}(\text{CH}_2)_2\text{CH}_3</math></p> <p>(D) <math>\text{CH}_3(\text{CH}_2)_3\text{CH}_2\text{OH}</math></p> <p><b>Answer is D.</b></p>
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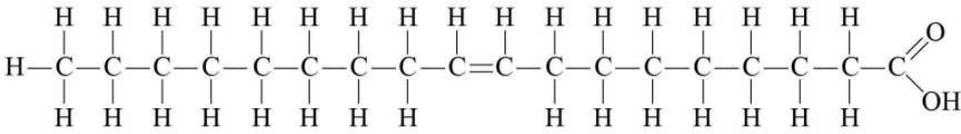
<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 20</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Identify the ester linkage in aspartame.</p> <p>(A) </p> <p>(B) </p> <p>(C) </p> <p>(D) </p> <p><b>Answer is B.</b></p>
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<p><b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 4</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Oil of wintergreen is a chemical compound with the following chemical structure.</p> <p></p> <p>Identify the functional groups present in oil of wintergreen.</p> <p>(A) <b>alcohol and ester – Answer</b></p> <p>(B) alcohol and ketone</p> <p>(C) alcohol and aldehyde</p> <p>(D) alcohol and carboxylic acid</p>
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<b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 8</b>  <b>Properties and structure of organic materials</b>	An organic compound, X, reacts with sodium hydrogen carbonate to form carbon dioxide gas. Compound X is (A) an amine. (B) a haloalkane. <b>(C) a carboxylic acid. – Answer</b> (D) a primary alcohol.
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<b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 11</b>  <b>Properties and structure of organic materials</b>	Determine the colour of a solution with a pH of 9.6 containing bromocresol green indicator. (A) pink <b>(B) blue – Answer</b> (C) green (D) yellow
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<b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 12</b>  <b>Properties and structure of organic materials</b>	 <p>Apply IUPAC rules to name the molecule.</p> (A) <i>cis</i> -2-pentene (B) <i>trans</i> -2-pentene (C) <i>cis</i> -1-ethyl-2-methylethene (D) <i>trans</i> -1-ethyl-2-methylethene  <b>Answer is A.</b>
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<b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 15</b>  <b>Properties and structure of organic materials</b>	 <p>This compound is an unsaturated fatty acid because it contains a</p> (A) <b>double bond and a carboxylic acid group. – Answer</b> (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.
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<b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 19</b>  <b>Properties and structure of organic materials</b>	Dispersion forces, hydrogen bonding, disulphide bridges and ionic bonding all contribute to the (A) primary structure of proteins. (B) secondary structure of proteins. <b>(C) tertiary structure of proteins. – Answer</b> (D) quaternary structure of proteins.
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Marking Guide – Paper 1 Section 2

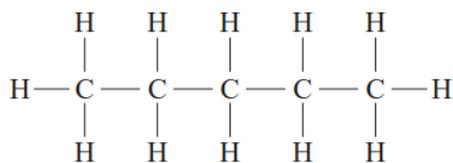
<p>2022 Paper 1 Section 2 Question 21</p> <p>Properties and structure of organic materials</p>	a) Identify whether 2-bromopropane is a saturated or unsaturated compound. Explain your reasoning. [2 marks]	
	Sample Response	The response
	2-bromopropane is saturated because it contains only single bonds.	<ul style="list-style-type: none"> <li>identifies 2-bromopropane is saturated [1 mark]</li> <li>indicates 2-bromopropane contains only single bonds [1 mark]</li> </ul>
	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.	<ul style="list-style-type: none"> <li>determines 2-bromopropane is a secondary halogenoalkane [1 mark]</li> <li>explains that the bromine (halogen) is bonded to a carbon that is attached to two other carbon atoms [1 mark]</li> </ul>

<p>2022 Paper 1 Section 2 Question 22</p> <p>Properties and structure of organic materials</p>	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
	$[H_3O^+] = 10^{-4} \text{ and } [F^-] = 10^{-4}$ $[HF] = \frac{[H_3O^+][F^-]}{K_a}$ $[HF] = \frac{10^{-4} \times 10^{-4}}{7.2 \times 10^{-4}}$ $[HF] = 1.4 \times 10^{-5} \text{ mol L}^{-1}$	<ul style="list-style-type: none"> <li>uses correct substitution [1 mark]</li> <li>calculates <math>[HF] = 1.4 \times 10^{-5}</math> [1 mark]</li> </ul>

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The structural formula for pentane (C<sub>5</sub>H<sub>12</sub>) 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
$  \begin{array}{ccccccc}  \text{CH}_3 & - & \text{CH}_2 & - & \text{CH} & - & \text{CH}_3 \\  & & & &   & & \\  & & & & \text{CH}_3 & & \\  \text{IUPAC name: 2-methylbutane}  \end{array}  $	<ul style="list-style-type: none"> <li>correctly determines structural formula for 2-methylbutane [1 mark]</li> <li>determines name [1 mark]</li> </ul>	Allow FT error for name.  Isomers can be given in either order.

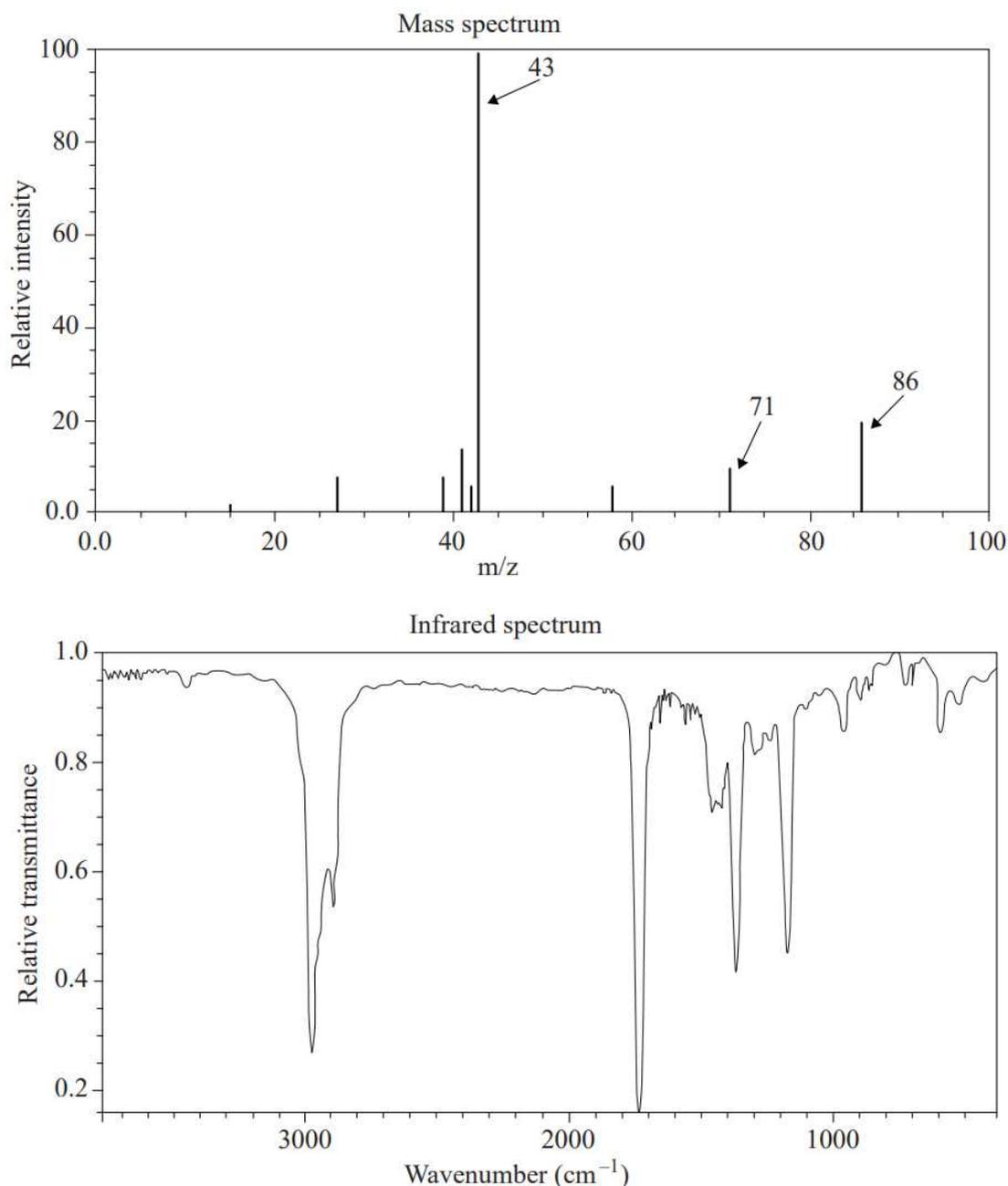
b) Isomer 2 [2 marks]

Sample Response	The response	Notes
$  \begin{array}{ccc}  & \text{CH}_3 & \\  &   & \\  \text{CH}_3 & - \text{C} & - \text{CH}_3 \\  &   & \\  & \text{CH}_3 & \\  \text{IUPAC name: 2,2-dimethylpropane}  \end{array}  $	<ul style="list-style-type: none"> <li>correctly determines structural formula for 2,2-dimethylpropane [1 mark]</li> <li>determines name [1 mark]</li> </ul>	Allow FT error for name.

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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]

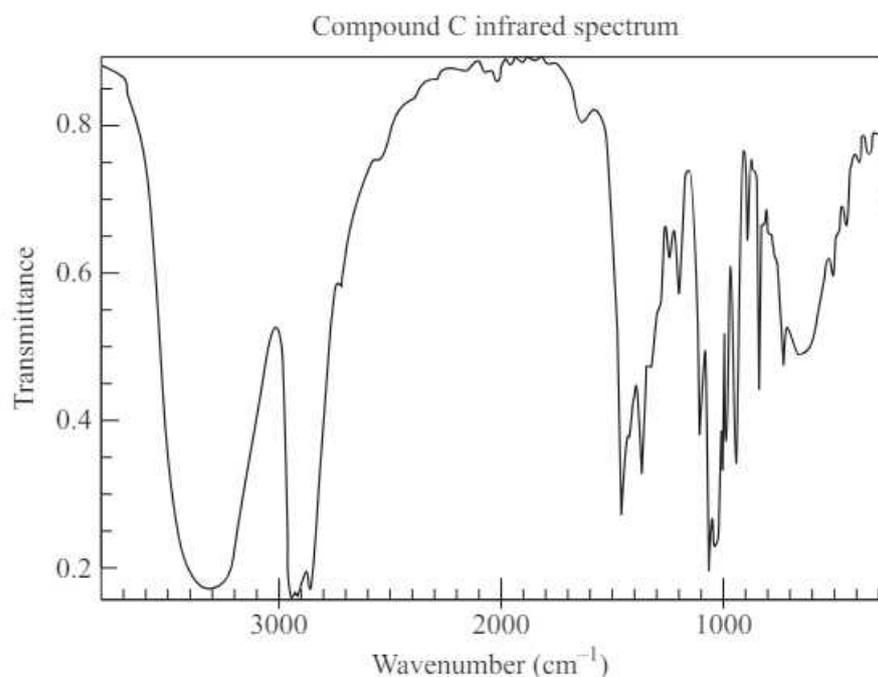
Sample Response	The response
<p>The peak in the IR spectrum at 1700–1750 corresponds to a C=O bond in either an aldehyde or a ketone. There is no stretch in the IR peak at 2720–3100, therefore, the molecule is not an aldehyde and must be a ketone Fragment at <math>m/z = 43</math> is <math>CH_3CH_2CH_2^+</math> and <math>COCH_3^+</math> Fragment at <math>m/z = 71</math> is <math>CH_3CH_2CH_2CO^+</math> Empirical formula = 86. This corresponds to the molecular mass shown on the mass spectrum. Therefore, the molecular formula is <math>C_5H_{10}O</math>.</p> $  \begin{array}{ccccccc}  & H & & H & & H & & H \\  &   & &   & &   & &   \\  H & - C & - & C & - & C & - & C & - & C & - & H \\  &   & &    & &   & &   & &   \\  & H & & O & & H & & H & & H  \end{array}  $	<ul style="list-style-type: none"> <li>identifies IR peak at 1700–1750 corresponds to a C=O bond in aldehyde or ketone [1 mark]</li> <li>indicates that X is a ketone [1 mark]</li> <li>identifies mass fragment at               <ul style="list-style-type: none"> <li>– 43 <math>m/z</math> as <math>CH_3CH_2CH_2^+</math> and <math>COCH_3^+</math></li> </ul> </li> <li>OR</li> <li>– 71 <math>m/z</math> as <math>CH_3CH_2CH_2CO^+</math> [1 mark]</li> <li>uses mass spectrum data to show that the molecular formula for X is <math>C_5H_{10}O</math> [1 mark]</li> <li>provides correct structural formula for pentan-2-one [1 mark]</li> </ul>

Marking Guide – Paper 2 Section 1

<p><b>2023</b> <b>Paper 2</b> <b>Section 1</b> <b>Question 1</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Polylactic acid (PLA) and low-density polyethylene (LDPE) are both used to produce plastic wrapping film.</p>																							
	<table border="1"> <thead> <tr> <th>Plastic</th> <th>Composition</th> <th>Density (g/cm<sup>3</sup>)</th> <th>Tensile stress (MPa)</th> <th>Elongation (%)</th> <th>Degradation rate</th> </tr> </thead> <tbody> <tr> <td>PLA</td> <td>plant-based</td> <td>1.24</td> <td>60</td> <td>6</td> <td>slow</td> </tr> <tr> <td>LDPE</td> <td>petrochemical-based</td> <td>0.92</td> <td>12</td> <td>148</td> <td>none</td> </tr> </tbody> </table>						Plastic	Composition	Density (g/cm <sup>3</sup> )	Tensile stress (MPa)	Elongation (%)	Degradation rate	PLA	plant-based	1.24	60	6	slow	LDPE	petrochemical-based	0.92	12	148	none
	Plastic	Composition	Density (g/cm <sup>3</sup> )	Tensile stress (MPa)	Elongation (%)	Degradation rate																		
	PLA	plant-based	1.24	60	6	slow																		
LDPE	petrochemical-based	0.92	12	148	none																			
<p>Analyse the data to discuss one advantage and one disadvantage of using PLA rather than LDPE to produce plastic wrapping film. [2 marks]</p>																								
<p><b>Sample response</b></p> <p>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.</p>			<p><b>The response</b></p> <ul style="list-style-type: none"> <li>identifies an advantage of using PLA using data [1 mark]</li> <li>identifies a disadvantage of using PLA using data [1 mark]</li> </ul>																					

<p><b>2023</b> <b>Paper 2</b> <b>Section 1</b> <b>Question 2</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Compare the structure of <math>\alpha</math>-helix and <math>\beta</math>-pleated sheets in the secondary structure of proteins. [3 marks]</p>	
	<p><b>Sample response</b></p> <p>Similarity: <math>\alpha</math>-helix structure and <math>\beta</math>-pleated sheets both form H-bonds between two peptide bonds on polypeptide chains. Difference: <math>\alpha</math>-helix structure contains intra-chain H-bonds while <math>\beta</math>-pleated sheets contain inter-chain H-bonds. Significance: <math>\alpha</math>-helix structure produces a regular coiled configuration, whereas <math>\beta</math>-pleated structure produces a sheet.</p>	<p><b>The response</b></p> <ul style="list-style-type: none"> <li>identifies both contain H-bonds between peptide bonds in the polypeptide chain [1 mark]</li> <li>identifies <math>\alpha</math>-helix structure contains intra-chain H-bonds while <math>\beta</math>-pleated sheets contain inter-chain H-bonds [1 mark]</li> <li>explains <math>\alpha</math>-helix is coiled and <math>\beta</math>-pleated forms sheets [1 mark]</li> </ul>

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
<p>Compound C is an alcohol which can be inferred from the broad peak between 3200–3600 <math>cm^{-1}</math> on infrared spectrum which indicates the presence of an OH functional group.</p> <p>Compound C cannot be an aldehyde as there is no peak at 1700–1750 <math>cm^{-1}</math> on infrared spectrum, therefore the compound does not contain a C=O functional group.</p> <p>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.</p>	<ul style="list-style-type: none"> <li>determines that compound C is an alcohol [1 mark]</li> <li>explains that the peak at 3200–3600 indicates OH functional group [1 mark]</li> <li>explains that no peak at 2500–3000 indicates that compound C is not a carboxylic acid [1 mark]</li> <li>explains that no peak at 1700–1750 indicates that compound C is not an aldehyde [1 mark]</li> </ul>

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

Sample response	The response
<p>Isomer 1: <math>\begin{array}{c} CH_2-CH_2-CH_2-CH_3 \\   \\ OH \end{array}</math></p> <p>IUPAC name: 1-butanol</p> <p>Isomer 2: <math>\begin{array}{c} CH_3-CH_2-CH_2-CH_3 \\   \\ OH \end{array}</math></p> <p>IUPAC name: 2-butanol</p>	<ul style="list-style-type: none"> <li>deduces the structural formula and IUPAC name for               <ul style="list-style-type: none"> <li>– an isomer [1 mark]</li> <li>– a second isomer [1 mark]</li> </ul> </li> </ul>

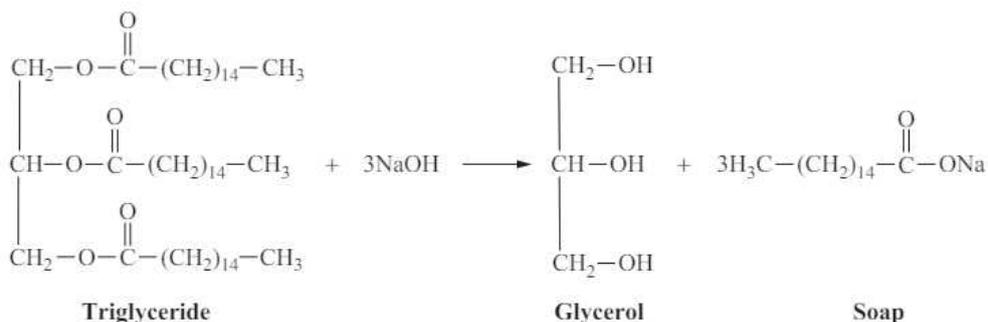
(c) Distinguish between structural and geometric isomers. [2 marks]

Sample response	The response
<p>Structural isomers have the same molecular formula but different structures.</p> <p>Geometric isomers have the same order of atom bonding but the atoms are arranged differently in space.</p>	<ul style="list-style-type: none"> <li>explains structural isomers have the same molecular formula but different structure [1 mark]</li> <li>explains geometric isomers have the same bonding of atoms, but the atoms are arranged differently in space [1 mark]</li> </ul>

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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]

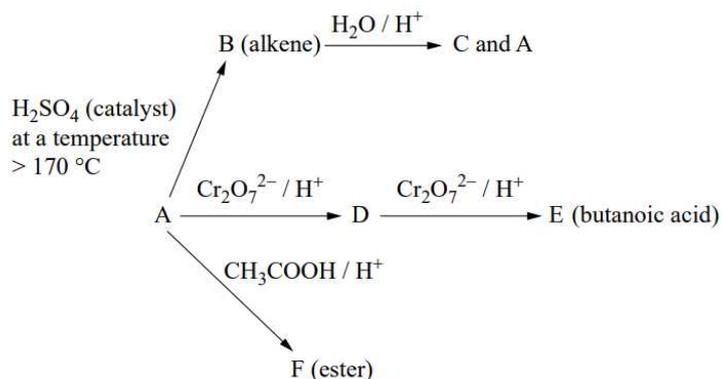
(c) Explain how the cleaning action of soap is related to its structure. [4 marks]

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.	<ul style="list-style-type: none"> <li>• identifies soap contains a polar and non-polar region [1 mark]</li> <li>• explains that fatty acid group is non-polar and dissolves in oil [1 mark]</li> <li>• explains ionic salt group is polar and dissolves in water [1 mark]</li> <li>• explains how soap acts as a bridge to remove oils from water [1 mark]</li> </ul>

2022  
Paper 2  
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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
$\begin{array}{cccc} \text{H} & \text{H} & \text{H} & \text{H} \\   &   &   &   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{O}-\text{H} \\   &   &   &   \\ \text{H} & \text{H} & \text{H} & \text{H} \end{array}$ Compound A is butanol.	<ul style="list-style-type: none"> <li>• deduces structural formula for butanol [1 mark]</li> <li>• provides IUPAC name [1 mark]</li> </ul>

ii) Compound C

Sample Response	The response
$\begin{array}{cccc} \text{CH}_3 & -\text{CH}- & \text{CH}_2- & \text{CH}_3 \\ &   & & \\ & \text{OH} & & \end{array}$ Compound C is 2-butanol.	<ul style="list-style-type: none"> <li>• deduces structural formula for 2-butanol [1 mark]</li> <li>• provides IUPAC name [1 mark]</li> </ul>

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
$\begin{array}{ccccccc} & \text{H} & & & & & \\ &   & & \text{O} & & & \\ \text{H} & -\text{C} & - & \text{C} & & & \\ &   & & // & & & \\ & \text{H} & & \text{O} & & & \\ & & &   & & & \\ & & & \text{O} & - & \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{H} \\ & & & & &   &   &   &   & \\ & & & & & \text{H} & \text{H} & \text{H} & \text{H} & \\ & & & & & \text{H} & \text{H} & \text{H} & \text{H} & \end{array}$ Compound F is butyl ethanoate.	<ul style="list-style-type: none"> <li>• provides structural formula for butyl ethanoate [1 mark]</li> <li>• provides IUPAC name as butyl ethanoate [1 mark]</li> </ul>

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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>Sample Response</b>	<b>The response</b>
Peptide bond Water is formed	<ul style="list-style-type: none"><li>• identifies peptide bond [1 mark]</li><li>• identifies water is formed [1 mark]</li></ul>

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]

<b>Sample Response</b>	<b>The response</b>
6 tripeptides can be formed: Gly-His-Lys and Gly-Lys-His	<ul style="list-style-type: none"><li>• determines 6 tripeptides can be formed [1 mark]</li><li>• describes one tripeptide [1 mark]</li><li>• describes a second tripeptide [1 mark]</li></ul>

c) Explain how the pH of the buffer solution can be used to separate histidine, lysine and glycine through electrophoresis. [3 marks]

<b>Sample Response</b>	<b>The response</b>
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.	<ul style="list-style-type: none"><li>• explains when buffer solution is pH 7.6</li><li>- histidine is neutral and will not migrate [1 mark]</li><li>- Gly forms a negative ion and migrates towards anode (positive terminal) [1 mark]</li><li>- Lys forms a positive ion and migrates towards the cathode (negative terminal) [1 mark]</li></ul>

2021  
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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 <sub>2</sub> ) water	No reaction	No reaction	No reaction	Decolourised

Test 2	A	B	C
Excess acidified potassium manganate(VII) (KMnO <sub>4</sub> ) 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 <sub>2</sub> (aq).	<ul style="list-style-type: none"> <li>identifies Compound D as 1-butene [1 mark]</li> <li>indicates that Compound D undergoes addition [1 mark]</li> </ul>	For 1-butene, accept but-1-ene.

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

Sample Response	The response	Notes
$\text{CH}_2\text{CHCH}_2\text{CH}_3 + \text{Br}_2 \rightarrow \text{CH}_2(\text{Br})\text{CH}(\text{Br})\text{CH}_2\text{CH}_3$ IUPAC name: 1,2-dibromobutane	<ul style="list-style-type: none"> <li>indicates balanced equation with the correct structural formula for reactants and products [1 mark]</li> <li>correctly names 1,2-dibromobutane [1 mark]</li> </ul>	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.	<ul style="list-style-type: none"> <li>identifies Compound C as butane [1 mark]</li> <li>identifies that Compound C cannot be oxidised [1 mark]</li> <li>concludes that Compound C is unreactive and saturated [1 mark]</li> </ul>	For saturated, accept contains only single bonds.  Acceptable response is to identify that Compound C cannot undergo an addition reaction.

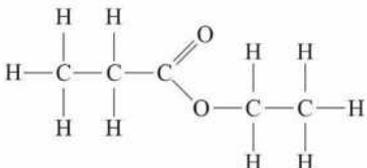
d) Draw the structural formula of Compound Y. [1 mark]

Sample Response	The response	Notes
$\begin{array}{cccc} \text{H} & \text{H} & \text{O} & \text{H} \\   &   &    &   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\   &   & &   \\ \text{H} & \text{H} & & \text{H} \end{array}$	<ul style="list-style-type: none"> <li>provides correct structural formula for butanone for Compound Y [1 mark]</li> </ul>	Acceptable response is Compound Y = CH <sub>3</sub> COCH <sub>2</sub> CH <sub>3</sub>

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 <sub>3</sub> CH <sub>2</sub> COOCH <sub>2</sub> CH <sub>3</sub>

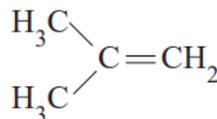
g) Apply IUPAC rules to name Compound Z. [1 mark]

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
$2(\text{CH}_3)_2\text{C} = \text{CH}_2 + 2\text{H}_2\text{O} \xrightarrow{\text{H}^+} (\text{CH}_3)_3\text{C}(\text{OH}) + (\text{CH}_3)_2\text{CHCH}_2\text{OH}$	<ul style="list-style-type: none"> <li>identifies (CH<sub>3</sub>)<sub>3</sub>C(OH) as a product [1 mark]</li> <li>identifies (CH<sub>3</sub>)<sub>2</sub>CHCH<sub>2</sub>OH as a product [1 mark]</li> </ul>	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 <sub>3</sub> ) <sub>3</sub> C(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
<p><math>(\text{CH}_3)_2\text{CHCH}_2\text{OH}</math> is a primary alcohol and <math>(\text{CH}_3)_3\text{C}(\text{OH})</math> is a tertiary alcohol.</p> <p>Therefore, they have different boiling points.</p> <p>Experimental technique: distillation</p> <p>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.</p> <p>Therefore, the intermolecular forces are stronger and the boiling point higher for <math>(\text{CH}_3)_2\text{CHCH}_2\text{OH}</math>.</p>	<ul style="list-style-type: none"><li>• identifies the products are primary and tertiary alcohols [1 mark]</li><li>• identifies boiling point as physical property that can be used to separate the alcohols [1 mark]</li><li>• identifies distillation as a suitable experimental technique [1 mark]</li><li>• links the position of the hydroxyl group in the primary alcohol to increased hydrogen bonding [1 mark]</li><li>• indicates that stronger intermolecular forces result in a higher boiling point for the primary alcohol [1 mark]</li></ul>

## Unit 4 – Topic 2: Chemical synthesis and design

### Paper 1 Section 1

<p>2023 Paper 1 Section 1 Question 6</p> <p>Chemical synthesis and design</p>	<p>Identify the reactants that undergo a condensation reaction to produce the molecule shown.</p> $\text{H}_3\text{C}-\text{CH}_2-\text{CH}_2-\overset{\text{O}}{\parallel}{\text{C}}-\underset{\text{H}}{\text{N}}-\text{CH}_2-\text{CH}_2-\text{CH}_3$ <p>(A) 1-butanol and propanamine (B) 1-propanol and butanamine (C) butanoic acid and propanamine (D) propanoic acid and butanamine</p>
<p>2023 Paper 1 Section 1 Question 13</p> <p>Chemical synthesis and design</p>	<p>Identify the reaction used to produce methanol and triglycerides.</p> <p>(A) oxidation (B) substitution (C) saponification (D) transesterification</p>
<p>2023 Paper 1 Section 1 Question 20</p> <p>Chemical synthesis and design</p>	<p>The structural formula for a polypeptide is shown.</p> <p>Identify the three amino acids present from left to right.</p> <p>(A) Arg, Cys, Met (B) Asp, Cys, Ala (C) Glu, Cys, Asp (D) Ile, Cys, Gly</p>
<p>2022 Paper 1 Section 1 Question 4</p> <p>Chemical synthesis and design</p>	<p>Which pair of reagents would react to form a glycosidic bond?</p> <p>(A) lysine and aniline (B) glucose and galactose (C) methanol and butanoic acid (D) glycerol and sodium hydroxide</p>

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 ( $\alpha$ -amylase) of starch biomass to form glucose	Fermentation of glucose to form bioethanol (yeast)	Easier	Faster
Cellulose	Acid hydrolysis ( $\text{H}_2\text{SO}_4(\text{aq})$ at $320\text{ }^\circ\text{C}$ and $25\text{ MPa}$ ) 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]

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b) Explain why cellulose is harder to convert to glucose than starch. [3 marks]

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c) After 48 hours of fermentation, a 15% w/v glucose solution produces  $37.5\text{ g L}^{-1}$  of ethanol. Calculate the percentage yield of ethanol. Show your working. [3 marks]

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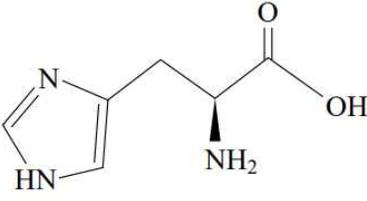
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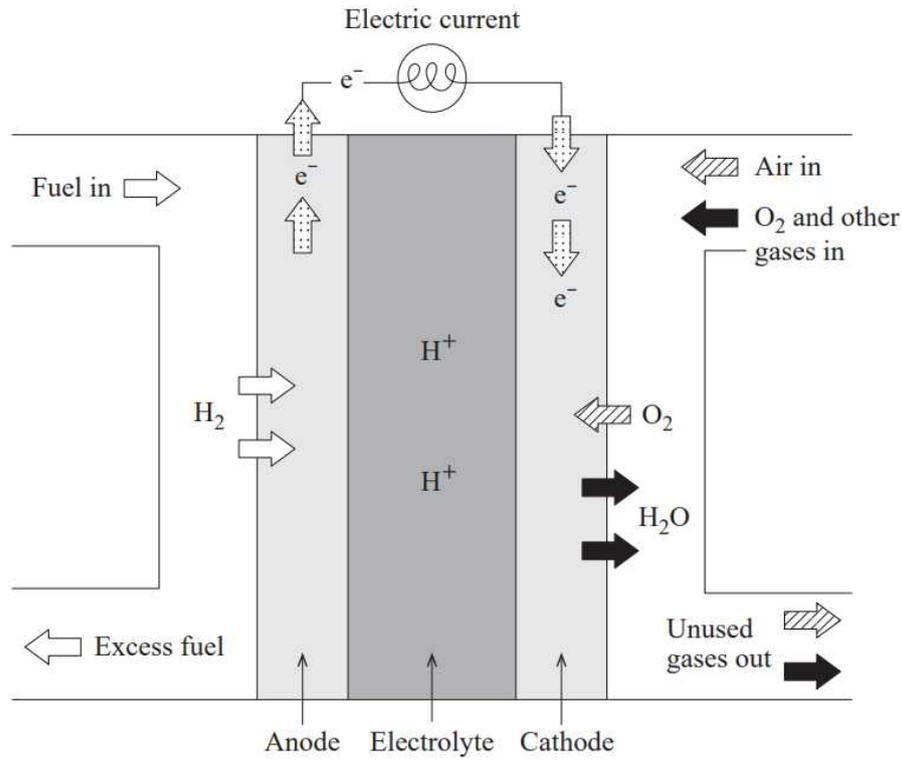
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Ethanol yield = \_\_\_\_\_ % (to one decimal place)

<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 5</b></p> <p><b>Chemical synthesis and design</b></p>	<p>Phosphorus pentoxide is prepared by burning phosphorus in oxygen.</p> $\text{P}_4(\text{s}) + 5\text{O}_2(\text{g}) \rightarrow \text{P}_4\text{O}_{10}(\text{s})$ <p>Calculate the percentage yield if 10.0 g of <math>\text{P}_4\text{O}_{10}</math> is produced when 0.200 mol of <math>\text{P}_4</math> and 0.200 mol of <math>\text{O}_2</math> are reacted.</p> <p>(A) 2.0% (B) 3.5% (C) 17.6% (D) 88.0%</p>
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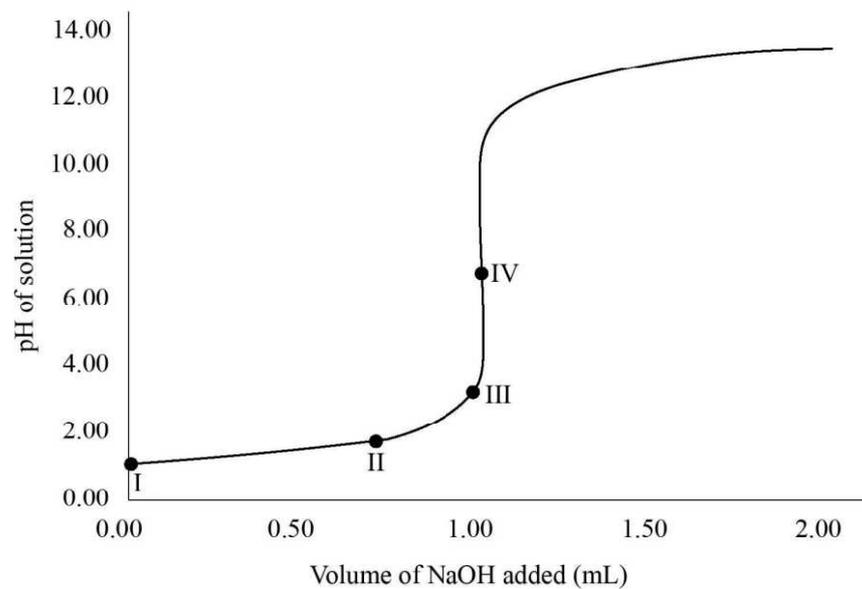
<p><b>2022</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 15</b></p> <p><b>Chemical synthesis and design</b></p>	<p>The structure of an amino acid is shown.</p>  <p>This molecule contains an amine group and a</p> <p>(A) carboxyl group. (B) hydroxy group. (C) methyl group. (D) ketone group.</p>
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<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 8</b></p> <p><b>Chemical synthesis and design</b></p>	 <p>Identify the operating conditions for the hydrogen fuel cell.</p> <p>(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</p>
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<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 12</b></p> <p><b>Chemical synthesis and design</b></p>	<p>Green chemistry principles include the design of chemical synthesis processes that</p> <p>(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.</p>
<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 16</b></p> <p><b>Chemical synthesis and design</b></p>	<p>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.</p> $2\text{CH}_3\text{COOH}(\text{aq}) + \text{MgCO}_3(\text{s}) \rightarrow (\text{CH}_3\text{COO})_2\text{Mg}(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$ <p>(A) 44% (B) 58% (C) 88% (D) 100%</p>
<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 19</b></p> <p><b>Chemical synthesis and design</b></p>	<p>To form ethanol biofuel in the fermentation of glucose, a catalyst is used because</p> <p>(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.</p>
<p><b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 1</b></p> <p><b>Chemical synthesis and design</b></p>	<p>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</p> <p>(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.</p>
<p><b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 2</b></p> <p><b>Chemical synthesis and design</b></p>	<p><math>\text{Mg}(\text{s}) + 2\text{Ag}^+(\text{aq}) \rightarrow 2\text{Ag}(\text{s}) + \text{Mg}^{2+}(\text{aq})</math></p> <p>Determine which of the following statements is true for the chemical reaction.</p> <p>(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.</p>
<p><b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 3</b></p> <p><b>Chemical synthesis and design</b></p>	<p></p> <p>This general chemical equation represents the following type of reaction.</p> <p>(A) addition (B) hydrolysis (C) esterification (D) condensation</p>

2020  
Paper 1  
Section 1  
Question 13

Chemical  
synthesis and  
design



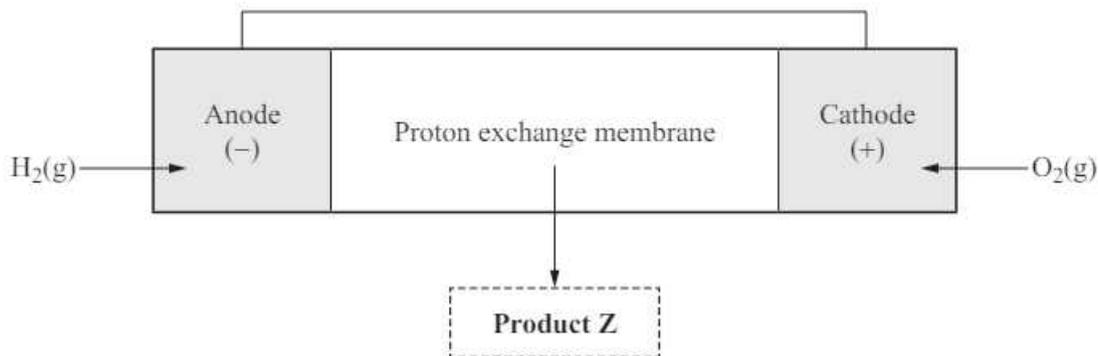
Identify the equivalence point on the titration curve.

- (A) I
- (B) II
- (C) III
- (D) IV

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]

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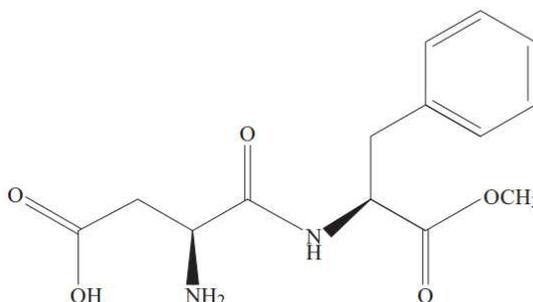


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2021  
Paper 1  
Section 2  
Question 23

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]

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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]

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c) Explain why the reference amino acids are included on the TLC plate. [1 mark]

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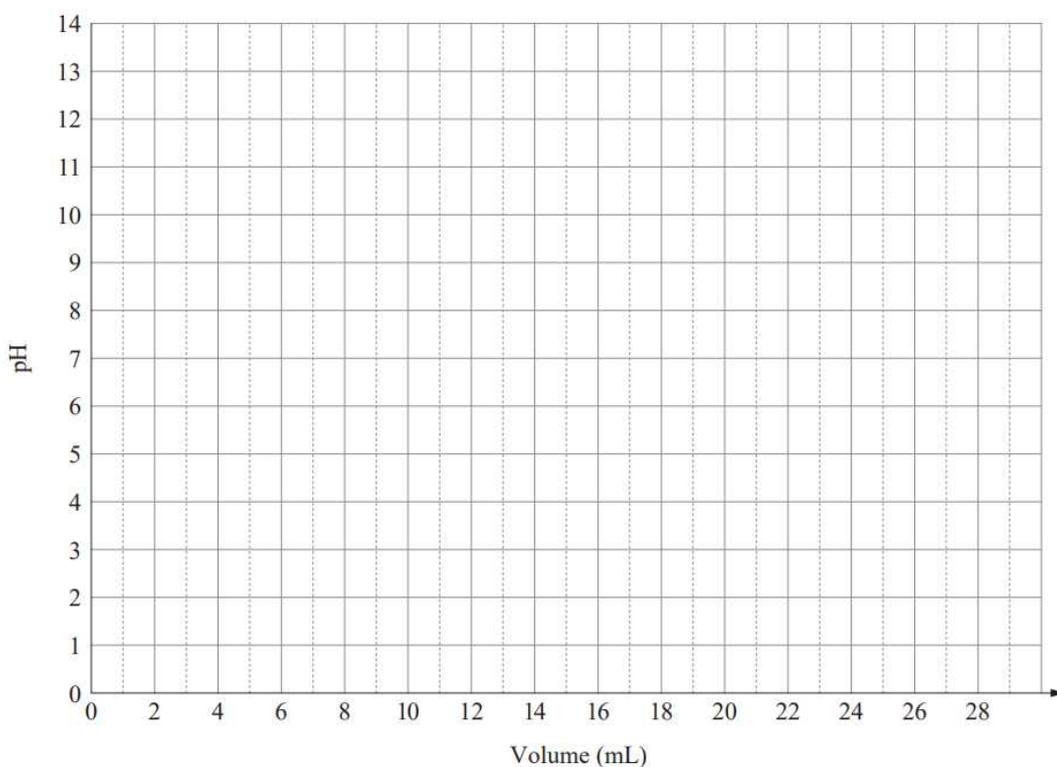
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**2021  
Paper 1  
Section 2  
Question 28**

**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.

<b>2020</b> <b>Paper 1</b> <b>Section 2</b> <b>Question 21</b>  <b>Chemical</b> <b>synthesis and</b> <b>design</b>	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]



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]

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c) Identify the functional group formed by the reaction of the monomers in PET. [1 mark]

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d) Determine the type of polymerisation used to form PP. [1 mark]

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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]

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**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]

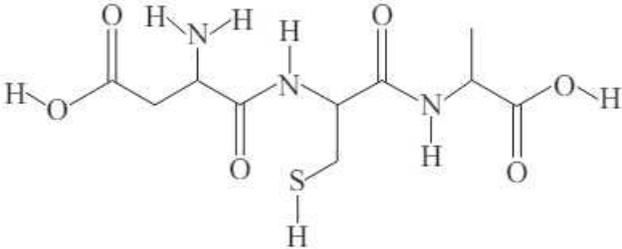
b) Calculate the atom economy for the production of ethanol by fermentation of glucose. [2 marks]

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

<p>2023 Paper 1 Section 1 Question 6</p> <p>Chemical synthesis and design</p>	<p>Identify the reactants that undergo a condensation reaction to produce the molecule shown.</p> $\text{H}_3\text{C}-\text{CH}_2-\text{CH}_2-\overset{\text{O}}{\parallel}{\text{C}}-\underset{\text{H}}{\text{N}}-\text{CH}_2-\text{CH}_2-\text{CH}_3$ <p>(A) 1-butanol and propanamine (B) 1-propanol and butanamine (C) butanoic acid and propanamine (D) propanoic acid and butanamine</p> <p><b>Answer is C.</b></p>
<p>2023 Paper 1 Section 1 Question 13</p> <p>Chemical synthesis and design</p>	<p>Identify the reaction used to produce methanol and triglycerides.</p> <p>(A) oxidation (B) substitution (C) saponification (D) transesterification – <b>Answer</b></p>
<p>2023 Paper 1 Section 1 Question 20</p> <p>Chemical synthesis and design</p>	<p>The structural formula for a polypeptide is shown.</p>  <p>Identify the three amino acids present from left to right.</p> <p>(A) Arg, Cys, Met (B) Asp, Cys, Ala (C) Glu, Cys, Asp (D) <b>Ile, Cys, Gly – Answer</b></p>
<p>2022 Paper 1 Section 1 Question 4</p> <p>Chemical synthesis and design</p>	<p>Which pair of reagents would react to form a glycosidic bond?</p> <p>(A) lysine and aniline (B) <b>glucose and galactose – Answer</b> (C) methanol and butanoic acid (D) glycerol and sodium hydroxide</p>

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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 ( $\alpha$ -amylase) of starch biomass to form glucose	Fermentation of glucose to form bioethanol (yeast)	Easier	Faster
Cellulose	Acid hydrolysis ( $\text{H}_2\text{SO}_4(\text{aq})$ ) at $320\text{ }^\circ\text{C}$ and $25\text{ MPa}$ 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	<ul style="list-style-type: none"> <li>identifies fermentation requires yeast as a catalyst [1 mark]</li> <li>identifies that yeast is temperature-sensitive [1 mark]</li> </ul>

b) Explain why cellulose is harder to convert to glucose than starch. [3 marks]

Sample Response	The response
Cellulose is a linear polymer. The $\beta$ -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.	<ul style="list-style-type: none"> <li>identifies cellulose is a linear polymer [1 mark]</li> <li>identifies monomers can pack closely together [1 mark]</li> <li>explains increased H-bonding between adjacent chains makes hydrolysis of cellulose more difficult [1 mark]</li> </ul>

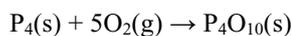
c) After 48 hours of fermentation, a 15% w/v glucose solution produces  $37.5\text{ g L}^{-1}$  of ethanol. Calculate the percentage yield of ethanol. Show your working. [3 marks]

Sample Response	The response
$\text{Moles } \text{C}_6\text{H}_{12}\text{O}_6 = \frac{150}{180.18} = 0.833$ $\text{Moles } \text{CH}_3\text{CH}_2\text{OH} = 0.83 \times 2 = 1.67$ $\text{Mass } \text{CH}_3\text{CH}_2\text{OH} = 1.67 \times 46.08 = 76.72\text{ g}$ $\text{Ethanol yield} = \frac{37.5}{\text{theoretical yield}} = \frac{37.5}{76.72} = 48.9\%$	<ul style="list-style-type: none"> <li>determines 150 g glucose can produce 1.67 M of ethanol [1 mark]</li> <li>calculates theoretical mass of ethanol as 76.72 g [1 mark]</li> <li>calculates % yield of ethanol is 48.9% [1 mark]</li> </ul>

2022  
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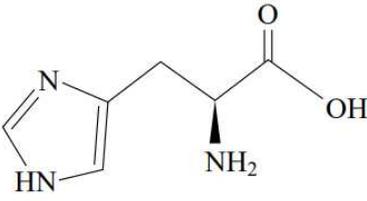
Chemical  
synthesis and  
design

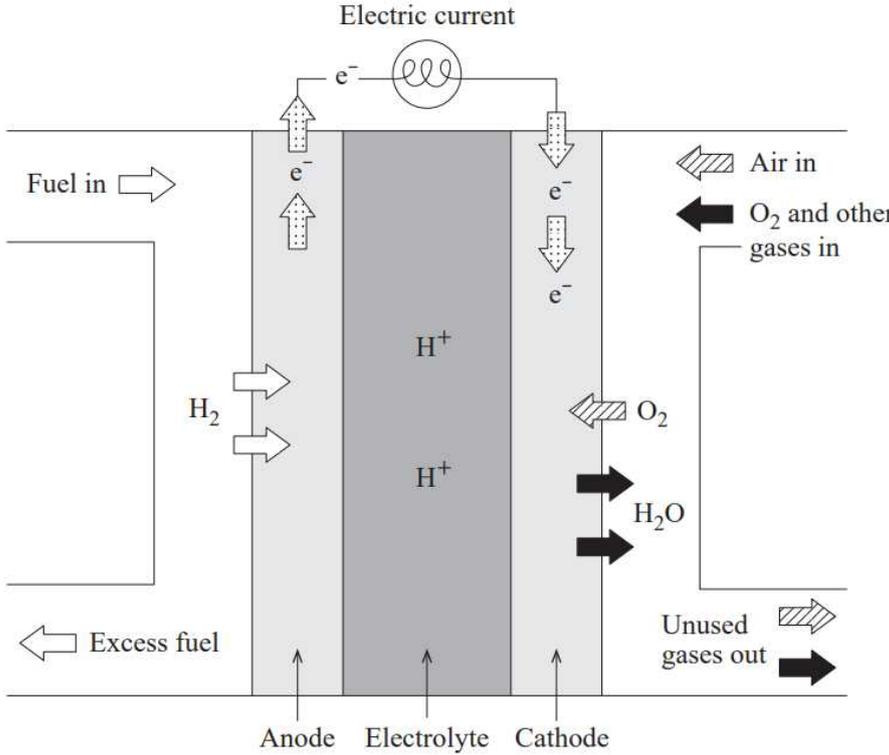
Phosphorus pentoxide is prepared by burning phosphorus in oxygen.



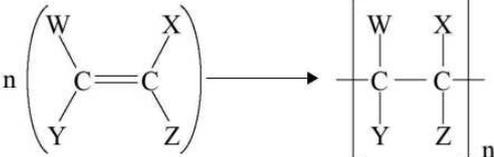
Calculate the percentage yield if 10.0 g of  $\text{P}_4\text{O}_{10}$  is produced when 0.200 mol of  $\text{P}_4$  and 0.200 mol of  $\text{O}_2$  are reacted.

- (A) 2.0%  
(B) 3.5%  
(C) 17.6%  
(D) 88.0% – Answer

<p>2022 Paper 1 Section 1 Question 15</p> <p>Chemical synthesis and design</p>	<p>The structure of an amino acid is shown.</p>  <p>This molecule contains an amine group and a</p> <p>(A) <b>carboxyl group.</b> – Answer (B) hydroxy group. (C) methyl group. (D) ketone group.</p>
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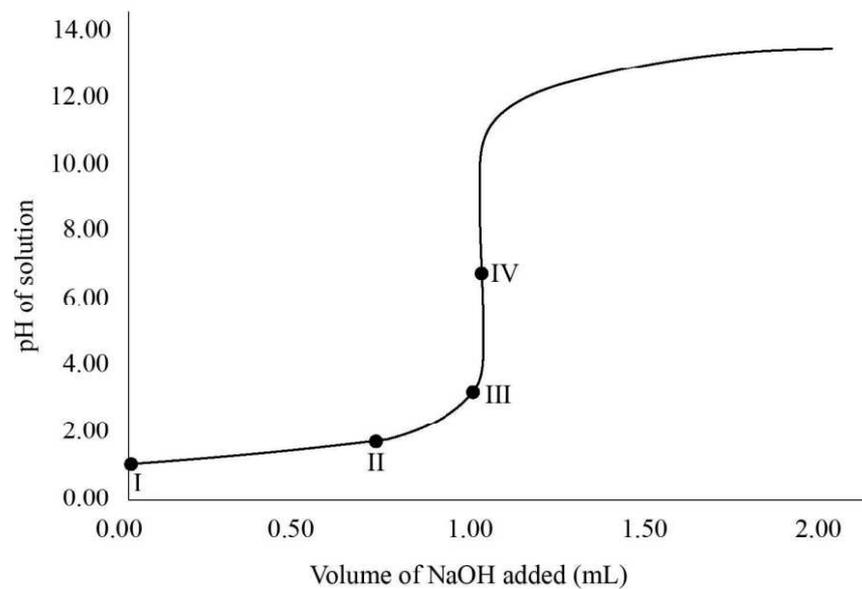
<p>2021 Paper 1 Section 1 Question 8</p> <p>Chemical synthesis and design</p>	 <p>Identify the operating conditions for the hydrogen fuel cell.</p> <p>(A) acidic conditions with hydrogen given off as an unused gas (B) alkaline conditions with hydrogen given off as an unused gas (C) <b>acidic conditions with hydrogen ions present in the electrolyte</b> – Answer (D) alkaline conditions with hydrogen ions present in the electrolyte</p>
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<p>2021 Paper 1 Section 1 Question 12</p> <p>Chemical synthesis and design</p>	<p>Green chemistry principles include the design of chemical synthesis processes that</p> <p>(A) <b>use renewable raw materials and minimise unwanted products.</b> – 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.</p>
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<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 16</b></p> <p><b>Chemical synthesis and design</b></p>	<p>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.</p> $2\text{CH}_3\text{COOH}(\text{aq}) + \text{MgCO}_3(\text{s}) \rightarrow (\text{CH}_3\text{COO})_2\text{Mg}(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$ <p>(A) 44% (B) 58% (C) <b>88% – Answer</b> (D) 100%</p>
<p><b>2021</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 19</b></p> <p><b>Chemical synthesis and design</b></p>	<p>To form ethanol biofuel in the fermentation of glucose, a catalyst is used because</p> <p>(A) <b>less energy is required and the rate of reaction is increased. – Answer</b> (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.</p>
<p><b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 1</b></p> <p><b>Chemical synthesis and design</b></p>	<p>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</p> <p>(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) <b>equal to the rate of condensation but not equal to zero. – Answer</b></p>
<p><b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 1</b></p> <p><b>Chemical synthesis and design</b></p>	<p>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</p> <p>(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) <b>equal to the rate of condensation but not equal to zero. – Answer</b></p>
<p><b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 2</b></p> <p><b>Chemical synthesis and design</b></p>	<p><math>\text{Mg}(\text{s}) + 2\text{Ag}^+(\text{aq}) \rightarrow 2\text{Ag}(\text{s}) + \text{Mg}^{2+}(\text{aq})</math></p> <p>Determine which of the following statements is true for the chemical reaction.</p> <p>(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) <b>equal to the rate of condensation but not equal to zero. – Answer</b></p>
<p><b>2020</b> <b>Paper 1</b> <b>Section 1</b> <b>Question 3</b></p> <p><b>Chemical synthesis and design</b></p>	<p>  </p> <p>This general chemical equation represents the following type of reaction.</p> <p>(A) <b>addition – Answer</b> (B) hydrolysis (C) esterification (D) condensation</p>

2020  
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Chemical  
synthesis and  
design



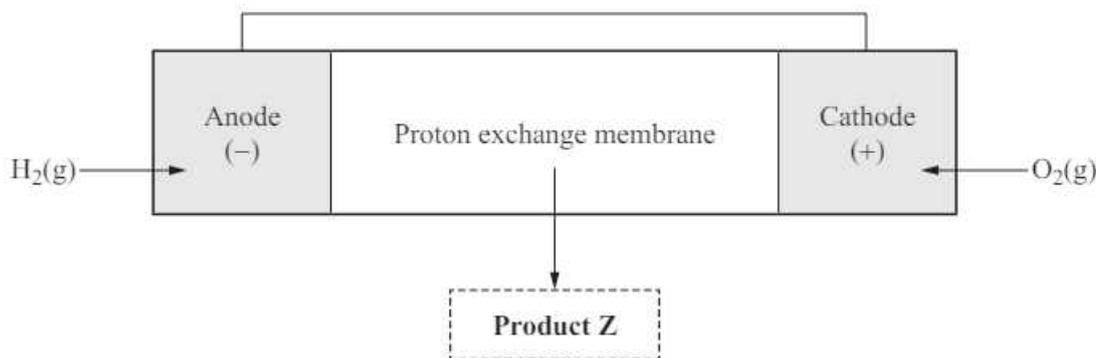
Identify the equivalence point on the titration curve.

- (A) I
- (B) II
- (C) III
- (D) IV – Answer**

2023  
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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: $2\text{H}_2(\text{g}) \rightarrow 4\text{H}^+(\text{aq}) + 4\text{e}^-$	<ul style="list-style-type: none"> <li>identifies anode half-equation [1 mark]</li> </ul>
Cathode half-equation: $\text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}(\text{l})$	<ul style="list-style-type: none"> <li>identifies cathode half-equation [1 mark]</li> </ul>

(b) Identify product Z. [1 mark]

Sample response	The response
Product Z is water.	<ul style="list-style-type: none"> <li>identifies product Z is water [1 mark]</li> </ul>

(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.	<ul style="list-style-type: none"> <li>identifies electrons and hydrogen ions move from the anode to the cathode [1 mark]</li> <li>identifies hydrogen ions move through the proton exchange membrane while electrons flow through the wire [1 mark]</li> <li>identifies that movement of electrons creates potential difference [1 mark]</li> </ul>

2022  
Paper 1  
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Chemical  
synthesis and  
design

Ibuprofen is manufactured using two different processes.

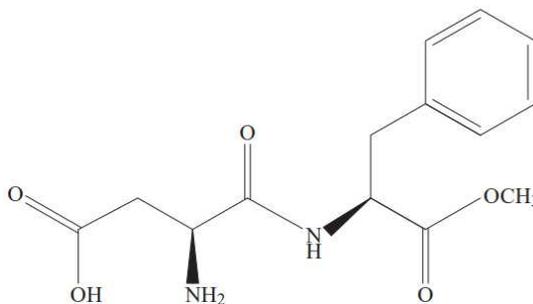
Process	Number of reagents used	Reagents		Ibuprofen		Waste products	
		Atoms	M <sub>r</sub>	Atoms	M <sub>r</sub>	Atoms	M <sub>r</sub>
1	7	C <sub>20</sub> H <sub>42</sub> NO <sub>10</sub> ClNa	514.5	C <sub>13</sub> H <sub>18</sub> O <sub>2</sub>	206.0	C <sub>7</sub> H <sub>24</sub> NO <sub>8</sub> ClNa	308.5
2	4	C <sub>15</sub> H <sub>22</sub> O <sub>4</sub>	266.0	C <sub>13</sub> H <sub>18</sub> O <sub>2</sub>	206.0	C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>	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
<p>Process 1: atom economy = <math>206.0/514.5 \times 100 = 40.04\%</math></p> <p>Process 2: atom economy = <math>206.0/266.0 \times 100 = 77.44\%</math></p> <p>Process 2 has 37.4% better atom economy than process 1</p> <p>Economic impact: Process 2 has a better atom economy than process 1 (fewer reagents are required).</p> <p>Environmental impact: Process 2 is greener than process 1 because fewer waste products (atoms) are produced.</p>	<ul style="list-style-type: none"> <li>calculates atom economy for               <ul style="list-style-type: none"> <li>- Process 1 as 40% [1 mark]</li> <li>- Process 2 as 77% [1 mark]</li> </ul> </li> <li>concludes process 2 is               <ul style="list-style-type: none"> <li>- cheaper as fewer reagent atoms are required [1 mark]</li> <li>- greener as fewer waste atoms are produced [1 mark]</li> </ul> </li> </ul>

2021  
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Chemical  
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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	<ul style="list-style-type: none"> <li>correctly identifies aspartic acid and phenylalanine [1 mark]</li> </ul>	<p>For aspartic acid, accept Asp.</p> <p>For phenylalanine, accept Phe.</p> <p>Accept correctly drawn diagrams.</p>

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.	<ul style="list-style-type: none"> <li>indicates that isoleucine is non-polar [1 mark]</li> <li>indicates that Spot A is non-polar and travels a similar distance to isoleucine [1 mark]</li> <li>determines that Spot A is phenylalanine [1 mark]</li> </ul>	Acceptable response indicates Spot A has a similar $R_f$ value (distance travelled) as isoleucine and is therefore non-polar.

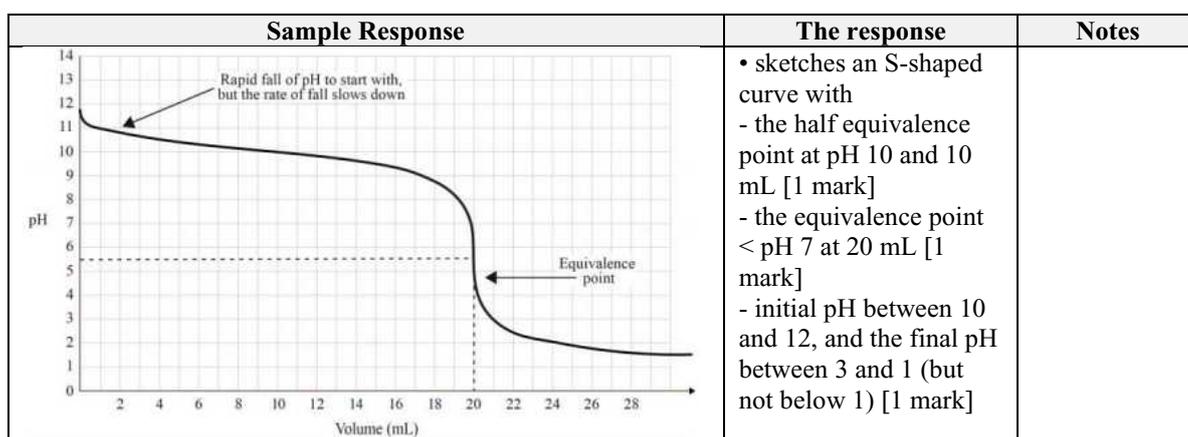
c) Explain why the reference amino acids are included on the TLC plate. [1 mark]

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.

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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.



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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
<p>Both starch and cellulose form 1-4 glycosidic links.</p> <p>However, starch is a polymer of <math>\alpha</math>-glucose and cellulose is a polymer of <math>\beta</math>-glucose.</p> <p>Starch forms a linear polymer due to 1-4 <math>\alpha</math>-glycosidic links (amylose) and a branched polymer due to 1-4 and 1-6 <math>\alpha</math>-glycosidic links (amylopectin). Cellulose only exists as a linear polymer with 1-4, <math>\beta</math>-glycosidic links.</p>	<ul style="list-style-type: none"> <li>identifies that both contain 1-4 links [1 mark]</li> <li>identifies that starch is a polymer of <math>\alpha</math>-glucose and cellulose is a polymer of <math>\beta</math>-glucose [1 mark]</li> <li>indicates that starch can be linear due to 1-4 <math>\alpha</math>-glycosidic links (amylose) and branched due to 1-4 and 1-6 <math>\alpha</math>-glycosidic links [1 mark]</li> <li>indicates that cellulose only exists as a linear polymer with 1-4, <math>\beta</math>-glycosidic links [1 mark]</li> </ul>

Marking Guide – Paper 2 Section 1

<p><b>2023</b> <b>Paper 2</b> <b>Section 1</b> <b>Question 9</b></p> <p><b>Chemical synthesis and design</b></p>	<p>Aspirin (C<sub>9</sub>H<sub>8</sub>O<sub>4</sub>) can be produced from a reaction between salicylic acid (C<sub>7</sub>H<sub>6</sub>O<sub>3</sub>) and acetic anhydride (C<sub>4</sub>H<sub>6</sub>O<sub>3</sub>) with ethanoic acid being a minor product.</p> $\text{C}_7\text{H}_6\text{O}_3(\text{s}) + \text{C}_4\text{H}_6\text{O}_3(\text{aq}) \rightarrow \text{C}_9\text{H}_8\text{O}_4(\text{s}) + \text{C}_2\text{H}_4\text{O}_2(\text{aq})$ <p>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.</p> <p style="text-align: right;">[4 marks]</p>			
	<table border="1"> <thead> <tr> <th>Sample response</th> <th>The response</th> </tr> </thead> <tbody> <tr> <td> <p>1:1 Aspirin : salicylic acid (SA)</p> <math display="block">n(\text{aspirin}) = \frac{8.25}{(9 \times 12.01) + (8 \times 1.01) + (4 \times 16.00)} = \frac{8.25}{180.17} = 0.0458 \text{ mol}</math> <math display="block">n(\text{SA}) = \frac{0.0458}{0.60} = 0.0763 \text{ mol}</math> <math display="block">m(\text{SA}) = 0.0763 \times 138.13 = 10.5 \text{ g}</math> </td> <td> <ul style="list-style-type: none"> <li>determines molar mass aspirin is 180.17 [1 mark]</li> <li>determines moles aspirin [1 mark]</li> <li>determines moles salicylic acid [1 mark]</li> <li>calculates mass salicylic acid [1 mark]</li> </ul> </td> </tr> </tbody> </table>	Sample response	The response	<p>1:1 Aspirin : salicylic acid (SA)</p> $n(\text{aspirin}) = \frac{8.25}{(9 \times 12.01) + (8 \times 1.01) + (4 \times 16.00)} = \frac{8.25}{180.17} = 0.0458 \text{ mol}$ $n(\text{SA}) = \frac{0.0458}{0.60} = 0.0763 \text{ mol}$ $m(\text{SA}) = 0.0763 \times 138.13 = 10.5 \text{ g}$
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<p><b>2021</b> <b>Paper 2</b> <b>Section 1</b> <b>Question 2</b></p> <p><b>Chemical synthesis and design</b></p>	<p>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.</p> <p>a) Draw the structural formulas of the monomers used to form PET. [2 marks]</p> <p>i) Carboxylic acid monomer</p> <p>ii) Alcohol monomer</p>															
	<table border="1"> <thead> <tr> <th>Sample Response</th> <th>The response</th> </tr> </thead> <tbody> <tr> <td> <p>i) carboxylic acid monomer</p> <p>ii) alcohol monomer</p> <math display="block">\text{HO}-\text{CH}_2-\text{CH}_2-\text{OH}</math> </td> <td> <ul style="list-style-type: none"> <li>provides the correct structural formula for                             <ul style="list-style-type: none"> <li>benzene-1,4-dicarboxylic acid (terephthalic acid) [1 mark]</li> <li>ethane-1,2-diol (ethylene glycol) [1 mark]</li> </ul> </li> </ul> </td> </tr> </tbody> </table> <p>b) Determine the type of polymerisation used to form PET. [1 mark]</p> <table border="1"> <thead> <tr> <th>Sample Response</th> <th>The response</th> <th>Notes</th> </tr> </thead> <tbody> <tr> <td>condensation</td> <td> <ul style="list-style-type: none"> <li>determines polymerisation as condensation [1 mark]</li> </ul> </td> <td>For condensation, accept:                             <ul style="list-style-type: none"> <li>elimination</li> <li>esterification.</li> </ul> </td> </tr> </tbody> </table> <p>c) Identify the functional group formed by the reaction of the monomers in PET. [1 mark]</p> <table border="1"> <thead> <tr> <th>Sample Response</th> <th>The response</th> <th>Notes</th> </tr> </thead> <tbody> <tr> <td>Ester</td> <td> <ul style="list-style-type: none"> <li>identifies ester as the functional group [1 mark]</li> </ul> </td> <td>Also accept:                             <ul style="list-style-type: none"> <li>RCOOR<sup>1</sup></li> <li>carboalkoxy.</li> </ul> </td> </tr> </tbody> </table>	Sample Response	The response	<p>i) carboxylic acid monomer</p> <p>ii) alcohol monomer</p> $\text{HO}-\text{CH}_2-\text{CH}_2-\text{OH}$	<ul style="list-style-type: none"> <li>provides the correct structural formula for                             <ul style="list-style-type: none"> <li>benzene-1,4-dicarboxylic acid (terephthalic acid) [1 mark]</li> <li>ethane-1,2-diol (ethylene glycol) [1 mark]</li> </ul> </li> </ul>	Sample Response	The response	Notes	condensation	<ul style="list-style-type: none"> <li>determines polymerisation as condensation [1 mark]</li> </ul>	For condensation, accept: <ul style="list-style-type: none"> <li>elimination</li> <li>esterification.</li> </ul>	Sample Response	The response	Notes	Ester	<ul style="list-style-type: none"> <li>identifies ester as the functional group [1 mark]</li> </ul>
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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
<p>Structural features</p> <p>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.</p> <p>Properties</p> <p>Isotactic — chains can pack closer together, resulting in greater intermolecular forces. Isotactic PP is therefore stronger than syntactic PP.</p>	<ul style="list-style-type: none"> <li>• identifies regular arrangement methyl groups [1 mark]</li> <li>• identifies methyl groups on the opposite side of the chain for syntactic and same side of the chain for isotactic PP [1 mark]</li> <li>• indicates that isotactic chains can pack closer together [1 mark]</li> <li>• indicates increased intermolecular forces for isotactic PP [1 mark]</li> <li>• indicates increased strength for isotactic PP [1 mark]</li> </ul>	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
$\text{C}_2\text{H}_{12}\text{O}_6(\text{aq}) \xrightarrow{\text{yeast}} 2\text{CH}_3\text{CH}_2\text{OH}(\text{aq}) + 2\text{CO}_2(\text{g})$	<ul style="list-style-type: none"> <li>• provides correct reactants and products [1 mark]</li> <li>• correctly balances the equation [1 mark]</li> <li>• indicates that yeast is required as a catalyst [1 mark]</li> </ul>

b) Calculate the atom economy for the production of ethanol by fermentation of glucose. [2 marks]

Sample Response	The response	Notes
<p>Molar mass (ethanol) = 46.08 g</p> <p>Molar mass (glucose) = 180.18 g</p> $\text{atom economy} = \frac{2 \times 46.08}{180.18} \times 100$ $\text{atom economy} = \frac{2 \times 46.08}{180.18} \times 100 = 51.148 \% \approx 51\%$ <p>Atom economy = 51%</p>	<ul style="list-style-type: none"> <li>• shows substitution correctly performed [1 mark]</li> <li>• determines atom economy [1 mark]</li> </ul>	<p>Allow FT error from incorrect molar masses.</p> <p>Do not penalise for incorrect decimal places/significant figures.</p>

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
<p>Hydration atom economy = 100%</p> <p>Fermentation atom economy = 51%</p> <p>Therefore, production of ethene by hydration is greener.</p>	<ul style="list-style-type: none"> <li>• determines atom economy for hydration reaction is 100% [1 mark]</li> <li>• identifies that hydration reaction is greener [1 mark]</li> </ul>

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]

<b>Sample Response</b>	<b>The response</b>
Use of renewable feedstocks	• provides use of renewable feedstocks [1 mark]
Design for energy efficiency	• provides design for energy efficiency [1 mark]