The background of the entire page is a vibrant blue water surface with white foam from waves, creating a dynamic and textured appearance. The text is centered and overlaid on this background.

# **Essential Insight Exam Guide**

**Chemistry**  
Year 12 WACE  
Western Australian Curriculum

2025 Edition

William Zheng

# Essential Insight Exam Guide

## Chemistry

### Year 12 WACE

Link: <https://eibooks.com.au/wace>

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#### Acknowledgements

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# Contents

<b>Unit 3 – Equilibrium, Acids and bases, and redox reactions</b> .....	<b>4</b>
<b>Unit 3 – Chemical equilibrium systems</b> .....	<b>4</b>
Section 1 .....	4
Section 2 .....	12
Section 3 .....	21
Marking Guide – Section 1 .....	29
Marking Guide – Section 2 .....	37
Marking Guide – Section 3 .....	45
<b>Unit 3 – Acids and bases</b> .....	<b>51</b>
Section 1 .....	51
Section 2 .....	57
Section 3 .....	69
Marking Guide – Section 1 .....	79
Marking Guide – Section 2 .....	86
Marking Guide – Section 3 .....	97
<b>Unit 3 – Oxidation and reduction</b> .....	<b>106</b>
Section 1 .....	106
Section 2 .....	114
Section 3 .....	123
Marking Guide – Section 1 .....	129
Marking Guide – Section 2 .....	138
Marking Guide – Section 3 .....	151
<b>Unit 4 – Organic chemistry and chemical synthesis</b> .....	<b>159</b>
<b>Unit 4 – Properties and structure of organic materials</b> .....	<b>159</b>
Section 1 .....	159
Section 2 .....	167
Section 3 .....	184
Marking Guide – Section 1 .....	211
Marking Guide – Section 2 .....	219
Marking Guide – Section 3 .....	237
<b>Unit 4 – Chemical synthesis</b> .....	<b>265</b>
Section 1 .....	265
Section 2 .....	269
Section 3 .....	273
Marking Guide – Section 1 .....	288
Marking Guide – Section 2 .....	292
Marking Guide – Section 3 .....	296
<b>Unit 3 and 4 – Science Inquiry Skills</b> .....	<b>311</b>
Section 1 .....	311
Section 2 .....	313
Section 3 .....	315
Marking Guide – Section 1 .....	317
Marking Guide – Section 2 .....	319
Marking Guide – Section 3 .....	322

## Notes

- Some question material has not been released by SCSA due to copyright restrictions and are not able to be included in this exam guide. This has been flagged in the relevant questions in the exam guide. Teachers may still be able to locate many of these sources and provide these to students by following the links at the end of the original SCSA exams on the SCSA website.

## Unit 3 – Equilibrium, Acids and bases, and redox reactions

### Unit 3 – Chemical equilibrium systems

#### Section 1

<b>2023 Section 1 Question 1</b>  <b>Chemical equilibrium systems</b>	<p>Which of the following is likely to occur due to the increase of carbon dioxide levels in the atmosphere?</p> <p>(a) oceans cool and absorb less carbon dioxide from the atmosphere (b) it will be more difficult for crustations to construct their shells (c) the pH of oceans will increase, becoming more acidic (d) the availability of carbonate ions to marine organisms will increase</p>
<b>2023 Section 1 Question 3</b>  <b>Chemical equilibrium systems</b>	<p>The concentration of chloride ions in the ocean is approximately 35 000 ppm. Which of the following ions is unlikely to be present?</p> <p>(a) Ag<sup>+</sup> (b) Pb<sup>2+</sup> (c) Mg<sup>2+</sup> (d) K<sup>+</sup></p>
<b>2023 Section 1 Question 17</b>  <b>Chemical equilibrium systems</b>	<p>In the conversion between sulfur dioxide and sulfur trioxide in a sealed vessel, the following equilibrium is established:</p> $2 \text{SO}_3(\text{g}) \rightleftharpoons 2 \text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \quad \Delta H = 198 \text{ kJ mol}^{-1}$ <p>For this system, which of the following statements about the equilibrium constant K is correct? K will</p> <p>(a) increase if the temperature of the system is decreased. (b) decrease if the partial pressure of SO<sub>2</sub>(g) is increased. (c) increase if the temperature of the system is increased. (d) increase if the pressure of the system is increased.</p>

<p><b>2023</b> <b>Section 1</b> <b>Question 21</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Consider the following energy profile diagram for a reversible chemical reaction.</p> <div style="text-align: center; margin: 10px 0;"> </div> <p>Which of the following statements about this reaction are correct?</p> <p>(i) The reaction mixture will cool as the reaction proceeds.  (ii) Y will reduce in magnitude if a catalyst is used.  (iii) The activation energy for the reverse reaction is X – Y.  (iv) <math>\Delta H</math> for the reverse reaction is +X.  (v) The forward reaction is likely to be faster than the reverse reaction.</p> <p>(a) i, ii and iv  (b) ii, iv and v  (c) ii, iii and iv  (d) i, iv and v</p>
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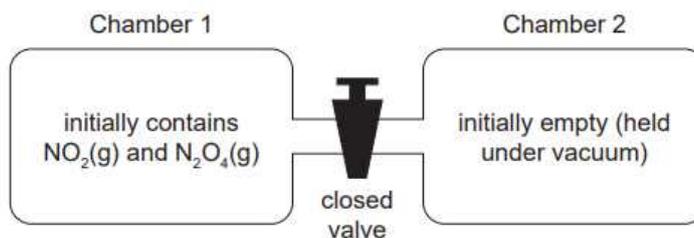
<p><b>2022</b> <b>Section 1</b> <b>Question 3</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Which of the following may occur in a closed chemical system?</p> <p>(a) Energy and matter are exchanged with the surroundings.  (b) Energy, but not matter, is exchanged with the surroundings.  (c) Matter, but not energy, is exchanged with the surroundings.  (d) Neither energy nor matter are exchanged with the surroundings.</p>
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<p><b>2022</b> <b>Section 1</b> <b>Question 10</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Which of the following is the correct equilibrium constant expression for the dissolution of calcium hydroxide, represented by the following equation?</p> $\text{Ca(OH)}_2(\text{s}) \rightleftharpoons \text{Ca}^{2+}(\text{aq}) + 2 \text{OH}^{-}(\text{aq})$ <p>(a) <math>K = \frac{[\text{Ca}^{2+}] [\text{OH}^{-}]^2}{[\text{Ca(OH)}_2]}</math></p> <p>(b) <math>K = \frac{[\text{Ca(OH)}_2]}{[\text{Ca}^{2+}] [\text{OH}^{-}]^2}</math></p> <p>(c) <math>K = [\text{Ca}^{2+}] [\text{OH}^{-}]^2</math></p> <p>(d) <math>K = \frac{1}{[\text{Ca}^{2+}] [\text{OH}^{-}]^2}</math></p>
<p><b>2021</b> <b>Section 1</b> <b>Question 15</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Which of the following processes does not contribute to the building of weaker seashells through ocean acidification?</p> <p>(a) <math>\text{HCO}_3^{-}(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{CO}_3^{2-}(\text{aq}) + \text{H}_3\text{O}^{+}(\text{aq})</math></p> <p>(b) <math>2 \text{H}^{+}(\text{aq}) + \text{CaCO}_3(\text{s}) \rightleftharpoons \text{Ca}^{2+}(\text{aq}) + \text{CO}_2(\text{aq}) + \text{H}_2\text{O}(\ell)</math></p> <p>(c) <math>\text{CO}_2(\text{g}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{H}_2\text{CO}_3(\text{aq})</math></p> <p>(d) <math>\text{H}_2\text{CO}_3(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{HCO}_3^{-}(\text{aq}) + \text{H}_3\text{O}^{+}(\text{aq})</math></p>
<p><b>2021</b> <b>Section 1</b> <b>Question 20</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Consider the following reversible reaction:</p> $2 \text{NO}(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons 2 \text{NOCl}(\text{g}) \quad K_c = 6.5 \times 10^4 \text{ at } 35 \text{ }^\circ\text{C}$ <p>Which of the following statements describes the relative concentrations of reactants and products in this system when equilibrium is established in a closed vessel at 35 °C?</p> <p>(a) The concentrations of reactants and products will be equal.</p> <p>(b) There will be a greater concentration of products than reactants.</p> <p>(c) The reactant concentration will be greater than that of the products.</p> <p>(d) The concentrations of NOCl and NO will be double the concentration of Cl<sub>2</sub>.</p>
<p><b>2021</b> <b>Section 1</b> <b>Question 23</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>The equilibrium position of a system depends on the concentrations of</p> <p>(a) reactants only.</p> <p>(b) products only.</p> <p>(c) reactants and products.</p> <p>(d) neither reactants nor products.</p>

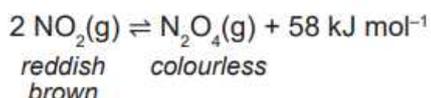
**2021  
Section 1  
Question  
24-25**

**Chemical  
equilibrium  
systems**

Questions 24 and 25 refer to the following information. Equal moles of nitrogen dioxide gas (NO<sub>2</sub>) and dinitrogen tetroxide gas (N<sub>2</sub>O<sub>4</sub>) are sealed inside one half of a two-chamber reactor as shown below. The temperature inside both chambers is 25 °C.



After a while, the following equilibrium is established inside Chamber 1:



24. More N<sub>2</sub>O<sub>4</sub> (g) is added to Chamber 1. What observations would be made about the colour of the gas mixture and its temperature after a new equilibrium is established?

	Gas mixture colour	Temperature
(a)	darker brown	higher
(b)	darker brown	lower
(c)	paler brown	higher
(d)	paler brown	lower

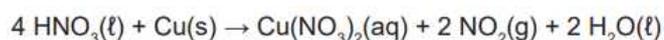
25. The valve between the chambers is opened, allowing the gas mixture in Chamber 1 to fill both chambers. Which statement describes the initial and final observations of the gas mixture's colour as a new equilibrium is established?

	Initial observation when tap is opened	Observation as equilibrium is re-established
(a)	paler brown	became darker
(b)	paler brown	became paler
(c)	darker brown	became darker
(d)	darker brown	became paler

**2020  
Section 1  
Question 7**

**Chemical  
equilibrium  
systems**

The following equation shows the reaction between copper and concentrated nitric acid:

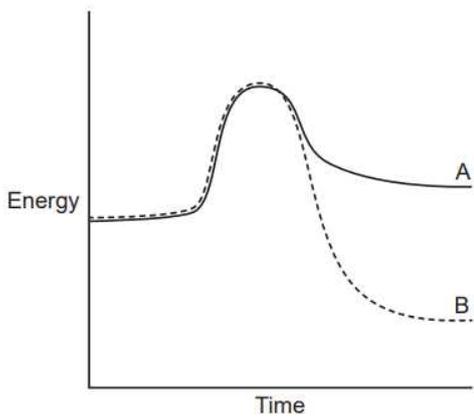


Observable changes associated with this reaction are the dissolving of the copper, the formation of a deep blue solution and the evolution of a pungent brown gas. Which of the following are some of the atomic/molecular scale events needed for these observable changes to occur?

- (i) collisions between HNO<sub>3</sub> molecules and Cu atoms
- (ii) donation and acceptance of protons
- (iii) reduction of copper atoms

- (a) i only
- (b) ii only
- (c) i and iii only
- (d) i, ii and iii

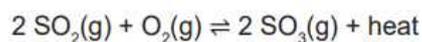
<b>2020</b> <b>Section 1</b> <b>Question 16</b>  <b>Chemical equilibrium systems</b>	Which of the following is <b>not</b> a characteristic of a system in dynamic equilibrium?  (a) The mass of the reactants equals the mass of the products. (b) Reactants are forming products and products are forming reactants. (c) The rates of the forward and reverse reactions are equal. (d) The position of the equilibrium is affected by temperature.
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<b>2020</b> <b>Section 1</b> <b>Question 8</b>  <b>Chemical equilibrium systems</b>	Energy profile diagrams for two different chemical reactions (A and B) are shown below.   <p style="text-align: center;">Time</p> <p>Which of these reactions is the more likely to be reversible and why?</p> <p>(a) Reaction A, because its forward reaction is endothermic.          (b) Reaction B, because its forward reaction is exothermic.          (c) Reaction A, because the activation energy of its reverse reaction is smaller than that for Reaction B.          (d) Neither, because the activation energies of their forward reactions are the same.</p>
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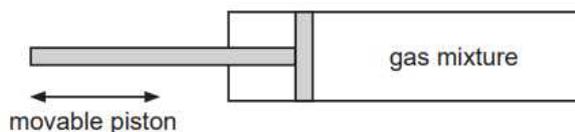
2020  
Section 1  
Question  
24

Chemical  
equilibrium  
systems

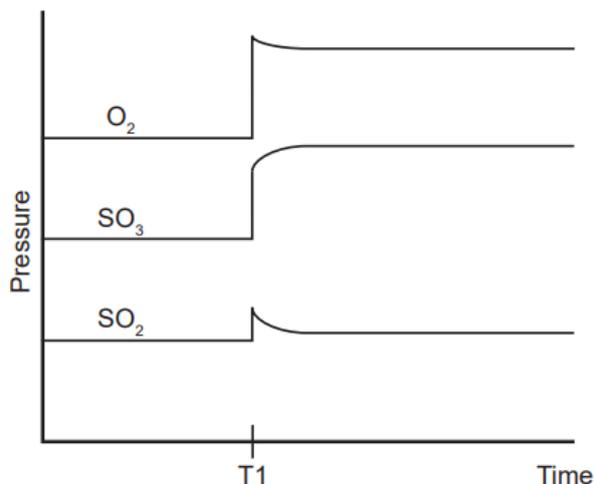
Consider the following equilibrium:



A mixture of these gases was at equilibrium in a sealed container with a movable piston, as shown below.



A change was applied to the system at T1 and the results of this change are shown in the following graph.



What was the change that occurred at T1?

- (a) An inert gas was added to the reaction vessel.
- (b) The reaction vessel was heated.
- (c) A catalyst was added to the reaction vessel.
- (d) The volume of the reaction vessel was decreased.

<b>2019</b> <b>Section 1</b> <b>Question 2</b>  <b>Chemical equilibrium systems</b>	The Haber Process involves the following equilibrium reaction: $\text{N}_2(\text{g}) + 3 \text{H}_2(\text{g}) \rightleftharpoons 2 \text{NH}_3(\text{g})$									
	A number of closed reaction vessels were set up containing the gases shown in the table below. <table border="1" style="margin: 10px auto;"> <thead> <tr> <th>Reaction vessel</th> <th>Gases initially present</th> </tr> </thead> <tbody> <tr> <td>i</td> <td>nitrogen, hydrogen</td> </tr> <tr> <td>ii</td> <td>nitrogen</td> </tr> <tr> <td>iii</td> <td>ammonia</td> </tr> <tr> <td>iv</td> <td>hydrogen, ammonia</td> </tr> </tbody> </table> <p>In which of the above closed reaction vessels would equilibrium be established after a period of time?</p> <p>(a) i only          (b) i and iii only          (c) i, iii and iv only          (d) ii, iii and iv only</p>	Reaction vessel	Gases initially present	i	nitrogen, hydrogen	ii	nitrogen	iii	ammonia	iv
Reaction vessel	Gases initially present									
i	nitrogen, hydrogen									
ii	nitrogen									
iii	ammonia									
iv	hydrogen, ammonia									

<b>2019</b> <b>Section 1</b> <b>Question 12</b>  <b>Chemical equilibrium systems</b>	The United Nations Kyoto Protocol and the Intergovernmental Panel on Climate Change aim to secure a global commitment to reducing greenhouse gas emissions over the next few decades.
	Which of the following equations shows the production of a greenhouse gas? <p>(i) <math>\text{O}_2 + \text{O} \rightarrow \text{O}_3</math></p> <p>(ii) <math>\text{C} + \text{O}_2 \rightarrow \text{CO}_2</math></p> <p>(iii) <math>\text{CH}_4 + 2 \text{O}_2 \rightarrow \text{CO}_2 + 2 \text{H}_2\text{O}</math></p> <p>(iv) <math>\text{CO}_2 + 4 \text{H}_2 \rightarrow \text{CH}_4 + 2 \text{H}_2\text{O}</math></p> <p>(v) <math>\text{NH}_4\text{NO}_3 \rightarrow 2 \text{H}_2\text{O} + \text{N}_2\text{O}</math></p> <p>(a) i and ii only          (b) ii and iii only          (c) iii, iv and v only          (d) i, ii, iii, iv and v</p>

**2019  
Section 1  
Question  
19-21**

**Chemical  
equilibrium  
systems**

The following information relates to Questions 19, 20 and 21.

A group of Year 12 Chemistry students wanted to know whether increasing ocean acidity increases the rate at which sea shells,  $\text{CaCO}_3$ , dissolve. They went to a beach to collect seawater and sea shells. In their school laboratory they crushed the sea shells and added 2.00 g of the resulting powder to five clean 250 mL beakers, each of which had been placed on top of its own electronic balance.

They split the seawater into five portions and bubbled carbon dioxide gas into four of the portions for different amounts of time. This gave the students 'natural' seawater plus four seawater samples of different pH. The various seawaters (150 mL portions) were then added to the beakers, with the weight of each beaker and its contents being recorded at timed intervals.

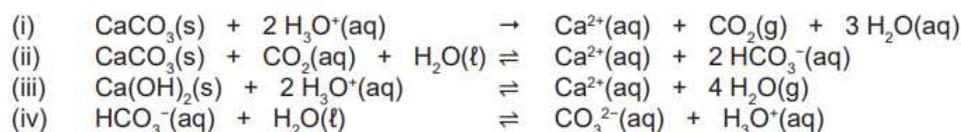
19. Which one of the following proposes a suitable hypothesis for the investigation?

- (a) As the seawater becomes more acidic, the sea shell powder will dissolve faster.
- (b) The sea shell powder will dissolve fastest in the most acidic seawater.
- (c) Adding carbon dioxide to seawater changes the pH of the seawater.
- (d) More of the sea shell powder will dissolve as time progresses.

20. Which one of the following pairs of statements on the validity and reliability of the investigation is correct?

	<b>Validity</b>	<b>Reliability</b>
(a)	It is valid because the investigation allows them to determine if seawater pH affects the rate of sea shell dissolution.	It is reliable because the trials were performed in a laboratory.
(b)	It is not valid because the investigation was simulated in a laboratory and not performed in a real ocean.	It is not reliable because only one trial was performed at each different pH value.
(c)	It is not valid because the investigation was simulated in a laboratory and not performed in a real ocean.	It is reliable because trials were performed at five different pH values.
(d)	It is valid because the investigation allows them to determine if seawater pH affects the rate of sea shell dissolution.	Its reliability could be improved by conducting multiple trials at each different pH value.

21. Which of the following reactions is/are likely to be occurring within the beakers during the investigation?



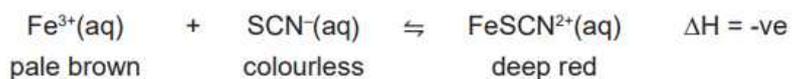
- (a) i and ii only
- (b) i, ii and iv only
- (c) iii only
- (d) i, ii, iii and iv

## Section 2

**2022  
Section 2  
Question  
26**

**Chemical  
equilibrium  
systems**

Consider the following system at equilibrium:



For each of the applied changes after equilibrium is re-established, predict the:

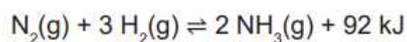
- shift in equilibrium position (left, right or no change)
- rate of the forward reaction compared to the original rate (increase, decrease or no change)
- colour of the reaction mixture.

Change	Shift in equilibrium position (left, right or no change)	Rate of the forward reaction compared to original rate (increase, decrease or no change)	Colour of reaction mixture
The reaction mixture is heated			
A few crystals of $\text{FeCl}_3$ are added			
Water is added to the reaction mixture			
A few drops of concentrated $\text{Na}_3\text{PO}_4$ are added			

2021  
Section 2  
Question  
32

Chemical  
equilibrium  
systems

Ammonia is manufactured industrially by the Haber process, the reaction equation being:

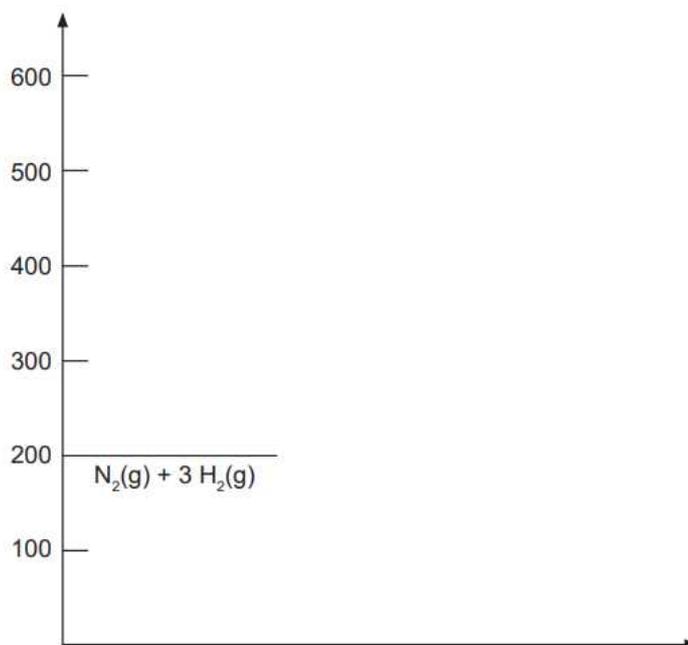


At 400 °C the equilibrium constant of this reaction is equal to  $1.60 \times 10^{-4}$  and the activation energy of the forward reaction is approximately  $4.00 \times 10^2 \text{ kJ mol}^{-1}$ .

(a) Write the equilibrium constant expression for this reaction. (2 marks)

(b) Use the following axes to sketch an energy profile diagram for the Haber process. Label the:

- axes
- products
- activation energy
- change in enthalpy. (4 marks)





**2020  
Section 2  
Question  
27**

**Chemical  
equilibrium  
systems**

Write balanced equations for any reactions occurring between the following substances and describe the observation(s).

If there is no reaction, write 'no reaction' for the equation and if there is no change observed, write 'no visible reaction' for the observations. Where applicable, use the colours stated in the Chemistry Data Booklet.

Iron filings and dilute hydrochloric acid

Equation

Observation(s)

Chromium(III) nitrate solution and magnesium ribbon

Equation

Observation(s)

Potassium chloride solution and bromine water

Equation

Observation(s)



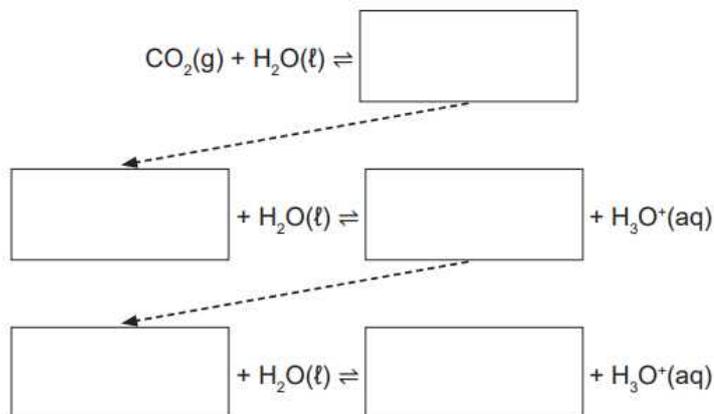


2020  
Section 2  
Question  
31

Chemical  
equilibrium  
systems

The amount of carbon dioxide in the Earth's atmosphere is increasing, leading to more carbon dioxide dissolving in the oceans and hence ocean acidification.

(a) Complete the following sequence of equations to show what happens to carbon dioxide when it dissolves in water. (3 marks)



(b) Other than death, state **two** consequences of the above sequence of equations on marine organisms with shells. (2 marks)

One:

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Two:

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(c) Use Le Châtelier's Principle and the sequence of equations in part (a) to predict what might happen, in relation to ocean acidification, if the United Nations Kyoto Protocol is discarded. Explain your reasoning. (4 marks)

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(c) Sketch and label a line on your graph in part (a) that shows the effect of conducting the same experiment at a higher temperature. (2 marks)

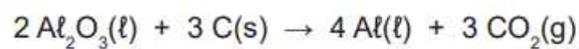






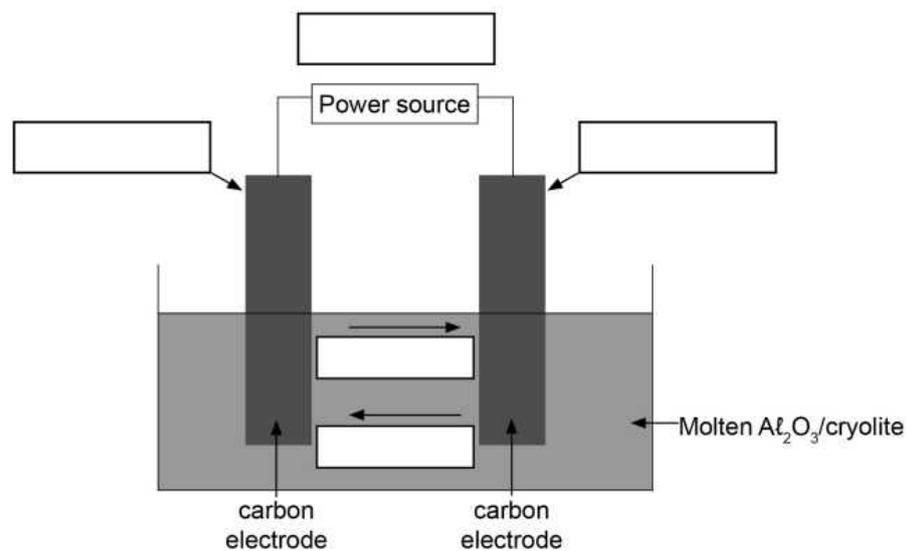


Aluminium can be refined through electrolysis. Molten aluminium oxide, which is mixed with a substance called cryolite to reduce the melting point, is electrolysed to produce aluminium and carbon dioxide, which is represented by the following equation:



(d) On the diagram below, correctly place the following in the boxes:

- anode
- cathode
- direction of cation flow and direction of anion flow
- direction of electron flow. (3 marks)



**2021  
Section 3  
Question  
37**

**Chemical  
equilibrium  
systems**

A chemist was asked to develop a method of recycling used cathodes from a new type of lithium battery. The cathodes were a mixture of lithium cobalt oxide ( $\text{LiCoO}_2$ ) and manganese (Mn). Each cathode contained 57.29% cobalt by mass.

Preliminary trials showed that the used cathodes would dissolve completely if enough sulfuric acid was added and if enough time was allowed. The chemist decided to conduct detailed trials to see how the sulfuric acid concentration affected the rate at which the used cathodes dissolved.

Each trial was performed in a sealed, oxygen-free reactor using 5.00 L of sulfuric acid and 0.531 kg of used cathodes. Trials were also performed in the presence of  $\text{Fe}^{2+}$  ions to see if these ions had a catalytic effect. All trials lasted for 15 minutes with the reactor solutions then analysed for their concentrations of  $\text{Li}^+$ ,  $\text{Co}^{2+}$ ,  $\text{Mn}^{2+}$  and, where relevant,  $\text{Fe}^{2+}$ .

The results of the  $\text{Co}^{2+}$  and  $\text{Fe}^{2+}$  analyses are summarised in the following table.

Trial	Initial solution composition		Solution composition after 15 minutes	
	$\text{H}_2\text{SO}_4$ ( $\text{mol L}^{-1}$ )	$\text{Fe}^{2+}$ ( $\times 10^{-1} \text{ mol L}^{-1}$ )	$\text{Co}^{2+}$ ( $\times 10^{-1} \text{ mol L}^{-1}$ )	$\text{Fe}^{2+}$ ( $\times 10^{-1} \text{ mol L}^{-1}$ )
1	1.37	0.00	4.24	0.00
2	3.01	0.00	4.92	0.00
3	5.91	3.31	7.20	3.29
4	7.40	0.00	5.94	0.00
5	8.80	0.00	6.96	0.00
6	8.80	6.62	9.95	6.61

(a) (i) Which trial number(s) will allow the chemist to investigate the relationship between the sulfuric acid concentration and the amount of cobalt extracted? (1 mark)

(ii) Use collision theory to explain the effect of acid concentration on the rate at which the used cathodes dissolved. (3 marks)



(d) Calculate the percentage, by mass, of lithium in a used cathode. Give your answer to the appropriate number of significant figures. (4 marks)

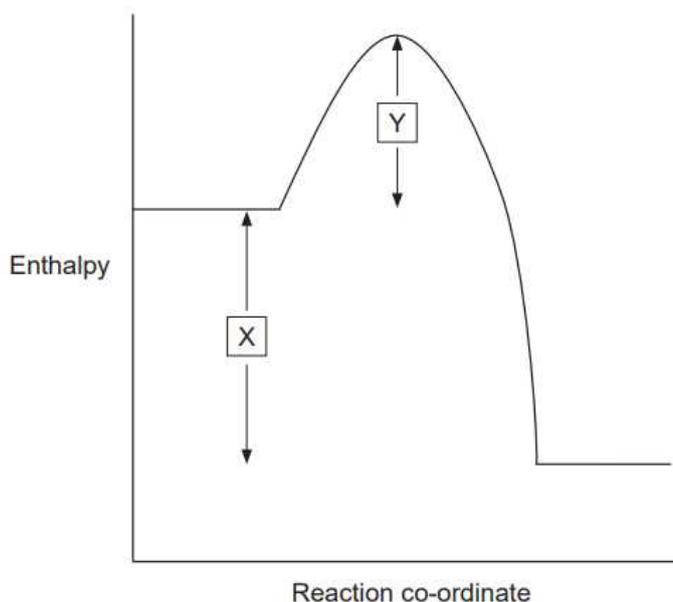
## Marking Guide – Section 1

<b>2023</b> <b>Section 1</b> <b>Question 1</b>  <b>Chemical equilibrium systems</b>	Which of the following is likely to occur due to the increase of carbon dioxide levels in the atmosphere?  (a) oceans cool and absorb less carbon dioxide from the atmosphere <b>(b) it will be more difficult for crustations to construct their shells – Answer</b> (c) the pH of oceans will increase, becoming more acidic (d) the availability of carbonate ions to marine organisms will increase
<b>2023</b> <b>Section 1</b> <b>Question 3</b>  <b>Chemical equilibrium systems</b>	The concentration of chloride ions in the ocean is approximately 35 000 ppm. Which of the following ions is unlikely to be present?  <b>(a) Ag<sup>+</sup> – Answer</b> (b) Pb <sup>2+</sup> (c) Mg <sup>2+</sup> (d) K <sup>+</sup>
<b>2023</b> <b>Section 1</b> <b>Question 17</b>  <b>Chemical equilibrium systems</b>	In the conversion between sulfur dioxide and sulfur trioxide in a sealed vessel, the following equilibrium is established:  $2 \text{SO}_3(\text{g}) \rightleftharpoons 2 \text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \quad \Delta H = 198 \text{ kJ mol}^{-1}$  For this system, which of the following statements about the equilibrium constant K is correct? K will  (a) increase if the temperature of the system is decreased. (b) decrease if the partial pressure of SO <sub>2</sub> (g) is increased. <b>(c) increase if the temperature of the system is increased. – Answer</b> (d) increase if the pressure of the system is increased.

2023  
Section 1  
Question  
21

Chemical  
equilibrium  
systems

Consider the following energy profile diagram for a reversible chemical reaction.



Which of the following statements about this reaction are correct?

- (i) The reaction mixture will cool as the reaction proceeds.
- (ii) Y will reduce in magnitude if a catalyst is used.
- (iii) The activation energy for the reverse reaction is  $X - Y$ .
- (iv)  $\Delta H$  for the reverse reaction is  $+X$ .
- (v) The forward reaction is likely to be faster than the reverse reaction.

- (a) i, ii and iv
- (b) ii, iv and v – Answer**
- (c) ii, iii and iv
- (d) i, iv and v

2022  
Section 1  
Question 3

Chemical  
equilibrium  
systems

Which of the following may occur in a closed chemical system?

- (a) Energy and matter are exchanged with the surroundings.
- (b) Energy, but not matter, is exchanged with the surroundings. – Answer**
- (c) Matter, but not energy, is exchanged with the surroundings.
- (d) Neither energy nor matter are exchanged with the surroundings.

<p><b>2022</b> <b>Section 1</b> <b>Question</b> <b>10</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Which of the following is the correct equilibrium constant expression for the dissolution of calcium hydroxide, represented by the following equation?</p> $\text{Ca(OH)}_2(\text{s}) \rightleftharpoons \text{Ca}^{2+}(\text{aq}) + 2 \text{OH}^{-}(\text{aq})$ <p>(a) <math>K = \frac{[\text{Ca}^{2+}] [\text{OH}^{-}]^2}{[\text{Ca(OH)}_2]}</math></p> <p>(b) <math>K = \frac{[\text{Ca(OH)}_2]}{[\text{Ca}^{2+}] [\text{OH}^{-}]^2}</math></p> <p>(c) <math>K = [\text{Ca}^{2+}] [\text{OH}^{-}]^2</math></p> <p>(d) <math>K = \frac{1}{[\text{Ca}^{2+}] [\text{OH}^{-}]^2}</math></p> <p><b>Answer is C.</b></p>
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<p><b>2021</b> <b>Section 1</b> <b>Question</b> <b>15</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Which of the following processes does not contribute to the building of weaker seashells through ocean acidification?</p> <p>(a) <math>\text{HCO}_3^{-}(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{CO}_3^{2-}(\text{aq}) + \text{H}_3\text{O}^{+}(\text{aq})</math></p> <p>(b) <math>2 \text{H}^{+}(\text{aq}) + \text{CaCO}_3(\text{s}) \rightleftharpoons \text{Ca}^{2+}(\text{aq}) + \text{CO}_2(\text{aq}) + \text{H}_2\text{O}(\ell)</math></p> <p>(c) <math>\text{CO}_2(\text{g}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{H}_2\text{CO}_3(\text{aq})</math></p> <p>(d) <math>\text{H}_2\text{CO}_3(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{HCO}_3^{-}(\text{aq}) + \text{H}_3\text{O}^{+}(\text{aq})</math></p> <p><b>Answer is b.</b></p>
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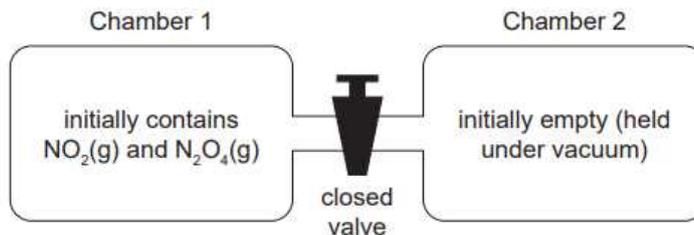
<p><b>2021</b> <b>Section 1</b> <b>Question</b> <b>20</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Consider the following reversible reaction:</p> $2 \text{NO}(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons 2 \text{NOCl}(\text{g}) \quad K_c = 6.5 \times 10^4 \text{ at } 35 \text{ }^\circ\text{C}$ <p>Which of the following statements describes the relative concentrations of reactants and products in this system when equilibrium is established in a closed vessel at 35 °C?</p> <p>(a) The concentrations of reactants and products will be equal.</p> <p><b>(b) There will be a greater concentration of products than reactants. – Answer</b></p> <p>(c) The reactant concentration will be greater than that of the products.</p> <p>(d) The concentrations of NOCl and NO will be double the concentration of Cl<sub>2</sub>.</p>
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<p><b>2021</b> <b>Section 1</b> <b>Question</b> <b>23</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>The equilibrium position of a system depends on the concentrations of</p> <p>(a) reactants only.</p> <p>(b) products only.</p> <p><b>(c) reactants and products. – Answer</b></p> <p>(d) neither reactants nor products.</p>
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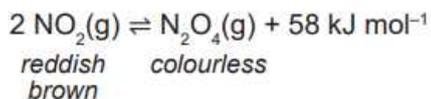
2021  
Section 1  
Question  
24-25

Chemical  
equilibrium  
systems

Questions 24 and 25 refer to the following information. Equal moles of nitrogen dioxide gas ( $\text{NO}_2$ ) and dinitrogen tetroxide gas ( $\text{N}_2\text{O}_4$ ) are sealed inside one half of a two-chamber reactor as shown below. The temperature inside both chambers is  $25^\circ\text{C}$ .



After a while, the following equilibrium is established inside Chamber 1:



24. More  $\text{N}_2\text{O}_4$  (g) is added to Chamber 1. What observations would be made about the colour of the gas mixture and its temperature after a new equilibrium is established?

	Gas mixture colour	Temperature
(a)	darker brown	higher
(b)	darker brown	lower
(c)	paler brown	higher
(d)	paler brown	lower

**Answer is b.**

25. The valve between the chambers is opened, allowing the gas mixture in Chamber 1 to fill both chambers. Which statement describes the initial and final observations of the gas mixture's colour as a new equilibrium is established?

	Initial observation when tap is opened	Observation as equilibrium is re-established
(a)	paler brown	became darker
(b)	paler brown	became paler
(c)	darker brown	became darker
(d)	darker brown	became paler

**Answer is a.**

<p><b>2020</b> <b>Section 1</b> <b>Question 7</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>The following equation shows the reaction between copper and concentrated nitric acid:</p> $4 \text{HNO}_3(\ell) + \text{Cu}(\text{s}) \rightarrow \text{Cu}(\text{NO}_3)_2(\text{aq}) + 2 \text{NO}_2(\text{g}) + 2 \text{H}_2\text{O}(\ell)$ <p>Observable changes associated with this reaction are the dissolving of the copper, the formation of a deep blue solution and the evolution of a pungent brown gas. Which of the following are some of the atomic/molecular scale events needed for these observable changes to occur?</p> <p>(i) collisions between HNO<sub>3</sub> molecules and Cu atoms (ii) donation and acceptance of protons (iii) reduction of copper atoms</p> <p><b>(a) i only – Answer</b> (b) ii only (c) i and iii only (d) i, ii and iii</p>
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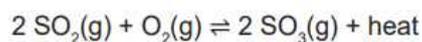
<p><b>2020</b> <b>Section 1</b> <b>Question 16</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Which of the following is <b>not</b> a characteristic of a system in dynamic equilibrium?</p> <p><b>(a) The mass of the reactants equals the mass of the products. – Answer</b> (b) Reactants are forming products and products are forming reactants. (c) The rates of the forward and reverse reactions are equal. (d) The position of the equilibrium is affected by temperature.</p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 8</b></p> <p><b>Chemical equilibrium systems</b></p>	<p>Energy profile diagrams for two different chemical reactions (A and B) are shown below.</p> <p>Which of these reactions is the more likely to be reversible and why?</p> <p>(a) Reaction A, because its forward reaction is endothermic. (b) Reaction B, because its forward reaction is exothermic. <b>(c) Reaction A, because the activation energy of its reverse reaction is smaller than that for Reaction B. – Answer</b> (d) Neither, because the activation energies of their forward reactions are the same.</p>
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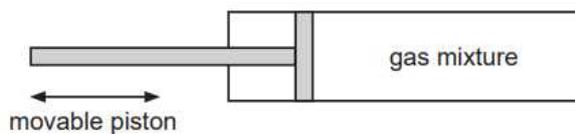
2020  
Section 1  
Question  
24

Chemical  
equilibrium  
systems

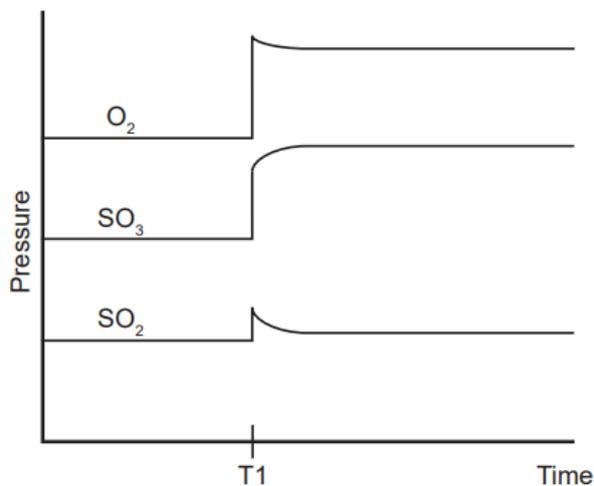
Consider the following equilibrium:



A mixture of these gases was at equilibrium in a sealed container with a movable piston, as shown below.



A change was applied to the system at T1 and the results of this change are shown in the following graph.



What was the change that occurred at T1?

- (a) An inert gas was added to the reaction vessel.
- (b) The reaction vessel was heated.
- (c) A catalyst was added to the reaction vessel.
- (d) The volume of the reaction vessel was decreased. – Answer**

<b>2019</b> <b>Section 1</b> <b>Question 2</b>  <b>Chemical equilibrium systems</b>	The Haber Process involves the following equilibrium reaction: $\text{N}_2(\text{g}) + 3 \text{H}_2(\text{g}) \rightleftharpoons 2 \text{NH}_3(\text{g})$									
	A number of closed reaction vessels were set up containing the gases shown in the table below. <table border="1" style="margin: 10px auto;"> <thead> <tr> <th>Reaction vessel</th> <th>Gases initially present</th> </tr> </thead> <tbody> <tr> <td>i</td> <td>nitrogen, hydrogen</td> </tr> <tr> <td>ii</td> <td>nitrogen</td> </tr> <tr> <td>iii</td> <td>ammonia</td> </tr> <tr> <td>iv</td> <td>hydrogen, ammonia</td> </tr> </tbody> </table> <p>In which of the above closed reaction vessels would equilibrium be established after a period of time?</p> <p>(a) i only          (b) i and iii only  <b>(c) i, iii and iv only – Answer</b>          (d) ii, iii and iv only</p>	Reaction vessel	Gases initially present	i	nitrogen, hydrogen	ii	nitrogen	iii	ammonia	iv
Reaction vessel	Gases initially present									
i	nitrogen, hydrogen									
ii	nitrogen									
iii	ammonia									
iv	hydrogen, ammonia									

<b>2019</b> <b>Section 1</b> <b>Question 12</b>  <b>Chemical equilibrium systems</b>	The United Nations Kyoto Protocol and the Intergovernmental Panel on Climate Change aim to secure a global commitment to reducing greenhouse gas emissions over the next few decades.
	Which of the following equations shows the production of a greenhouse gas? <p>(i) <math>\text{O}_2 + \text{O} \rightarrow \text{O}_3</math></p> <p>(ii) <math>\text{C} + \text{O}_2 \rightarrow \text{CO}_2</math></p> <p>(iii) <math>\text{CH}_4 + 2 \text{O}_2 \rightarrow \text{CO}_2 + 2 \text{H}_2\text{O}</math></p> <p>(iv) <math>\text{CO}_2 + 4 \text{H}_2 \rightarrow \text{CH}_4 + 2 \text{H}_2\text{O}</math></p> <p>(v) <math>\text{NH}_4\text{NO}_3 \rightarrow 2 \text{H}_2\text{O} + \text{N}_2\text{O}</math></p> <p>(a) i and ii only          (b) ii and iii only          (c) iii, iv and v only  <b>(d) i, ii, iii, iv and v – Answer</b></p>

**2019  
Section 1  
Question  
19-21**

**Chemical  
equilibrium  
systems**

The following information relates to Questions 19, 20 and 21.

A group of Year 12 Chemistry students wanted to know whether increasing ocean acidity increases the rate at which sea shells,  $\text{CaCO}_3$ , dissolve. They went to a beach to collect seawater and sea shells. In their school laboratory they crushed the sea shells and added 2.00 g of the resulting powder to five clean 250 mL beakers, each of which had been placed on top of its own electronic balance.

They split the seawater into five portions and bubbled carbon dioxide gas into four of the portions for different amounts of time. This gave the students 'natural' seawater plus four seawater samples of different pH. The various seawaters (150 mL portions) were then added to the beakers, with the weight of each beaker and its contents being recorded at timed intervals.

19. Which one of the following proposes a suitable hypothesis for the investigation?

- (a) **As the seawater becomes more acidic, the sea shell powder will dissolve faster. – Answer**  
 (b) The sea shell powder will dissolve fastest in the most acidic seawater.  
 (c) Adding carbon dioxide to seawater changes the pH of the seawater.  
 (d) More of the sea shell powder will dissolve as time progresses.

20. Which one of the following pairs of statements on the validity and reliability of the investigation is correct?

	Validity	Reliability
(a)	It is valid because the investigation allows them to determine if seawater pH affects the rate of sea shell dissolution.	It is reliable because the trials were performed in a laboratory.
(b)	It is not valid because the investigation was simulated in a laboratory and not performed in a real ocean.	It is not reliable because only one trial was performed at each different pH value.
(c)	It is not valid because the investigation was simulated in a laboratory and not performed in a real ocean.	It is reliable because trials were performed at five different pH values.
(d)	It is valid because the investigation allows them to determine if seawater pH affects the rate of sea shell dissolution.	Its reliability could be improved by conducting multiple trials at each different pH value.

**Answer is d.**

21. Which of the following reactions is/are likely to be occurring within the beakers during the investigation?

- (i)  $\text{CaCO}_3(\text{s}) + 2 \text{H}_3\text{O}^+(\text{aq}) \rightarrow \text{Ca}^{2+}(\text{aq}) + \text{CO}_2(\text{g}) + 3 \text{H}_2\text{O}(\text{aq})$   
 (ii)  $\text{CaCO}_3(\text{s}) + \text{CO}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Ca}^{2+}(\text{aq}) + 2 \text{HCO}_3^-(\text{aq})$   
 (iii)  $\text{Ca}(\text{OH})_2(\text{s}) + 2 \text{H}_3\text{O}^+(\text{aq}) \rightleftharpoons \text{Ca}^{2+}(\text{aq}) + 4 \text{H}_2\text{O}(\text{g})$   
 (iv)  $\text{HCO}_3^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{CO}_3^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$

- (a) i and ii only  
**(b) i, ii and iv only – Answer**  
 (c) iii only  
 (d) i, ii, iii and iv

Marking Guide – Section 2

**2022  
Section 2  
Question  
26**

**Chemical equilibrium systems**

Consider the following system at equilibrium:

$$\text{Fe}^{3+}(\text{aq}) + \text{SCN}^{-}(\text{aq}) \rightleftharpoons \text{FeSCN}^{2+}(\text{aq}) \quad \Delta H = -ve$$

pale brown                      colourless                      deep red

For each of the applied changes after equilibrium is re-established, predict the:

- shift in equilibrium position (left, right or no change)
- rate of the forward reaction compared to the original rate (increase, decrease or no change)
- colour of the reaction mixture.

Description		Marks
Correctly predicts the shift in equilibrium position.		1–4
Correctly predicts the effect on rate of the forward reaction.		1–4
Correctly predicts the colour of the reaction mixture.		1–4
<b>Total</b>		<b>12</b>

Accept arrows for equilibrium position shift but not for rate of forward reaction.

Change	Shift in equilibrium position (left, right or no change)	Rate of the forward reaction compared to original rate (increase, decrease or no change)	Colour of reaction mixture
The reaction mixture is heated	Left	Increase	(More) brown/orange/pale brown
A few crystals of FeCl <sub>3</sub> are added	Right	Increase	(More) red/deeper red
Water is added to the reaction mixture	Left	Decrease	(Very) pale brown
A few drops of concentrated Na <sub>3</sub> PO <sub>4</sub> are added	Left	Decrease	(Very) pale brown

Note: The colour choice must represent the correct equilibrium shift direction.

**2021  
Section 2  
Question  
32**

**Chemical equilibrium systems**

Ammonia is manufactured industrially by the Haber process, the reaction equation being:

$$\text{N}_2(\text{g}) + 3 \text{H}_2(\text{g}) \rightleftharpoons 2 \text{NH}_3(\text{g}) + 92 \text{ kJ}$$

At 400 °C the equilibrium constant of this reaction is equal to  $1.60 \times 10^{-4}$  and the activation energy of the forward reaction is approximately  $4.00 \times 10^2 \text{ kJ mol}^{-1}$ .

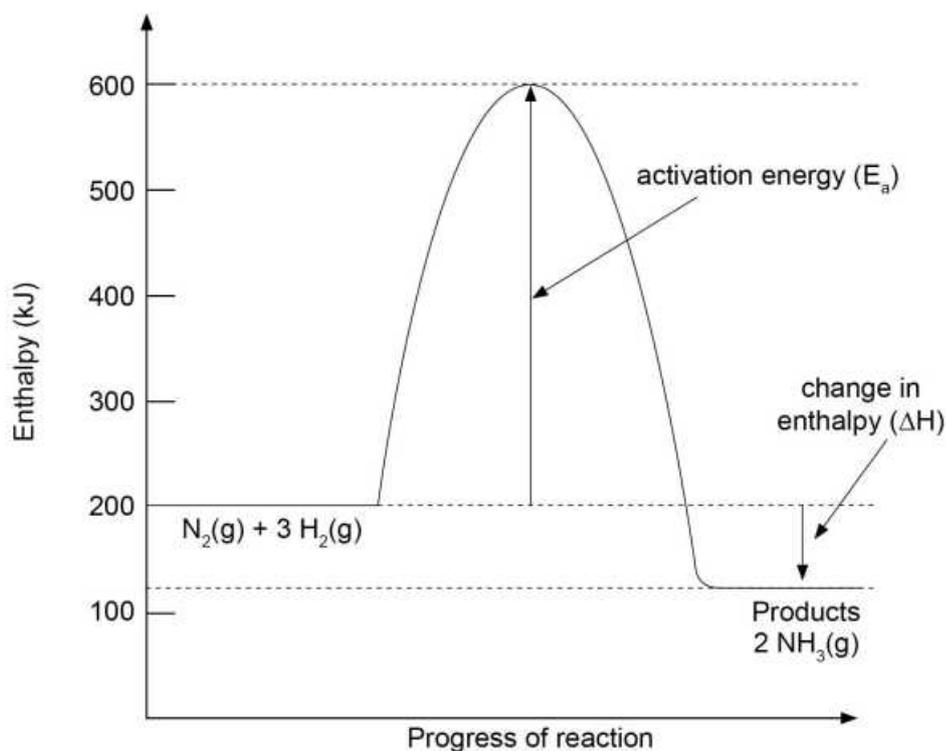
(a) Write the equilibrium constant expression for this reaction. (2 marks)

Description	Marks
Products over reactants with appropriate brackets	1
Inclusion of correct indices	1
<b>Total</b>	<b>2</b>

$$K = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3} \text{ or } K = \frac{p(\text{NH}_3)^2}{p(\text{N}_2)p(\text{H}_2)^3}$$

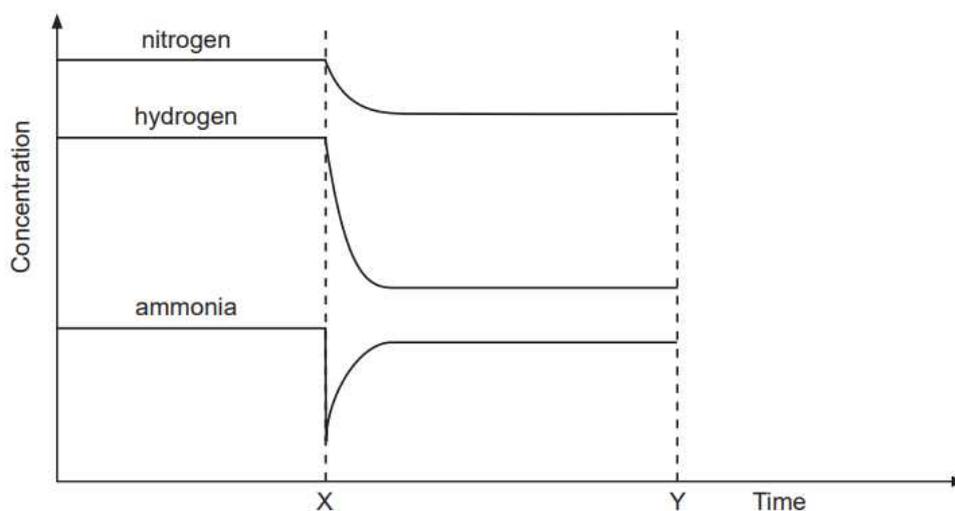
(b) Use the following axes to sketch an energy profile diagram for the Haber process. Label the:

- axes
- products
- activation energy
- change in enthalpy. (4 marks)



Description	Marks
Labelling x-axis and y-axes, including units for y-axis	1
Peak goes up to 600 kJ and the activation energy ( $E_a$ ) is labelled	1
The change in enthalpy is labelled and is equal to approximately -92 kJ	1
Products are labelled	1
<b>Total</b>	<b>4</b>

Some hydrogen, nitrogen and ammonia were sealed in a reaction vessel and their concentrations were monitored for a period of time, as shown in the following graph:



(c) A change was made to the reaction system at time X. Identify this change and use collision theory to explain the shapes of the curves in the region X–Y. (5 marks)

Description	Marks
Ammonia was (instantaneously) removed from the system (at equilibrium/with the rate of the forward reaction equal to the rate of the reverse reaction).	1
(The reduced concentration of ammonia molecules) results in a lower frequency of collisions between ammonia molecules and as a result lowering the rate of the reverse reaction.	1
The rate of the forward reaction is now higher than the reverse reaction.	1
Which results in an increase in concentration of ammonia and a decrease in the concentrations of hydrogen and nitrogen.	1
This continues until the rates of forward and reverse reactions are equal; (establishing a new equilibrium) and the concentrations are then constant.	1
<b>Total</b>	<b>5</b>

(d) The temperature of the reaction system was increased at time Y. Show on the graph how this affected the concentrations of hydrogen, nitrogen and ammonia as the system returned to equilibrium. (3 marks)

Description	Marks
Curved lines showing direction of change for all three species.	1
Stoichiometric ratios correct.	1
All three reaching equilibrium at the same time.	1
<b>Total</b>	<b>3</b>

**2020  
Section 2  
Question  
27**

**Chemical  
equilibrium  
systems**

Write balanced equations for any reactions occurring between the following substances and describe the observation(s).

If there is no reaction, write 'no reaction' for the equation and if there is no change observed, write 'no visible reaction' for the observations. Where applicable, use the colours stated in the Chemistry Data Booklet.

Iron filings and dilute hydrochloric acid

Description	Marks
<b>Equation</b> $\text{Fe(s)} + 2 \text{H}^+(\text{aq}) \rightarrow \text{Fe}^{2+}(\text{aq}) + \text{H}_2(\text{g})$ or $\text{Fe(s)} + 2 \text{HCl}(\text{aq}) \rightarrow \text{FeCl}_2(\text{aq}) + \text{H}_2(\text{g})$	
correct species	1
correct balancing	1
<b>Observations</b> Any two of the following: <ul style="list-style-type: none"> <li>• colourless, (odourless) bubbles /effervescence/gas</li> <li>• silver/grey solid dissolves</li> <li>• (pale) green solution formed</li> </ul>	1
<b>Total</b>	<b>3</b>
Note: <ul style="list-style-type: none"> <li>• State symbols are not required for full marks.</li> <li>• The candidate must provide a minimum of two correct observations for the mark to be allocated.</li> <li>• Do not accept 'clear solution' without reference to colour.</li> <li>• Each observation requires a colour (or colourless) specified.</li> </ul>	

Chromium(III) nitrate solution and magnesium ribbon

Description	Marks
<b>Equation</b> $2 \text{Cr}^{3+}(\text{aq}) + 3 \text{Mg}(\text{s}) \rightarrow 2 \text{Cr}(\text{s}) + 3 \text{Mg}^{2+}(\text{aq})$ <b>or</b> $2 \text{Cr}(\text{NO}_3)_3(\text{aq}) + 3 \text{Mg}(\text{s}) \rightarrow 2 \text{Cr}(\text{s}) + 3 \text{Mg}(\text{NO}_3)_2(\text{aq})$	
correct species	1
correct balancing	1
<b>Observations</b> Any two of the following: <ul style="list-style-type: none"> <li>silver/grey solid dissolves</li> <li>blackish/grey/silver solid forms</li> <li>solution becomes less green/colourless</li> </ul>	1
<b>Total</b>	<b>3</b>
Note: <ul style="list-style-type: none"> <li>State symbols are not required for full marks.</li> <li>The candidate must provide a minimum of two correct observations for the mark to be allocated.</li> <li>Do not accept 'clear solution' without reference to colour.</li> <li>Each observation requires a colour (or colourless) specified.</li> </ul>	

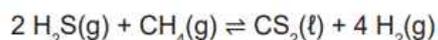
Potassium chloride solution and bromine water

Description	Marks
<b>Equation</b> <ul style="list-style-type: none"> <li>a statement indicating 'no reaction'</li> </ul>	1
<b>Observations</b> <ul style="list-style-type: none"> <li>a statement indicating 'no visible reaction'</li> </ul>	1
<b>Total</b>	<b>2</b>
Note: <ul style="list-style-type: none"> <li>Accept colourless solution mixed with orange/brown/red solution and no further change observed (or similar).</li> <li>Do not accept NVR or NR.</li> </ul>	

**2020  
Section 2  
Question  
29**

**Chemical  
equilibrium  
systems**

Some hydrogen sulfide and methane were sealed inside a reaction vessel and the following equilibrium was established:



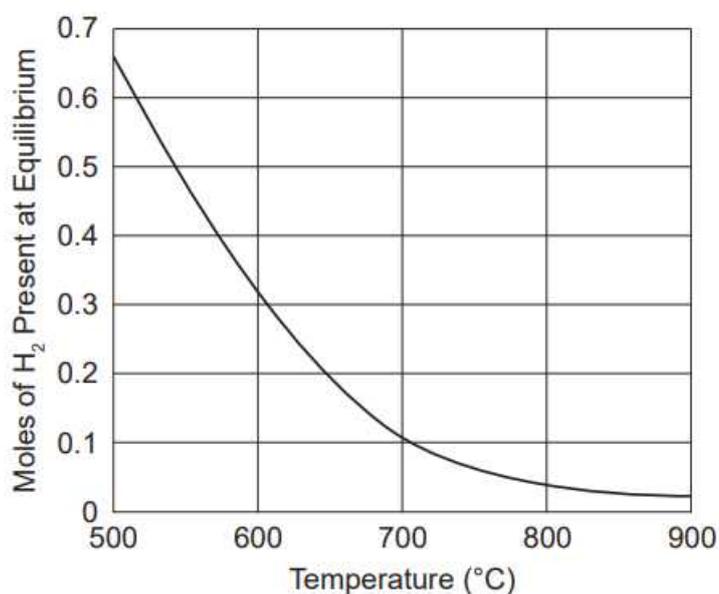
(a) Write the equilibrium constant expression (K) for this reaction system. (2 marks)

Description	Marks
$K = \frac{[\text{H}_2]^4}{[\text{H}_2\text{S}]^2 [\text{CH}_4]}$ (one minor error is 1 mark only)	1-2
<b>Total</b>	<b>2</b>
Note: <ul style="list-style-type: none"> <li>Minor errors include one superscript missing or K= missing.</li> <li>Accept partial pressures.</li> </ul>	

(b) Some methane was removed from the reaction vessel. What effect did this have on the position of the equilibrium? Use collision theory to justify your answer. (5 marks)

Description	Marks
Reduced concentration/pressure of $\text{CH}_4$ means a decrease in the frequency of collisions between $\text{CH}_4$ and $\text{H}_2\text{S}$ molecules.	1
This decreases the rate of the forward reaction.	1
The rate of the reverse reaction is not affected initially.	1
The rate of the reverse reaction, therefore, is greater than the rate of the forward reaction.	1
The equilibrium position, therefore, shifts to the left/equilibrium favours the reverse reaction.	1
<b>Total</b>	<b>5</b>

The temperature inside the reaction vessel was increased. The heating process was stopped every so often and, once equilibrium had been established at the attained temperature, the amount of hydrogen present in the system was measured. The results are shown on the following graph.



(c) Using the graph and your answer to part (a), predict the effect of an increase in temperature on the numerical value of  $K$ . Justify your prediction. (4 marks)

Description	Marks
Value of $K$ decreases	1
The graph shows that as the temperature increases the number of moles (yield) of $\text{H}_2$ present at equilibrium decreases.	1
Recognises any two of: <ul style="list-style-type: none"> <li><math>[\text{H}_2\text{S}]</math> and <math>[\text{CH}_4]</math> increase</li> <li><math>[\text{H}_2]</math> decreases</li> <li>the reverse reaction has been favoured.</li> </ul>	1–2
<b>Total</b>	<b>4</b>
<b>Note:</b> <ul style="list-style-type: none"> <li>A justification based on Le Châtelier's Principle is acceptable. For example: As temperature increases, an endothermic reaction is favoured. This is the reverse reaction in this case.</li> </ul>	

2020  
Section 2  
Question  
31

Chemical  
equilibrium  
systems

The amount of carbon dioxide in the Earth's atmosphere is increasing, leading to more carbon dioxide dissolving in the oceans and hence ocean acidification.

(a) Complete the following sequence of equations to show what happens to carbon dioxide when it dissolves in water. (3 marks)

Description	Marks
$\text{CO}_2(\text{g}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \boxed{\text{H}_2\text{CO}_3(\text{aq})}$	1
$\text{H}_2\text{CO}_3(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \boxed{\text{HCO}_3^-(\text{aq})} + \text{H}_3\text{O}^+(\text{aq})$	1
$\text{HCO}_3^-(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \boxed{\text{CO}_3^{2-}(\text{aq})} + \text{H}_3\text{O}^+(\text{aq})$	1
<b>Total</b>	<b>3</b>
Note: <ul style="list-style-type: none"> <li>• Only allocate marks for the species in the boxes shown above.</li> <li>• State symbols are desirable but not essential.</li> </ul>	

(b) Other than death, state **two** consequences of the above sequence of equations on marine organisms with shells. (2 marks)

Description	Marks
States a plausible consequence	1
States another (different) plausible consequence	1
<b>Total</b>	<b>2</b>
Answers could include: <ul style="list-style-type: none"> <li>• building shells becomes harder</li> <li>• weaker/thinner shells/poor quality shells</li> <li>• makes organisms more vulnerable to predators</li> <li>• less likely to grow large</li> <li>• less likely to reproduce.</li> </ul>	
Note: <ul style="list-style-type: none"> <li>• Do not accept answers that refer to coral reefs or habitats.</li> </ul>	

(c) Use Le Châtelier's Principle and the sequence of equations in part (a) to predict what might happen, in relation to ocean acidification, if the United Nations Kyoto Protocol is discarded. Explain your reasoning. (4 marks)

Description	Marks
If the Kyoto Protocol is discarded then it is likely that there will be increased CO <sub>2</sub> emissions into the atmosphere that lead to increased amounts of CO <sub>2</sub> dissolved in the oceans.	1
Therefore, the forward reactions in the above sequence of reactions will be favoured.	1
The result is an increase in the concentration of H <sub>3</sub> O <sup>+</sup> ions.	1
The prediction is, therefore, that the pH of oceans will decrease even more.	1
<b>Total</b>	<b>4</b>
Note: • Accept oceans become more acidic.	

**2019  
Section 2  
Question  
34**

**Chemical  
equilibrium  
systems**

Consider the reaction between magnesium carbonate, MgCO<sub>3</sub>(s), and dilute nitric acid, HNO<sub>3</sub>(aq).



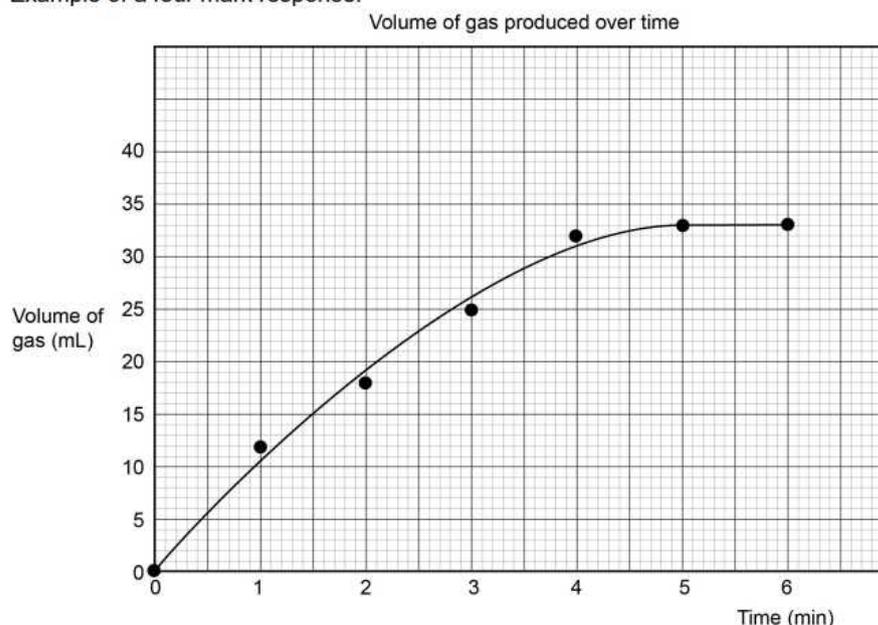
The following data was obtained from the addition of excess 0.500 mol L<sup>-1</sup> nitric acid to 5.00 g of magnesium carbonate.

<b>Time (min)</b>	0	1.0	2.0	3.0	4.0	5.0	6.0
<b>Volume of gas produced (mL)</b>	0	12	18	25	32	33	33

(a) Draw a labelled graph of the data provided in the grid below. (4 marks)

Description	Marks
Correctly labelled axes showing names and units	1
Appropriate scale	1
Correctly plotted points	1
Curve of best fit	1
<b>Total</b>	<b>4</b>

Example of a four mark response:



**Note:**

- Axes reversed – maximum 3 marks.
- No marks have been allocated for a title.

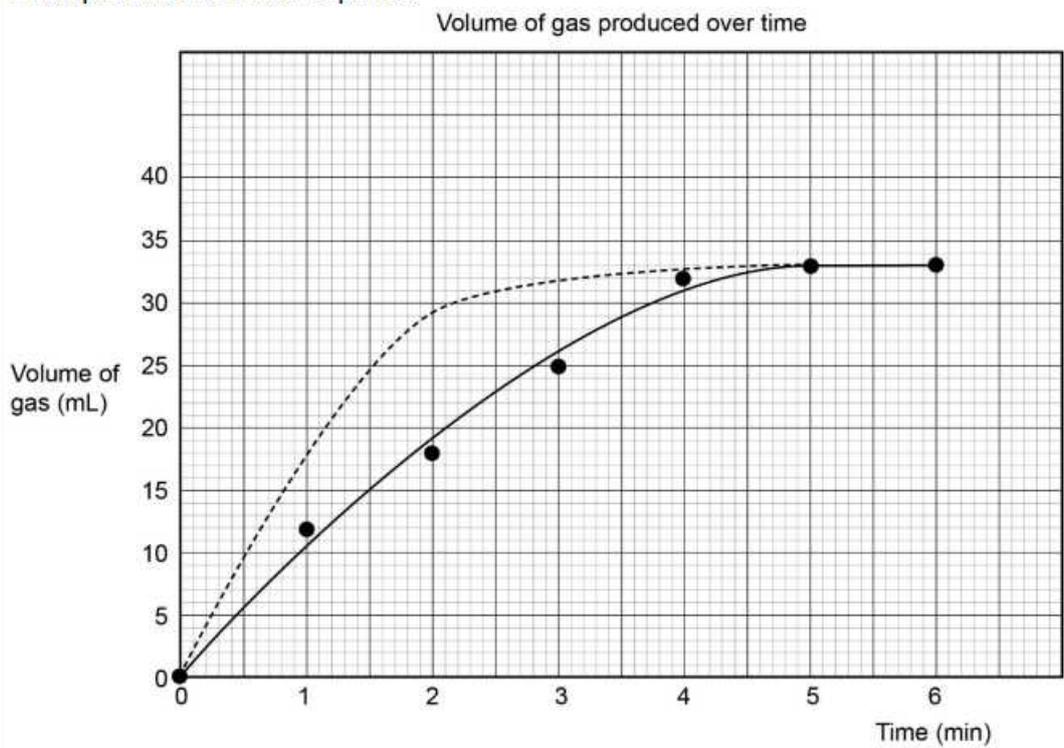
(b) Explain the shape of your graph in part (a) by referring to Collision Theory. (6 marks)

Description	Marks
Recognition that the rate at which carbon dioxide is evolved is a measure of the rate of reaction. The rate of change to the volume of the gas is a measure of reaction rate	1
From 0 to 4 minutes:	
• the slope of the curve decreases (indicates) /rate decreases	1
• concentration of $H^+$ decreases due to its consumption in the reaction	1
• surface area of $MgCO_3$ decrease	1
• therefore the frequency of collisions decreases.	1
After 4 minutes:	
• the magnesium carbonate all consumed, no more $CO_2$ produced, curve plateaus.	1
<b>Total</b>	<b>6</b>
<b>Note:</b>	
• For full marks, there must be reference to the specific particles involved in the reaction and the term 'frequency of collision' must be used.	

(c) Sketch and label a line on your graph in part (a) that shows the effect of conducting the same experiment at a higher temperature. (2 marks)

Description	Marks
Initial slope is steeper	1
Levels out earlier	1
<b>Total</b>	<b>2</b>

Example of a two mark response:

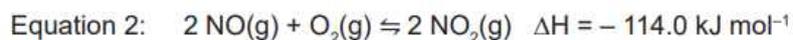
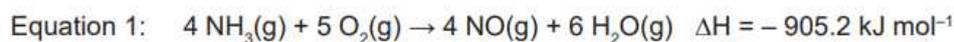


Marking Guide – Section 3

2023  
Section 3  
Question  
35

Chemical  
equilibrium  
systems

The Ostwald process is used in the conversion of ammonia to nitric acid according to the equations below.



(a) The reaction in Equation 1 is carried out with a platinum-rhodium catalyst at approximately 850.0 °C and 1500 kPa. Using collision theory, account for these conditions. (8 marks)

Description	Marks
<p><b>Catalyst</b></p> <ul style="list-style-type: none"> <li>Recognition that rate is increased as the platinum-rhodium catalyst provides an alternate reaction pathway with a lower activation energy</li> <li>Recognition that there are an increased proportion of reacting particles colliding with energy greater than the activation energy (resulting in an increased frequency of successful collisions)</li> </ul>	1–2
<p><b>Temperature</b></p> <ul style="list-style-type: none"> <li>Recognition that increased temperature increases the average kinetic energy of particles and they collide more frequently</li> <li>Recognition that the increased proportion of collisions will have energy higher than the activation energy (which has been lowered due to the catalyst)</li> <li>Recognition that a greater proportion of collisions are therefore successful (leading to an increased rate of reaction)</li> </ul>	1–3
<p><b>Pressure</b></p> <ul style="list-style-type: none"> <li>Recognition that increased pressure reduces the space between reacting particles</li> <li>Recognition that at high pressure particles collide more frequently</li> <li>Recognition that this leads to a higher frequency of successful collisions</li> </ul>	1–3
<b>Total</b>	<b>8</b>

(b) A nitric acid plant requires a production of 1095 tonnes of nitric acid by means of the Ostwald process each day. If the conversion of ammonia to nitric acid is 77.65% efficient, calculate the volume of ammonia at standard temperature and pressure (STP) that must be fed into the process each day. Give your answer to the appropriate number of significant figures. (6 marks)

Description	Marks
$m(\text{HNO}_3)_{\text{required}} = 1.095 \times 10^9 \text{ g}$	1
$n(\text{HNO}_3)_{\text{required}} = \frac{1.095 \times 10^9}{63.018} = 1.738 \times 10^7 \text{ mol}$	1
$n(\text{NH}_3)_{\text{required } 100\%} = \frac{12}{8} 1.738 \times 10^7 = 2.606 \times 10^7 \text{ mol}$	1
$n(\text{NH}_3)_{\text{required } 77.65\%} = \frac{100}{77.65} \times 2.606 \times 10^7 = 3.356 \times 10^7 \text{ mol}$	1
$v(\text{NH}_3)_{\text{STP}} = 3.356 \times 10^7 \times 22.71 = 7.621 \times 10^8 \text{ L}$	1
Answer to 4 significant figures	1
<b>Total</b>	<b>6</b>
Accept other relevant answers.	

**2022  
Section 3  
Question  
35**

**Chemical  
equilibrium  
systems**

Thermite is a mixture of aluminium and iron(III) oxide that, when ignited, rapidly produces a large amount of heat as it burns. The reaction is represented by the equation:



The heat produced in the reaction is sufficient to melt iron, which is why the reaction is used to weld iron railway tracks.

(a) Use the following axes to sketch an energy profile diagram for the thermite reaction. Label the:

- axes
- reactants and products
- activation energy
- change in enthalpy. (4 marks)

Description	Marks
correctly labelled axes	1
correctly labelled reactants and products	1
$E_a$ and $\Delta H$ correctly labelled	1
Scale (large values for $E_a$ and $\Delta H$ )	1
<b>Total</b>	<b>4</b>

Maximum 3 marks if an endothermic energy profile is drawn.

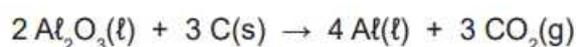
(b) In order for the reaction to occur, the iron(III) oxide and aluminium are mixed as powders and a heat source, such as burning magnesium, is used to ignite the mixture. Using your understanding of collision theory, explain these observations. (4 marks)

Description	Marks
Recognition that a high activation energy requires an additional energy source for the reaction to occur.	1
For successful reactions, particles must collide with sufficient energy.	1
Recognition that powders have a large surface area, and so there are more particles available for reaction.	1
Increased availability of particles increases likelihood of collisions (frequency of collisions) and so reaction more likely to occur.	1
<b>Total</b>	<b>4</b>

(c) If the thermite reaction is 89.5% efficient, what mass of iron(III) oxide will be required to produce 667 kg of iron? Give your answer to the appropriate number of significant figures. (6 marks)

Description	Marks
$m(\text{Fe}) = 667 \times 1000$ $= 6.67 \times 10^5 \text{ g}$	1
$n(\text{Fe}) = \frac{6.67 \times 10^5}{55.85}$ $= 1.194 \times 10^4 \text{ mol}$	1
$n(\text{Fe}_2\text{O}_3) = \frac{1}{2}(1.194 \times 10^4)$ $= 5.971 \times 10^3 \text{ mol}$	1
$m(\text{Fe}_2\text{O}_3) = 5.971 \times 10^3(159.7)$ $= 9.536 \times 10^5 \text{ g}$	1
$m(\text{Fe}_2\text{O}_3) = \frac{100}{89.5} \times (9.536 \times 10^5)$ $= 1.07 \times 10^6 \text{ g}$	1
Answer given to three significant figures.	1
<b>Total</b>	<b>6</b>

Aluminium can be refined through electrolysis. Molten aluminium oxide, which is mixed with a substance called cryolite to reduce the melting point, is electrolysed to produce aluminium and carbon dioxide, which is represented by the following equation:



(d) On the diagram below, correctly place the following in the boxes:

- anode
- cathode
- direction of cation flow and direction of anion flow
- direction of electron flow. (3 marks)

Description	Marks
anode and cathode correctly labelled	1
cations shown flowing to cathode and anions shown flowing to anode	1
electrons shown flowing towards cathode	1
<b>Total</b>	<b>3</b>

Note: all answers can be flipped for full marks.

**2021  
Section 3  
Question  
37**

**Chemical  
equilibrium  
systems**

A chemist was asked to develop a method of recycling used cathodes from a new type of lithium battery. The cathodes were a mixture of lithium cobalt oxide ( $\text{LiCoO}_2$ ) and manganese (Mn). Each cathode contained 57.29% cobalt by mass.

Preliminary trials showed that the used cathodes would dissolve completely if enough sulfuric acid was added and if enough time was allowed. The chemist decided to conduct detailed trials to see how the sulfuric acid concentration affected the rate at which the used cathodes dissolved.

Each trial was performed in a sealed, oxygen-free reactor using 5.00 L of sulfuric acid and 0.531 kg of used cathodes. Trials were also performed in the presence of  $\text{Fe}^{2+}$  ions to see if these ions had a catalytic effect. All trials lasted for 15 minutes with the reactor solutions then analysed for their concentrations of  $\text{Li}^+$ ,  $\text{Co}^{2+}$ ,  $\text{Mn}^{2+}$  and, where relevant,  $\text{Fe}^{2+}$ .

The results of the  $\text{Co}^{2+}$  and  $\text{Fe}^{2+}$  analyses are summarised in the following table.

Trial	Initial solution composition		Solution composition after 15 minutes	
	$\text{H}_2\text{SO}_4$ ( $\text{mol L}^{-1}$ )	$\text{Fe}^{2+}$ ( $\times 10^{-1} \text{ mol L}^{-1}$ )	$\text{Co}^{2+}$ ( $\times 10^{-1} \text{ mol L}^{-1}$ )	$\text{Fe}^{2+}$ ( $\times 10^{-1} \text{ mol L}^{-1}$ )
1	1.37	0.00	4.24	0.00
2	3.01	0.00	4.92	0.00
3	5.91	3.31	7.20	3.29
4	7.40	0.00	5.94	0.00
5	8.80	0.00	6.96	0.00
6	8.80	6.62	9.95	6.61

(a) (i) Which trial number(s) will allow the chemist to investigate the relationship between the sulfuric acid concentration and the amount of cobalt extracted? (1 mark)

Description	Marks
Trials 1, 2, 4 and 5	1
<b>Total</b>	<b>1</b>

(ii) Use collision theory to explain the effect of acid concentration on the rate at which the used cathodes dissolved. (3 marks)

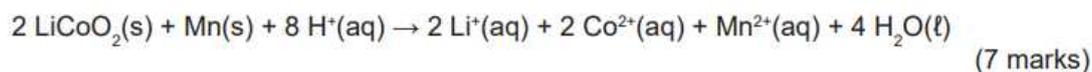
Description	Marks
The higher the acid concentration the faster the used cathodes dissolved.	1
Using collision theory, the higher the $\text{H}^+$ concentration, the greater the frequency of collisions between $\text{H}^+$ ions and the used cathode components.	1
When there is a higher frequency of collisions occurring between the reactants, the rate of reaction (used cathode dissolution) is faster.	1
<b>Total</b>	<b>3</b>

(b) Do  $\text{Fe}^{2+}$  ions catalyse the dissolution of cobalt in sulfuric acid? Justify your answer. (3 marks)

Description	Marks
Yes, the $\text{Fe}^{2+}$ catalyses the reaction.	1
Trials using $\text{Fe}^{2+}$ dissolve more Co from the cathode in the time given (in trials 5 and 6).	1
$\text{Fe}^{2+}$ is a catalyst because it was not consumed (in trials 3 and 6).	1
<b>Total</b>	<b>3</b>

(c) Would the used cathodes dissolve completely in Trial 2 assuming enough time was allowed? Support your answer with relevant calculations.

The dissolution reaction is:



Description	Marks
$m(\text{Co in electrode}) = 0.5729 \times 531 = 304.21 \text{ g}$	1
$n(\text{Co}) = 304.21/58.93 = 5.1622 \text{ mol}$	1
$n(\text{Co}) = n(\text{LiCoO}_2) = 5.1622 \text{ mol}$	1
$m(\text{LiCoO}_2) = 5.1622 \times 97.87 = 505.2 \text{ g}$	1
$m(\text{Mn}) = 531 - 505.2 = 25.78 \text{ g}$	1
$n(\text{Mn}) = 25.78/54.94 = 0.4692 \text{ mol}$	1
$n(\text{Mn}) < \frac{1}{2} n(\text{LiCoO}_2)$ , therefore the cathodes will not dissolve completely.	1
<b>Total</b>	<b>7</b>

(d) Calculate the percentage, by mass, of lithium in a used cathode. Give your answer to the appropriate number of significant figures. (4 marks)

Description	Marks
$n(\text{Li}) = n(\text{Co}) = 5.16 \text{ mol}$	1
$m(\text{Li}) = 5.16 \times 6.94 = 35.81 \text{ g}$	1
$\% \text{ Li in a spent electrode} = 35.81/531 \times 100 = 6.74\%$	1
$\% \text{ Li is given correct to 3 significant figures}$	1
<b>Total</b>	<b>4</b>
<b>Note:</b> If student correctly determines %Li from an incorrect value from part (c), still award full marks.	

## Unit 3 – Acids and bases

### Section 1

<b>2023</b> <b>Section 1</b> <b>Question 18</b> <b>Acids and bases</b>	<p>Which of the following lists contains compounds that will all produce a basic solution when dissolved in water?</p> <p>(a) sodium hydroxide, ammonium chloride, potassium carbonate, sodium ethanoate (b) sodium ethanoate, barium hydroxide, ammonia, sodium carbonate (c) ammonium iodide, copper(II) sulfate, sodium sulfite, sodium oxide (d) potassium hydrogencarbonate, iron(III) oxide, sodium iodide, lead(II) sulfate</p>
<b>2023</b> <b>Section 1</b> <b>Question 19</b> <b>Acids and bases</b>	<p>What can be concluded from the statement <math>K_w = [\text{H}^+][\text{OH}^-] = 1.0 \times 10^{-14}</math> at 25 °C?</p> <p>(a) Pure water has a pH of 14. (b) Pure water does not react with acids or bases. (c) The concentration of hydrogen and hydroxide ions is not equal. (d) The concentration of hydrogen ions is <math>1.0 \times 10^{-7}</math> mol L<sup>-1</sup>.</p>
<b>2022</b> <b>Section 1</b> <b>Question 1</b> <b>Acids and bases</b>	<p>Consider the following statements about acid-base indicators. Acid-base indicators</p> <p>(i) change colour as the concentration of hydrogen ions changes. (ii) are weak acids or bases. (iii) must not react with the reactants or products in a titration. (iv) must be used in large volumes for the best results.</p> <p>Which of the above statements is/are correct?</p> <p>(a) i only (b) i and ii (c) i and iii (d) i, ii, iii and iv</p>
<b>2022</b> <b>Section 1</b> <b>Question 5</b> <b>Acids and bases</b>	<p>Which of the following pairs, in equimolar amounts, would result in an acidic buffer solution?</p> <p>(i) <math>\text{CH}_3\text{COOH}/\text{CH}_3\text{COO}^-</math> (ii) <math>\text{H}_2\text{CO}_3/\text{HCO}_3^-</math> (iii) <math>\text{NH}_3/\text{NH}_4^+</math> (iv) <math>\text{H}_2\text{SO}_4/\text{HSO}_4^-</math> (v) <math>\text{CH}_3\text{NH}_2/\text{CH}_3\text{NH}_3^+</math></p> <p>(a) i, ii and iv (b) iii and v (c) ii, iii and v (d) i and ii</p>
<b>2022</b> <b>Section 1</b> <b>Question 9</b> <b>Acids and bases</b>	<p>Consider an acid-base titration between hydrochloric acid solution and ammonia solution. Which of the following actions is <b>least</b> likely to cause an error when calculating the concentration of hydrochloric acid?</p> <p>(a) cleaning the pipette with distilled water before each titration (b) rinsing the sides of the conical flask with distilled water during the titration (c) measuring the ammonia solution in a 20 mL measuring cylinder (d) leaving the funnel in the burette for each titration</p>

<b>2022</b> <b>Section 1</b> <b>Question</b> <b>11</b>  <b>Acids and</b> <b>bases</b>	Select the <b>best</b> reason why the Brønsted-Lowry model is preferred over the Arrhenius model of Acids and bases. The Brønsted-Lowry model  (a) includes a wider range of substances and can be used more broadly. (b) demonstrates when hydrogen atoms are replaced by metals. (c) easily identifies that acids produce hydrogen ions and bases produce hydroxide ions. (d) demonstrates that non-metal oxides dissolve in water to produce acidic solutions.
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<b>2022</b> <b>Section 1</b> <b>Question</b> <b>12</b>  <b>Acids and</b> <b>bases</b>	A student tested an acid with a pH meter. When dipped into the acid the pH was shown to be 4. What is the concentration of hydrogen ions in this solution?  (a) 0.0004 mol L <sup>-1</sup> (b) 0.00001 mol L <sup>-1</sup> (c) 0.0001 mol L <sup>-1</sup> (d) 0.004 mol L <sup>-1</sup>
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<b>2022</b> <b>Section 1</b> <b>Question</b> <b>13</b>  <b>Acids and</b> <b>bases</b>	Identify the <b>weakest</b> acid in the following series.  <table border="1" style="margin-left: 40px;"> <thead> <tr> <th></th> <th>Name</th> <th>Formula</th> <th>K<sub>a</sub> (25 °C)</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>acetic acid</td> <td>CH<sub>3</sub>COOH</td> <td>1.8 × 10<sup>-5</sup></td> </tr> <tr> <td>(b)</td> <td>chloroacetic acid</td> <td>ClCH<sub>2</sub>COOH</td> <td>1.3 × 10<sup>-3</sup></td> </tr> <tr> <td>(c)</td> <td>dichloroacetic acid</td> <td>Cl<sub>2</sub>CHCOOH</td> <td>4.5 × 10<sup>-2</sup></td> </tr> <tr> <td>(d)</td> <td>trichloroacetic acid</td> <td>CCl<sub>3</sub>COOH</td> <td>2.2 × 10<sup>-1</sup></td> </tr> </tbody> </table>		Name	Formula	K <sub>a</sub> (25 °C)	(a)	acetic acid	CH <sub>3</sub> COOH	1.8 × 10 <sup>-5</sup>	(b)	chloroacetic acid	ClCH <sub>2</sub> COOH	1.3 × 10 <sup>-3</sup>	(c)	dichloroacetic acid	Cl <sub>2</sub> CHCOOH	4.5 × 10 <sup>-2</sup>	(d)	trichloroacetic acid	CCl <sub>3</sub> COOH	2.2 × 10 <sup>-1</sup>
	Name	Formula	K <sub>a</sub> (25 °C)																		
(a)	acetic acid	CH <sub>3</sub> COOH	1.8 × 10 <sup>-5</sup>																		
(b)	chloroacetic acid	ClCH <sub>2</sub> COOH	1.3 × 10 <sup>-3</sup>																		
(c)	dichloroacetic acid	Cl <sub>2</sub> CHCOOH	4.5 × 10 <sup>-2</sup>																		
(d)	trichloroacetic acid	CCl <sub>3</sub> COOH	2.2 × 10 <sup>-1</sup>																		

<b>2022</b> <b>Section 1</b> <b>Question</b> <b>14</b>  <b>Acids and</b> <b>bases</b>	Which of the following equations represents the HPO <sub>4</sub> <sup>2-</sup> ion acting as a Brønsted-Lowry acid?  (a) HPO <sub>4</sub> <sup>2-</sup> (aq) + H <sub>3</sub> O <sup>+</sup> (aq) ⇌ H <sub>2</sub> PO <sub>4</sub> <sup>-</sup> (aq) + H <sub>2</sub> O(l) (b) HPO <sub>4</sub> <sup>2-</sup> (aq) + H <sub>2</sub> O(l) ⇌ H <sub>2</sub> PO <sub>4</sub> <sup>-</sup> (aq) + OH <sup>-</sup> (aq) (c) HPO <sub>4</sub> <sup>2-</sup> (aq) ⇌ H <sup>+</sup> (aq) + PO <sub>4</sub> <sup>3-</sup> (aq) (d) HPO <sub>4</sub> <sup>2-</sup> (aq) + H <sub>2</sub> O(l) ⇌ PO <sub>4</sub> <sup>3-</sup> (aq) + H <sub>3</sub> O <sup>+</sup> (aq)
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<b>2022</b> <b>Section 1</b> <b>Question</b> <b>20</b>  <b>Acids and</b> <b>bases</b>	Which of the following is the dominant form of serine in acidic conditions?  <table border="1" style="margin-left: 40px;"> <tbody> <tr> <td>(a)</td> <td style="text-align: center;"> <math display="block">\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_3\text{N}^+\text{-CH-COOH} \end{array}</math> </td> </tr> <tr> <td>(b)</td> <td style="text-align: center;"> <math display="block">\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_2\text{N-CH-COOH} \end{array}</math> </td> </tr> <tr> <td>(c)</td> <td style="text-align: center;"> <math display="block">\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_2\text{N-CH-COO}^- \end{array}</math> </td> </tr> <tr> <td>(d)</td> <td style="text-align: center;"> <math display="block">\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_3\text{N}^+\text{-CH-COO}^- \end{array}</math> </td> </tr> </tbody> </table>	(a)	$\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_3\text{N}^+\text{-CH-COOH} \end{array}$	(b)	$\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_2\text{N-CH-COOH} \end{array}$	(c)	$\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_2\text{N-CH-COO}^- \end{array}$	(d)	$\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_3\text{N}^+\text{-CH-COO}^- \end{array}$
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(d)	$\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_3\text{N}^+\text{-CH-COO}^- \end{array}$								

**2021 Section 1 Question 3**  
**Acids and bases**

Consider the acids listed in the following table.

Name	Formula	$K_a$ (25 °C)
bromoacetic acid	$\text{CH}_2\text{BrCOOH}$	$1.38 \times 10^{-3}$
dibromoacetic acid	$\text{CHBr}_2\text{COOH}$	$3.31 \times 10^{-2}$
tribromoacetic acid	$\text{CBr}_3\text{COOH}$	$1.91 \times 10^{-1}$

Which of the following identifies the strongest acid and classifies it correctly as monoprotic, diprotic or triprotic?

	Strongest acid	Classification
(a)	bromoacetic acid	monoprotic
(b)	dibromoacetic acid	diprotic
(c)	tribromoacetic acid	monoprotic
(d)	tribromoacetic acid	triprotic

**2021 Section 1 Question 8**  
**Acids and bases**

Which of the following equation/s demonstrate/s the Arrhenius model of Acids and bases?

(i)  $\text{HCl}(\text{aq}) \rightarrow \text{H}^+(\text{aq}) + \text{Cl}^-(\text{aq})$   
(ii)  $\text{CH}_3\text{COOH}(\text{aq}) + \text{H}_2\text{O}(\ell) \rightarrow \text{CH}_3\text{COO}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$   
(iii)  $\text{KOH}(\text{aq}) \rightarrow \text{K}^+(\text{aq}) + \text{OH}^-(\text{aq})$   
(iv)  $\text{H}_2\text{PO}_3^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq}) \rightarrow \text{H}_2\text{O}(\ell) + \text{H}_3\text{PO}_4(\text{aq})$

(a) i, ii, iii and iv  
(b) i only  
(c) ii and iii only  
(d) i and iii only

**2021 Section 1 Question 9**  
**Acids and bases**

The net ionic equation for the predominant hydrolysis reaction occurring in a 1.00 mol L<sup>-1</sup> potassium hydrogensulfate solution is:

(a)  $\text{KHSO}_4(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{K}^+(\text{aq}) + \text{H}_2\text{SO}_4(\text{aq}) + \text{OH}^-(\text{aq})$   
(b)  $\text{K}^+(\text{aq}) + \text{HSO}_4^-(\text{aq}) \rightleftharpoons \text{K}^+(\text{aq}) + \text{H}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq})$   
(c)  $\text{HSO}_4^-(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{H}_2\text{SO}_4(\text{aq}) + \text{OH}^-(\text{aq})$   
(d)  $\text{HSO}_4^-(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{SO}_4^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$

**2021 Section 1 Question 14**  
**Acids and bases**

Consider the following pH values for a range of substances.

pH	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Substance	Battery acid	Stomach acid	Lemon juice	Orange juice	Beer	Black coffee	Milk	Blood	Sea water	Toothpaste	Laundry detergent	Bathroom cleaner	Hair straightener	Oven cleaner	Drain cleaner

Based on these pH values, which one of the following statements about the concentration of hydronium ions is true?

(a) It is 1000 times greater in sea water than in bathroom cleaner.  
(b) It is twice as great in beer as it is in lemon juice.  
(c) It is three times greater in beer than in hair straightener.  
(d) It is 1 000 000 times greater in hair straightener than in milk.



<p><b>2020</b> <b>Section 1</b> <b>Question 15</b></p> <p><b>Acids and bases</b></p>	<p>The reaction of aniline (C<sub>6</sub>H<sub>5</sub>NH<sub>2</sub>) with water is an equilibrium process:</p> $\text{C}_6\text{H}_5\text{NH}_2(\ell) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{C}_6\text{H}_5\text{NH}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$ <p>A conjugate acid-base pair in this process is</p> <p>(a) C<sub>6</sub>H<sub>5</sub>NH<sup>-</sup> and H<sub>2</sub>O          (b) C<sub>6</sub>H<sub>5</sub>NH<sub>2</sub> and C<sub>6</sub>H<sub>5</sub>NH<sup>-</sup>          (c) C<sub>6</sub>H<sub>5</sub>NH<sup>-</sup> and H<sub>3</sub>O<sup>+</sup>          (d) H<sub>3</sub>O<sup>+</sup> and C<sub>6</sub>H<sub>5</sub>NH<sub>2</sub></p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 17</b></p> <p><b>Acids and bases</b></p>	<p>Acid-base indicators</p> <p>(a) are oxidising or reducing agents.          (b) change colour at a specific pH value.          (c) are strong acids or bases.          (d) are weak acids or bases.</p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 18</b></p> <p><b>Acids and bases</b></p>	<p>A chemist prepares solutions of nitrous acid and hydrocyanic acid that have the same concentration.</p> <p>The K<sub>a</sub> values of these acids are:</p> <ul style="list-style-type: none"> <li>nitrous acid (HNO<sub>2</sub>) is 4.6 x 10<sup>-4</sup></li> <li>hydrocyanic acid (HCN) is 6.17 x 10<sup>-10</sup>.</li> </ul> <p>Which of these two acids is the stronger and which has the higher pH?</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th>Stronger acid</th> <th>Higher pH</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>nitrous acid</td> <td>nitrous acid</td> </tr> <tr> <td>(b)</td> <td>nitrous acid</td> <td>hydrocyanic acid</td> </tr> <tr> <td>(c)</td> <td>hydrocyanic acid</td> <td>hydrocyanic acid</td> </tr> <tr> <td>(d)</td> <td>hydrocyanic acid</td> <td>nitrous acid</td> </tr> </tbody> </table>		Stronger acid	Higher pH	(a)	nitrous acid	nitrous acid	(b)	nitrous acid	hydrocyanic acid	(c)	hydrocyanic acid	hydrocyanic acid	(d)	hydrocyanic acid	nitrous acid
	Stronger acid	Higher pH														
(a)	nitrous acid	nitrous acid														
(b)	nitrous acid	hydrocyanic acid														
(c)	hydrocyanic acid	hydrocyanic acid														
(d)	hydrocyanic acid	nitrous acid														

<p><b>2020</b> <b>Section 1</b> <b>Question 25</b></p> <p><b>Acids and bases</b></p>	<p>A chemist performed an acid-base titration. The acid was in a burette and a pipette was used to deliver a known quantity of the base into a conical flask. Which of the following gives the final rinse solution for each of these pieces of equipment?</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th colspan="3">Final rinse solution</th> </tr> <tr> <th></th> <th>Burette</th> <th>Pipette</th> <th>Conical flask</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>acid</td> <td>water</td> <td>base</td> </tr> <tr> <td>(b)</td> <td>acid</td> <td>base</td> <td>water</td> </tr> <tr> <td>(c)</td> <td>water</td> <td>base</td> <td>water</td> </tr> <tr> <td>(d)</td> <td>water</td> <td>water</td> <td>base</td> </tr> </tbody> </table>		Final rinse solution				Burette	Pipette	Conical flask	(a)	acid	water	base	(b)	acid	base	water	(c)	water	base	water	(d)	water	water	base
	Final rinse solution																								
	Burette	Pipette	Conical flask																						
(a)	acid	water	base																						
(b)	acid	base	water																						
(c)	water	base	water																						
(d)	water	water	base																						

<p><b>2019</b> <b>Section 1</b> <b>Question 1</b></p> <p><b>Acids and bases</b></p>	<p>Boric acid, which is a weak acid, was titrated with standardised sodium hydroxide solution.</p> <p>Which one of the indicators listed below would be the <b>most</b> suitable to use in this titration?</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th>Indicator</th> <th>Range of colour change (pH)</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>thymol blue</td> <td>1 – 3</td> </tr> <tr> <td>(b)</td> <td>bromocresol green</td> <td>3.8 – 5.4</td> </tr> <tr> <td>(c)</td> <td>cresolphthalein</td> <td>8 – 10</td> </tr> <tr> <td>(d)</td> <td>alizarin yellow</td> <td>10 – 12</td> </tr> </tbody> </table>		Indicator	Range of colour change (pH)	(a)	thymol blue	1 – 3	(b)	bromocresol green	3.8 – 5.4	(c)	cresolphthalein	8 – 10	(d)	alizarin yellow	10 – 12
	Indicator	Range of colour change (pH)														
(a)	thymol blue	1 – 3														
(b)	bromocresol green	3.8 – 5.4														
(c)	cresolphthalein	8 – 10														
(d)	alizarin yellow	10 – 12														

<p><b>2019</b> <b>Section 1</b> <b>Question 8</b></p> <p><b>Acids and bases</b></p>	<p>A distinguishing feature of strong acids is that they</p> <p>(a) produce high concentrations of hydronium ions (<math>\text{H}_3\text{O}^+</math>) in solution.            (b) have high acidity constants.            (c) contain loosely-held hydrogen ions (<math>\text{H}^+</math>) in solution.            (d) ionise rather than dissociate in water.</p>
<p><b>2019</b> <b>Section 1</b> <b>Question 16</b></p> <p><b>Acids and bases</b></p>	<p>Which one of the following statements about an aqueous solution with a pH less than zero at 25.0 °C is true?</p> <p>(a) Such a solution cannot exist at 25.0 °C.            (b) There are no <math>\text{OH}^-(\text{aq})</math> ions present.            (c) The concentration of <math>\text{H}^+(\text{aq})</math> ions is much greater than the concentration of <math>\text{OH}^-(\text{aq})</math> ions.            (d) There are no <math>\text{H}^+(\text{aq})</math> ions present as they have formed water molecules through the process of neutralisation.</p>
<p><b>2019</b> <b>Section 1</b> <b>Question 24</b></p> <p><b>Acids and bases</b></p>	<p>Which one of the following underlined species is acting as an acid?</p> <p>(a) <math>\underline{\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2} + \text{CH}_3\text{COOH} \rightleftharpoons \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_3^+ + \text{CH}_3\text{COO}^-</math>            (b) <math>\text{HSO}_3^- + \text{NH}_3 \rightleftharpoons \underline{\text{SO}_3^{2-}} + \text{NH}_4^+</math>            (c) <math>\text{NH}_4^+ + \text{CH}_3\text{COO}^- \rightleftharpoons \underline{\text{NH}_3} + \text{CH}_3\text{COOH}</math>            (d) <math>\underline{[\text{Fe}(\text{H}_2\text{O})_6]^{3+}} + \text{H}_2\text{O} \rightleftharpoons [\text{Fe}(\text{OH})(\text{H}_2\text{O})_5]^{2+} + \text{H}_3\text{O}^+</math></p>

Section 2

2023  
Section 2  
Question  
26

Acids and  
bases

Nitrous acid,  $\text{HNO}_2$ , and formic acid,  $\text{HCOOH}$ , are both monoprotic weak acids.

(a) Outline the difference between the terms 'monoprotic' and 'polyprotic'. Use equations to illustrate your answer. (4 marks)

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(b) Using the Brønsted-Lowry model of acids and bases, write the ionisation equations for both acids. (2 marks)

Nitrous acid	
Formic acid	

(c) In the equations above, circle the Brønsted-Lowry bases. (2 marks)

(d) Using **one** of the two acids as an example, describe how Arrhenius theory of acids and bases differs from Brønsted-Lowry theory. Include an appropriate Arrhenius theory equation in your answer. (3 marks)

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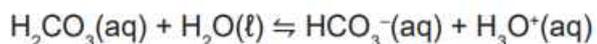
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**2023**  
**Section 2**  
**Question**  
**28**

**Acids and**  
**bases**

The pH of blood is maintained in a narrow range by the carbonic acid and hydrogencarbonate buffer system, represented by the following equilibrium:



(a) Define the term 'buffer' and identify the chemical species in this system responsible for its buffering capacity. Specify the role of each chemical species you identify in your answer. (3 marks)

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(b) Explain what will happen in the blood when there is an elevated concentration of carbon dioxide. Predict how blood pH is affected. Include relevant equations in your answer. (5 marks)

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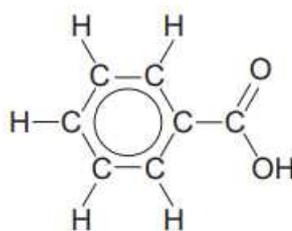




2021  
Section 2  
Question  
28

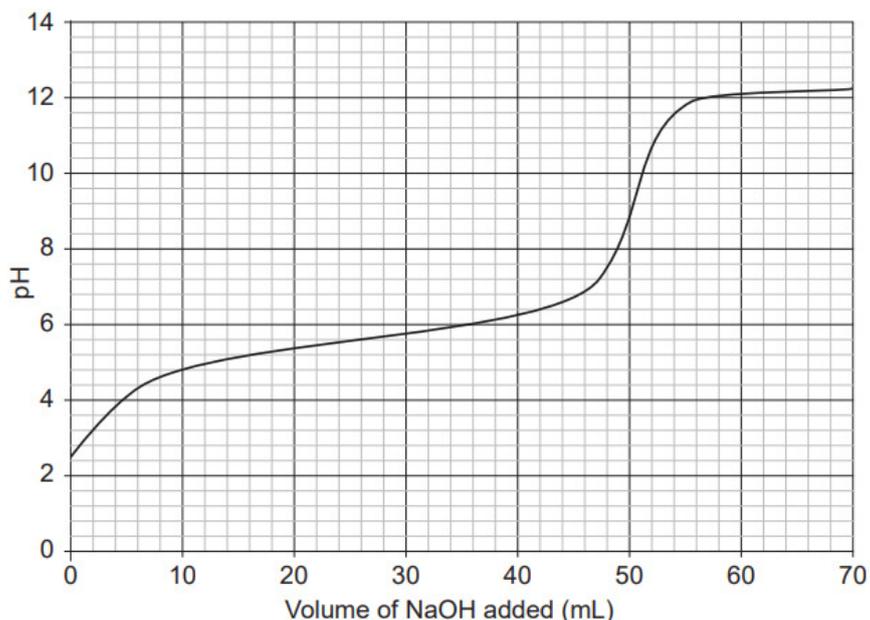
Acids and  
bases

Benzoic acid ( $C_6H_5COOH$ ) is a weak acid. Its structural formula is shown below.



Benzoic acid has a range of uses, including the manufacture of dyes, perfumes and insect repellents. The benzoic acid content of these products can be determined by titration with sodium hydroxide. The salt produced in the titration reaction is sodium benzoate,  $C_6H_5COONa$ .

The following graph shows a typical acid-base titration curve for benzoic acid and sodium hydroxide.



(a) Which of the indicators listed in the following table would be most suitable for use in this titration? With reference to the above titration curve, explain your choice. (3 marks)

Name of Indicator	pH Range
Bromocresol green	3.8 – 5.4
Azolitmin	4.5 – 8.3
Cresolphthalein	8.2 – 9.8
Indigo carmine	11.4 – 13.0

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**2019  
Section 2  
Question  
27**

**Acids and  
bases**

Calcium hypochlorite,  $\text{Ca}(\text{OCl})_2(\text{s})$ , is used for the treatment of water in swimming pools and is sold as 'pool chlorine'.

(a) Explain why a basic solution is produced when 'pool chlorine' is dissolved in the pool water. Include an equation in your answer. (4 marks)

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Equation

A pool chemical used to counteract the basicity of the pool water is hydrochloric acid,  $\text{HCl}(\text{aq})$ . It is sold as 'pool acid'.

(b) State what happens to the pH of the pool water when 'pool acid' is added to the pool water. Include an equation to illustrate your statement. (3 marks)

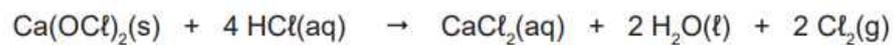
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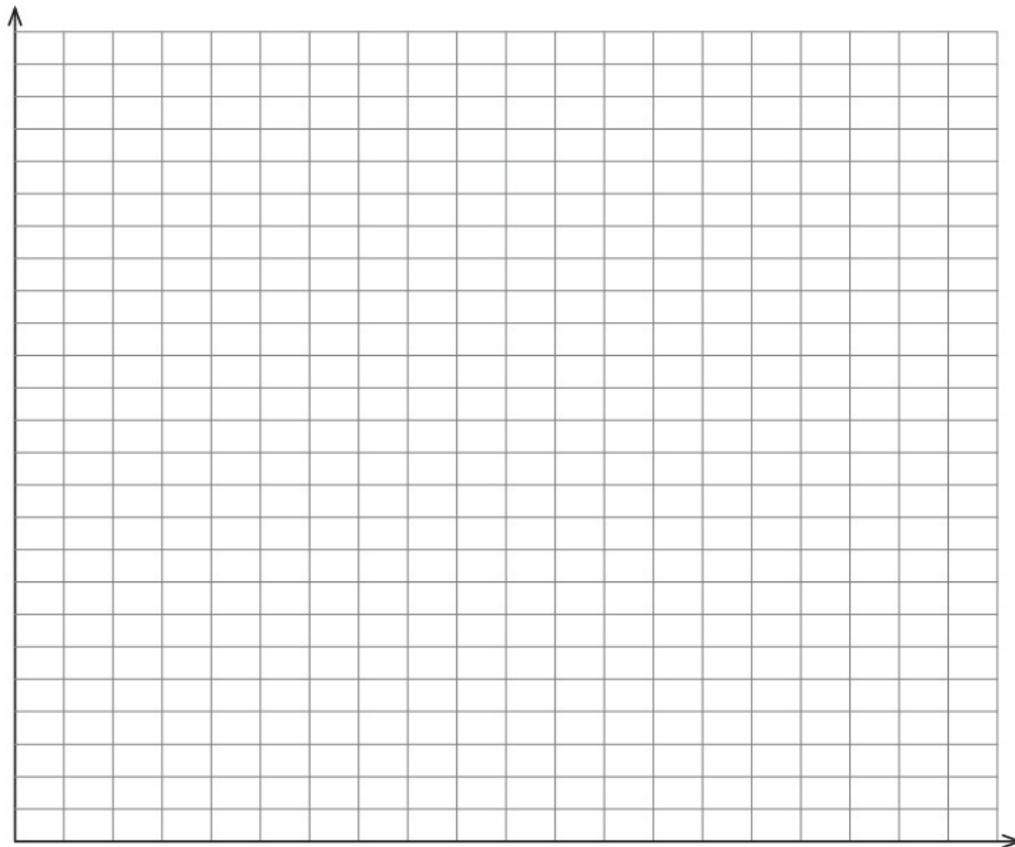
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Equation

'Pool chlorine' and 'pool acid' must be stored separately from each other because calcium hypochlorite can react explosively on contact with hydrochloric acid. The equation for this reaction is given below.



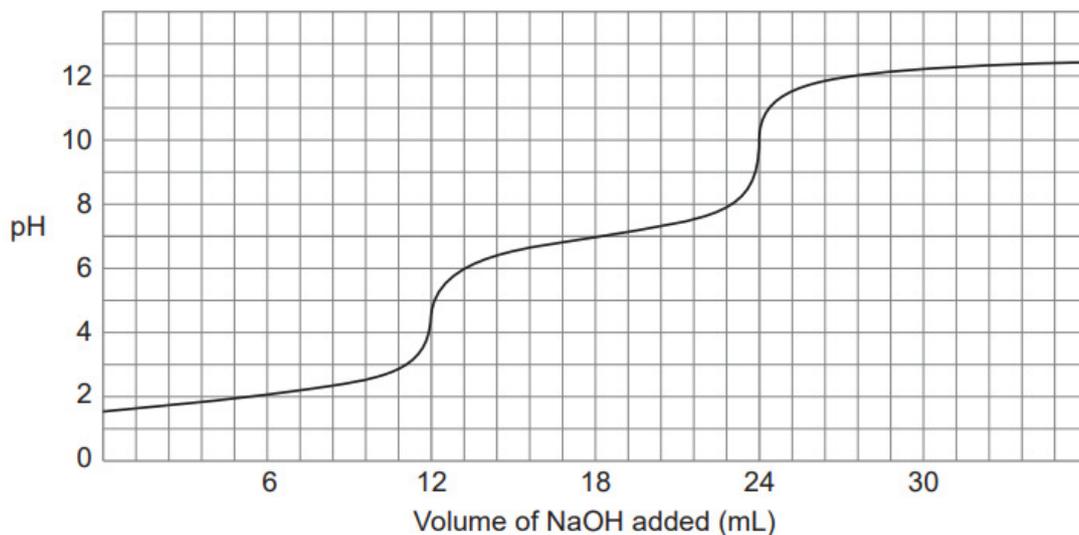
(c) Sketch a clearly-labelled energy profile diagram illustrating the reaction between the 'pool chlorine' and the 'pool acid'. (6 marks)



2019  
Section 2  
Question  
35

Acids and  
bases

Consider the following acid-base titration curve that is produced by the addition of 0.166 mol L<sup>-1</sup> sodium hydroxide solution to 20.00 mL of an approximately 0.1 mol L<sup>-1</sup> diprotic acid.



(a) (i) Indicate whether the diprotic acid is most likely to be sulfuric acid, H<sub>2</sub>SO<sub>4</sub>(aq) or sulfurous acid, H<sub>2</sub>SO<sub>3</sub>(aq), by circling your choice below. (1 mark)

Sulfuric acid

Sulfurous acid

(ii) Making reference to the titration curve shown above, give two reasons for your answer. (2 marks)

One:

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Two:

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(b) Predict the effect (increase, decrease or no change) on the calculated concentration of the acid for the following two systematic errors that can occur in a titration and justify your choice. (4 marks)

Systematic Error		Effect on calculated concentration of acid (circle)	Justification
I	Only rinsing the pipette with distilled water before use	increase decrease no change	
II	Using an indicator with an end point of pH = 4.5	increase decrease no change	

(c) State one reason why these errors are classified as systematic errors rather than random errors. (1 mark)

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(b) Hydrochloric acid must be standardised against a primary standard before it can be used in titrations such as the one described in part (a). List three properties of substances suitable for use as primary standards. (3 marks)

One:

Two:

Three:

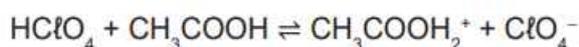
(c) Methyl orange, which changes colour between a pH of 3.1 and a pH of 4.4, was chosen as the indicator for this reaction. Justify, with the aid of an equation, the selection of this indicator for the titration. (4 marks)

2021  
Section 3  
Question  
35

Acids and  
bases

Smoking is hazardous to a person's health and one option to help quit smoking is the use of nicotine patches. These patches, when placed on the skin, release small amounts of nicotine with the aim of reducing cigarette craving.

The nicotine content of these patches can be determined by titration. The titrating solution is prepared by mixing perchloric acid ( $\text{HClO}_4$ ) with glacial acetic acid, resulting in the following equilibrium:



The species that reacts with nicotine during the titration is  $\text{CH}_3\text{COOH}_2^+$ . 'Glacial' means that the acetic acid does not contain any water.

The perchloric acid/acetic acid solution must be standardised before use and this can be done by titrating it with a solution made from a primary standard.

(a) Other than possessing a relatively high molar mass, state **two** characteristics required of a substance for it to be used as a primary standard. (2 marks)

One:

Two:

A brand of nicotine patches comes in dose sizes of 7 mg, 14 mg and 21 mg. A manufacturing error produced a batch of unlabelled boxes of patches. A chemist was given the task of identifying the dose size so that the boxes could be accurately labelled and then sold.

The chemist took one of the boxes and extracted all the nicotine from the 14 patches it contained. The nicotine extract was then made up to a total of 100.0 mL using a suitable solvent. Aliquots of the resulting solution (20.0 mL) were then titrated with standardised  $0.0483 \text{ mol L}^{-1}$  perchloric acid/acetic acid solution, requiring an average of 15.11 mL to reach the end point.

(b) Complete the following table by writing the name of the most suitable piece of equipment to use for each task. (3 marks)

Task	Piece of equipment to use
Making exactly 100.0 mL of nicotine-containing solution	
Measuring a 20.0 mL aliquot of the nicotine-containing solution	
Adding the perchloric acid/acetic acid solution to the nicotine-containing solution	




**2020  
Section 3  
Question  
37**

**Acids and  
bases**

A student standardised an approximately  $0.1 \text{ mol L}^{-1}$  sodium hydroxide solution with a standard  $0.0958 \text{ mol L}^{-1}$  hydrochloric acid solution. The student pipetted  $20.00 \text{ mL}$  of the sodium hydroxide solution into a conical flask, added 2 drops of indicator and titrated to the end point with the hydrochloric acid. Five titrations were performed.

(a) Below is a table of the student's results. Determine the average titre. (1 mark)

Titration number	Burette readings (mL)		
	Initial	Final	Titre
Rough	1.35	22.45	21.10
1	21.45	41.50	20.05
2	3.50	23.65	20.15
3	23.65	43.05	19.40
4	2.75	22.85	20.10
<b>Average titre</b>			

(b) Show that the concentration of the sodium hydroxide solution is  $0.0963 \text{ mol L}^{-1}$ , correct to three significant figures. (3 marks)






2019  
Section 3  
Question  
39

Acids and  
bases

Herbicides are chemicals that kill plants, including weeds. The label of a commercially-available herbicide concentrate is shown below.

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A chemist was given the task of verifying the concentrations of sodium chloride and acetic (ethanoic) acid stated for this herbicide.

The sodium chloride content of the herbicide was analysed. It was found to be consistent within the tolerance of  $\pm 5.00\%$  of the stated concentration. The chemist then performed a series of titrations with sodium hydroxide to measure the acetic (ethanoic) acid concentration.

The herbicide solution used in the titrations was prepared by pipetting 5.00 mL of the concentrate into a 250.0 mL volumetric flask. The solution in the flask was then made up to the mark with distilled water.

A 20.00 mL sample of the diluted herbicide was pipetted into a conical flask and a few drops of a suitable indicator were added. This solutions was then titrated with standardised 0.0947 mol L<sup>-1</sup> NaOH solution.

(a) Complete the table and determine the average titre. (2 marks)

Titration number	Burette readings (mL)		Titre
	Initial	Final	
1	1.28	20.75	
2	20.75	40.19	
3	1.48	21.82	
4	21.82	41.21	
Average titre			

(b) Identify with what solution each of these pieces of glassware should be rinsed prior to their use in these titrations. (3 marks)

Glassware item	Rinse solution
5.00 mL pipette	
20.00 mL pipette	
250.0 mL volumetric flask	

(c) Demonstrate whether or not the experimentally-determined value of the acetic (ethanoic) acid concentration matches the value given on the herbicide label, bearing in mind that a difference of  $\pm 5.00\%$  is considered acceptable. Show **all** workings and reasoning. (8 marks)

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## Marking Guide – Section 1

<p><b>2023</b> <b>Section 1</b> <b>Question 18</b></p> <p><b>Acids and bases</b></p>	<p>Which of the following lists contains compounds that will all produce a basic solution when dissolved in water?</p> <p>(a) sodium hydroxide, ammonium chloride, potassium carbonate, sodium ethanoate  <b>(b) sodium ethanoate, barium hydroxide, ammonia, sodium carbonate – Answer</b>            (c) ammonium iodide, copper(II) sulfate, sodium sulfite, sodium oxide            (d) potassium hydrogencarbonate, iron(III) oxide, sodium iodide, lead(II) sulfate</p>
<p><b>2023</b> <b>Section 1</b> <b>Question 19</b></p> <p><b>Acids and bases</b></p>	<p>What can be concluded from the statement <math>K_w = [\text{H}^+][\text{OH}^-] = 1.0 \times 10^{-14}</math> at 25 °C?</p> <p>(a) Pure water has a pH of 14.            (b) Pure water does not react with acids or bases.            (c) The concentration of hydrogen and hydroxide ions is not equal.  <b>(d) The concentration of hydrogen ions is <math>1.0 \times 10^{-7}</math> mol L<sup>-1</sup>. – Answer</b></p>
<p><b>2022</b> <b>Section 1</b> <b>Question 1</b></p> <p><b>Acids and bases</b></p>	<p>Consider the following statements about acid-base indicators. Acid-base indicators</p> <p>(i) change colour as the concentration of hydrogen ions changes.            (ii) are weak acids or bases.            (iii) must not react with the reactants or products in a titration.            (iv) must be used in large volumes for the best results.</p> <p>Which of the above statements is/are correct?</p> <p>(a) i only  <b>(b) i and ii – Answer</b>            (c) i and iii            (d) i, ii, iii and iv</p>
<p><b>2022</b> <b>Section 1</b> <b>Question 5</b></p> <p><b>Acids and bases</b></p>	<p>Which of the following pairs, in equimolar amounts, would result in an acidic buffer solution?</p> <p>(i) <math>\text{CH}_3\text{COOH}/\text{CH}_3\text{COO}^-</math>            (ii) <math>\text{H}_2\text{CO}_3/\text{HCO}_3^-</math>            (iii) <math>\text{NH}_3/\text{NH}_4^+</math>            (iv) <math>\text{H}_2\text{SO}_4/\text{HSO}_4^-</math>            (v) <math>\text{CH}_3\text{NH}_2/\text{CH}_3\text{NH}_3^+</math></p> <p>(a) i, ii and iv            (b) iii and v            (c) ii, iii and v            (d) i and ii</p> <p><b>Answer is D.</b></p>
<p><b>2022</b> <b>Section 1</b> <b>Question 9</b></p> <p><b>Acids and bases</b></p>	<p>Consider an acid-base titration between hydrochloric acid solution and ammonia solution. Which of the following actions is <b>least</b> likely to cause an error when calculating the concentration of hydrochloric acid?</p> <p>(a) cleaning the pipette with distilled water before each titration  <b>(b) rinsing the sides of the conical flask with distilled water during the titration – Answer</b>            (c) measuring the ammonia solution in a 20 mL measuring cylinder            (d) leaving the funnel in the burette for each titration</p>

<b>2022</b> <b>Section 1</b> <b>Question 11</b>  <b>Acids and bases</b>	Select the <b>best</b> reason why the Brønsted-Lowry model is preferred over the Arrhenius model of Acids and bases. The Brønsted-Lowry model  <b>(a) includes a wider range of substances and can be used more broadly. – Answer</b> (b) demonstrates when hydrogen atoms are replaced by metals. (c) easily identifies that acids produce hydrogen ions and bases produce hydroxide ions. (d) demonstrates that non-metal oxides dissolve in water to produce acidic solutions.
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<b>2022</b> <b>Section 1</b> <b>Question 12</b>  <b>Acids and bases</b>	A student tested an acid with a pH meter. When dipped into the acid the pH was shown to be 4. What is the concentration of hydrogen ions in this solution?  (a) 0.0004 mol L <sup>-1</sup> (b) 0.00001 mol L <sup>-1</sup> <b>(c) 0.0001 mol L<sup>-1</sup> – Answer</b> (d) 0.004 mol L <sup>-1</sup>
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<b>2022</b> <b>Section 1</b> <b>Question 13</b>  <b>Acids and bases</b>	Identify the <b>weakest</b> acid in the following series.  <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th>Name</th> <th>Formula</th> <th>K<sub>a</sub> (25 °C)</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>acetic acid</td> <td>CH<sub>3</sub>COOH</td> <td>1.8 × 10<sup>-5</sup></td> </tr> <tr> <td>(b)</td> <td>chloroacetic acid</td> <td>ClCH<sub>2</sub>COOH</td> <td>1.3 × 10<sup>-3</sup></td> </tr> <tr> <td>(c)</td> <td>dichloroacetic acid</td> <td>Cl<sub>2</sub>CHCOOH</td> <td>4.5 × 10<sup>-2</sup></td> </tr> <tr> <td>(d)</td> <td>trichloroacetic acid</td> <td>CCl<sub>3</sub>COOH</td> <td>2.2 × 10<sup>-1</sup></td> </tr> </tbody> </table> <b>Answer is A.</b>		Name	Formula	K <sub>a</sub> (25 °C)	(a)	acetic acid	CH <sub>3</sub> COOH	1.8 × 10 <sup>-5</sup>	(b)	chloroacetic acid	ClCH <sub>2</sub> COOH	1.3 × 10 <sup>-3</sup>	(c)	dichloroacetic acid	Cl <sub>2</sub> CHCOOH	4.5 × 10 <sup>-2</sup>	(d)	trichloroacetic acid	CCl <sub>3</sub> COOH	2.2 × 10 <sup>-1</sup>
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<b>2022</b> <b>Section 1</b> <b>Question 14</b>  <b>Acids and bases</b>	Which of the following equations represents the HPO <sub>4</sub> <sup>2-</sup> ion acting as a Brønsted-Lowry acid?  (a) HPO <sub>4</sub> <sup>2-</sup> (aq) + H <sub>3</sub> O <sup>+</sup> (aq) ⇌ H <sub>2</sub> PO <sub>4</sub> <sup>-</sup> (aq) + H <sub>2</sub> O(l) (b) HPO <sub>4</sub> <sup>2-</sup> (aq) + H <sub>2</sub> O(l) ⇌ H <sub>2</sub> PO <sub>4</sub> <sup>-</sup> (aq) + OH <sup>-</sup> (aq) (c) HPO <sub>4</sub> <sup>2-</sup> (aq) ⇌ H <sup>+</sup> (aq) + PO <sub>4</sub> <sup>3-</sup> (aq) (d) HPO <sub>4</sub> <sup>2-</sup> (aq) + H <sub>2</sub> O(l) ⇌ PO <sub>4</sub> <sup>3-</sup> (aq) + H <sub>3</sub> O <sup>+</sup> (aq)  <b>Answer is D.</b>
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<b>2022</b> <b>Section 1</b> <b>Question 20</b>  <b>Acids and bases</b>	Which of the following is the dominant form of serine in acidic conditions?  <table border="1" style="margin-left: auto; margin-right: auto;"> <tbody> <tr> <td>(a)</td> <td style="text-align: center;"> <math display="block">\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_3\text{N}^+\text{-CH-COOH} \end{array}</math> </td> </tr> <tr> <td>(b)</td> <td style="text-align: center;"> <math display="block">\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_2\text{N-CH-COOH} \end{array}</math> </td> </tr> <tr> <td>(c)</td> <td style="text-align: center;"> <math display="block">\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_2\text{N-CH-COO}^- \end{array}</math> </td> </tr> <tr> <td>(d)</td> <td style="text-align: center;"> <math display="block">\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_3\text{N}^+\text{-CH-COO}^- \end{array}</math> </td> </tr> </tbody> </table> <b>Answer is a.</b>	(a)	$\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_3\text{N}^+\text{-CH-COOH} \end{array}$	(b)	$\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_2\text{N-CH-COOH} \end{array}$	(c)	$\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_2\text{N-CH-COO}^- \end{array}$	(d)	$\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_3\text{N}^+\text{-CH-COO}^- \end{array}$
(a)	$\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_3\text{N}^+\text{-CH-COOH} \end{array}$								
(b)	$\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_2\text{N-CH-COOH} \end{array}$								
(c)	$\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_2\text{N-CH-COO}^- \end{array}$								
(d)	$\begin{array}{c} \text{CH}_2\text{-OH} \\   \\ \text{H}_3\text{N}^+\text{-CH-COO}^- \end{array}$								

<b>2021</b> <b>Section 1</b> <b>Question 3</b>  <b>Acids and bases</b>	Consider the acids listed in the following table.														
	<table border="1"> <thead> <tr> <th>Name</th> <th>Formula</th> <th><math>K_a</math> (25 °C)</th> </tr> </thead> <tbody> <tr> <td>bromoacetic acid</td> <td><math>\text{CH}_2\text{BrCOOH}</math></td> <td><math>1.38 \times 10^{-3}</math></td> </tr> <tr> <td>dibromoacetic acid</td> <td><math>\text{CHBr}_2\text{COOH}</math></td> <td><math>3.31 \times 10^{-2}</math></td> </tr> <tr> <td>tribromoacetic acid</td> <td><math>\text{CBr}_3\text{COOH}</math></td> <td><math>1.91 \times 10^{-1}</math></td> </tr> </tbody> </table>	Name	Formula	$K_a$ (25 °C)	bromoacetic acid	$\text{CH}_2\text{BrCOOH}$	$1.38 \times 10^{-3}$	dibromoacetic acid	$\text{CHBr}_2\text{COOH}$	$3.31 \times 10^{-2}$	tribromoacetic acid	$\text{CBr}_3\text{COOH}$	$1.91 \times 10^{-1}$		
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tribromoacetic acid	$\text{CBr}_3\text{COOH}$	$1.91 \times 10^{-1}$													
Which of the following identifies the strongest acid and classifies it correctly as monoprotic, diprotic or triprotic?															
<table border="1"> <thead> <tr> <th></th> <th>Strongest acid</th> <th>Classification</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>bromoacetic acid</td> <td>monoprotic</td> </tr> <tr> <td>(b)</td> <td>dibromoacetic acid</td> <td>diprotic</td> </tr> <tr> <td>(c)</td> <td>tribromoacetic acid</td> <td>monoprotic</td> </tr> <tr> <td>(d)</td> <td>tribromoacetic acid</td> <td>triprotic</td> </tr> </tbody> </table>		Strongest acid	Classification	(a)	bromoacetic acid	monoprotic	(b)	dibromoacetic acid	diprotic	(c)	tribromoacetic acid	monoprotic	(d)	tribromoacetic acid	triprotic
	Strongest acid	Classification													
(a)	bromoacetic acid	monoprotic													
(b)	dibromoacetic acid	diprotic													
(c)	tribromoacetic acid	monoprotic													
(d)	tribromoacetic acid	triprotic													

**Answer is c.**

<b>2021</b> <b>Section 1</b> <b>Question 8</b>  <b>Acids and bases</b>	Which of the following equation/s demonstrate/s the Arrhenius model of Acids and bases?
	<p>(i) <math>\text{HCl}(\text{aq}) \rightarrow \text{H}^+(\text{aq}) + \text{Cl}^-(\text{aq})</math></p> <p>(ii) <math>\text{CH}_3\text{COOH}(\text{aq}) + \text{H}_2\text{O}(\ell) \rightarrow \text{CH}_3\text{COO}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})</math></p> <p>(iii) <math>\text{KOH}(\text{aq}) \rightarrow \text{K}^+(\text{aq}) + \text{OH}^-(\text{aq})</math></p> <p>(iv) <math>\text{H}_2\text{PO}_3^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq}) \rightarrow \text{H}_2\text{O}(\ell) + \text{H}_3\text{PO}_4(\text{aq})</math></p> <p>(a) i, ii, iii and iv            (b) i only            (c) ii and iii only  <b>(d) i and iii only – Answer</b></p>

<b>2021</b> <b>Section 1</b> <b>Question 9</b>  <b>Acids and bases</b>	The net ionic equation for the predominant hydrolysis reaction occurring in a 1.00 mol L <sup>-1</sup> potassium hydrogensulfate solution is:
	<p>(a) <math>\text{KHSO}_4(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{K}^+(\text{aq}) + \text{H}_2\text{SO}_4(\text{aq}) + \text{OH}^-(\text{aq})</math></p> <p>(b) <math>\text{K}^+(\text{aq}) + \text{HSO}_4^-(\text{aq}) \rightleftharpoons \text{K}^+(\text{aq}) + \text{H}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq})</math></p> <p>(c) <math>\text{HSO}_4^-(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{H}_2\text{SO}_4(\text{aq}) + \text{OH}^-(\text{aq})</math></p> <p>(d) <math>\text{HSO}_4^-(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{SO}_4^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})</math></p> <p><b>Answer is d.</b></p>

2021 Section 1 Question 14  Acids and bases	Consider the following pH values for a range of substances.																															
	<table border="1"> <thead> <tr> <th>pH</th> <th>0</th> <th>1</th> <th>2</th> <th>3</th> <th>4</th> <th>5</th> <th>6</th> <th>7</th> <th>8</th> <th>9</th> <th>10</th> <th>11</th> <th>12</th> <th>13</th> <th>14</th> </tr> </thead> <tbody> <tr> <td>Substance</td> <td>Battery acid</td> <td>Stomach acid</td> <td>Lemon juice</td> <td>Orange juice</td> <td>Beer</td> <td>Black coffee</td> <td>Milk</td> <td>Blood</td> <td>Sea water</td> <td>Toothpaste</td> <td>Laundry detergent</td> <td>Bathroom cleaner</td> <td>Hair straightener</td> <td>Oven cleaner</td> <td>Drain cleaner</td> </tr> </tbody> </table> <p>Based on these pH values, which one of the following statements about the concentration of hydronium ions is true?</p> <p>(a) It is 1000 times greater in sea water than in bathroom cleaner. – Answer  (b) It is twice as great in beer as it is in lemon juice.  (c) It is three times greater in beer than in hair straightener.  (d) It is 1 000 000 times greater in hair straightener than in milk.</p>	pH	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Substance	Battery acid	Stomach acid	Lemon juice	Orange juice	Beer	Black coffee	Milk	Blood	Sea water	Toothpaste	Laundry detergent	Bathroom cleaner	Hair straightener	Oven cleaner
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Substance	Battery acid	Stomach acid	Lemon juice	Orange juice	Beer	Black coffee	Milk	Blood	Sea water	Toothpaste	Laundry detergent	Bathroom cleaner	Hair straightener	Oven cleaner	Drain cleaner																	

2021 Section 1 Question 18  Acids and bases	An example of a random error in a titration is
	<p>(a) reading solution volumes to the bottom of the meniscus.  <b>(b) a gas bubble in the burette tap that comes out during a titration. – Answer</b>  (c) calculating the concentration of the primary standard incorrectly.  (d) rinsing down the sides of the conical flasks during titrations.</p>

2021 Section 1 Question 21  Acids and bases	Identify a conjugate acid-base pair in the reaction represented by the following equation:
	$\text{H}_2\text{PO}_4^-(\text{aq}) + \text{CH}_3\text{NH}_2(\text{aq}) \rightleftharpoons \text{CH}_3\text{NH}_3^+(\text{aq}) + \text{HPO}_4^{2-}(\text{aq})$ <p>(a) <math>\text{H}_2\text{PO}_4^-(\text{aq})</math> and <math>\text{CH}_3\text{NH}_2(\text{aq})</math>  (b) <math>\text{CH}_3\text{NH}_3^+(\text{aq})</math> and <math>\text{HPO}_4^{2-}(\text{aq})</math>  (c) <math>\text{H}_2\text{PO}_4^-(\text{aq})</math> and <math>\text{HPO}_4^{2-}(\text{aq})</math>  (d) <math>\text{H}_2\text{PO}_4^-(\text{aq})</math> and <math>\text{CH}_3\text{NH}_3^+(\text{aq})</math></p> <p><b>Answer is c.</b></p>

2020 Section 1 Question 2  Acids and bases	Which of the following classifies the given acids as monoprotic or polyprotic?														
	<table border="1"> <thead> <tr> <th></th> <th>Monoprotic</th> <th>Polyprotic</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>HCl</td> <td>CH<sub>3</sub>COOH</td> </tr> <tr> <td>(b)</td> <td>CH<sub>3</sub>CH<sub>2</sub>COOH</td> <td>H<sub>2</sub>SO<sub>4</sub></td> </tr> <tr> <td>(c)</td> <td>CH<sub>3</sub>COOH</td> <td>CH<sub>3</sub>CH<sub>2</sub>COOH</td> </tr> <tr> <td>(d)</td> <td>H<sub>2</sub>SO<sub>4</sub></td> <td>HCl</td> </tr> </tbody> </table> <p><b>Answer is b.</b></p>		Monoprotic	Polyprotic	(a)	HCl	CH <sub>3</sub> COOH	(b)	CH <sub>3</sub> CH <sub>2</sub> COOH	H <sub>2</sub> SO <sub>4</sub>	(c)	CH <sub>3</sub> COOH	CH <sub>3</sub> CH <sub>2</sub> COOH	(d)	H <sub>2</sub> SO <sub>4</sub>
	Monoprotic	Polyprotic													
(a)	HCl	CH <sub>3</sub> COOH													
(b)	CH <sub>3</sub> CH <sub>2</sub> COOH	H <sub>2</sub> SO <sub>4</sub>													
(c)	CH <sub>3</sub> COOH	CH <sub>3</sub> CH <sub>2</sub> COOH													
(d)	H <sub>2</sub> SO <sub>4</sub>	HCl													



<b>2020</b> <b>Section 1</b> <b>Question 18</b>  <b>Acids and bases</b>	<p>A chemist prepares solutions of nitrous acid and hydrocyanic acid that have the same concentration.</p> <p>The <math>K_a</math> values of these acids are:</p> <ul style="list-style-type: none"> <li>nitrous acid (<math>\text{HNO}_2</math>) is <math>4.6 \times 10^{-4}</math></li> <li>hydrocyanic acid (<math>\text{HCN}</math>) is <math>6.17 \times 10^{-10}</math>.</li> </ul> <p>Which of these two acids is the stronger and which has the higher pH?</p>														
	<table border="1"> <thead> <tr> <th></th> <th>Stronger acid</th> <th>Higher pH</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>nitrous acid</td> <td>nitrous acid</td> </tr> <tr> <td>(b)</td> <td>nitrous acid</td> <td>hydrocyanic acid</td> </tr> <tr> <td>(c)</td> <td>hydrocyanic acid</td> <td>hydrocyanic acid</td> </tr> <tr> <td>(d)</td> <td>hydrocyanic acid</td> <td>nitrous acid</td> </tr> </tbody> </table> <p><b>Answer is b.</b></p>		Stronger acid	Higher pH	(a)	nitrous acid	nitrous acid	(b)	nitrous acid	hydrocyanic acid	(c)	hydrocyanic acid	hydrocyanic acid	(d)	hydrocyanic acid
	Stronger acid	Higher pH													
(a)	nitrous acid	nitrous acid													
(b)	nitrous acid	hydrocyanic acid													
(c)	hydrocyanic acid	hydrocyanic acid													
(d)	hydrocyanic acid	nitrous acid													

<b>2020</b> <b>Section 1</b> <b>Question 25</b>  <b>Acids and bases</b>	<p>A chemist performed an acid-base titration. The acid was in a burette and a pipette was used to deliver a known quantity of the base into a conical flask. Which of the following gives the final rinse solution for each of these pieces of equipment?</p>																							
	<table border="1"> <thead> <tr> <th></th> <th colspan="3">Final rinse solution</th> </tr> <tr> <th></th> <th>Burette</th> <th>Pipette</th> <th>Conical flask</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>acid</td> <td>water</td> <td>base</td> </tr> <tr> <td>(b)</td> <td>acid</td> <td>base</td> <td>water</td> </tr> <tr> <td>(c)</td> <td>water</td> <td>base</td> <td>water</td> </tr> <tr> <td>(d)</td> <td>water</td> <td>water</td> <td>base</td> </tr> </tbody> </table> <p><b>Answer is b.</b></p>		Final rinse solution				Burette	Pipette	Conical flask	(a)	acid	water	base	(b)	acid	base	water	(c)	water	base	water	(d)	water	water
	Final rinse solution																							
	Burette	Pipette	Conical flask																					
(a)	acid	water	base																					
(b)	acid	base	water																					
(c)	water	base	water																					
(d)	water	water	base																					

<b>2019</b> <b>Section 1</b> <b>Question 1</b>  <b>Acids and bases</b>	<p>Boric acid, which is a weak acid, was titrated with standardised sodium hydroxide solution.</p> <p>Which one of the indicators listed below would be the <b>most</b> suitable to use in this titration?</p>														
	<table border="1"> <thead> <tr> <th></th> <th>Indicator</th> <th>Range of colour change (pH)</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>thymol blue</td> <td>1 – 3</td> </tr> <tr> <td>(b)</td> <td>bromocresol green</td> <td>3.8 – 5.4</td> </tr> <tr> <td>(c)</td> <td>cresolphthalein</td> <td>8 – 10</td> </tr> <tr> <td>(d)</td> <td>alizarin yellow</td> <td>10 – 12</td> </tr> </tbody> </table> <p><b>Answer is c.</b></p>		Indicator	Range of colour change (pH)	(a)	thymol blue	1 – 3	(b)	bromocresol green	3.8 – 5.4	(c)	cresolphthalein	8 – 10	(d)	alizarin yellow
	Indicator	Range of colour change (pH)													
(a)	thymol blue	1 – 3													
(b)	bromocresol green	3.8 – 5.4													
(c)	cresolphthalein	8 – 10													
(d)	alizarin yellow	10 – 12													

<b>2019</b> <b>Section 1</b> <b>Question 8</b>  <b>Acids and bases</b>	<p>A distinguishing feature of strong acids is that they</p>
	<p>(a) produce high concentrations of hydronium ions (<math>\text{H}_3\text{O}^+</math>) in solution.</p> <p><b>(b) have high acidity constants. – Answer</b></p> <p>(c) contain loosely-held hydrogen ions (<math>\text{H}^+</math>) in solution.</p> <p>(d) ionise rather than dissociate in water.</p>

<b>2019</b> <b>Section 1</b> <b>Question</b> <b>16</b>  <b>Acids and</b> <b>bases</b>	Which one of the following statements about an aqueous solution with a pH less than zero at 25.0 °C is true?  (a) Such a solution cannot exist at 25.0 °C. (b) There are no OH <sup>-</sup> (aq) ions present. <b>(c) The concentration of H<sup>+</sup>(aq) ions is much greater than the concentration of OH<sup>-</sup> (aq) ions.</b> – Answer (d) There are no H <sup>+</sup> (aq) ions present as they have formed water molecules through the process of neutralisation.
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<b>2019</b> <b>Section 1</b> <b>Question</b> <b>24</b>  <b>Acids and</b> <b>bases</b>	Which one of the following underlined species is acting as an acid?  (a) <u>CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>NH<sub>2</sub></u> + CH <sub>3</sub> COOH ⇌ CH <sub>3</sub> CH <sub>2</sub> CH <sub>2</sub> CH <sub>2</sub> NH <sub>3</sub> <sup>+</sup> + CH <sub>3</sub> COO <sup>-</sup> (b) HSO <sub>3</sub> <sup>-</sup> + NH <sub>3</sub> ⇌ <u>SO<sub>3</sub><sup>2-</sup></u> + NH <sub>4</sub> <sup>+</sup> (c) NH <sub>4</sub> <sup>+</sup> + CH <sub>3</sub> COO <sup>-</sup> ⇌ <u>NH<sub>3</sub></u> + CH <sub>3</sub> COOH (d) <u>[Fe(H<sub>2</sub>O)<sub>6</sub>]<sup>3+</sup></u> + H <sub>2</sub> O ⇌ [Fe(OH)(H <sub>2</sub> O) <sub>5</sub> ] <sup>2+</sup> + H <sub>3</sub> O <sup>+</sup>  <b>Answer is d.</b>
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Marking Guide – Section 2

2023  
Section 2  
Question  
26

Acids and  
bases

Nitrous acid,  $\text{HNO}_2$ , and formic acid,  $\text{HCOOH}$ , are both monoprotic weak acids.

(a) Outline the difference between the terms ‘monoprotic’ and ‘polyprotic’. Use equations to illustrate your answer. (4 marks)

Description	Marks
monoprotic – one hydrogen ion available for ionisation	1
polyprotic – two or more hydrogen ions available for ionisation	1
minimum of two appropriate equations	1–2
<b>Total</b>	<b>4</b>
$\text{HX} + \text{H}_2\text{O} \rightarrow \text{X}^- + \text{H}_3\text{O}^+$ $\text{H}_2\text{X} + \text{H}_2\text{O} \rightarrow \text{HX}^- + \text{H}_3\text{O}^+$ $\text{HX}^- + \text{H}_2\text{O} \rightleftharpoons \text{X}^{2-} + \text{H}_3\text{O}^+$	
Note: accept Arrhenius equations	

(b) Using the Brønsted-Lowry model of acids and bases, write the ionisation equations for both acids. (2 marks)

Description	Marks
Both equations correct	2
One equation correct	1
<b>Total</b>	<b>2</b>
$\text{HNO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{NO}_2^- + \text{H}_3\text{O}^+$ $\text{HCOOH} + \text{H}_2\text{O} \rightleftharpoons \text{HCOO}^- + \text{H}_3\text{O}^+$	
Note: award a maximum of 1 mark if double arrows not present	

(c) In the equations above, circle the Brønsted-Lowry bases. (2 marks)

Description	Marks
All Brønsted-Lowry bases correctly circled	2
Two Brønsted-Lowry bases correctly circled	1
<b>Total</b>	<b>2</b>
$\text{H}_2\text{O}, \text{NO}_2^-, \text{HCOO}^-$	

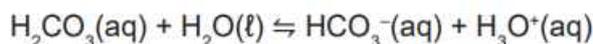
(d) Using **one** of the two acids as an example, describe how Arrhenius theory of acids and bases differs from Brønsted-Lowry theory. Include an appropriate Arrhenius theory equation in your answer. (3 marks)

Description	Marks
Recognition that an Arrhenius acid is a substance that will (ionise and) produce $\text{H}^+$ in aqueous solution	1
Recognition that Brønsted-Lowry acid-base reaction involves proton transfer/acids donate protons	1
Appropriate equation	1
<b>Total</b>	<b>3</b>
$\text{HNO}_2 \rightleftharpoons \text{H}^+ + \text{NO}_2^-$ or $\text{HCOOH} \rightleftharpoons \text{H}^+ + \text{HCOO}^-$	

**2023  
Section 2  
Question  
28**

**Acids and  
bases**

The pH of blood is maintained in a narrow range by the carbonic acid and hydrogencarbonate buffer system, represented by the following equilibrium:



(a) Define the term 'buffer' and identify the chemical species in this system responsible for its buffering capacity. Specify the role of each chemical species you identify in your answer. (3 marks)

Description	Marks
Recognition that a buffer resists changes to pH when small amounts of acid or base are added to the solution	1
Recognition that in this system $\text{H}_2\text{CO}_3$ (is the weak acid that) reacts with any added base	1
Recognition that in this system $\text{HCO}_3^-$ (is the conjugate base that) reacts with any added acid	1
<b>Total</b>	<b>3</b>
Accept other relevant answers.	

(b) Explain what will happen in the blood when there is an elevated concentration of carbon dioxide. Predict how blood pH is affected. Include relevant equations in your answer. (5 marks)

Description	Marks
Recognition that elevated concentration of carbon dioxide in the blood increases the concentration of carbonic acid in the blood	1
Equation: $\text{CO}_2(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{H}_2\text{CO}_3(\text{aq})$	1
Recognition that the increase in blood carbonic acid concentration shifts the blood buffer equilibrium to the right, increasing $\text{H}_3\text{O}^+$ concentration	1
Recognition that the $\text{HCO}_3^-$ will react with the additional $\text{H}_3\text{O}^+$ , or equation: $\text{HCO}_3^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq}) \rightarrow \text{H}_2\text{CO}_3(\text{aq}) + \text{H}_2\text{O}(\ell)$	1
Recognition that there is a small decrease in pH	1
<b>Total</b>	<b>5</b>

**2023  
Section 2  
Question  
33**

**Acids and  
bases**

A barium hydroxide solution is titrated against an ammonium chloride solution to produce barium chloride, ammonia and water.

(a) Write a balanced ionic equation for this reaction. (2 marks)

Description	Marks
Equation $\text{OH}^-(\text{aq}) + \text{NH}_4^+(\text{aq}) \rightarrow \text{NH}_3(\text{aq}) + \text{H}_2\text{O}(\ell)$	
Correct species	1
Correct balancing	1
<b>Total</b>	<b>2</b>
Note: if molecular equation, award maximum of 1 mark.	

Consider the following indicators

Indicator	pH change range	Colour change
Methyl orange	3.1–4.4	Red to yellow
Bromothymol blue	6.2–7.6	Yellow to blue
Phenolphthalein	8.3–10.0	Colourless to pink

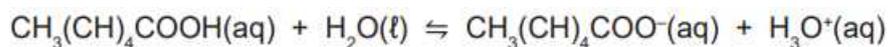
(b) Identify the most appropriate indicator for this titration and justify your choice, using an equation to support your answer. (5 marks)

Description	Marks
Phenolphthalein	1
Recognition that (at the equivalence point) the ammonia hydrolyses to produce $\text{OH}^-$	1
Recognition that at (equivalence point) $[\text{OH}^-] > [\text{H}^+]$ (and solution is basic)	1
Recognition that indicator changes in the basic range/indicator colour change/end point is a similar pH to the equivalence point	1
Appropriate equation $\text{NH}_3(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq})$	1
<b>Total</b>	<b>5</b>

**2023  
Section 2  
Question  
34**

**Acids and  
bases**

Sorbic acid is a monoprotic weak acid that occurs widely in nature and is used as a food preservative due to its antimicrobial properties. The ionisation of sorbic acid in water to the sorbate ion and hydronium ion is shown in the equation below:



(a) Write the equilibrium constant K expression for the ionisation of sorbic acid in water. (2 marks)

Description	Marks
$K = \frac{[\text{CH}_3(\text{CH})_4\text{COO}^-][\text{H}_3\text{O}^+]}{[\text{CH}_3(\text{CH})_4\text{COOH}]}$	1–2
<b>Total</b>	<b>2</b>

(b) Under certain conditions, a  $0.250 \text{ mol L}^{-1}$  aqueous solution of sorbic acid has a pH of 2.23. Calculate the concentration of  $\text{H}_3\text{O}^+$  to determine the percentage yield of the sorbate ion at equilibrium in 1.00 L of the solution. (4 marks)

Description	Marks
$[\text{H}_3\text{O}^+] = 10^{-\text{pH}} = 10^{-2.23} = 5.89 \times 10^{-3} \text{ mol L}^{-1}$	1
for 1.00 L solution $n(\text{H}_3\text{O}^+) = n(\text{CH}_3(\text{CH})_4\text{COO}^-) = 5.89 \times 10^{-3} \text{ mol}$	1
for 1.00 L solution $n(\text{CH}_3(\text{CH})_4\text{COOH}) = 0.250 \text{ mol}$	1
% yield sorbate ion $= n(\text{CH}_3\text{CH}(\text{OH})\text{COO}^-) / n(\text{CH}_3\text{CH}(\text{OH})\text{COOH}) \times 100$ $= (5.89 \times 10^{-3} / 0.250) \times 100$ $= 2.36 \%$	1
<b>Total</b>	<b>4</b>

(c) Explain the classification of sorbic acid as a weak acid with reference to both your answer to part (b) above and its acidity constant value  $K_a = 1.73 \times 10^{-5}$  ( $20^\circ\text{C}$ ). (3 marks)

Description	Marks
Recognition that weak acids undergo partial/incomplete ionisation in water	1
Explanation that the answer to part (b) is numerically small, indicating that only a small percentage of sorbic acid in solution is ionised	1
Recognition that the value of $K_a$ is less than one which indicates a greater proportion of reactants compared to products	1
<b>Total</b>	<b>3</b>
Note: accept answer based on the small value of $K_a$ .	

**2022**  
**Section 2**  
**Question**  
**28**

**Acids and**  
**bases**

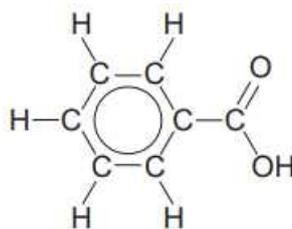
Explain why potassium hydrogensulfite,  $\text{KHSO}_3$ , produces an acidic solution when dissolved in water, while potassium hydrogencarbonate,  $\text{KHCO}_3$ , produces a basic solution when dissolved in water. Use equations to illustrate your explanation.

Description	Marks
Recognition that the $\text{K}^+$ ions in solution are neutral/do not react with water.	1
Recognition that the $\text{HSO}_3^-$ and $\text{HCO}_3^-$ ions undergo hydrolysis reactions	1
Recognition that for the hydrolysis reactions for $\text{HSO}_3^-$ , the reaction that produces $\text{H}_3\text{O}^+$ occurs to a greater extent than the reaction that produces $\text{OH}^-$ , (therefore the solution will be acidic)	1
Recognition that for the hydrolysis reactions for $\text{HCO}_3^-$ , the reaction that produces $\text{OH}^-$ occurs to a greater extent than the reaction that produces $\text{H}_3\text{O}^+$ , (therefore the solution is basic).	1
Recognition that a basic solution has a greater concentration of $\text{OH}^-$ ions than $\text{H}_3\text{O}^+$ ions/an acidic solution has a greater concentration of $\text{H}_3\text{O}^+$ ions than $\text{OH}^-$ ions.	1
Minimum of two appropriate equations, which could include: At least one equation for $\text{HSO}_3^-$ $\text{HSO}_3^-(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{SO}_3^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$ $(\text{HSO}_3^-(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{H}_2\text{SO}_3(\text{aq}) + \text{OH}^-(\text{aq}))$	1
At least one equation for $\text{HCO}_3^-$ $\text{HCO}_3^-(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{H}_2\text{CO}_3(\text{aq}) + \text{OH}^-(\text{aq})$ $(\text{HCO}_3^-(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{CO}_3^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq}))$	1
<b>Total</b>	<b>7</b>

2021  
Section 2  
Question  
28

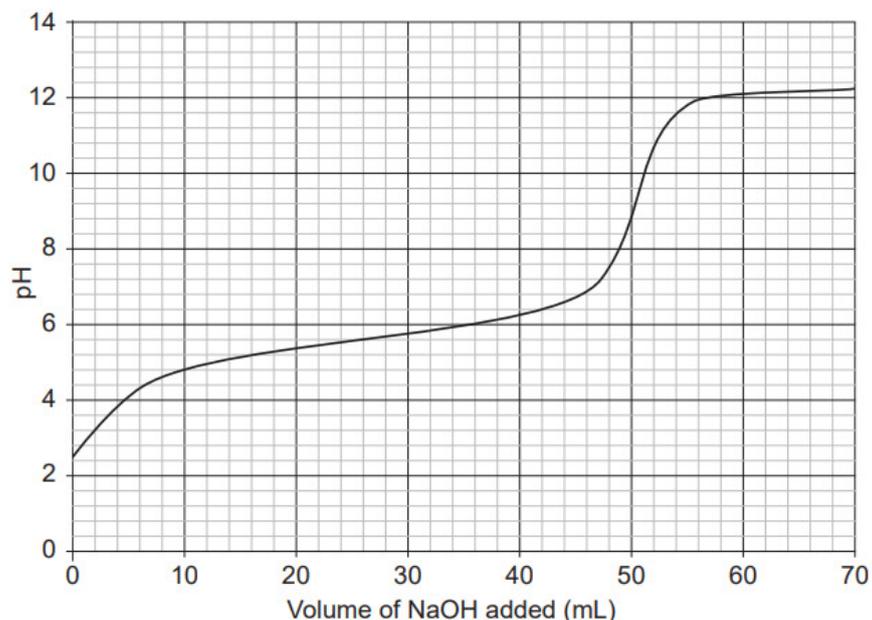
Acids and  
bases

Benzoic acid ( $C_6H_5COOH$ ) is a weak acid. Its structural formula is shown below.



Benzoic acid has a range of uses, including the manufacture of dyes, perfumes and insect repellents. The benzoic acid content of these products can be determined by titration with sodium hydroxide. The salt produced in the titration reaction is sodium benzoate,  $C_6H_5COONa$ .

The following graph shows a typical acid-base titration curve for benzoic acid and sodium hydroxide.



(a) Which of the indicators listed in the following table would be most suitable for use in this titration? With reference to the above titration curve, explain your choice. (3 marks)

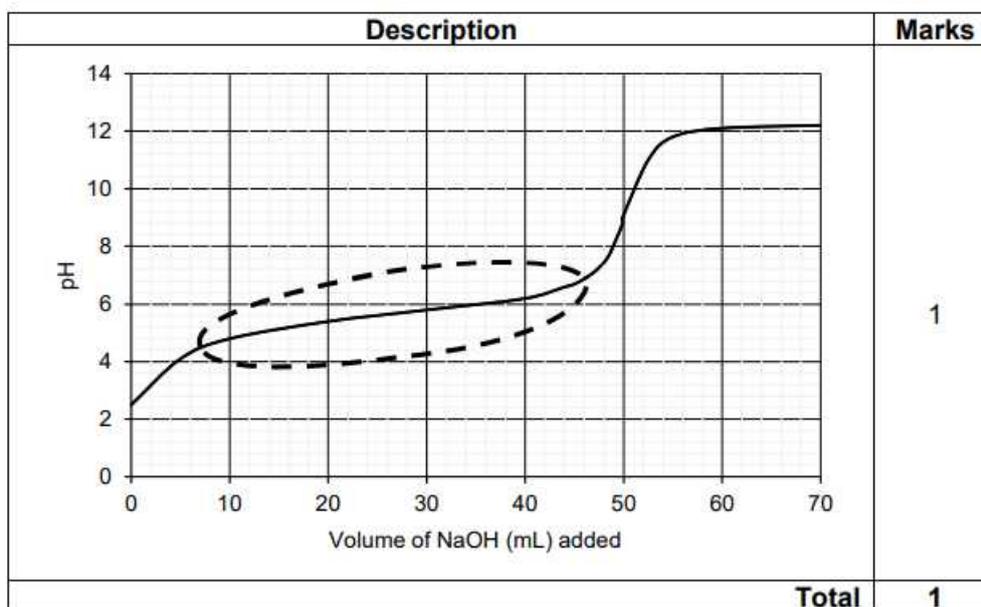
Name of Indicator	pH Range
Bromocresol green	3.8 – 5.4
Azolitmin	4.5 – 8.3
Cresolphthalein	8.2 – 9.8
Indigo carmine	11.4 – 13.0

Name of Indicator	pH Range
Bromocresol green	3.8–5.4
Azolitmin	4.5–8.3
Cresolphthalein	8.2–9.8
Indigo carmine	11.4–13.0

Description	Marks
The end point of a titration/the indicator changing colour should be as close as possible to the equivalence point.	1
Recognition that the equivalence point of this titration is about pH 9.	1
Therefore, cresolphthalein is the most suitable (because it is the only listed indicator that changes colour at this desired pH).	1
<b>Total</b>	<b>3</b>
Note: • No marks allocated for stating that it is a weak acid–strong base titration.	

(b) Buffering is observed during this titration.

(i) Circle the region on the titration curve on page 14 (above) to show where the buffering occurs. (1 mark)



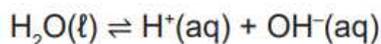
(ii) Define the term buffering and explain why it occurs during this titration in the region that you circled in part (b)(i). Include an equation to support your explanation. (5 marks)

Description	Marks
Buffering is the ability of a solution to resist significant changes to its pH when small quantities of acid or base are added to it.	1
Buffering occurs in the circled region because a weak acid ( $C_6H_5COOH$ ) and its conjugate base ( $C_6H_5COO^-$ ) are both present.	1
Equation: $C_6H_5COOH(aq) + OH^-(aq) \rightarrow C_6H_5COO^-(aq) + H_2O(l)$ or $C_6H_5COOH(aq) + H_2O(l) \rightleftharpoons C_6H_5COO^-(aq) + H_3O^+(aq)$	1–2
In the buffering region there is no significant/dramatic increase in pH because the added hydroxide ions are consumed by the benzoic acid.	1
<b>Total</b>	<b>5</b>
Note: • State symbols are not required in the equation/s. • Equation/s must include the correct arrow/s for full marks to be awarded.	

2021  
Section 2  
Question  
29

Acids and  
bases

Water can self-ionise, as shown by the following equation:



The reaction equilibrium and the pH of water are both affected by changes in temperature. The data in the following table show how changing the temperature affects the pH of pure water.

Temperature (°C)	pH of water
0	7.47
25	7.00
50	6.63
75	6.35

(a) Show how the tabulated data and Le Châtelier's Principle can be used to deduce whether the self-ionisation of water is exothermic or endothermic. Calculations are **not** required. (5 marks)

Description	Marks
The data in the table shows that the pH of pure water decreases as the temperature increases.	1
This means that the hydrogen (hydronium) ion concentration increases as the temperature increases.	1
The increase in $[\text{H}^+]$ shows the forward reaction (self-ionisation of water) has been favoured at higher temperature.	1
(Le Châtelier's Principle predicts) as temperature increases, the endothermic direction is favoured.	1
The forward reaction (self-ionisation of water) is, therefore, endothermic.	1
<b>Total</b>	<b>5</b>

(b) Calculate the  $\text{H}^+(\text{aq})$  and  $\text{OH}^-(\text{aq})$  concentrations of pure water at  $100.0\text{ }^\circ\text{C}$  given that  $K_w$  is equal to  $5.13 \times 10^{-15}$  at that temperature. (2 marks)

Description	Marks
Recognition that, in pure water, $[\text{H}^+] = [\text{OH}^-]$ regardless of the temperature	1
$[\text{H}^+] = [\text{OH}^-] = \sqrt{5.13 \times 10^{-15}} = 7.16 \times 10^{-8} \text{ mol L}^{-1}$	1
<b>Total</b>	<b>2</b>

**2019  
Section 2  
Question  
27**

**Acids and  
bases**

Calcium hypochlorite,  $\text{Ca}(\text{OCl})_2(\text{s})$ , is used for the treatment of water in swimming pools and is sold as 'pool chlorine'.

(a) Explain why a basic solution is produced when 'pool chlorine' is dissolved in the pool water. Include an equation in your answer. (4 marks)

Description	Marks
This basicity is due to the hydrolysis of the hypochlorite ion	1
causing an <b>excess</b> of $\text{OH}^-(\text{aq})$ ions in solution or $[\text{OH}^-] > [\text{H}^+]$	1
Two marks for an equation	
Correct reactants and products	1
Equation is balanced	1
<b>Total</b>	<b>4</b>
Example of a two mark equation: $\text{OCl}^-(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{HOCl}(\text{aq}) + \text{OH}^-(\text{aq})$	
Alternate equation: $\text{Ca}(\text{OCl})_2(\text{s}) + 2 \text{H}_2\text{O}(\ell) \rightleftharpoons 2 \text{HOCl}(\text{aq}) + \text{Ca}^{2+}(\text{aq}) + 2 \text{OH}^-(\text{aq})$	
<b>Note:</b> The term 'hydrolysis', while desirable, is not essential; recognition that the hypochlorite ion reacts with water to produce hydroxide ions will suffice. Just saying hydrolysis is insufficient for a mark without referring to the production of the hydroxide ion.	

A pool chemical used to counteract the basicity of the pool water is hydrochloric acid,  $\text{HCl}(\text{aq})$ . It is sold as 'pool acid'.

(b) State what happens to the pH of the pool water when 'pool acid' is added to the pool water. Include an equation to illustrate your statement. (3 marks)

Description	Marks
The pH will decrease as more 'Pool Acid' is added	1
Two marks for an equation	
Correct reactants and products	1
Equation is balanced	1
<b>Total</b>	<b>3</b>
Example of a two mark equation: $\text{OCl}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq}) \rightleftharpoons \text{HOCl}(\text{aq}) + \text{H}_2\text{O}(\ell)$	
Accept $\begin{aligned} \text{OCl}^-(\text{aq}) + \text{H}^+(\text{aq}) &\rightleftharpoons \text{HOCl}(\text{aq}) \\ \text{H}_3\text{O}^+(\text{aq}) + \text{OH}^-(\text{aq}) &\rightleftharpoons 2 \text{H}_2\text{O}(\ell) \\ \text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) &\rightleftharpoons \text{H}_2\text{O}(\ell) \end{aligned}$	

'Pool chlorine' and 'pool acid' must be stored separately from each other because calcium hypochlorite can react explosively on contact with hydrochloric acid. The equation for this reaction is given below.



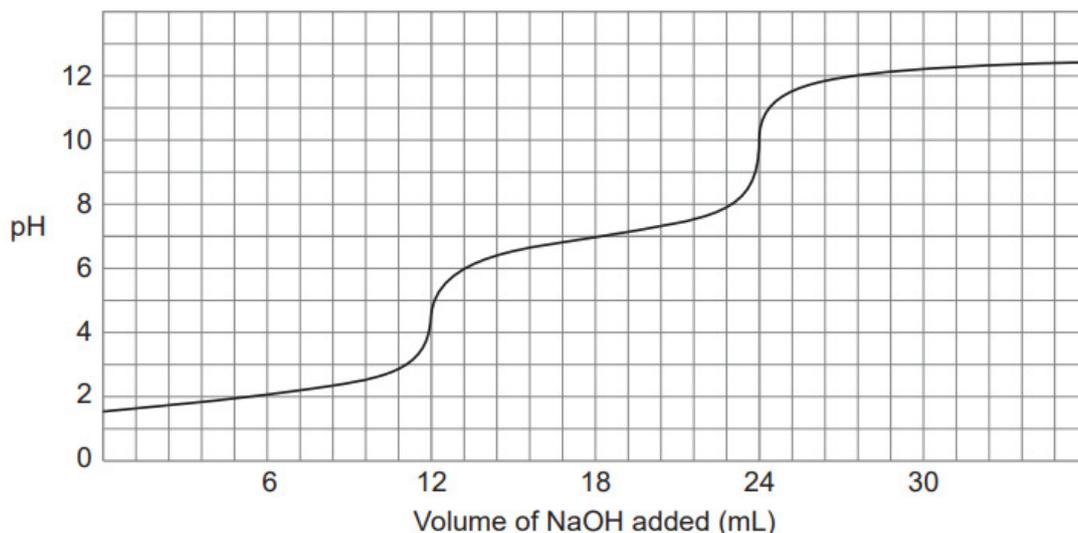
(c) Sketch a clearly-labelled energy profile diagram illustrating the reaction between the 'pool chlorine' and the 'pool acid'. (6 marks)

Description	Marks
Diagram appropriately labelled:	
vertical axis (Potential) Energy or $E_p$ or Enthalpy (H) <b>and</b> horizontal axis Reaction Co-ordinate or Reaction Progress	1
reactants on LHS horizontal line <b>and</b> products on RHS horizontal line	1
$E_a$ : Activation Energy <b>and</b> $\Delta H$ : Change in Enthalpy or Heat of Reaction	1
Sketch clearly shows:	
$\Delta H$ is negative	1
$\Delta H$ is relatively large	1
$E_a$ is very small relative to $\Delta H$ .	1
<b>Total</b>	<b>6</b>

2019  
Section 2  
Question  
35

Acids and  
bases

Consider the following acid-base titration curve that is produced by the addition of 0.166 mol L<sup>-1</sup> sodium hydroxide solution to 20.00 mL of an approximately 0.1 mol L<sup>-1</sup> diprotic acid.



(a) (i) Indicate whether the diprotic acid is most likely to be sulfuric acid, H<sub>2</sub>SO<sub>4</sub>(aq) or sulfurous acid, H<sub>2</sub>SO<sub>3</sub>(aq), by circling your choice below. (1 mark)

Description	Marks
Sulfurous acid (is circled)	1
<b>Total</b>	<b>1</b>

(ii) Making reference to the titration curve shown above, give two reasons for your answer. (2 marks)

Description	Marks
One mark for each reason	
<p>Answers could include:</p> <ul style="list-style-type: none"> <li>0.100 mol L<sup>-1</sup> sulfuric acid would have a starting pH less than 1</li> <li>while the starting pH for sulfurous acid would be greater than 1 as it is a weak acid</li> </ul> <p style="text-align: center; border: 1px solid gray; padding: 5px;">For copyright reasons this text cannot be reproduced in the online version of this document, but may be viewed at the link listed on the acknowledgements page.</p> <p><b>or</b></p> <p>sulfuric acid is a strong acid so its titration curve would have only one plateaux and one end point</p> <ul style="list-style-type: none"> <li>the equivalence point of a strong acid titration is usually listed as 7.00. In the case of sulfuric acid, the second step of dissociation is not that strong, and end point is shifted up by tenths of the pH unit - but still very close to 7</li> <li>the first equivalence point is less than 7 (~4.2), the second equivalence point is (~9.6); this indicates a weak acid – thus sulfurous acid.</li> </ul>	1–2
<b>Total</b>	<b>2</b>

(b) Predict the effect (increase, decrease or no change) on the calculated concentration of the acid for the following two systematic errors that can occur in a titration and justify your choice. (4 marks)

Description	Marks
<b>Error I</b>	
Circles decrease	1
Justification: <ul style="list-style-type: none"> <li>states that the acid solution is diluted (and so amount of NaOH(aq) required to reach equivalence point is less).</li> </ul>	1
<b>Error II</b>	
Circles decrease	1
Justification: <ul style="list-style-type: none"> <li>states that as only first equivalence point reached, (less NaOH(aq) added than required to completely neutralised acid).</li> </ul>	1
<b>or</b>	
Circles no change	1
Justification: <ul style="list-style-type: none"> <li>states first equivalence point reached and so requires calculation adjustments</li> </ul>	1
<b>Total</b>	<b>4</b>
<b>Note:</b> <ul style="list-style-type: none"> <li>The justification must be correct for the noted change (increase, decrease, no change) to be allocated a mark.</li> </ul>	

(c) State one reason why these errors are classified as systematic errors rather than random errors. (1 mark)

Description	Marks
Each error produces volumes of NaOH used that are either consistently above or below the actual value	1
<b>Total</b>	<b>1</b>
<b>Note:</b> <ul style="list-style-type: none"> <li>Just stating the same mistake is made each time is insufficient for a mark.</li> </ul>	

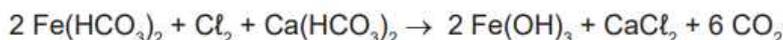
Marking Guide – Section 3

2023  
Section 3  
Question  
38

Acids and  
bases

Groundwater, in addition to dam water and desalinated seawater, is part of the water supply to Perth homes. Groundwater contains a wide variety of chemicals that can affect the quality of drinking water. One of the contaminants is iron, often found in the form of iron(II) hydrogencarbonate.

The iron can be removed by the addition of chlorine gas. Enough calcium hydrogencarbonate is added to maintain a slightly basic pH. The reaction can be represented by the following equation:



(a) 7.00 g of chlorine gas is bubbled through 30 000 L of groundwater containing 39 010 mg of iron(II) hydrogencarbonate to which 16.22 g of calcium hydrogencarbonate has been added. Calculate the mass of iron(III) hydroxide that will be precipitated. (8 marks)

Description	Marks
$n(\text{Cl}_2) = 7.00/70.9$ $= 0.0987 \text{ mol}$	1
$n(\text{Fe}(\text{HCO}_3)_2) = 39010/1000/177.886$ $= 0.2193 \text{ mol}$	1
$n(\text{Ca}(\text{HCO}_3)_2) = 16.22/162.116$ $= 0.100 \text{ mol}$	1
1 mole of $\text{Cl}_2$ reacts with 2 moles of $\text{Fe}(\text{HCO}_3)_2$ and 1 mole of $\text{Ca}(\text{HCO}_3)_2$ 0.0987 mol of $\text{Cl}_2$ will react with 0.197 mol $\text{Fe}(\text{HCO}_3)_2$ and 0.0987 mol of $\text{Ca}(\text{HCO}_3)_2$ Since $n(\text{Fe}(\text{HCO}_3)_2)$ required is less than $n(\text{Fe}(\text{HCO}_3)_2)$ available and the $n(\text{Ca}(\text{HCO}_3)_2)$ required is less than the $n(\text{Ca}(\text{HCO}_3)_2)$ available $\text{Cl}_2$ is limiting reagent (or similar explicit statement)	1–3
$n(\text{Fe}(\text{OH})_3) = 2n(\text{Cl}_2)$ $= 0.197 \text{ mol}$	1
$m(\text{Fe}(\text{OH})_3) = 0.197 \times 106.874$ $= 21.1 \text{ g}$	1
<b>Total</b>	<b>8</b>

(b) Calculate the concentration of calcium chloride in the final solution. (2 marks)

Description	Marks
$n(\text{CaCl}_2) = n(\text{Cl}_2)$ $= 0.0987 \text{ mole}$	1
$c(\text{CaCl}_2) = 0.0987/30000$ $= 3.29 \times 10^{-6} \text{ mol L}^{-1}$	1
<b>Total</b>	<b>2</b>

**2022**  
**Section 3**  
**Question**  
**38**

**Acids and**  
**bases**

A tablet used to reduce the effects of indigestion contained a mixture of sodium hydrogencarbonate and sodium carbonate.

Five tablets were crushed and dissolved in distilled water, which was added to a volumetric flask and the volume made up to 250.0 mL.

Aliquots (25.00 mL) of the solution were transferred to conical flasks and titrated against a 0.0955 mol L<sup>-1</sup> solution of hydrochloric acid.

The masses of sodium hydrogencarbonate and sodium carbonate in each tablet were found to be:

- sodium hydrogencarbonate – 106.5 mg
- sodium carbonate – 187.5 mg.

(a) Calculate the average titre that would have been obtained to produce these results. Use the following molar masses in your calculation:

- M(NaHCO<sub>3</sub>) = 84.008 g mol<sup>-1</sup>
- M(Na<sub>2</sub>CO<sub>3</sub>) = 105.99 g mol<sup>-1</sup>. (8 marks)

Description	Marks
$n(\text{NaHCO}_3) = \frac{0.1065}{84.008} \times 5$ $= 6.339 \times 10^{-3} \text{ mol in 250 mL}$	1
$n(\text{Na}_2\text{CO}_3) = \frac{0.1875}{105.99} \times 5$ $= 8.845 \times 10^{-3} \text{ mol in 250 mL}$	1
$n(\text{NaHCO}_3) = \frac{25}{250} \times 6.339 \times 10^{-3}$ $= 6.339 \times 10^{-4} \text{ mol in one aliquot}$	1
$n(\text{Na}_2\text{CO}_3) = \frac{25}{250} \times 8.845 \times 10^{-3}$ $= 8.845 \times 10^{-4} \text{ mol in one aliquot}$	1
Recognition that $n(\text{H}^+) = n(\text{NaHCO}_3)$ in titration $= 6.339 \times 10^{-4} \text{ mol}$	1
Recognition that $n(\text{H}^+) = 2 n(\text{Na}_2\text{CO}_3)$ in titration $= 2(8.845 \times 10^{-4})$ $= 1.769 \times 10^{-3} \text{ mol}$	1
$n(\text{H}^+ \text{ total}) = 6.339 \times 10^{-4} + 1.769 \times 10^{-3}$ $= 2.403 \times 10^{-3} \text{ mol}$	1
$V(\text{HCl required}) = \frac{2.403 \times 10^{-3}}{0.0955}$ $= 0.02516 \text{ L (25.16 mL)}$	1
<b>Total</b>	<b>8</b>
<b>Note: accept alternative approaches.</b>	

(b) Hydrochloric acid must be standardised against a primary standard before it can be used in titrations such as the one described in part (a). List three properties of substances suitable for use as primary standards. (3 marks)

Description	Marks
Lists three properties of substances used as primary standards	3
Lists two properties of substances used as primary standards	2
States one property of substances used as primary standards	1
<b>Total</b>	<b>3</b>

Answers could include:

- high molar mass
- not hygroscopic
- not deliquescent
- available with a known purity
- does not react with substances in the atmosphere (e.g. CO<sub>2</sub>)
- (highly) soluble
- predictive reactivity.

(c) Methyl orange, which changes colour between a pH of 3.1 and a pH of 4.4, was chosen as the indicator for this reaction. Justify, with the aid of an equation, the selection of this indicator for the titration. (4 marks)

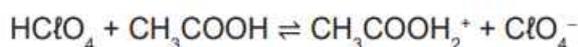
Description	Marks
Recognition that CO <sub>2</sub> is produced in the reaction with acid	1
Recognition that CO <sub>2</sub> reacts with water to produce H <sub>3</sub> O <sup>+</sup>	1
therefore, at the equivalence point there will be a greater concentration of H <sub>3</sub> O <sup>+</sup> than OH <sup>-</sup> , so the solution will have a pH of less than 7	1
appropriate equation (accept any reasonable, correct equation) e.g. CO <sub>2</sub> (aq) + 2 H <sub>2</sub> O(l) ⇌ HCO <sub>3</sub> <sup>-</sup> + H <sub>3</sub> O <sup>+</sup> (aq) H <sub>2</sub> CO <sub>3</sub> (aq) + H <sub>2</sub> O(l) ⇌ HCO <sub>3</sub> <sup>-</sup> + H <sub>3</sub> O <sup>+</sup> (aq)	1
<b>Total</b>	<b>4</b>

2021  
Section 3  
Question  
35

Acids and  
bases

Smoking is hazardous to a person's health and one option to help quit smoking is the use of nicotine patches. These patches, when placed on the skin, release small amounts of nicotine with the aim of reducing cigarette craving.

The nicotine content of these patches can be determined by titration. The titrating solution is prepared by mixing perchloric acid ( $\text{HClO}_4$ ) with glacial acetic acid, resulting in the following equilibrium:



The species that reacts with nicotine during the titration is  $\text{CH}_3\text{COOH}_2^+$ . 'Glacial' means that the acetic acid does not contain any water.

The perchloric acid/acetic acid solution must be standardised before use and this can be done by titrating it with a solution made from a primary standard.

(a) Other than possessing a relatively high molar mass, state **two** characteristics required of a substance for it to be used as a primary standard. (2 marks)

Description	Marks
Any two relevant points. Answers could include: <ul style="list-style-type: none"> <li>available in very high purity</li> <li>known purity</li> <li>very low reactivity with <math>\text{CO}_2</math> and/or <math>\text{O}_2</math></li> <li>not deliquescent</li> <li>not hygroscopic</li> <li>predictable reactivity</li> <li>(highly) soluble.</li> </ul>	1–2
<b>Total</b>	<b>2</b>
<b>Note:</b> <ul style="list-style-type: none"> <li>For (highly) soluble, accept '(highly) soluble in water', even though these titrations are not performed in an aqueous medium.</li> </ul>	

A brand of nicotine patches comes in dose sizes of 7 mg, 14 mg and 21 mg. A manufacturing error produced a batch of unlabelled boxes of patches. A chemist was given the task of identifying the dose size so that the boxes could be accurately labelled and then sold.

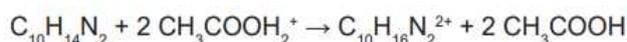
The chemist took one of the boxes and extracted all the nicotine from the 14 patches it contained. The nicotine extract was then made up to a total of 100.0 mL using a suitable solvent. Aliquots of the resulting solution (20.0 mL) were then titrated with standardised  $0.0483 \text{ mol L}^{-1}$  perchloric acid/acetic acid solution, requiring an average of 15.11 mL to reach the end point.

(b) Complete the following table by writing the name of the most suitable piece of equipment to use for each task. (3 marks)

Task	Piece of equipment to use	Marks
Making exactly 100.0 mL of nicotine-containing solution	volumetric flask	1
Measuring a 20.0 mL aliquot of the nicotine-containing solution	pipette	1
Adding the perchloric acid/acetic acid solution to the nicotine-containing solution	burette	1
<b>Total</b>		<b>3</b>

(c) Use the chemist's titration data to identify the nicotine dosage of the patches in the unlabelled boxes. Show all of your working.

The molecular formula of nicotine is  $C_{10}H_{14}N_2$  and the titration reaction is:



(7 marks)

Description	Marks
$n(\text{acid})$ in 15.11 mL = $cV = 0.0483 \times 0.01511 = 7.298 \times 10^{-4}$ mol	1
$n(\text{nicotine})$ in 20.0 mL = $\frac{1}{2} \times 0.000730 = 0.000365$ mol	1
$n(\text{nicotine})$ in 100.0 mL = $0.000365 \times 5 = 0.00182$ mol	1
$M(\text{nicotine}) = (10 \times 12.01) + (14 \times 1.008) + (2 \times 14.01) = 162.232$ g mol <sup>-1</sup>	1
$m(\text{nicotine})$ in 100.0 mL = $162.232 \times 0.00182 = 0.296$ g	1
$m(\text{nicotine})$ in 1 patch = $0.296/14 = 0.0211$ g	1
thus the boxes contain 21 mg patches	1
<b>Total</b>	<b>7</b>

**2020  
Section 3  
Question  
37**

**Acids and  
bases**

A student standardised an approximately 0.1 mol L<sup>-1</sup> sodium hydroxide solution with a standard 0.0958 mol L<sup>-1</sup> hydrochloric acid solution. The student pipetted 20.00 mL of the sodium hydroxide solution into a conical flask, added 2 drops of indicator and titrated to the end point with the hydrochloric acid. Five titrations were performed.

(a) Below is a table of the student's results. Determine the average titre. (1 mark)

Titration number	Burette readings (mL)		
	Initial	Final	Titre
Rough	1.35	22.45	21.10
1	21.45	41.50	20.05
2	3.50	23.65	20.15
3	23.65	43.05	19.40
4	2.75	22.85	20.10
<b>Average titre</b>			

Description	Marks
Average titre = $(20.05 + 20.15 + 20.10)/3 = 20.10$ mL	1
<b>Total</b>	<b>1</b>
Note: • Also accept 20.1 mL as the average titre.	

(b) Show that the concentration of the sodium hydroxide solution is 0.0963 mol L<sup>-1</sup>, correct to three significant figures. (3 marks)

Description	Marks
$n(\text{HCl}) = cV = 0.0958 \times 0.0201 = 0.00193 \text{ mol}$	1
1 mol NaOH reacts with 1 mol HCl	1
$c(\text{NaOH}) = 0.00193/0.020 = 0.0963 \text{ mol L}^{-1}$	1
<b>Total</b>	<b>3</b>

The student used the standardised sodium hydroxide solution to determine the percentage by mass of phosphoric acid (H<sub>3</sub>PO<sub>4</sub>) in a commercial brand of rust remover.

The student weighed a sample of the rust remover into a small beaker and then transferred it to a 250.0 mL volumetric flask. The beaker was rinsed several times with distilled water and each time the wash water was added to the volumetric flask. The volumetric flask was then made up to the mark with more distilled water. The student titrated 10.00 mL aliquots of the diluted rust remover with the standardised sodium hydroxide solution.

The student's results were as follows:

- mass of undiluted rust remover = 10.05 g
- average titre of standardised sodium hydroxide solution = 24.45 mL.

(c) Calculate the percentage, by mass, of phosphoric acid in the original, undiluted rust remover. Express your answer to the appropriate number of significant figures. Assume that the rust remover contains no other substances that react with sodium hydroxide. (8 marks)

Description	Marks
$n(\text{NaOH}) = 0.0963 \times 0.0245 = 0.00235 \text{ mol}$	1
Stoichiometry: $3 \text{ NaOH} + \text{H}_3\text{PO}_4 \rightarrow \text{Na}_3\text{PO}_4 + 3 \text{ H}_2\text{O}$ So, 3 NaOH:1H <sub>3</sub> PO <sub>4</sub>	1
$n(\text{H}_3\text{PO}_4 \text{ reacting in the titration}) = (1 \times 0.00235)/3$ $= 0.000785 \text{ mol in } 10 \text{ mL}$	1
$n(\text{H}_3\text{PO}_4 \text{ in } 250 \text{ mL volumetric flask}) = (0.000785 \times 250)/10$ $= 0.0196 \text{ mol in } 10.05 \text{ g}$	1
$M(\text{H}_3\text{PO}_4) = 97.994 \text{ g mol}^{-1}$	1
$m(\text{H}_3\text{PO}_4 \text{ in rust cleaner sample}) = 0.0196 \times 97.994 = 1.92 \text{ g}$	1
$\% \text{ H}_3\text{PO}_4 \text{ in the rust cleaner} = (1.92/10.05) \times 100 = 19.1\%$	1
3 significant figures = 19.1%	1
<b>Total</b>	<b>8</b>

or

Description	Marks
$n(\text{NaOH}) = 0.0963 \times 0.0245 = 0.00235 \text{ mol}$	1
Stoichiometry: $2 \text{ NaOH} + \text{H}_3\text{PO}_4 \rightarrow \text{Na}_2\text{HPO}_4 + 2 \text{ H}_2\text{O}$ So, 2 NaOH:1 H <sub>3</sub> PO <sub>4</sub>	1
$n(\text{H}_3\text{PO}_4 \text{ reacting in the titration}) = (1 \times 0.00235)/2$ $= 0.00118 \text{ mol in } 10 \text{ mL}$	1
$n(\text{H}_3\text{PO}_4 \text{ in } 250 \text{ mL volumetric flask}) = (0.00118 \times 250)/10$ $= 0.0294 \text{ mol in } 10.05 \text{ g}$	1
$M(\text{H}_3\text{PO}_4) = 97.994 \text{ g mol}^{-1}$	1
$m(\text{H}_3\text{PO}_4 \text{ in rust cleaner sample}) = 0.0294 \times 97.994 = 2.88 \text{ g}$	1
$\% \text{ H}_3\text{PO}_4 \text{ in the rust cleaner} = (2.88/10.05) \times 100 = 28.7\%$	1
3 significant figures = 28.7%	1
<b>Total</b>	<b>8</b>

Note:

- Phosphoric acid is a weak acid with only two of its three hydrogen atoms reacting with hydroxide to give the 2:1 ratio of NaOH:H<sub>3</sub>PO<sub>4</sub>. This is beyond the scope of the syllabus, and was not expected of students.

The following table provides some information about three different acid-base indicators.

Indicator	pH range	Acid colour	Base colour
methyl orange	3.2 – 4.4	red	yellow
bromothymol blue	6.0 – 7.6	yellow	blue
phenolphthalein	8.3 – 10.0	colourless	pink

(d) Which of these indicators should the student use when titrating phosphoric acid with sodium hydroxide? Justify your choice with the aid of a relevant balanced chemical equation. (5 marks)

Description	Marks
Phenolphthalein	1
Recognition that $\text{PO}_4^{3-}$ present in the solution at equivalence point. ( $3 \text{OH}^-(\text{aq}) + \text{H}_3\text{PO}_4(\text{aq}) \rightarrow \text{PO}_4^{3-}(\text{aq}) + 3 \text{H}_2\text{O}(\ell)$ )	1
The phosphate ion undergoes hydrolysis to form hydroxide ions. $\text{PO}_4^{3-} + \text{H}_2\text{O} \rightleftharpoons \text{HPO}_4^{2-} + \text{OH}^-$	1
The solution at the equivalence point will be (slightly) basic (with a pH of approximately 9) due to the excess of hydroxide ions ( $[\text{OH}^-] > [\text{H}^+]$ )	1
The pH at which the indicator changes colour approximates the pH of the equivalence point.	1
<b>Total</b>	<b>5</b>
<p>Note:</p> <ul style="list-style-type: none"> <li>No hydrolysis equation – maximum 4 marks</li> <li>Do not accept a statement about strong base is added to weak acid, gives a weakly basic solution as part of the explanation.</li> </ul> <p><b>Alternative responses that some students may provide</b></p> <p>Methyl orange The pH of the first equivalence point is around 4.7. If students identify this and supply appropriate logic with equations, up to full marks may be awarded.</p> <p>If a student recognises that the third equivalence point is beyond the end point of phenolphthalein and explains why none of the indicators would be appropriate with sufficient reasoning, up to full marks may be awarded.</p>	

**2019  
Section 3  
Question  
39**

**Acids and  
bases**

Herbicides are chemicals that kill plants, including weeds. The label of a commercially-available herbicide concentrate is shown below.

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A chemist was given the task of verifying the concentrations of sodium chloride and acetic (ethanoic) acid stated for this herbicide.

The sodium chloride content of the herbicide was analysed. It was found to be consistent within the tolerance of  $\pm 5.00\%$  of the stated concentration. The chemist then performed a series of titrations with sodium hydroxide to measure the acetic (ethanoic) acid concentration.

The herbicide solution used in the titrations was prepared by pipetting 5.00 mL of the concentrate into a 250.0 mL volumetric flask. The solution in the flask was then made up to the mark with distilled water.

A 20.00 mL sample of the diluted herbicide was pipetted into a conical flask and a few drops of a suitable indicator were added. This solutions was then titrated with standardised 0.0947 mol L<sup>-1</sup> NaOH solution.

(a) Complete the table and determine the average titre. (2 marks)

Titration number	Burette readings (mL)		Titre
	Initial	Final	
1	1.28	20.75	
2	20.75	40.19	
3	1.48	21.82	
4	21.82	41.21	
Average titre			

Description	Marks												
Table correctly completed	1												
Average titre correctly calculated	1												
Example of a two mark response:													
<table border="1"> <thead> <tr> <th>Titration Number</th> <th>Volume Added (mL)</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>19.47</td> </tr> <tr> <td>2</td> <td>19.44</td> </tr> <tr> <td>3</td> <td>20.34</td> </tr> <tr> <td>4</td> <td>19.39</td> </tr> <tr> <td><b>Average titre</b></td> <td><b>19.43(3)</b></td> </tr> </tbody> </table>		Titration Number	Volume Added (mL)	1	19.47	2	19.44	3	20.34	4	19.39	<b>Average titre</b>	<b>19.43(3)</b>
Titration Number	Volume Added (mL)												
1	19.47												
2	19.44												
3	20.34												
4	19.39												
<b>Average titre</b>	<b>19.43(3)</b>												
<b>Total</b>	<b>2</b>												

(b) Identify with what solution each of these pieces of glassware should be rinsed prior to their use in these titrations. (3 marks)

Description		Marks
Glassware item	Rinse solution	
5.00 mL pipette	The (concentrated) herbicide	1
20.00 mL pipette	diluted herbicide	1
250.0 mL volumetric flask	Distilled (deionised) water	1
<b>Total</b>		<b>3</b>

(c) Demonstrate whether or not the experimentally-determined value of the acetic (ethanoic) acid concentration matches the value given on the herbicide label, bearing in mind that a difference of  $\pm 5.00\%$  is considered acceptable. Show **all** workings and reasoning. (8 marks)

Description	Marks
Average NaOH titre volume from part (a) = 0.01943 L	
Moles NaOH on average $n = cV = 0.0947 \times 0.01943$ $= 0.001840 \text{ mol}$	1
In 20 mL conical flask $n(\text{CH}_3\text{COOH}) = n(\text{NaOH}) = 0.001840 \text{ mol}$	1
Concentration = $0.001840 / 0.02$ $= 0.09200 \text{ mol L}^{-1}$	1
In 250 mL volumetric flask, $n = 0.09200 \times 0.25$ $= 0.02300 \text{ mol}$	1
All from 5 mL sample... original concentration $= 0.02300 / 0.005$ $= 4.6001 \text{ mol L}^{-1}$	1
$c(\text{CH}_3\text{COOH}) = 4.6001 \times 60.052$ $= 276 \text{ g/L}$	1
The 5% range 295 is 280.25 – 309.75	1
<ul style="list-style-type: none"> <li>No</li> <li>The experimentally determined concentration of acetic acid of <math>276.3 \text{ g L}^{-1}</math> falls outside of the error range (280.25 – 309.75 <math>\text{g L}^{-1}</math>) stated on the package and so does NOT match the value given on the herbicide label.</li> </ul>	1
<b>Total</b>	<b>8</b>
<p><b>Note:</b></p> <ul style="list-style-type: none"> <li>If the correct answer is clearly stated, full marks maybe awarded for: <ul style="list-style-type: none"> <li>the correct calculated concentration and error range is calculated</li> <li>and the calculations and reasoning provided clearly demonstrates a correct method for determining the answer.</li> </ul> </li> <li>If the answer is incorrect or ambiguous, marks may be awarded to the parts correctly completed as set out above.</li> </ul>	

## Unit 3 – Oxidation and reduction

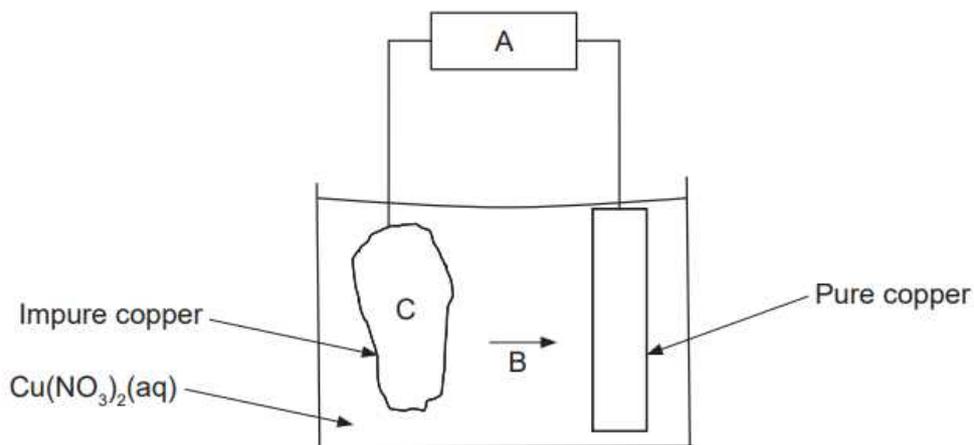
### Section 1

<b>2023</b> <b>Section 1</b> <b>Question 4</b>  <b>Oxidation and reduction</b>	In which of the following is vanadium in a +4 oxidation state?  (a) $\text{NH}_4\text{VO}_3$ (b) $\text{VOSO}_4$ (c) $\text{V}(\text{H}_2\text{O})_6^{3+}$ (d) $\text{V}_2\text{O}_5$
<b>2023</b> <b>Section 1</b> <b>Question 5</b>  <b>Oxidation and reduction</b>	Identify the oxidant in the following equation.  $2 \text{BrO}_3^- (\text{aq}) + 10 \text{I}^- (\text{aq}) + 12 \text{H}^+ (\text{aq}) \rightarrow \text{Br}_2 (\text{aq}) + 5 \text{I}_2 (\text{aq}) + 6 \text{H}_2\text{O} (\ell)$  (a) $\text{BrO}_3^- (\text{aq})$ (b) $\text{I}^- (\text{aq})$ (c) $\text{H}^+ (\text{aq})$ (d) $\text{Br}_2 (\text{aq})$
<b>2023</b> <b>Section 1</b> <b>Question 15</b>  <b>Oxidation and reduction</b>	15. Which of the following reactions will occur spontaneously under standard conditions at 25 °C?  (i) $\text{H}_2 (\text{g}) + \text{O}_2 (\text{g}) \rightleftharpoons \text{H}_2\text{O}_2 (\text{aq})$ (ii) $\text{Ni}^{2+} (\text{aq}) + 2 \text{Fe}^{2+} (\text{aq}) \rightleftharpoons \text{Ni} (\text{s}) + 2 \text{Fe}^{3+} (\text{aq})$ (iii) $\text{H}_2\text{O}_2 (\text{aq}) + 2 \text{CO}_2 (\text{g}) \rightleftharpoons \text{H}_2\text{C}_2\text{O}_4 (\text{aq}) + \text{O}_2 (\text{g})$ (iv) $\text{O}_2 (\text{g}) + 2 \text{H}_2\text{S} (\text{aq}) \rightleftharpoons 2 \text{S} (\text{s}) + 2 \text{H}_2\text{O} (\ell)$  (a) i and iv (b) ii and iii (c) iii and iv (d) i and ii
<b>2023</b> <b>Section 1</b> <b>Question 20</b>  <b>Oxidation and reduction</b>	An electrochemical cell, reaction shown below, has an $E^\circ$ value of +0.89 V.  $4 \text{V}^{3+} (\text{aq}) + 2 \text{H}_2\text{O} (\ell) + \text{O}_2 (\text{g}) \rightleftharpoons 4 \text{VO}^{2+} (\text{aq}) + 4 \text{H}^+ (\text{aq})$  What is the standard reduction potential for the half-equation below?  $\text{VO}^{2+} + 2 \text{H}^+ + \text{e}^- \rightleftharpoons \text{V}^{3+} + \text{H}_2\text{O}$  (a) -0.34 V (b) +1.57 V (c) +0.34 V (d) -1.57 V

2023  
Section 1  
Question  
23

Oxidation  
and  
reduction

The cell below was set up by a student to demonstrate the purification of copper.



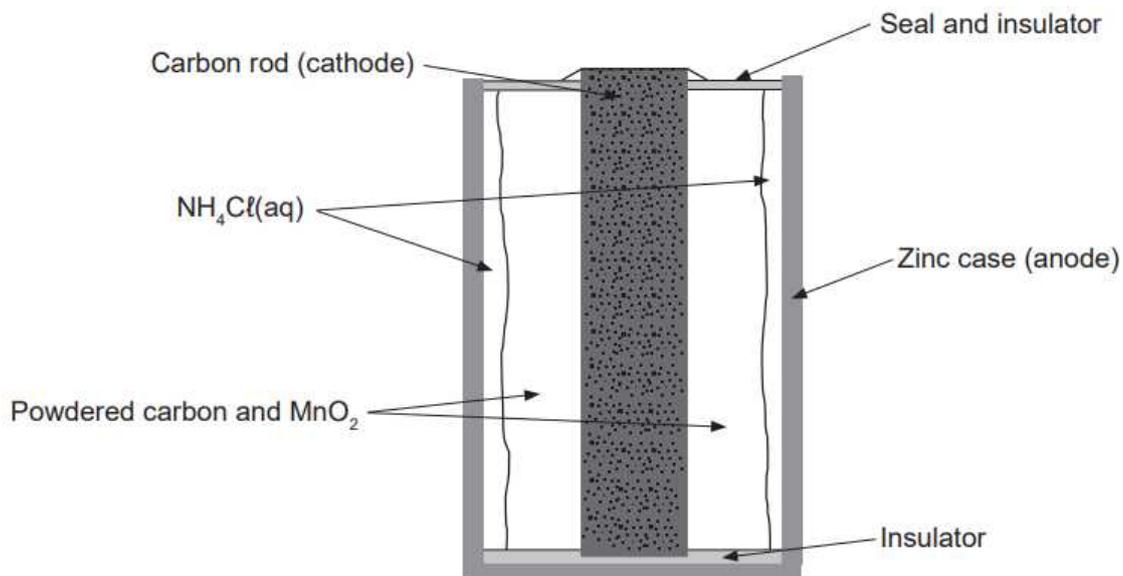
Which of the following are the correct labels, A, B and C, on the diagram?

	A	B	C
(a)	Voltmeter	Direction of anion flow	Anode
(b)	Power supply	Direction of cation flow	Anode
(c)	Voltmeter	Direction of anion flow	Cathode
(d)	Power supply	Direction of cation flow	Cathode

2023  
Section 1  
Question  
24

Oxidation  
and  
reduction

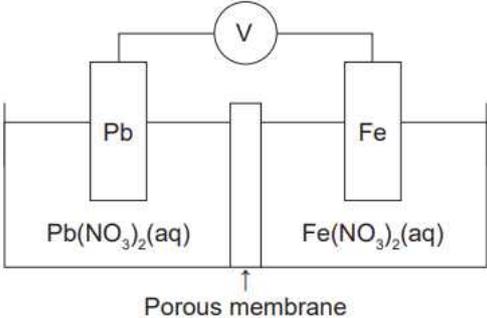
Question 24 refers to the following diagram.



For the Leclanché dry cell shown above, which of the following statements best describes the role of the electrodes?

- (a) The zinc is oxidised; reduction of manganese dioxide occurs at the carbon.
- (b) The zinc is reduced; carbon is oxidised.
- (c) The carbon is reduced; oxidation of manganese dioxide occurs at the zinc.
- (d) The carbon is reduced; zinc is oxidised.

<p><b>2022</b> <b>Section 1</b> <b>Question 2</b></p> <p><b>Oxidation and reduction</b></p>	<p>Which of the following pairs represents the greatest difference in oxidation state of the underlined element?</p> <p>(a) <u>Mn</u><sup>2+</sup> and <u>KMn</u>O<sub>4</sub>          (b) <u>Cr</u>O<sub>4</sub><sup>2-</sup> and <u>Cr</u><sub>2</sub>O<sub>7</sub><sup>2-</sup>          (c) <u>Cl</u><sup>-</sup> and <u>HCl</u>O<sub>4</sub>          (d) <u>S</u><sup>2-</sup> and <u>SO</u><sub>3</sub><sup>2-</sup></p>
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<p><b>2022</b> <b>Section 1</b> <b>Question 15-17</b></p> <p><b>Oxidation and reduction</b></p>	<p>Questions 15 to 17 refer to the electrochemical cell below.</p>  <p>15. Which of the following series of labels <b>best</b> represents the cell above?</p> <table border="1"> <thead> <tr> <th></th> <th>Anode</th> <th>Cathode</th> <th>Direction of electron flow</th> <th>Direction of anion flow</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>lead</td> <td>iron</td> <td>←</td> <td>→</td> </tr> <tr> <td>(b)</td> <td>lead</td> <td>iron</td> <td>→</td> <td>←</td> </tr> <tr> <td>(c)</td> <td>iron</td> <td>lead</td> <td>→</td> <td>→</td> </tr> <tr> <td>(d)</td> <td>iron</td> <td>lead</td> <td>←</td> <td>→</td> </tr> </tbody> </table> <p>16. Using the standard reduction potentials, determine the theoretical value that the voltmeter would show for this electrochemical cell?</p> <p>(a) +0.31 V          (b) +0.57 V          (c) +0.64 V          (d) +0.90 V</p> <p>17. Which of the following reasons would cause the voltmeter to show a different value to the theoretical voltage?</p> <p>(i) the cell is at 100 kPa          (ii) the cell is at 20 °C          (iii) the Pb(NO<sub>3</sub>)<sub>2</sub> solution is 0.1 mol L<sup>-1</sup> and the Fe(NO<sub>3</sub>)<sub>2</sub> solution is 0.2 mol L<sup>-1</sup>          (iv) the lead and iron electrodes are in the opposite solution to that shown in the diagram above</p> <p>(a) i and ii          (b) ii and iii          (c) ii, iii and iv          (d) iii and iv</p>		Anode	Cathode	Direction of electron flow	Direction of anion flow	(a)	lead	iron	←	→	(b)	lead	iron	→	←	(c)	iron	lead	→	→	(d)	iron	lead	←	→
	Anode	Cathode	Direction of electron flow	Direction of anion flow																						
(a)	lead	iron	←	→																						
(b)	lead	iron	→	←																						
(c)	iron	lead	→	→																						
(d)	iron	lead	←	→																						

<p><b>2021</b> <b>Section 1</b> <b>Question 1</b></p> <p><b>Oxidation and reduction</b></p>	<p>Which of the following statements is/are true for redox reactions?</p> <p>(i) Redox reactions involve the transfer of electrons from one species to another.  (ii) Complete combustion is a redox reaction, but incomplete combustion is not.  (iii) Oxidation is the gain of electrons while reduction is the loss of electrons.  (iv) Oxidation and reduction occur simultaneously.</p> <p>(a) i only  (b) i, ii and iv only  (c) i, iii and iv only  (d) i and iv only</p>
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<p><b>2021</b> <b>Section 1</b> <b>Question 10</b></p> <p><b>Oxidation and reduction</b></p>	<p>Which of the following identifies the recharging ability of a particular type of electrochemical cell and provides an appropriate example?</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th>Electrochemical cell</th> <th>Rechargeable</th> <th>Example</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>primary</td> <td>no</td> <td>Leclanché cell</td> </tr> <tr> <td>(b)</td> <td>secondary</td> <td>no</td> <td>lead-acid accumulator</td> </tr> <tr> <td>(c)</td> <td>primary</td> <td>yes</td> <td>lead-acid accumulator</td> </tr> <tr> <td>(d)</td> <td>secondary</td> <td>yes</td> <td>Leclanché cell</td> </tr> </tbody> </table>		Electrochemical cell	Rechargeable	Example	(a)	primary	no	Leclanché cell	(b)	secondary	no	lead-acid accumulator	(c)	primary	yes	lead-acid accumulator	(d)	secondary	yes	Leclanché cell
	Electrochemical cell	Rechargeable	Example																		
(a)	primary	no	Leclanché cell																		
(b)	secondary	no	lead-acid accumulator																		
(c)	primary	yes	lead-acid accumulator																		
(d)	secondary	yes	Leclanché cell																		

<p><b>2021</b> <b>Section 1</b> <b>Question 12-13</b></p> <p><b>Oxidation and reduction</b></p>	<p>Questions 12 and 13 refer to the following electrochemical cell, which contains a light globe.</p> <p>12. Which combination of electrodes and aqueous electrolytes will result in the possibility of the globe glowing? Assume standard conditions.</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th colspan="2">Half cell 1</th> <th colspan="2">Half cell 2</th> </tr> <tr> <th></th> <th>Electrode</th> <th>Electrolyte</th> <th>Electrode</th> <th>Electrolyte</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>graphite</td> <td><math>\text{Ni}(\text{NO}_3)_2(\text{aq})</math></td> <td>silver</td> <td><math>\text{AgNO}_3(\text{aq})</math></td> </tr> <tr> <td>(b)</td> <td>silver</td> <td><math>\text{Ni}(\text{NO}_3)_2(\text{aq})</math></td> <td>graphite</td> <td><math>\text{AgNO}_3(\text{aq})</math></td> </tr> <tr> <td>(c)</td> <td>nickel</td> <td><math>\text{Ni}(\text{NO}_3)_2(\text{aq})</math></td> <td>silver</td> <td><math>\text{AgNO}_3(\text{aq})</math></td> </tr> <tr> <td>(d)</td> <td>nickel</td> <td><math>\text{AgNO}_3(\text{aq})</math></td> <td>silver</td> <td><math>\text{Ni}(\text{NO}_3)_2(\text{aq})</math></td> </tr> </tbody> </table> <p>13. The salt bridge</p> <p>(a) provides the ions that are oxidised or reduced at the electrodes.  (b) maintains the overall electrical and pH neutrality of the cell by facilitating the transfer of electrons and ions from one half cell to another.  (c) provides the <math>\text{H}_3\text{O}^+</math> and <math>\text{OH}^-</math> ions needed to maintain the pH neutrality of each half cell, preventing the build-up of electrical charge in the electrolytes.  (d) provides ions and facilitates ion movement between the half cells to complete the electrical circuit.</p>		Half cell 1		Half cell 2			Electrode	Electrolyte	Electrode	Electrolyte	(a)	graphite	$\text{Ni}(\text{NO}_3)_2(\text{aq})$	silver	$\text{AgNO}_3(\text{aq})$	(b)	silver	$\text{Ni}(\text{NO}_3)_2(\text{aq})$	graphite	$\text{AgNO}_3(\text{aq})$	(c)	nickel	$\text{Ni}(\text{NO}_3)_2(\text{aq})$	silver	$\text{AgNO}_3(\text{aq})$	(d)	nickel	$\text{AgNO}_3(\text{aq})$	silver	$\text{Ni}(\text{NO}_3)_2(\text{aq})$
	Half cell 1		Half cell 2																												
	Electrode	Electrolyte	Electrode	Electrolyte																											
(a)	graphite	$\text{Ni}(\text{NO}_3)_2(\text{aq})$	silver	$\text{AgNO}_3(\text{aq})$																											
(b)	silver	$\text{Ni}(\text{NO}_3)_2(\text{aq})$	graphite	$\text{AgNO}_3(\text{aq})$																											
(c)	nickel	$\text{Ni}(\text{NO}_3)_2(\text{aq})$	silver	$\text{AgNO}_3(\text{aq})$																											
(d)	nickel	$\text{AgNO}_3(\text{aq})$	silver	$\text{Ni}(\text{NO}_3)_2(\text{aq})$																											

<p><b>2021</b> <b>Section 1</b> <b>Question 22</b></p> <p><b>Oxidation and reduction</b></p>	<p>In an electrolytic cell used for plating objects with gold</p> <p>(a) the object to be plated is the anode.  (b) there must be a salt bridge connecting the anode and cathode half-cells.  (c) the reaction is spontaneous and so no external potential difference is required.  (d) a piece of pure gold is used as the positively charged electrode.</p>
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<b>2020</b> <b>Section 1</b> <b>Question 1</b>  <b>Oxidation and reduction</b>	Holmium (Ho) reacts quickly with hot water to form holmium hydroxide and hydrogen: $2 \text{Ho(s)} + 6 \text{H}_2\text{O(l)} \rightarrow 2 \text{Ho(OH)}_3 \text{(aq)} + 3 \text{H}_2\text{(g)}$ The oxidising and reducing agents in this equation are														
	<table border="1"> <thead> <tr> <th></th> <th>Oxidising agent</th> <th>Reducing agent</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>H<sub>2</sub>O</td> <td>H<sub>2</sub></td> </tr> <tr> <td>(b)</td> <td>Ho</td> <td>H<sub>2</sub>O</td> </tr> <tr> <td>(c)</td> <td>H<sub>2</sub>O</td> <td>Ho</td> </tr> <tr> <td>(d)</td> <td>Ho(OH)<sub>3</sub></td> <td>Ho</td> </tr> </tbody> </table>		Oxidising agent	Reducing agent	(a)	H <sub>2</sub> O	H <sub>2</sub>	(b)	Ho	H <sub>2</sub> O	(c)	H <sub>2</sub> O	Ho	(d)	Ho(OH) <sub>3</sub>
	Oxidising agent	Reducing agent													
(a)	H <sub>2</sub> O	H <sub>2</sub>													
(b)	Ho	H <sub>2</sub> O													
(c)	H <sub>2</sub> O	Ho													
(d)	Ho(OH) <sub>3</sub>	Ho													

<b>2020</b> <b>Section 1</b> <b>Question 3</b>  <b>Oxidation and reduction</b>	Oxidation-reduction reactions involve the transfer of (a) protons. (b) electrons. (c) hydroxide ions. (d) hydrogen ions.
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<b>2020</b> <b>Section 1</b> <b>Question 5</b>  <b>Oxidation and reduction</b>	Which of the following statements about pure water are correct? (i) Pure water is a weak electrolyte that undergoes self-ionisation. (ii) The equilibrium constant for the ionisation of pure water at 25 °C is 1.00 x 10 <sup>-14</sup> . (iii) Pure water ionises completely at 25 °C, hence [H <sup>+</sup> ] = [OH <sup>-</sup> ]. (iv) The ionisation of pure water produces twice as many hydrogen ions as hydroxide ions.  (a) i and ii only (b) ii and iii only (c) iii and iv only (d) i, ii, iii and iv
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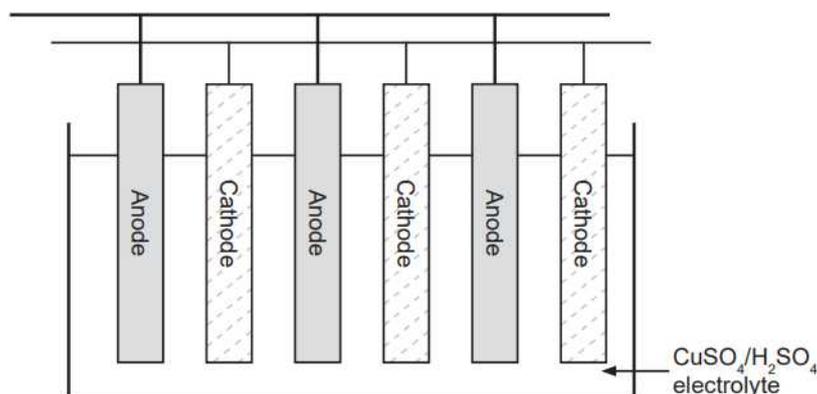
<b>2020</b> <b>Section 1</b> <b>Question 6</b>  <b>Oxidation and reduction</b>	What type of redox reaction occurs in a galvanic cell and what is one possible use for such a cell?  <table border="1"> <thead> <tr> <th></th> <th>Type of redox reaction</th> <th>Possible use of a galvanic cell</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>non-spontaneous</td> <td>the plating of cheap metallic objects with precious metals</td> </tr> <tr> <td>(b)</td> <td>spontaneous</td> <td>the plating of cheap metallic objects with precious metals</td> </tr> <tr> <td>(c)</td> <td>non-spontaneous</td> <td>the production of an electric current for a torch</td> </tr> <tr> <td>(d)</td> <td>spontaneous</td> <td>the production of an electric current for a torch</td> </tr> </tbody> </table>		Type of redox reaction	Possible use of a galvanic cell	(a)	non-spontaneous	the plating of cheap metallic objects with precious metals	(b)	spontaneous	the plating of cheap metallic objects with precious metals	(c)	non-spontaneous	the production of an electric current for a torch	(d)	spontaneous	the production of an electric current for a torch
	Type of redox reaction	Possible use of a galvanic cell														
(a)	non-spontaneous	the plating of cheap metallic objects with precious metals														
(b)	spontaneous	the plating of cheap metallic objects with precious metals														
(c)	non-spontaneous	the production of an electric current for a torch														
(d)	spontaneous	the production of an electric current for a torch														

<b>2020</b> <b>Section 1</b> <b>Question 19</b>  <b>Oxidation and reduction</b>	The following half-equations show some predicted standard reduction potentials for seaborgium (Sg) oxides: $2 \text{SgO}_3\text{(s)} + 2 \text{H}^+\text{(aq)} + 2 \text{e}^- \rightarrow \text{Sg}_2\text{O}_5\text{(s)} + \text{H}_2\text{O(l)} \quad E^0 = -0.046 \text{ V}$ $\text{Sg}_2\text{O}_5\text{(s)} + 2 \text{H}^+\text{(aq)} + 2 \text{e}^- \rightarrow 2 \text{SgO}_2\text{(s)} + \text{H}_2\text{O(l)} \quad E^0 = +0.11 \text{ V}$ $\text{SgO}_2\text{(s)} + 4 \text{H}^+\text{(aq)} + \text{e}^- \rightarrow \text{Sg}^{3+}\text{(aq)} + 2 \text{H}_2\text{O(l)} \quad E^0 = -1.34 \text{ V}$ The strongest reducing agent is (a) SgO <sub>3</sub> (b) Sg <sub>2</sub> O <sub>5</sub> (c) SgO <sub>2</sub> (d) Sg <sup>3+</sup>
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2020  
Section 1  
Question 20

Oxidation  
and  
reduction

Impure copper must be purified before it is used in applications where very high electrical conductivity is required. The purification of copper, which is also known as electrorefining, can be performed in an electrochemical cell similar to the one shown below.



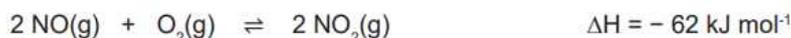
Which statement regarding this electrochemical cell is correct?

- (a) This cell requires the application of an external electrical potential difference for it to function.
- (b) During operation, the electrolyte becomes less blue because the concentration of  $\text{Cu}^{2+}$  ions in the electrolyte decreases.
- (c) This cell will not work because it does not have a salt bridge.
- (d) The impure copper is cast as cathodes.

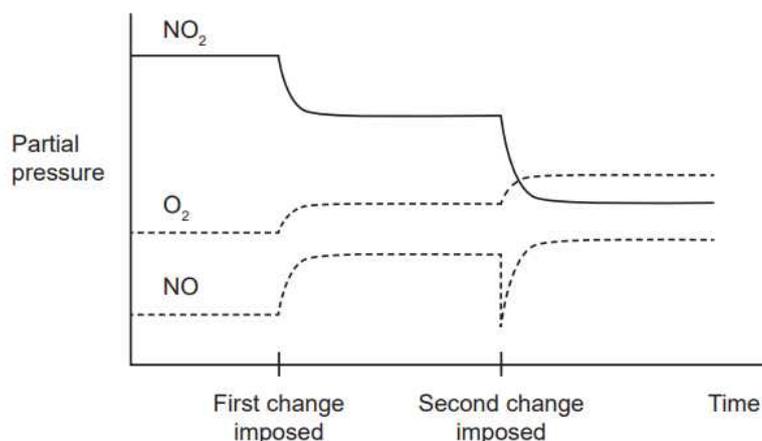
2019  
Section 1  
Question 3-4

Oxidation  
and  
reduction

Questions 3 and 4 refer to the following information. Nitrogen dioxide,  $\text{NO}_2(\text{g})$ , is formed when nitrogen monoxide,  $\text{NO}(\text{g})$ , undergoes oxidation as shown below.



A change was imposed on an equilibrium gas mixture of  $\text{NO}_2$ ,  $\text{NO}$  and  $\text{O}_2$ . The mixture returned to equilibrium and another change was imposed. The following graph shows the effects of the two changes.



3. Identify the imposed changes that **best** account for the shape of the graph.

	First change	Second change
(a)	the temperature is decreased	the partial pressure of $\text{O}_2$ is increased
(b)	the temperature is decreased	the partial pressure of $\text{NO}$ is decreased
(c)	the temperature is increased	the partial pressure of $\text{O}_2$ is increased
(d)	the temperature is increased	the partial pressure of $\text{NO}$ is decreased

4. What do the initial partial pressures of the three gases indicate?

- (a) The relative proportions of the gases present at equilibrium.
- (b) That there is initially no NO gas present in the system.
- (c) That the NO<sub>2</sub> gas reaches equilibrium first.
- (d) That the O<sub>2</sub> and NO gases are producing NO<sub>2</sub> at a faster rate than they are being formed.

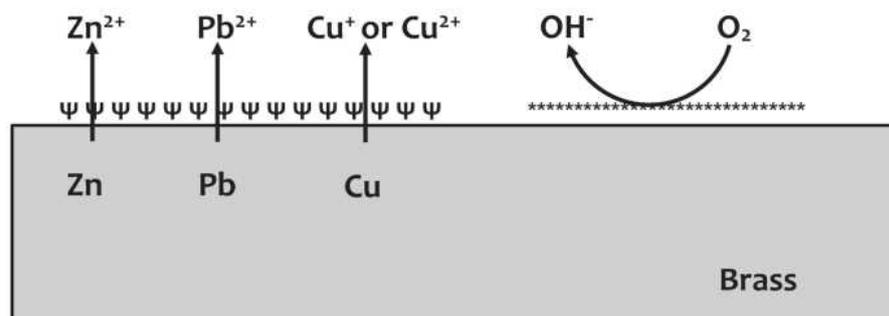
**2019  
Section 1  
Question  
5-7**

**Oxidation  
and  
reduction**

Questions 5, 6 and 7 refer to the following information.

The corrosion of brass plumbing fixtures has been identified as a possible cause of the presence of lead in drinking water. Brass is an alloy of copper and zinc but can also contain lead to improve machinability.

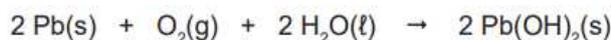
The corrosion of brass is a redox process, with an electrochemical cell forming on the surface of the brass as illustrated below.



5. Which one of the following correctly identifies the anodic region, cathodic region and direction of electron flow?

	Anodic region	Cathodic region	Direction of electron flow
(a)	Ψ	*	Ψ → *
(b)	*	Ψ	Ψ → *
(c)	Ψ	*	* → Ψ
(d)	*	Ψ	* → Ψ

6. The overall equation for the reaction of lead with oxygen is as follows:



What is the theoretical E<sup>0</sup> value for the overall Pb/O<sub>2</sub> reaction under standard conditions?

- (a) - 0.27 V
- (b) + 0.27 V
- (c) + 0.53 V
- (d) + 0.93 V

7. The composition of brass can be adjusted by adding various metals. Which one of the following metals would not undergo corrosion if added to brass?

- (a) silver
- (b) nickel
- (c) iron
- (d) strontium

<p><b>2019</b> <b>Section 1</b> <b>Question 10</b></p> <p><b>Oxidation and reduction</b></p>	<p>Which statement is correct?</p> <p>(a) Fluorine can be oxidised by potassium bromide solution but not by potassium iodide solution.  (b) Chlorine can be oxidised by potassium fluoride solution but not by potassium iodide solution.  (c) Chlorine can be reduced by potassium bromide solution but not by potassium iodide solution.  (d) Bromine can be reduced by potassium iodide solution but not by potassium chloride solution.</p>
<p><b>2019</b> <b>Section 1</b> <b>Question 17</b></p> <p><b>Oxidation and reduction</b></p>	<p>In which of the following sets do all the <b>bolded</b> and <u>underlined</u> atoms have the same oxidation number?</p> <p>(i) <math>\text{H}_2\text{O}</math>, <u><math>\text{O}_2</math></u>, <math>\text{H}_2\text{O}_2</math>  (ii) <math>\text{H}_2\text{O}_2</math>, <u><math>\text{NaCl}</math></u>, <math>\text{MgH}_2</math>  (iii) <u><math>\text{NaCl}</math></u>, <u><math>\text{Li}_2\text{CO}_3</math></u>, <u><math>\text{KOH}</math></u>  (iv) <u><math>\text{FeO}</math></u>, <u><math>\text{Fe}_2\text{O}_3</math></u>, <u><math>\text{Fe}</math></u></p> <p>(a) i and iv only  (b) ii and iii only  (c) iv only  (d) i, ii and iii only</p>
<p><b>2019</b> <b>Section 1</b> <b>Question 18</b></p> <p><b>Oxidation and reduction</b></p>	<p>Which one of the following could not be a product when propan-1-ol is oxidised?</p> <p>(a) <math>\text{CO}_2</math>  (b) <math>\text{CH}_3\text{CH}_2\text{CHO}</math>  (c) <math>\text{CH}_3\text{CH}_2\text{COOH}</math>  (d) <math>\text{CH}_3\text{COCH}_3</math></p>

Section 2

2023  
Section 2  
Question  
27

Oxidation  
and  
reduction

A carpenter left a pair of pliers outside over a rainy period, which subsequently became rusty, causing the joint to seize. Rather than buy a new pair of pliers, the carpenter decided to submerge the rusty part of the pliers in phosphoric acid to remove the rust. Phosphoric acid converts rust into another substance that can easily be washed away.



(a) Write an equation for the action of phosphoric acid on the rust. Assume rust is iron(III) oxide. Include state symbols in your answer. (3 marks)

(b) Identify the best method that the carpenter could use to protect the pliers from rusting further. Explain how this method would be effective. (3 marks)

Method:

Explanation:

The carpenter noticed that his toolboxes in the back of his truck were also rusting. He decided to explore the use of a sacrificial anode as an option to prevent the toolboxes rusting.

(c) State what a sacrificial anode is and explain how it is effective in preventing corrosion of the toolboxes. You should state which metal could be used for a sacrificial anode in your answer. (4 marks)



**2023  
Section 2  
Question  
30**

**Oxidation  
and  
reduction**

Write a balanced ionic equation for any reactions occurring between the following substances and state any observations before and after mixing.

If there is no reaction, write 'no reaction' for the equation and if there is no change observed write 'no visible reaction'. Use the colours stated in the Data booklet if required.

(a) A piece of iron wool is added to a 0.1 mol L<sup>-1</sup> solution of copper(II) sulfate. (4 marks)

Equation

Observations

(b) Calcium hydrogencarbonate powder is added to excess 1 mol L<sup>-1</sup> nitric acid. (4 marks)

Equation

Observations

(c) Excess chlorine gas is bubbled through a 0.1 mol L<sup>-1</sup> sodium bromide solution. (4 marks)

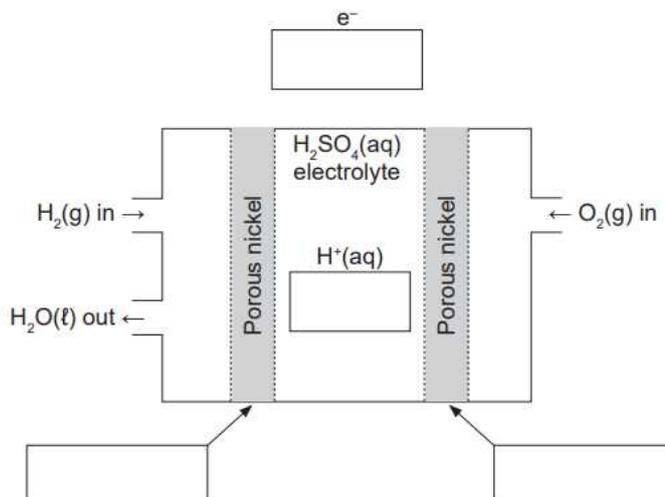
Equation

Observations

2021  
Section 2  
Question  
30

Oxidation  
and  
reduction

Fuel cells, such as the one shown in the diagram below, use gaseous hydrogen and oxygen to produce electricity.



In this particular fuel cell, which uses sulfuric acid as the electrolyte, the hydrogen and oxygen are circulated at very high pressure over porous nickel-platinum electrodes. Operating temperatures range from 25 to 90 °C.

(a) Complete the above diagram by adding labels/arrows to show the:

- anode
- cathode
- direction of electron flow
- direction of hydrogen ion flow. (4 marks)

(b) Write balanced half-equations for the oxidation and reduction reactions and the equation for the overall reaction occurring in this fuel cell. (4 marks)

Oxidation half-reaction	
Reduction half-reaction	
Overall redox reaction	

(c) This fuel cell typically produces 0.7 V, which is significantly less than the predicted value of 1.23 V. State **two** specific conditions of this cell that would account for this observation. (2 marks)

One:

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Two:

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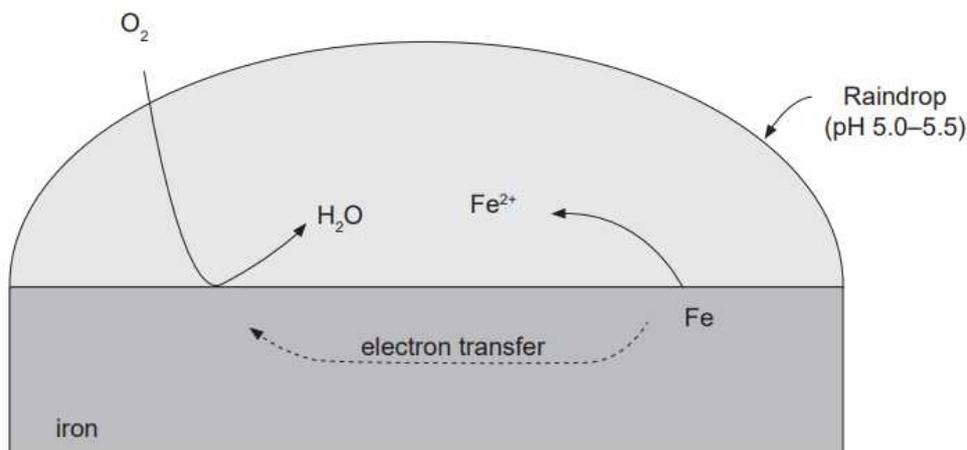
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**2021  
Section 2  
Question  
31**

**Oxidation  
and  
reduction**

The corrosion of iron is an electrochemical process that results in the formation of a reddish-brown solid commonly known as rust,  $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}(\text{s})$ . Iron objects exposed to rainwater corrode relatively quickly.

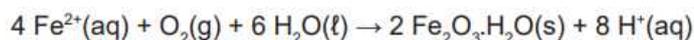
Iron corrosion occurs in two stages. During the first stage, an electrochemical cell is established on the iron surface, with electron transfer and  $\text{Fe}^{2+}$  ion formation occurring. This can be seen in the following diagram.



(a) Write half-equations and the overall balanced equation for the reaction occurring in the above electrochemical cell. State symbols are not required. (4 marks)

Oxidation half-equation	
Reduction half-equation	
Redox equation	

(b) During the second stage of iron corrosion, the newly formed  $\text{Fe}^{2+}$  ions migrate away from the iron surface and react with water and dissolved oxygen to form rust. The balanced equation for this reaction is shown below.



Use oxidation numbers to show that this reaction is a redox reaction. (2 marks)

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A corrosion chemist inspected an outdoor playground and found that most of the equipment containing iron showed signs of corrosion. The chemist suggested several different methods for protecting the playground equipment from further corrosion, including the use of sacrificial anodes.

(c) State what is a sacrificial anode. (1 mark)

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(d) State the name of a metal that can be used as a sacrificial anode to protect the equipment from further corrosion. Use Standard Reduction Potentials to justify your choice. (2 marks)

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**2020  
Section 2  
Question  
30**

**Oxidation  
and  
reduction**

Sulfur dioxide must be removed from waste industrial gases before they are released into the atmosphere. One method of doing this is the electrolytic conversion of sulfur dioxide into dithionate ( $\text{S}_2\text{O}_6^{2-}$ ):



(a) Identify the atom that is oxidised and the atom that is reduced in this reaction. (2 marks)

Atom that is oxidised	
Atom that is reduced	



**2019  
Section 2  
Question  
26**

**Oxidation  
and  
reduction**

Dilute hydrochloric acid,  $\text{HCl}(\text{aq})$ , is added to three labelled test tubes.

- (I) Excess copper metal,  $\text{Cu}(\text{s})$ , is added to the first test tube.
- (II) Excess copper(II) oxide,  $\text{CuO}(\text{s})$ , is added to the second test tube.
- (III) Excess copper(II) carbonate,  $\text{CuCO}_3(\text{s})$ , is added to the third test tube.

(a) Describe the contents of the first and second test tubes once any reactions are complete. (4 marks)

Test Tube	Description
(I)	
(II)	

(b) Write the balanced equation, with appropriate state symbols, for the reaction that takes place between the copper(II) oxide and the hydrochloric acid. (3 marks)

(c) If the labels of test tubes (II) and (III) became smudged, describe all the observations that could be used to distinguish between these test tubes once any reactions are complete. (2 marks)

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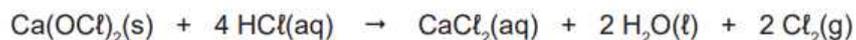
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**2019  
Section 2  
Question  
28**

**Oxidation  
and  
reduction**

As noted in Question 27, calcium hypochlorite and hydrochloric acid react according to the equation shown below.



In this reaction, the chlorine in calcium hypochlorite and the chloride from the hydrochloric acid are both converted to chlorine gas.

(a) What is the oxidation number for the chlorine in:

- calcium hypochlorite,  $\text{Ca}(\text{OCl})$
- hydrochloric acid,  $\text{HCl}$ ? (2 marks)

calcium hypochlorite

hydrochloric acid

Chlorine gas is produced by the oxidation of one of these substances and the reduction of the other.

(b) Write the **two** half-equations showing how chlorine gas is produced from both substances. (5 marks)

Oxidation half-equation

Reduction half-equation

### Section 3

**2022**  
**Section 3**  
**Question**  
**37**

**Oxidation**  
**and**  
**reduction**

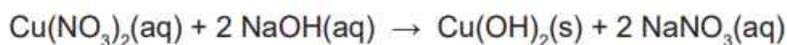
The copper cycle is a series of reactions involving copper.

Step 1: 2.54 g of copper is added to excess concentrated nitric acid to produce copper(II) nitrate, nitrogen dioxide and water.

(a) Write balanced half-equations for the oxidation and reduction reactions and a balanced overall redox equation for the reaction in Step 1. (5 marks)

Oxidation half-equation	
Reduction half-equation	
Overall redox equation	

Step 2: Copper(II) nitrate is added to excess sodium hydroxide solution, according to the following equation:



(b) Describe all the observations for this reaction, including colour changes. (2 marks)

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Step 3: Copper(II) hydroxide is heated to produce copper(II) oxide and water vapour.

(c) Write an equation for Step 3, including state symbols. (3 marks)

Step 4: Copper(II) oxide is added to excess dilute sulfuric acid solution.

(d) Write an equation for this reaction. (2 marks)



**2020  
Section 3  
Question  
36**

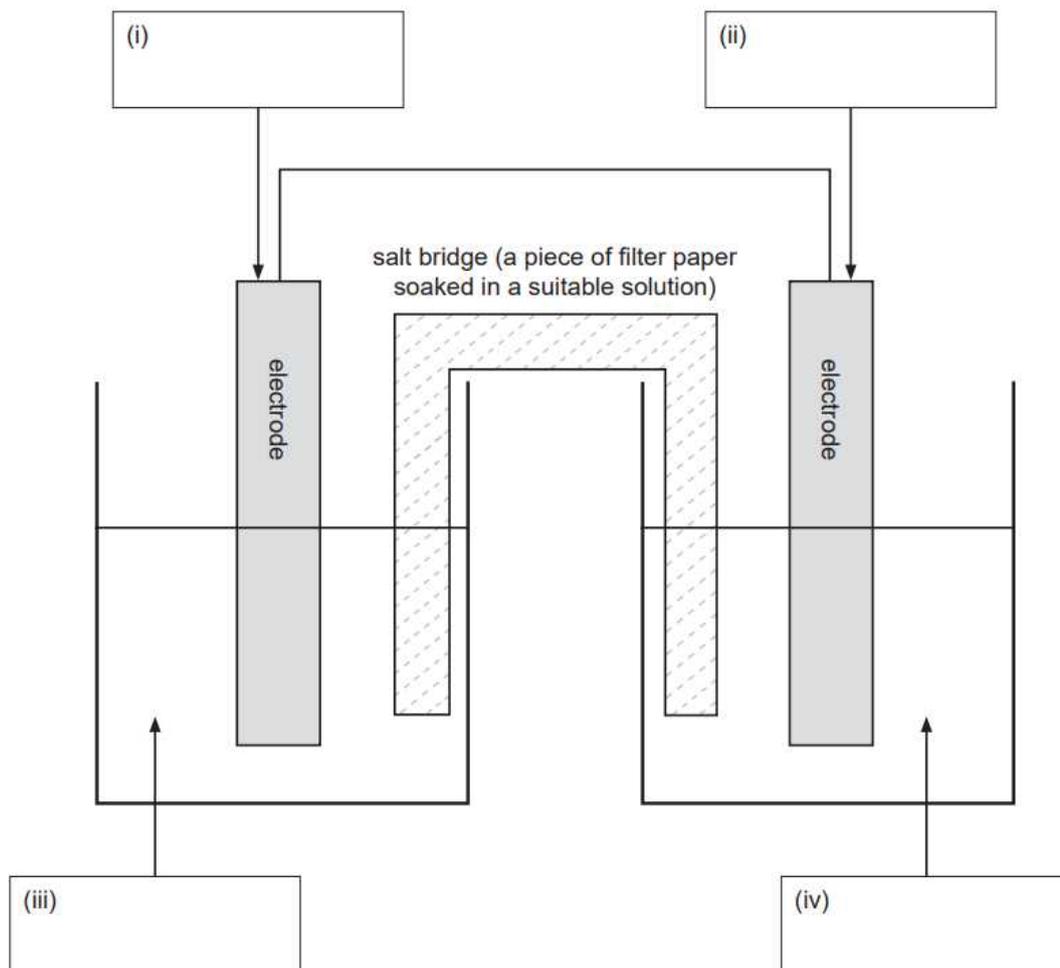
**Oxidation  
and  
reduction**

A student was asked to build a functioning galvanic cell, having been provided with all of the required hardware plus the following substances:

- a piece of magnesium measuring 1 mm by 2 cm by 6 cm
- a piece of copper measuring 1 mm by 2 cm by 6 cm
- a 6 cm long graphite (carbon) rod with a diameter of 1 cm
- 1.0 mol L<sup>-1</sup> sodium carbonate solution
- 1.0 mol L<sup>-1</sup> magnesium sulfate solution
- 1.0 mol L<sup>-1</sup> copper(II) sulfate solution.

There was no requirement for the student to use all of these substances.

(a) A partially-labelled diagram of the galvanic cell built by the student is shown below. What substances should the student have used in the parts labelled (i) to (iv) to build a functioning galvanic cell? Write the names of these substances in the boxes provided. (4 marks)



(b) Add arrows to the diagram in part (a) to show the direction of movement of electrons through the external circuit. (1 mark)

(c) Write the half-equations for the reactions occurring at the anode and the cathode in the student's galvanic cell. (4 marks)

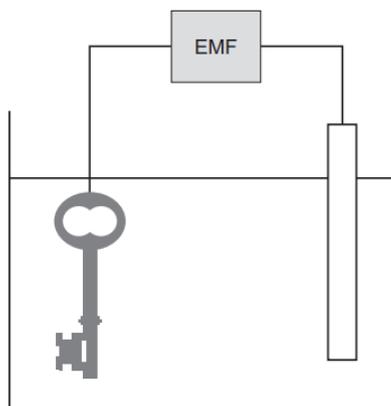
Anode half-equation	
Cathode half-equation	



2019  
Section 2  
Question  
31

Oxidation  
and  
reduction

A solution that contains silver cyanide,  $\text{AgCN}(\text{aq})$ , is used to plate a key with silver.



(a) Label the above diagram to show the:

- cathode and anode
- direction of electron flow
- direction of ion flow
- polarity (positive/negative) of each electrode. (4 marks)

A salt bridge is required in galvanic cells but is **not** required in the electroplating cell above.

(b) Explain this difference between these two cells. (3 marks)

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Use excerpts from the Material Safety Data Sheet for silver cyanide shown below to answer part (c) and part (d).

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(c) Explain why action is taken to maintain the pH above 8 as a safety precaution during the electroplating process using silver cyanide. (3 marks)

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(d) Suggest three other safety measures that should be taken during the electroplating process and indicate how each addresses a specific potential hazard to either the workers or the environment. (3 marks)

One:

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Two:

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Three:

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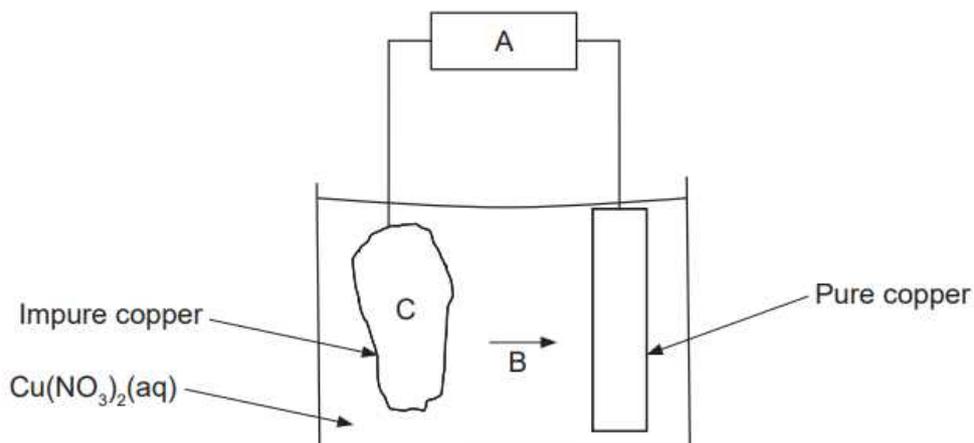
## Marking Guide – Section 1

<p><b>2023</b> <b>Section 1</b> <b>Question 4</b></p> <p><b>Oxidation and reduction</b></p>	<p>In which of the following is vanadium in a +4 oxidation state?</p> <p>(a) <math>\text{NH}_4\text{VO}_3</math>  <b>(b) <math>\text{VOSO}_4</math> – Answer</b>            (c) <math>\text{V}(\text{H}_2\text{O})_6^{3+}</math>            (d) <math>\text{V}_2\text{O}_5</math></p>
<p><b>2023</b> <b>Section 1</b> <b>Question 5</b></p> <p><b>Oxidation and reduction</b></p>	<p>Identify the oxidant in the following equation.</p> $2 \text{BrO}_3^- (\text{aq}) + 10 \text{I}^- (\text{aq}) + 12 \text{H}^+ (\text{aq}) \rightarrow \text{Br}_2 (\text{aq}) + 5 \text{I}_2 (\text{aq}) + 6 \text{H}_2\text{O} (\ell)$ <p><b>(a) <math>\text{BrO}_3^- (\text{aq})</math> – Answer</b>            (b) <math>\text{I}^- (\text{aq})</math>            (c) <math>\text{H}^+ (\text{aq})</math>            (d) <math>\text{Br}_2 (\text{aq})</math></p>
<p><b>2023</b> <b>Section 1</b> <b>Question 15</b></p> <p><b>Oxidation and reduction</b></p>	<p>15. Which of the following reactions will occur spontaneously under standard conditions at 25 °C?</p> <p>(i) <math>\text{H}_2 (\text{g}) + \text{O}_2 (\text{g}) \rightleftharpoons \text{H}_2\text{O}_2 (\text{aq})</math>            (ii) <math>\text{Ni}^{2+} (\text{aq}) + 2 \text{Fe}^{2+} (\text{aq}) \rightleftharpoons \text{Ni} (\text{s}) + 2 \text{Fe}^{3+} (\text{aq})</math>            (iii) <math>\text{H}_2\text{O}_2 (\text{aq}) + 2 \text{CO}_2 (\text{g}) \rightleftharpoons \text{H}_2\text{C}_2\text{O}_4 (\text{aq}) + \text{O}_2 (\text{g})</math>            (iv) <math>\text{O}_2 (\text{g}) + 2 \text{H}_2\text{S} (\text{aq}) \rightleftharpoons 2 \text{S} (\text{s}) + 2 \text{H}_2\text{O} (\ell)</math></p> <p><b>(a) i and iv – Answer</b>            (b) ii and iii            (c) iii and iv            (d) i and ii</p>
<p><b>2023</b> <b>Section 1</b> <b>Question 20</b></p> <p><b>Oxidation and reduction</b></p>	<p>An electrochemical cell, reaction shown below, has an <math>E^\circ</math> value of +0.89 V.</p> $4 \text{V}^{3+} (\text{aq}) + 2 \text{H}_2\text{O} (\ell) + \text{O}_2 (\text{g}) \rightleftharpoons 4 \text{VO}^{2+} (\text{aq}) + 4 \text{H}^+ (\text{aq})$ <p>What is the standard reduction potential for the half-equation below?</p> $\text{VO}^{2+} + 2 \text{H}^+ + \text{e}^- \rightleftharpoons \text{V}^{3+} + \text{H}_2\text{O}$ <p>(a) -0.34 V            (b) +1.57 V  <b>(c) +0.34 V – Answer</b>            (d) -1.57 V</p>

2023  
Section 1  
Question 23

Oxidation  
and  
reduction

The cell below was set up by a student to demonstrate the purification of copper.



Which of the following are the correct labels, A, B and C, on the diagram?

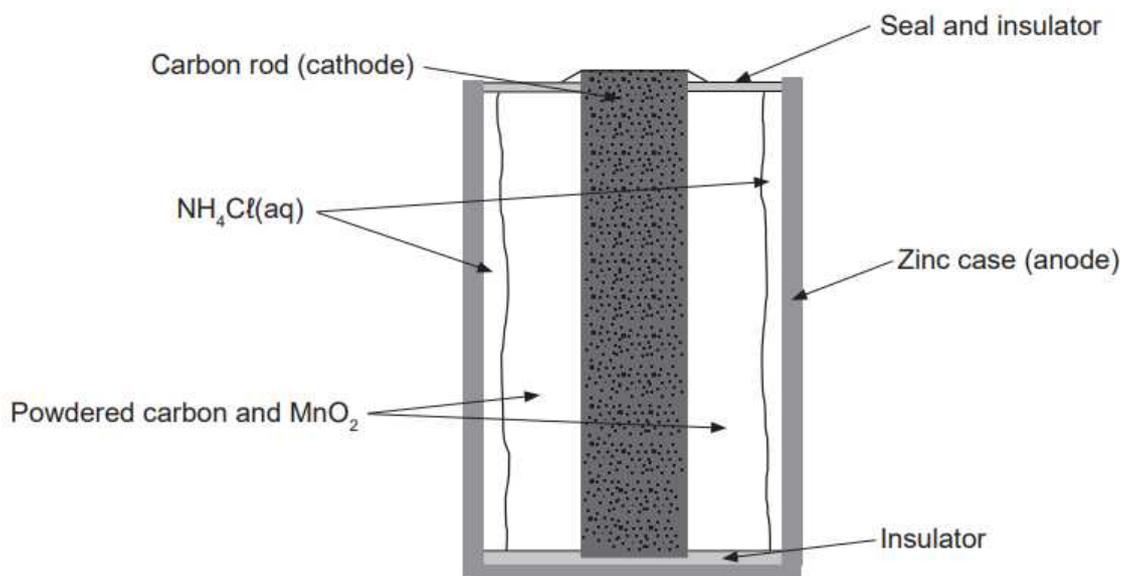
	A	B	C
(a)	Voltmeter	Direction of anion flow	Anode
(b)	Power supply	Direction of cation flow	Anode
(c)	Voltmeter	Direction of anion flow	Cathode
(d)	Power supply	Direction of cation flow	Cathode

Answer is b.

2023  
Section 1  
Question 24

Oxidation  
and  
reduction

Question 24 refers to the following diagram.



For the Leclanché dry cell shown above, which of the following statements best describes the role of the electrodes?

- (a) The zinc is oxidised; reduction of manganese dioxide occurs at the carbon. – Answer  
 (b) The zinc is reduced; carbon is oxidised.  
 (c) The carbon is reduced; oxidation of manganese dioxide occurs at the zinc.  
 (d) The carbon is reduced; zinc is oxidised.

<p><b>2022</b> <b>Section 1</b> <b>Question 2</b></p> <p><b>Oxidation and reduction</b></p>	<p>Which of the following pairs represents the greatest difference in oxidation state of the underlined element?</p> <p>(a) <u>Mn</u><sup>2+</sup> and <u>KMn</u>O<sub>4</sub>          (b) <u>Cr</u>O<sub>4</sub><sup>2-</sup> and <u>Cr</u><sub>2</sub>O<sub>7</sub><sup>2-</sup>          (c) <u>Cl</u><sup>-</sup> and <u>HCl</u>O<sub>4</sub>          (d) <u>S</u><sup>2-</sup> and <u>SO</u><sub>3</sub><sup>2-</sup></p> <p><b>Answer is C.</b></p>
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<p><b>2022</b> <b>Section 1</b> <b>Question 15-17</b></p> <p><b>Oxidation and reduction</b></p>	<p>Questions 15 to 17 refer to the electrochemical cell below.</p> <div style="text-align: center;"> <p style="text-align: center;">Porous membrane</p> </div> <p>15. Which of the following series of labels <b>best</b> represents the cell above?</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th>Anode</th> <th>Cathode</th> <th>Direction of electron flow</th> <th>Direction of anion flow</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>lead</td> <td>iron</td> <td>←</td> <td>→</td> </tr> <tr> <td>(b)</td> <td>lead</td> <td>iron</td> <td>→</td> <td>←</td> </tr> <tr> <td>(c)</td> <td>iron</td> <td>lead</td> <td>→</td> <td>→</td> </tr> <tr> <td>(d)</td> <td>iron</td> <td>lead</td> <td>←</td> <td>→</td> </tr> </tbody> </table> <p><b>Answer is D.</b></p> <p>16. Using the standard reduction potentials, determine the theoretical value that the voltmeter would show for this electrochemical cell?</p> <p><b>(a) +0.31 V – Answer</b>          (b) +0.57 V          (c) +0.64 V          (d) +0.90 V</p> <p>17. Which of the following reasons would cause the voltmeter to show a different value to the theoretical voltage?</p> <p>(i) the cell is at 100 kPa          (ii) the cell is at 20 °C          (iii) the Pb(NO<sub>3</sub>)<sub>2</sub> solution is 0.1 mol L<sup>-1</sup> and the Fe(NO<sub>3</sub>)<sub>2</sub> solution is 0.2 mol L<sup>-1</sup>          (iv) the lead and iron electrodes are in the opposite solution to that shown in the diagram above</p> <p>(a) i and ii          (b) ii and iii  <b>(c) ii, iii and iv – Answer</b>          (d) iii and iv</p>		Anode	Cathode	Direction of electron flow	Direction of anion flow	(a)	lead	iron	←	→	(b)	lead	iron	→	←	(c)	iron	lead	→	→	(d)	iron	lead	←	→
	Anode	Cathode	Direction of electron flow	Direction of anion flow																						
(a)	lead	iron	←	→																						
(b)	lead	iron	→	←																						
(c)	iron	lead	→	→																						
(d)	iron	lead	←	→																						

<b>2021</b> <b>Section 1</b> <b>Question 1</b>  <b>Oxidation and reduction</b>	Which of the following statements is/are true for redox reactions? (i) Redox reactions involve the transfer of electrons from one species to another. (ii) Complete combustion is a redox reaction, but incomplete combustion is not. (iii) Oxidation is the gain of electrons while reduction is the loss of electrons. (iv) Oxidation and reduction occur simultaneously.  (a) i only (b) i, ii and iv only (c) i, iii and iv only <b>(d) i and iv only – Answer</b>
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<b>2021</b> <b>Section 1</b> <b>Question 10</b>  <b>Oxidation and reduction</b>	Which of the following identifies the recharging ability of a particular type of electrochemical cell and provides an appropriate example?  <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th>Electrochemical cell</th> <th>Rechargeable</th> <th>Example</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>primary</td> <td>no</td> <td>Leclanché cell</td> </tr> <tr> <td>(b)</td> <td>secondary</td> <td>no</td> <td>lead-acid accumulator</td> </tr> <tr> <td>(c)</td> <td>primary</td> <td>yes</td> <td>lead-acid accumulator</td> </tr> <tr> <td>(d)</td> <td>secondary</td> <td>yes</td> <td>Leclanché cell</td> </tr> </tbody> </table> <b>Answer is a.</b>		Electrochemical cell	Rechargeable	Example	(a)	primary	no	Leclanché cell	(b)	secondary	no	lead-acid accumulator	(c)	primary	yes	lead-acid accumulator	(d)	secondary	yes	Leclanché cell
	Electrochemical cell	Rechargeable	Example																		
(a)	primary	no	Leclanché cell																		
(b)	secondary	no	lead-acid accumulator																		
(c)	primary	yes	lead-acid accumulator																		
(d)	secondary	yes	Leclanché cell																		

<b>2021</b> <b>Section 1</b> <b>Question 12-13</b>  <b>Oxidation and reduction</b>	Questions 12 and 13 refer to the following electrochemical cell, which contains a light globe.  12. Which combination of electrodes and aqueous electrolytes will result in the possibility of the globe glowing? Assume standard conditions.  <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th colspan="2">Half cell 1</th> <th colspan="2">Half cell 2</th> </tr> <tr> <th></th> <th>Electrode</th> <th>Electrolyte</th> <th>Electrode</th> <th>Electrolyte</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>graphite</td> <td>Ni(NO<sub>3</sub>)<sub>2</sub>(aq)</td> <td>silver</td> <td>AgNO<sub>3</sub>(aq)</td> </tr> <tr> <td>(b)</td> <td>silver</td> <td>Ni(NO<sub>3</sub>)<sub>2</sub>(aq)</td> <td>graphite</td> <td>AgNO<sub>3</sub>(aq)</td> </tr> <tr> <td>(c)</td> <td>nickel</td> <td>Ni(NO<sub>3</sub>)<sub>2</sub>(aq)</td> <td>silver</td> <td>AgNO<sub>3</sub>(aq)</td> </tr> <tr> <td>(d)</td> <td>nickel</td> <td>AgNO<sub>3</sub>(aq)</td> <td>silver</td> <td>Ni(NO<sub>3</sub>)<sub>2</sub>(aq)</td> </tr> </tbody> </table> <b>Answer is c.</b>  13. The salt bridge  (a) provides the ions that are oxidised or reduced at the electrodes. (b) maintains the overall electrical and pH neutrality of the cell by facilitating the transfer of electrons and ions from one half cell to another. (c) provides the H <sub>3</sub> O <sup>+</sup> and OH <sup>-</sup> ions needed to maintain the pH neutrality of each half cell, preventing the build-up of electrical charge in the electrolytes. <b>(d) provides ions and facilitates ion movement between the half cells to complete the electrical circuit. – Answer</b>		Half cell 1		Half cell 2			Electrode	Electrolyte	Electrode	Electrolyte	(a)	graphite	Ni(NO <sub>3</sub> ) <sub>2</sub> (aq)	silver	AgNO <sub>3</sub> (aq)	(b)	silver	Ni(NO <sub>3</sub> ) <sub>2</sub> (aq)	graphite	AgNO <sub>3</sub> (aq)	(c)	nickel	Ni(NO <sub>3</sub> ) <sub>2</sub> (aq)	silver	AgNO <sub>3</sub> (aq)	(d)	nickel	AgNO <sub>3</sub> (aq)	silver	Ni(NO <sub>3</sub> ) <sub>2</sub> (aq)
	Half cell 1		Half cell 2																												
	Electrode	Electrolyte	Electrode	Electrolyte																											
(a)	graphite	Ni(NO <sub>3</sub> ) <sub>2</sub> (aq)	silver	AgNO <sub>3</sub> (aq)																											
(b)	silver	Ni(NO <sub>3</sub> ) <sub>2</sub> (aq)	graphite	AgNO <sub>3</sub> (aq)																											
(c)	nickel	Ni(NO <sub>3</sub> ) <sub>2</sub> (aq)	silver	AgNO <sub>3</sub> (aq)																											
(d)	nickel	AgNO <sub>3</sub> (aq)	silver	Ni(NO <sub>3</sub> ) <sub>2</sub> (aq)																											

<b>2021</b> <b>Section 1</b> <b>Question 22</b>  <b>Oxidation and reduction</b>	In an electrolytic cell used for plating objects with gold  (a) the object to be plated is the anode. (b) there must be a salt bridge connecting the anode and cathode half-cells. (c) the reaction is spontaneous and so no external potential difference is required. <b>(d) a piece of pure gold is used as the positively charged electrode. – Answer</b>
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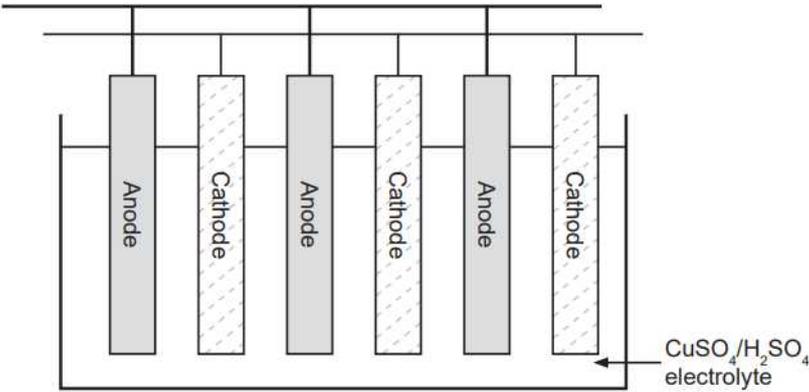
<p><b>2020</b> <b>Section 1</b> <b>Question 1</b></p> <p><b>Oxidation and reduction</b></p>	<p>Holmium (Ho) reacts quickly with hot water to form holmium hydroxide and hydrogen:</p> $2 \text{Ho(s)} + 6 \text{H}_2\text{O(l)} \rightarrow 2 \text{Ho(OH)}_3 \text{(aq)} + 3 \text{H}_2\text{(g)}$ <p>The oxidising and reducing agents in this equation are</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th>Oxidising agent</th> <th>Reducing agent</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>H<sub>2</sub>O</td> <td>H<sub>2</sub></td> </tr> <tr> <td>(b)</td> <td>Ho</td> <td>H<sub>2</sub>O</td> </tr> <tr> <td>(c)</td> <td>H<sub>2</sub>O</td> <td>Ho</td> </tr> <tr> <td>(d)</td> <td>Ho(OH)<sub>3</sub></td> <td>Ho</td> </tr> </tbody> </table> <p><b>Answer is c.</b></p>		Oxidising agent	Reducing agent	(a)	H <sub>2</sub> O	H <sub>2</sub>	(b)	Ho	H <sub>2</sub> O	(c)	H <sub>2</sub> O	Ho	(d)	Ho(OH) <sub>3</sub>	Ho
	Oxidising agent	Reducing agent														
(a)	H <sub>2</sub> O	H <sub>2</sub>														
(b)	Ho	H <sub>2</sub> O														
(c)	H <sub>2</sub> O	Ho														
(d)	Ho(OH) <sub>3</sub>	Ho														

<p><b>2020</b> <b>Section 1</b> <b>Question 3</b></p> <p><b>Oxidation and reduction</b></p>	<p>Oxidation-reduction reactions involve the transfer of</p> <p>(a) protons.  <b>(b) electrons. – Answer</b>  (c) hydroxide ions.  (d) hydrogen ions.</p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 5</b></p> <p><b>Oxidation and reduction</b></p>	<p>Which of the following statements about pure water are correct?</p> <p>(i) Pure water is a weak electrolyte that undergoes self-ionisation.  (ii) The equilibrium constant for the ionisation of pure water at 25 °C is 1.00 x 10<sup>-14</sup>.  (iii) Pure water ionises completely at 25 °C, hence [H<sup>+</sup>] = [OH<sup>-</sup>].  (iv) The ionisation of pure water produces twice as many hydrogen ions as hydroxide ions.</p> <p><b>(a) i and ii only – Answer</b>  (b) ii and iii only  (c) iii and iv only  (d) i, ii, iii and iv</p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 6</b></p> <p><b>Oxidation and reduction</b></p>	<p>What type of redox reaction occurs in a galvanic cell and what is one possible use for such a cell?</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th>Type of redox reaction</th> <th>Possible use of a galvanic cell</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>non-spontaneous</td> <td>the plating of cheap metallic objects with precious metals</td> </tr> <tr> <td>(b)</td> <td>spontaneous</td> <td>the plating of cheap metallic objects with precious metals</td> </tr> <tr> <td>(c)</td> <td>non-spontaneous</td> <td>the production of an electric current for a torch</td> </tr> <tr> <td>(d)</td> <td>spontaneous</td> <td>the production of an electric current for a torch</td> </tr> </tbody> </table> <p><b>Answer is d.</b></p>		Type of redox reaction	Possible use of a galvanic cell	(a)	non-spontaneous	the plating of cheap metallic objects with precious metals	(b)	spontaneous	the plating of cheap metallic objects with precious metals	(c)	non-spontaneous	the production of an electric current for a torch	(d)	spontaneous	the production of an electric current for a torch
	Type of redox reaction	Possible use of a galvanic cell														
(a)	non-spontaneous	the plating of cheap metallic objects with precious metals														
(b)	spontaneous	the plating of cheap metallic objects with precious metals														
(c)	non-spontaneous	the production of an electric current for a torch														
(d)	spontaneous	the production of an electric current for a torch														

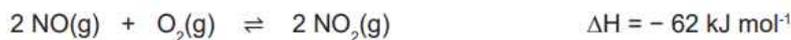
<p><b>2020 Section 1 Question 19</b></p> <p><b>Oxidation and reduction</b></p>	<p>The following half-equations show some predicted standard reduction potentials for seaborgium (Sg) oxides:</p> $2 \text{SgO}_3(\text{s}) + 2 \text{H}^+(\text{aq}) + 2 \text{e}^- \rightarrow \text{Sg}_2\text{O}_5(\text{s}) + \text{H}_2\text{O}(\text{l}) \quad E^\circ = -0.046 \text{ V}$ $\text{Sg}_2\text{O}_5(\text{s}) + 2 \text{H}^+(\text{aq}) + 2 \text{e}^- \rightarrow 2 \text{SgO}_2(\text{s}) + \text{H}_2\text{O}(\text{l}) \quad E^\circ = +0.11 \text{ V}$ $\text{SgO}_2(\text{s}) + 4 \text{H}^+(\text{aq}) + \text{e}^- \rightarrow \text{Sg}^{3+}(\text{aq}) + 2 \text{H}_2\text{O}(\text{l}) \quad E^\circ = -1.34 \text{ V}$ <p>The strongest reducing agent is</p> <p>(a) <math>\text{SgO}_3</math>  (b) <math>\text{Sg}_2\text{O}_5</math>  (c) <math>\text{SgO}_2</math>  (d) <math>\text{Sg}^{3+}</math></p> <p><b>Answer is d.</b></p>
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<p><b>2020 Section 1 Question 20</b></p> <p><b>Oxidation and reduction</b></p>	<p>Impure copper must be purified before it is used in applications where very high electrical conductivity is required. The purification of copper, which is also known as electrorefining, can be performed in an electrochemical cell similar to the one shown below.</p>  <p>Which statement regarding this electrochemical cell is correct?</p> <p><b>(a) This cell requires the application of an external electrical potential difference for it to function. – Answer</b>  (b) During operation, the electrolyte becomes less blue because the concentration of <math>\text{Cu}^{2+}</math> ions in the electrolyte decreases.  (c) This cell will not work because it does not have a salt bridge.  (d) The impure copper is cast as cathodes.</p>
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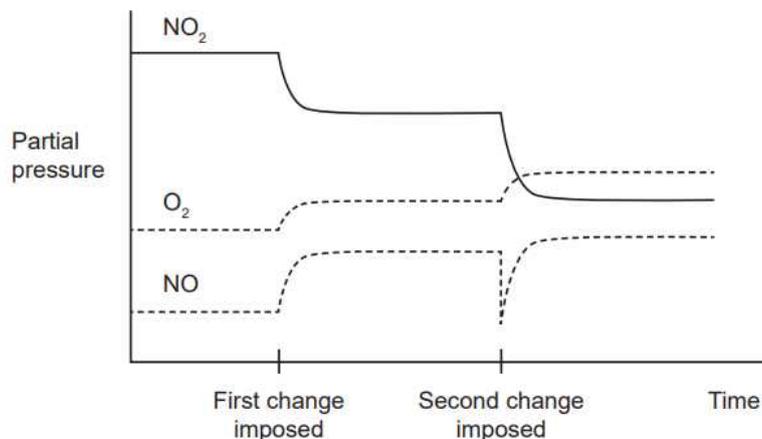
2019  
Section 1  
Question 3-4

Oxidation and reduction

Questions 3 and 4 refer to the following information. Nitrogen dioxide,  $\text{NO}_2(\text{g})$ , is formed when nitrogen monoxide,  $\text{NO}(\text{g})$ , undergoes oxidation as shown below.



A change was imposed on an equilibrium gas mixture of  $\text{NO}_2$ ,  $\text{NO}$  and  $\text{O}_2$ . The mixture returned to equilibrium and another change was imposed. The following graph shows the effects of the two changes.



3. Identify the imposed changes that **best** account for the shape of the graph.

	First change	Second change
(a)	the temperature is decreased	the partial pressure of $\text{O}_2$ is increased
(b)	the temperature is decreased	the partial pressure of $\text{NO}$ is decreased
(c)	the temperature is increased	the partial pressure of $\text{O}_2$ is increased
(d)	the temperature is increased	the partial pressure of $\text{NO}$ is decreased

**Answer is d.**

4. What do the initial partial pressures of the three gases indicate?

**(a) The relative proportions of the gases present at equilibrium. – Answer**

(b) That there is initially no  $\text{NO}$  gas present in the system.

(c) That the  $\text{NO}_2$  gas reaches equilibrium first.

(d) That the  $\text{O}_2$  and  $\text{NO}$  gases are producing  $\text{NO}_2$  at a faster rate than they are being formed.

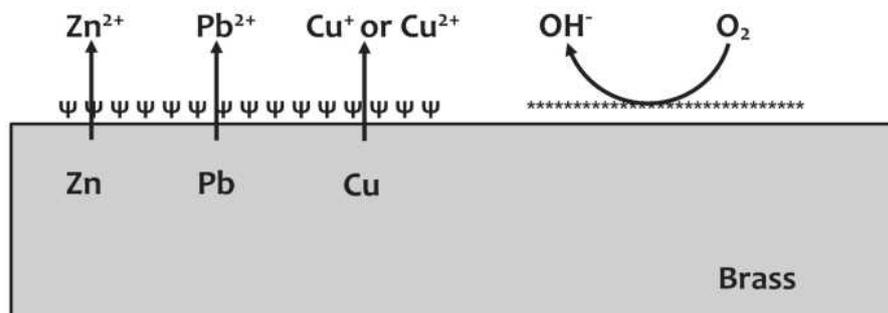
**2019  
Section 1  
Question  
5-7**

**Oxidation  
and  
reduction**

Questions 5, 6 and 7 refer to the following information.

The corrosion of brass plumbing fixtures has been identified as a possible cause of the presence of lead in drinking water. Brass is an alloy of copper and zinc but can also contain lead to improve machinability.

The corrosion of brass is a redox process, with an electrochemical cell forming on the surface of the brass as illustrated below.

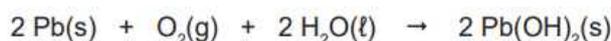


5. Which one of the following correctly identifies the anodic region, cathodic region and direction of electron flow?

	Anodic region	Cathodic region	Direction of electron flow
(a)	Ψ	*	Ψ → *
(b)	*	Ψ	Ψ → *
(c)	Ψ	*	* → Ψ
(d)	*	Ψ	* → Ψ

**Answer is a.**

6. The overall equation for the reaction of lead with oxygen is as follows:



What is the theoretical E<sup>0</sup> value for the overall Pb/O<sub>2</sub> reaction under standard conditions?

- (a) - 0.27 V
- (b) + 0.27 V
- (c) + 0.53 V – Answer**
- (d) + 0.93 V

7. The composition of brass can be adjusted by adding various metals. Which one of the following metals would not undergo corrosion if added to brass?

- (a) silver – Answer**
- (b) nickel
- (c) iron
- (d) strontium

**2019  
Section 1  
Question  
10**

**Oxidation  
and  
reduction**

Which statement is correct?

- (a) Fluorine can be oxidised by potassium bromide solution but not by potassium iodide solution.
- (b) Chlorine can be oxidised by potassium fluoride solution but not by potassium iodide solution.
- (c) Chlorine can be reduced by potassium bromide solution but not by potassium iodide solution.
- (d) Bromine can be reduced by potassium iodide solution but not by potassium chloride solution. – Answer**

<p><b>2019</b> <b>Section 1</b> <b>Question</b> <b>17</b></p> <p><b>Oxidation</b> <b>and</b> <b>reduction</b></p>	<p>In which of the following sets do all the <b>bolded</b> and <u>underlined</u> atoms have the same oxidation number?</p> <p>(i) <math>\text{H}_2\text{O}</math>, <math>\text{O}_2</math>, <math>\text{H}_2\text{O}_2</math>  (ii) <math>\text{H}_2\text{O}_2</math>, <math>\text{NaCl}</math>, <math>\text{MgH}_2</math>  (iii) <math>\text{NaCl}</math>, <math>\text{Li}_2\text{CO}_3</math>, <math>\text{KOH}</math>  (iv) <math>\text{FeO}</math>, <math>\text{Fe}_2\text{O}_3</math>, <math>\text{Fe}</math></p> <p>(a) i and iv only  <b>(b) ii and iii only – Answer</b>  (c) iv only  (d) i, ii and iii only</p>
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<p><b>2019</b> <b>Section 1</b> <b>Question</b> <b>18</b></p> <p><b>Oxidation</b> <b>and</b> <b>reduction</b></p>	<p>Which one of the following could not be a product when propan-1-ol is oxidised?</p> <p>(a) <math>\text{CO}_2</math>  (b) <math>\text{CH}_3\text{CH}_2\text{CHO}</math>  (c) <math>\text{CH}_3\text{CH}_2\text{COOH}</math>  <b>(d) <math>\text{CH}_3\text{COCH}_3</math> – Answer</b></p>
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Marking Guide – Section 2

2023  
Section 2  
Question  
27

Oxidation  
and  
reduction

A carpenter left a pair of pliers outside over a rainy period, which subsequently became rusty, causing the joint to seize. Rather than buy a new pair of pliers, the carpenter decided to submerge the rusty part of the pliers in phosphoric acid to remove the rust. Phosphoric acid converts rust into another substance that can easily be washed away.



(a) Write an equation for the action of phosphoric acid on the rust. Assume rust is iron(III) oxide. Include state symbols in your answer. (3 marks)

Description	Marks
Correct species	1
Correct balancing	1
Correct state symbols	1
<b>Total</b>	<b>3</b>
$\text{Fe}_2\text{O}_3(\text{s}) + 2 \text{H}_3\text{PO}_4(\text{aq}) \rightarrow 2 \text{FePO}_4(\text{s}) + 3 \text{H}_2\text{O}(\text{l})$	
Note: if incorrect equation, equation must have merit for balancing and state symbol marks to be awarded. e.g. iron(II) oxide is used	

(b) Identify the best method that the carpenter could use to protect the pliers from rusting further. Explain how this method would be effective. (3 marks)

Description	Marks
oiling/greasing	1
Recognition that the method provides a barrier	1
Recognition that the barrier prevents water (and oxygen) from contacting the iron, (preventing oxidation of the iron)	1
<b>Total</b>	<b>3</b>

The carpenter noticed that his toolboxes in the back of his truck were also rusting. He decided to explore the use of a sacrificial anode as an option to prevent the toolboxes rusting.

(c) State what a sacrificial anode is and explain how it is effective in preventing corrosion of the toolboxes. You should state which metal could be used for a sacrificial anode in your answer. (4 marks)

Description	Marks
Recognition that the sacrificial anode is a more reactive metal than the toolboxes (cathode)	1
Metals could include any one of: <ul style="list-style-type: none"> <li>• zinc</li> <li>• magnesium</li> <li>• chromium</li> <li>• manganese</li> <li>• aluminium</li> </ul>	1
Recognition that the two metals are touching/connected electrically	1
Recognition that the $E^\circ$ value of the anode is more negative compared to that of iron/is more readily oxidised/stronger reductant	1
<b>Total</b>	<b>4</b>
Note: do not accept reactive group 1 metals or Ca/Ba.	

**2023  
Section 2  
Question  
29**

**Oxidation  
and  
reduction**

Electrochemical cells are categorised as either galvanic cells or electrolytic cells. Identify **three** similarities and **three** differences with which to compare galvanic and electrolytic cells, using relevant examples of each cell type. You may choose to use diagrams to illustrate your answer.

Description	Marks
Similarities between galvanic and electrolytic cells	1–3
Differences between galvanic and electrolytic cells	1–3
Relevant examples	1–2
<b>Total</b>	<b>8</b>

Answers could include:

Similarities:

- oxidation occurs at the anode/reduction occurs at the cathode
- cations move towards the cathode/anions move towards the anode
- external circuit through which a current flows
- electrolyte for transfer of ions.

Differences (any three of the following):

- galvanic cell reactions are spontaneous while electrolytic cell reactions are not spontaneous
- galvanic cells generate a voltage/electric current while electrolytic cells require an external power source
- galvanic cells convert chemical energy to electrical energy while electrolytic cells convert electrical energy to chemical energy
- the charge on the anode of a galvanic cell is designated as negative while the charge on the anode of an electrolytic cell is designated as positive.

Examples could include:

- Galvanic cells:
  - Leclanché cell
  - lead-acid accumulator
  - fuel cells.
- Electrolytic cells:
  - recharging of cells
  - purification of copper cells
  - electroplating cells.

Note: similarities and differences may be provided on annotated diagrams.  
Accept other relevant answers.

**2023  
Section 2  
Question  
30**

**Oxidation  
and  
reduction**

Write a balanced ionic equation for any reactions occurring between the following substances and state any observations before and after mixing.

If there is no reaction, write 'no reaction' for the equation and if there is no change observed write 'no visible reaction'. Use the colours stated in the Data booklet if required.

(a) A piece of iron wool is added to a 0.1 mol L<sup>-1</sup> solution of copper(II) sulfate. (4 marks)

Description	Marks
Similarities between galvanic and electrolytic cells	1-3
Differences between galvanic and electrolytic cells	1-3
Relevant examples	1-2
<b>Total</b>	<b>8</b>

Answers could include:

Similarities:

- oxidation occurs at the anode/reduction occurs at the cathode
- cations move towards the cathode/anions move towards the anode
- external circuit through which a current flows
- electrolyte for transfer of ions.

Differences (any three of the following):

- galvanic cell reactions are spontaneous while electrolytic cell reactions are not spontaneous
- galvanic cells generate a voltage/electric current while electrolytic cells require an external power source
- galvanic cells convert chemical energy to electrical energy while electrolytic cells convert electrical energy to chemical energy
- the charge on the anode of a galvanic cell is designated as negative while the charge on the anode of an electrolytic cell is designated as positive.

Examples could include:

- Galvanic cells:
  - Leclanché cell
  - lead-acid accumulator
  - fuel cells.
- Electrolytic cells:
  - recharging of cells
  - purification of copper cells
  - electroplating cells.

Note: similarities and differences may be provided on annotated diagrams.  
Accept other relevant answers.

(b) Calcium hydrogencarbonate powder is added to excess 1 mol L<sup>-1</sup> nitric acid. (4 marks)

Description	Marks
Equation	
$\text{Ca}(\text{HCO}_3)_2(\text{s}) + 2 \text{H}^+(\text{aq}) \rightarrow \text{Ca}^{2+}(\text{aq}) + 2 \text{H}_2\text{O}(\text{l}) + 2 \text{CO}_2(\text{g})$	
Correct species	1
Correct balancing	1
Observed colour change/s	
white solid and colourless solution	1
solid dissolves/reacts and there is effervescence (bubbling)	1
<b>Total</b>	<b>4</b>

Note:

- maximum 1 mark for correct and balanced molecular equations
- each observation requires colours of reagents and change in the products
- state symbols are not required for full marks
- do not accept 'clear solution' without reference to colour.

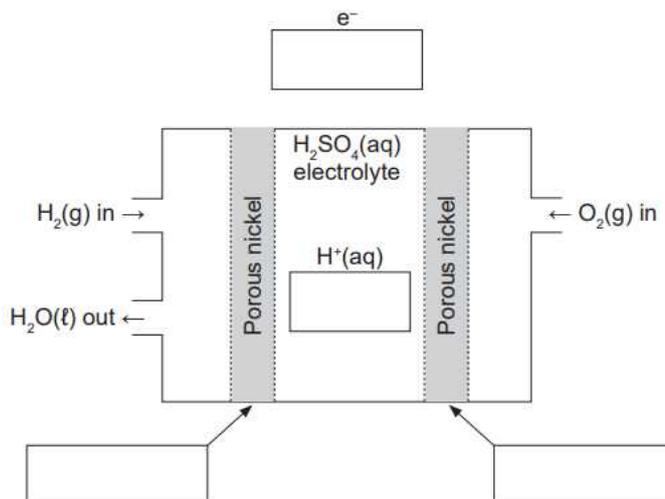
(c) Excess chlorine gas is bubbled through a 0.1 mol L<sup>-1</sup> sodium bromide solution. (4 marks)

Description	Marks
Equation	
$2 \text{Br}^{-}(\text{aq}) + \text{Cl}_2(\text{g}) \rightarrow \text{Br}_2(\text{aq}) + 2 \text{Cl}^{-}(\text{aq})$	
Correct species	1
Correct balancing	1
Observed colour change/s	
greenish-yellow gas is bubbled through a colourless solution	1
forms an orange solution	1
<b>Total</b>	<b>4</b>
Note:	
<ul style="list-style-type: none"><li>• maximum 1 mark for correct and balanced molecular equations</li><li>• each observation requires colours of reagents and change in the products</li><li>• state symbols are not required for full marks</li><li>• do not accept 'clear solution' without reference to colour.</li></ul>	

**2021  
Section 2  
Question  
30**

**Oxidation  
and  
reduction**

Fuel cells, such as the one shown in the diagram below, use gaseous hydrogen and oxygen to produce electricity.



In this particular fuel cell, which uses sulfuric acid as the electrolyte, the hydrogen and oxygen are circulated at very high pressure over porous nickel-platinum electrodes. Operating temperatures range from 25 to 90 °C.

(a) Complete the above diagram by adding labels/arrows to show the:

- anode
- cathode
- direction of electron flow
- direction of hydrogen ion flow. (4 marks)

Description	Marks
<p>The completed diagram shows the fuel cell with the following additions: an arrow labeled <math>e^-</math> pointing from the left terminal to the right terminal; an arrow labeled <math>H^+(aq)</math> pointing from the left porous nickel electrode to the right porous nickel electrode; a box labeled 'anode' with an arrow pointing to the left porous nickel electrode; and a box labeled 'cathode' with an arrow pointing to the right porous nickel electrode.</p>	1–4
<b>Total</b>	<b>4</b>

(b) Write balanced half-equations for the oxidation and reduction reactions and the equation for the overall reaction occurring in this fuel cell. (4 marks)

Description	Marks
Oxidation reaction: $\text{H}_2(\text{g}) \rightarrow 2 \text{H}^+(\text{aq}) + 2\text{e}^-$	1
Reduction reaction: $\text{O}_2(\text{g}) + 4 \text{H}^+(\text{aq}) + 4\text{e}^- \rightarrow + 2 \text{H}_2\text{O}(\text{l})$	1
Overall redox reaction: $2 \text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2 \text{H}_2\text{O}(\text{l})$	1
<ul style="list-style-type: none"> <li>• correct species</li> <li>• correct balancing</li> </ul>	1
<b>Total</b>	<b>4</b>
<b>Note:</b> <ul style="list-style-type: none"> <li>• State symbols are not required for full marks.</li> <li>• Equations must have merit to award marks for the overall reaction if either half reaction is incorrect, i.e. alkaline fuel cell equation is used.</li> </ul>	

(c) This fuel cell typically produces 0.7 V, which is significantly less than the predicted value of 1.23 V. State **two** specific conditions of this cell that would account for this observation. (2 marks)

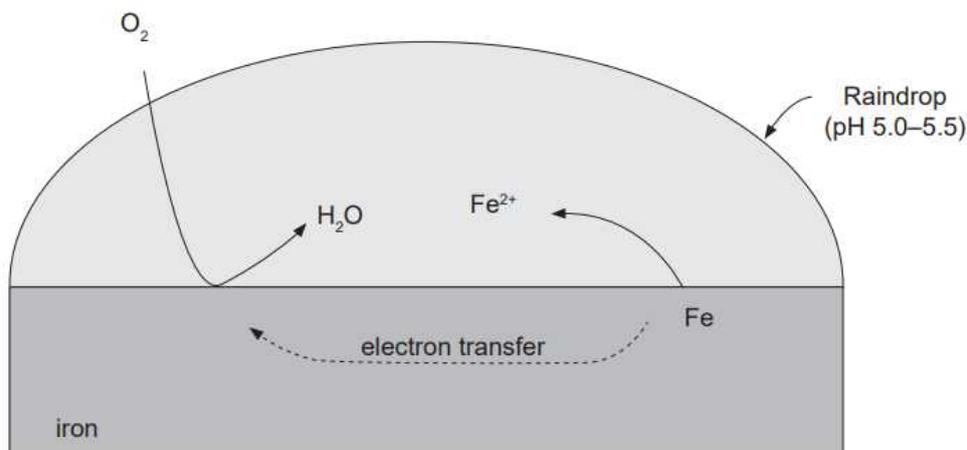
Description	Marks
Any two relevant points. Answers may include: <ul style="list-style-type: none"> <li>• The gas pressure is higher than standard pressure.</li> <li>• The cell runs between 25 °C and 90 °C.</li> <li>• Potential energy produced may be converted to heat.</li> <li>• Drop in voltage due to resistance in components.</li> </ul>	1–2
<b>Total</b>	<b>2</b>

**2021  
Section 2  
Question  
31**

**Oxidation  
and  
reduction**

The corrosion of iron is an electrochemical process that results in the formation of a reddish-brown solid commonly known as rust,  $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}(\text{s})$ . Iron objects exposed to rainwater corrode relatively quickly.

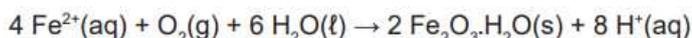
Iron corrosion occurs in two stages. During the first stage, an electrochemical cell is established on the iron surface, with electron transfer and  $\text{Fe}^{2+}$  ion formation occurring. This can be seen in the following diagram.



(a) Write half-equations and the overall balanced equation for the reaction occurring in the above electrochemical cell. State symbols are not required. (4 marks)

Description	Marks
Oxidation half-equation $\text{Fe}(\text{s}) \rightarrow \text{Fe}^{2+}(\text{aq}) + 2\text{e}^-$	1
Reduction half-equation $\text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^- \rightarrow 2\text{H}_2\text{O}(\text{l})$ or $\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + 4\text{e}^- \rightarrow 4\text{OH}^-(\text{aq})$	1
Redox equation 1 mark for correct species based on the half equations provided 1 mark for correct balancing $2\text{Fe}(\text{s}) + \text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) \rightarrow 2\text{Fe}^{2+}(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$ or $2\text{Fe}(\text{s}) + \text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{Fe}(\text{OH})_2(\text{s})$	1-2
<b>Total</b>	<b>4</b>
Note: • State symbols not required.	

(b) During the second stage of iron corrosion, the newly formed  $\text{Fe}^{2+}$  ions migrate away from the iron surface and react with water and dissolved oxygen to form rust. The balanced equation for this reaction is shown below.



Use oxidation numbers to show that this reaction is a redox reaction. (2 marks)

Description	Marks
The oxidation number of iron changes (increases) from +2 to +3.	1
The oxidation number of oxygen changes (decreases) from 0 to -2.	1
<b>Total</b>	<b>2</b>

A corrosion chemist inspected an outdoor playground and found that most of the equipment containing iron showed signs of corrosion. The chemist suggested several different methods for protecting the playground equipment from further corrosion, including the use of sacrificial anodes.

(c) State what is a sacrificial anode. (1 mark)

Description	Marks
A sacrificial anode is a piece of metal (that is connected to another metal) that is more easily oxidised/corroded than the metal being protected from corrosion (and so oxidises in preference to the metal being protected).	1
<b>Total</b>	<b>1</b>

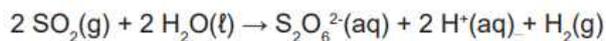
(d) State the name of a metal that can be used as a sacrificial anode to protect the equipment from further corrosion. Use Standard Reduction Potentials to justify your choice. (2 marks)

Description	Marks
Name of one specific metal that is below iron on the Standard Reduction Potential Table (chromium, zinc, manganese, or magnesium).	1
Statement acknowledging that the selected metal has a more negative $E^\ominus$ for reduction (or a more positive $E^\ominus$ for oxidation) when compared to iron.	1
<b>Total</b>	<b>2</b>
Note: <ul style="list-style-type: none"><li>• Do not accept reactive Group 1 metals or calcium.</li></ul>	

2020  
Section 2  
Question  
30

Oxidation  
and  
reduction

Sulfur dioxide must be removed from waste industrial gases before they are released into the atmosphere. One method of doing this is the electrolytic conversion of sulfur dioxide into dithionate ( $\text{S}_2\text{O}_6^{2-}$ ):



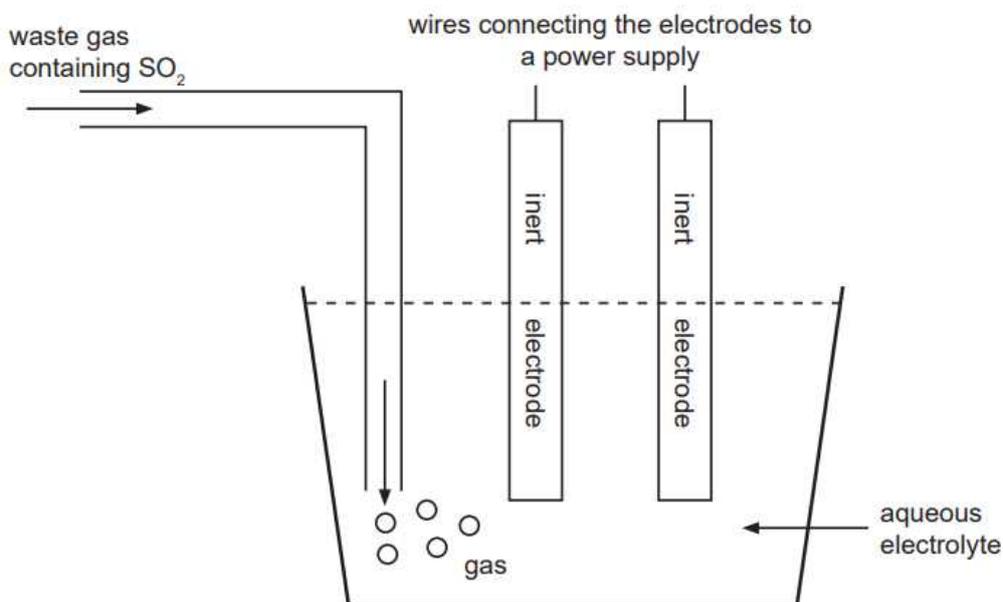
(a) Identify the atom that is oxidised and the atom that is reduced in this reaction. (2 marks)

Description	Marks
The atom that is oxidised is sulfur (or S).	1
The atom that is reduced is hydrogen (or H).	1
<b>Total</b>	<b>2</b>

Note:

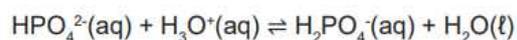
- Must have the actual atom. No marks allocated for  $\text{SO}_2$  being oxidised or  $\text{H}_2\text{O}$  being reduced.
- $\text{H}^+$  and  $\text{S}^{2-}$  are not acceptable answers.

An electrolytic cell, similar to the simplified one shown below, can be used for the above process.



A chemist, who was investigating this process, used 1.00 mol L<sup>-1</sup> sodium perchlorate (NaClO<sub>4</sub>) solution as the electrolyte. The chemist found that the pH of this electrolyte steadily decreased as more SO<sub>2</sub>- containing waste gas was treated. The final pH was 2.42.

The observed pH change prompted the chemist to change the electrolyte to a mixture of potassium hydrogen phosphate (K<sub>2</sub>HPO<sub>4</sub>) and potassium dihydrogenphosphate (KH<sub>2</sub>PO<sub>4</sub>), in which the following equilibrium occurred:



No significant pH changes occurred when this new electrolyte was used.

(b) Explain how the HPO<sub>4</sub><sup>2-</sup>/H<sub>2</sub>PO<sub>4</sub><sup>-</sup> prevented any significant pH change when the SO<sub>2</sub> was bubbled into the solution. (5 marks)

Description	Marks
Recognition that SO <sub>2</sub> reaction results in increase in the [H <sup>+</sup> ]	1
Recognition HPO <sub>4</sub> <sup>2-</sup> /H <sub>2</sub> PO <sub>4</sub> <sup>-</sup> is a buffer (because it is a weak base/weak acid combination)	1
Produced H <sup>+</sup> reacts with the HPO <sub>4</sub> <sup>2-</sup> base in the buffer.	1
Recognition that this consumes the majority of the added H <sup>+</sup> in the solution (therefore overall minimal increase in [H <sup>+</sup> ])	1
Recognition of how [H <sup>+</sup> ] links to pH	1
<b>Total</b>	<b>5</b>

**2019  
Section 2  
Question  
26**

**Oxidation  
and  
reduction**

Dilute hydrochloric acid, HCl(aq), is added to three labelled test tubes.

- (I) Excess copper metal, Cu(s), is added to the first test tube.  
 (II) Excess copper(II) oxide, CuO(s), is added to the second test tube.  
 (III) Excess copper(II) carbonate, CuCO<sub>3</sub> (s), is added to the third test tube.

(a) Describe the contents of the first and second test tubes once any reactions are complete. (4 marks)

Description	Marks
<b>Test Tube I</b>	
• salmon pink (brown/orange/copper colour) solid in	1
• a colourless liquid/solution	1
<b>Test Tube II</b>	
• black solid in a	1
• blue (green) liquid/solution	1
<b>Total</b>	<b>4</b>

(b) Write the balanced equation, with appropriate state symbols, for the reaction that takes place between the copper(II) oxide and the hydrochloric acid. (3 marks)

Description	Marks
Correct reactants and products	1
Balanced	1
Correct state symbols	1
<b>Total</b>	<b>3</b>
Example of a three mark response: $\text{CuO(s)} + 2 \text{H}^{\text{+}}(\text{aq}) \rightarrow \text{Cu}^{2\text{+}}(\text{aq}) + \text{H}_2\text{O}(\ell)$	

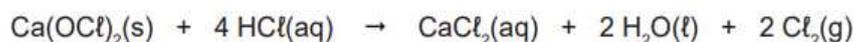
(c) If the labels of test tubes (II) and (III) became smudged, describe all the observations that could be used to distinguish between these test tubes once any reactions are complete. (2 marks)

Description	Marks
Test tube II contains a black solid while test tube III contains a green solid	2
Test tube II contains no sign of a gas while test tube III contains colourless bubbles (no colours described)	1
<b>Total</b>	<b>2</b>
<b>Note:</b> Colour of solid - reference to both test tubes must be made as they each contain a different colour.	

**2019**  
**Section 2**  
**Question**  
**28**

**Oxidation**  
**and**  
**reduction**

As noted in Question 27, calcium hypochlorite and hydrochloric acid react according to the equation shown below.



In this reaction, the chlorine in calcium hypochlorite and the chloride from the hydrochloric acid are both converted to chlorine gas.

(a) What is the oxidation number for the chlorine in:

- calcium hypochlorite,  $\text{Ca}(\text{OCl})_2$
- hydrochloric acid,  $\text{HCl}$ ? (2 marks)

Description	Marks
Calcium hypochlorite $\text{Ca}(\text{OCl})_2$ +1	1
Hydrochloric acid $\text{HCl}$ -1	1
<b>Total</b>	<b>2</b>

Chlorine gas is produced by the oxidation of one of these substances and the reduction of the other.

(b) Write the **two** half-equations showing how chlorine gas is produced from both substances. (5 marks)

Description	Marks
Correctly identifying which half-equation is oxidation and which is reduction	1
Oxidation half-equation	
One mark for correct reactants and products	1
One mark for correct balancing	1
Example of a two mark response: $2 \text{Cl}^-(\text{aq}) \rightarrow \text{Cl}_2(\text{g}) + 2\text{e}^-$	
Reduction half-equation	
One mark for correct reactants and products	1
One mark for correct balancing	1
Example of a two mark response: $\text{Ca}(\text{OCl})_2(\text{s}) + 4 \text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{Ca}^{2+}(\text{aq}) + 2 \text{H}_2\text{O}(\text{aq}) + \text{Cl}_2(\text{g})$	
<b>Total</b>	<b>5</b>

Marking Guide – Section 3

2022  
Section 3  
Question  
37

Oxidation  
and  
reduction

The copper cycle is a series of reactions involving copper.

Step 1: 2.54 g of copper is added to excess concentrated nitric acid to produce copper(II) nitrate, nitrogen dioxide and water.

(a) Write balanced half-equations for the oxidation and reduction reactions and a balanced overall redox equation for the reaction in Step 1. (5 marks)

Description		Marks
correctly places oxidation and reduction half-equations		1
Cu half-equation correct		1
reduction half equation has correct species		1
reduction half equation correctly balanced		1
overall equation is correctly balanced		1
<b>Total</b>		<b>5</b>
Oxidation half-equation	$\text{Cu} \rightarrow \text{Cu}^{2+} + 2 \text{e}^{-}$	
Reduction half-equation	$\text{NO}_3^{-} + 2 \text{H}^{+} + \text{e}^{-} \rightarrow \text{NO}_2 + \text{H}_2\text{O}$	
Overall redox equation	$\text{Cu} + 2 \text{NO}_3^{-} + 4 \text{H}^{+} \rightarrow \text{Cu}^{2+} + 2 \text{NO}_2 + 2 \text{H}_2\text{O}$	
Note: Equation must have some merit for follow through marks.		

Step 2: Copper(II) nitrate is added to excess sodium hydroxide solution, according to the following equation:



(b) Describe all the observations for this reaction, including colour changes. (2 marks)

Description		Marks
describes all observations, including reactants and products		2
describes some observations		1
<b>Total</b>		<b>2</b>
<ul style="list-style-type: none"> <li>a blue solution is added to a colourless solution</li> <li>a blue precipitate and a colourless solution are formed.</li> </ul>		

Step 3: Copper(II) hydroxide is heated to produce copper(II) oxide and water vapour.

(c) Write an equation for Step 3, including state symbols. (3 marks)

Description		Marks
correct species		1
correct balancing		1
correct state symbols		1
<b>Total</b>		<b>3</b>
$\text{Cu}(\text{OH})_2(\text{s}) \rightarrow \text{CuO}(\text{s}) + \text{H}_2\text{O}(\text{g})$		
Note: Equation must have some merit for follow through marks e.g. using CuOH instead of Cu(OH) <sub>2</sub>		

Step 4: Copper(II) oxide is added to excess dilute sulfuric acid solution.

(d) Write an equation for this reaction. (2 marks)

Description	Marks
correct species	1
correct balancing	1
<b>Total</b>	<b>2</b>
$\text{CuO(s)} + 2 \text{H}^{\text{(aq)}} \rightarrow \text{Cu}^{2\text{(aq)}} + \text{H}_2\text{O(l)}$	
Note: Equation must have some merit for follow through marks e.g. using $\text{Cu}_2\text{O}$ instead of $\text{CuO}$	

Step 5: Excess magnesium metal is added to the copper(II) sulfate solution.

(e) Write an equation for this reaction. (2 marks)

Description	Marks
correct species	1
correct balancing	1
<b>Total</b>	<b>2</b>
$\text{Mg(s)} + \text{Cu}^{2\text{(aq)}} \rightarrow \text{Mg}^{2\text{(aq)}} + \text{Cu(s)}$	

(f) If 0.616 g of magnesium was required to react with the copper(II) sulfate, calculate the mass of copper produced and, therefore, the percentage yield of copper from the series of reactions. (4 marks)

Description	Marks
$n(\text{Mg}) = \frac{0.616}{24.31}$ $= 2.534 \times 10^{-2} \text{ mol}$	1
$n(\text{Mg}) = n(\text{Cu})$	1
$m(\text{Cu}) = 63.55(2.534 \times 10^{-2})$ $= 1.61 \text{ g}$	1
$\% \text{ yield Cu} = \frac{1.61}{2.54} \times 100$ $= 63.4 \%$	1
<b>Total</b>	<b>4</b>

**2020  
Section 3  
Question  
36**

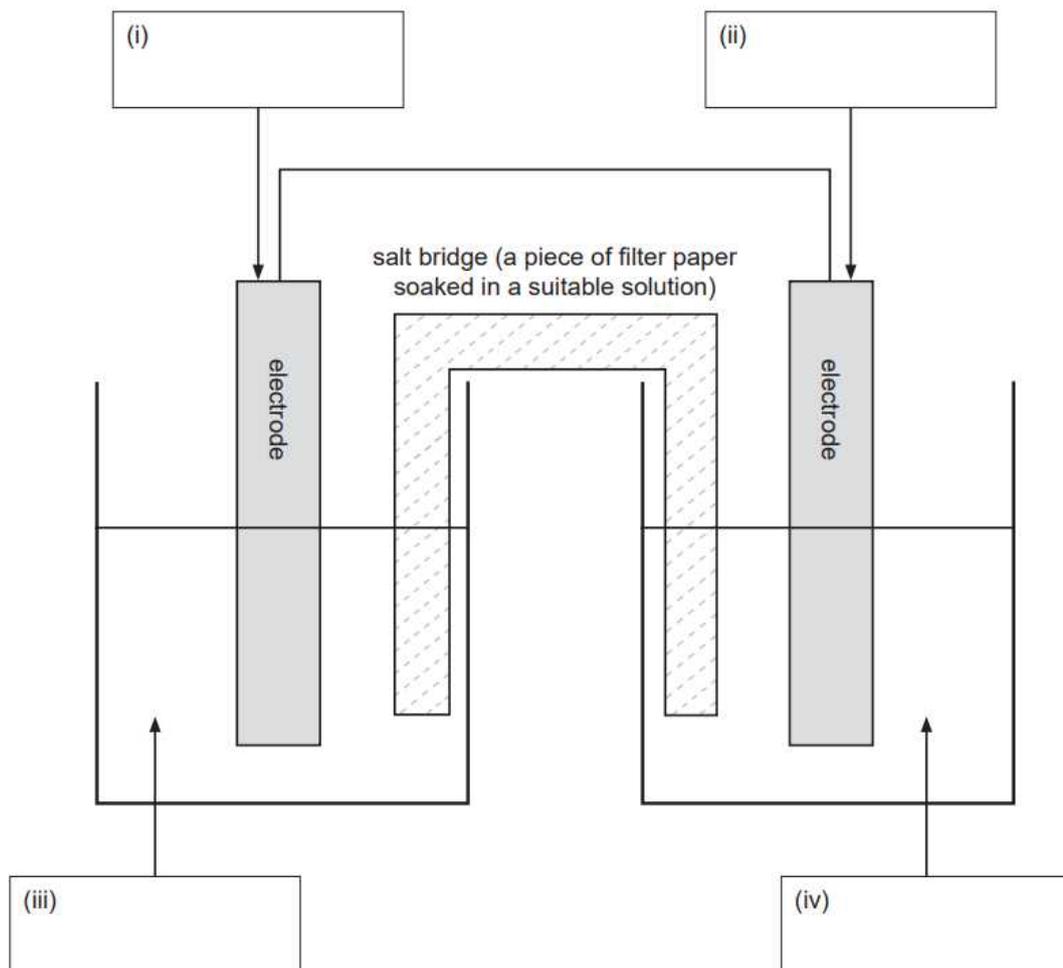
**Oxidation  
and  
reduction**

A student was asked to build a functioning galvanic cell, having been provided with all of the required hardware plus the following substances:

- a piece of magnesium measuring 1 mm by 2 cm by 6 cm
- a piece of copper measuring 1 mm by 2 cm by 6 cm
- a 6 cm long graphite (carbon) rod with a diameter of 1 cm
- 1.0 mol L<sup>-1</sup> sodium carbonate solution
- 1.0 mol L<sup>-1</sup> magnesium sulfate solution
- 1.0 mol L<sup>-1</sup> copper(II) sulfate solution.

There was no requirement for the student to use all of these substances.

(a) A partially-labelled diagram of the galvanic cell built by the student is shown below. What substances should the student have used in the parts labelled (i) to (iv) to build a functioning galvanic cell? Write the names of these substances in the boxes provided. (4 marks)



Description	Marks
<b>Option One</b>	
(i) magnesium	1
(ii) copper or graphite	1
(iii) (1.0 mol L <sup>-1</sup> ) magnesium sulfate (solution)	1
(iv) (1.0 mol L <sup>-1</sup> ) copper(II) sulfate (solution)	1
or	
<b>Option Two</b>	
(i) Copper or graphite	1
(ii) magnesium	1
(iii) (1.0 mol L <sup>-1</sup> ) copper(II) sulfate (solution)	1
(iv) (1.0 mol L <sup>-1</sup> ) magnesium sulfate (solution)	1
<b>Total</b>	<b>4</b>
Note:	
<ul style="list-style-type: none"> <li>Accept formulae instead of names.</li> </ul>	

(b) Add arrows to the diagram in part (a) to show the direction of movement of electrons through the external circuit. (1 mark)

Description	Marks
arrow on/near the wire pointing from Mg to Cu/C	1
<b>Total</b>	<b>1</b>

(c) Write the half-equations for the reactions occurring at the anode and the cathode in the student's galvanic cell. (4 marks)

Description	Marks
<b>Anode half-equation</b> Mg(s) → Mg <sup>2+</sup> (aq) + 2e <sup>-</sup>	1–2
<b>Cathode half-equation</b> Cu <sup>2+</sup> (aq) + 2e <sup>-</sup> → Cu(s)	1–2
<b>Total</b>	<b>4</b>
Note:	
<ul style="list-style-type: none"> <li>Anode and cathode reactions in wrong boxes – maximum of 3 marks.</li> <li>Negative charge missing from electrons – maximum of 3 marks.</li> <li>State symbols are not required.</li> </ul>	

(d) Calculate the electrical potential difference of the student's galvanic cell. Assume standard conditions. Include appropriate units in your answer. (2 marks)

Description	Marks
+2.70	1
V or Volts	1
<b>Total</b>	<b>2</b>
Note:	
<ul style="list-style-type: none"> <li>Must have correct value, with or without the '+' sign.</li> <li>Working out is not necessary (e.g. +2.36 + 0.34).</li> </ul>	

(e) Galvanic cells, such as the one shown in the diagram, need a salt bridge.

(i) State why galvanic cells need a salt bridge. (1 mark)

Description	Marks
Any one of the following: A salt bridge <ul style="list-style-type: none"><li>• maintains charge neutrality</li><li>• completes the circuit</li><li>• allows transfer of ions between two half-cells</li><li>• prevents polarisation.</li></ul>	1
<b>Total</b>	<b>1</b>

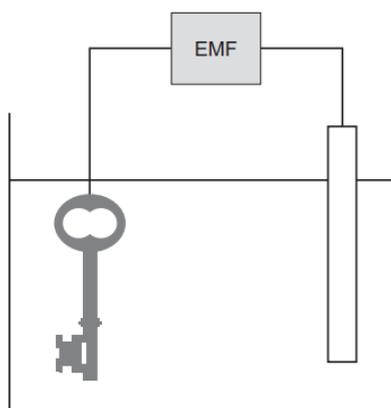
(ii) Describe, with reference to ion movement, how the salt bridge in a galvanic cell works. Also state why ion movement occurs as you have described. (4 marks)

Description	Marks
Negative ions travel through the salt bridge and move (migrate) into the anode half-cell	1
Due to an increase in positive ions/charge (as a result of the oxidation of magnesium producing positive ions that enter the electrolyte)	1
Positive ions travel through the salt bridge and move (migrate) into the cathode half-cell	1
Due to a removal of positive ions/charge (as a result of the reduction of copper ions from the electrolyte)	1
<b>Total</b>	<b>4</b>

2019  
Section 2  
Question  
31

Oxidation  
and  
reduction

A solution that contains silver cyanide,  $\text{AgCN}(\text{aq})$ , is used to plate a key with silver.

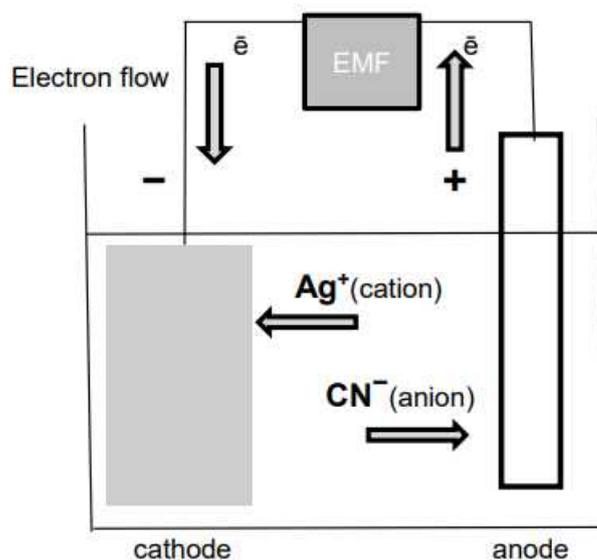


(a) Label the above diagram to show the:

- cathode and anode
- direction of electron flow
- direction of ion flow
- polarity (positive/negative) of each electrode. (4 marks)

Description	Marks
Diagram shows correctly labelled:	
cathode and anode	1
direction of electron flow	1
direction of ion flow (must show both ions)	1
polarity (positive/negative) of each electrode.	1
<b>Total</b>	<b>4</b>

Example of a four mark response:



**Note:**

- Allow follow through marks if anode and cathode are reversed.

A salt bridge is required in galvanic cells but is **not** required in the electroplating cell above.

(b) Explain this difference between these two cells. (3 marks)

Description	Marks
A salt bridge is required in a galvanic cell: to maintain electrical neutrality in a cell and any one of the following:	1
<ul style="list-style-type: none"> <li>to complete the circuit/connect the two cells</li> <li>required for ion flow</li> <li>electrons are forced through an external circuit.</li> </ul> and any one of the following:	1
<ul style="list-style-type: none"> <li>a salt bridge is not needed in the electrolytic cell because the reaction is not spontaneous (so no need to separate half cells)</li> <li>has an external power source.</li> </ul>	1
<b>Total</b>	<b>3</b>
<b>Note:</b>	
<ul style="list-style-type: none"> <li>Stating this is an electrolytic cell not a galvanic cell, while true, is insufficient for a mark.</li> </ul>	

Use excerpts from the Material Safety Data Sheet for silver cyanide shown below to answer part (c) and part (d).

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(c) Explain why action is taken to maintain the pH above 8 as a safety precaution during the electroplating process using silver cyanide. (3 marks)

Description	Marks
In acidic conditions: <ul style="list-style-type: none"> <li>the cyanide ion (in the electrolyte) can be converted to (the highly toxic) hydrogen cyanide gas, <b>or</b></li> <li>hydrogen cyanide gas (HCN(g)) is produced</li> </ul>	1
One mark each for any two of the following points: <ul style="list-style-type: none"> <li>by maintaining a basic pH in the electroplating cell limits the availability of H<sup>+</sup> ions</li> <li>without hydrogen ions HCN does not form in significantly dangerous concentration</li> <li>hydrogen cyanide is a weak acid. In the presence of hydroxide ions, the cyanide ion forms, reducing the likelihood of HCN existing in the solution</li> <li>Equation <math>\text{HCN(aq)} + \text{OH}^{\text{-}}(\text{aq}) \rightarrow \text{CN}^{\text{-}}(\text{aq}) + \text{H}_2\text{O}(\text{l})</math>.</li> </ul>	1-2
<b>Total</b>	<b>3</b>
<b>Note:</b>	
<ul style="list-style-type: none"> <li>The question can be answered in terms of equilibrium or candidates could also use hydrolysis of hydrogen cyanide equation.</li> <li>A traditional silver-plating solution contains KAg(CN)<sub>2</sub>(aq), KCN(aq), and K<sub>2</sub>CO<sub>3</sub>(aq). When sodium cyanide is added to a solution containing silver ions, AgCN first precipitates then dissolves when after adding more cyanide and cyanide ions are present in excess; the complex ions [Ag(CN)<sub>2</sub>]<sup>-</sup>(aq) and [Ag(CN)<sub>3</sub>]<sup>2-</sup>(aq) form.</li> <li>The electroplating plating of silver using the cyanide complex ions has been simplified for the sake of this question.</li> <li>Candidates are not required to know nor refer to the complex ions or processes involved.</li> </ul>	

(d) Suggest three other safety measures that should be taken during the electroplating process and indicate how each addresses a specific potential hazard to either the workers or the environment. (3 marks)

Description	Marks
One mark for each safety measure linked to a specific hazard (Reference to either the poisonous nature of the cyanide ion <b>or</b> the potential production of hydrogen cyanide gas.)	
Answers could include: <ul style="list-style-type: none"> <li>• recycle and reuse or dispose of used chemicals via chemical dump rather than down drains or directly into the environment to avoid poisoning waterways or groundwater systems</li> <li>• wear a protective apron and face shield whenever there is the slightest chance that you will be splashed to prevent cyanide from being absorbed through the skin</li> <li>• wear gloves when handling cyanide to prevent cyanide from being absorbed through the skin</li> <li>• ensure cyanide is stored in a closed container to avoid breathing in cyanide gas or dust</li> <li>• keep workplaces and stores dry and well ventilated to avoid breathing in cyanide gas or dust</li> <li>• wash and dry the respirator after each use and seal it in a clean plastic bag to avoid breathing in cyanide gas or dust.</li> </ul>	1–3
<b>Total</b>	<b>3</b>
<b>Note:</b> <ul style="list-style-type: none"> <li>• The safety measure must relate directly to the hazard stated.</li> <li>• While understanding that cyanide is poisonous, it is not required knowledge as the question can be answered by drawing on the information given in the question:               <ul style="list-style-type: none"> <li>• the production of hydrogen cyanide, HCN(g), is a highly toxic substance</li> <li>• cyanide poisoning is a potential risk.</li> </ul> </li> <li>• Candidates need to demonstrate understanding in identifying a hazard and then explain a related preventative step. Saying 'cyanide is poisonous so be careful not to come in contact with it', is insufficient.</li> </ul>	

## Unit 4 – Organic chemistry and chemical synthesis

### Unit 4 – Properties and structure of organic materials

#### Section 1

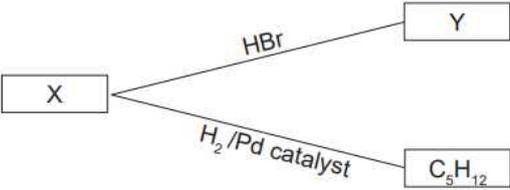
<b>2023</b> <b>Section 1</b> <b>Question 2</b>  <b>Properties and structure of organic materials</b>	Which of the following formulae represents an amide?  (a) $\text{CH}_3\text{CH}(\text{NH}_2)\text{CH}_3$ (b) $\text{CH}_3\text{COOCH}_3$ (c) $\text{CH}_3\text{CONHCH}_3$ (d) $\text{CH}_3\text{COCH}_2\text{NH}_2$
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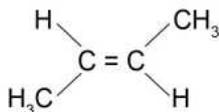
<b>2023</b> <b>Section 1</b> <b>Question 16</b>  <b>Properties and structure of organic materials</b>	Identify the monomer for the polymer shown below.   (a) $\text{CH}_3\text{CH}_2\text{CH}_3$ (b) $\text{CH}_2\text{CHCH}_3$ (c) $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$ (d) $\text{CH}_3\text{CHCHCH}_3$
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<b>2022</b> <b>Section 1</b> <b>Question 18</b>  <b>Properties and structure of organic materials</b>	The presence of a carboxylic acid functional group in an unknown organic compound may be identified by observing a reaction with which of the following?  (a) $\text{Cr}_2\text{O}_7^{2-}(\text{aq})$ (b) $\text{Br}_2(\text{aq})$ (c) $\text{Na}_2\text{SO}_4(\text{s})$ (d) $\text{Na}_2\text{CO}_3(\text{s})$
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<b>2022</b> <b>Section 1</b> <b>Question 19</b>  <b>Properties and structure of organic materials</b>	The following compounds have similar molar masses and polar functional groups. Which compound is expected to have the highest melting point?  <table border="1"><tr><td>(a)</td><td><math>\text{NH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2</math></td><td><math>88 \text{ g mol}^{-1}</math></td></tr><tr><td>(b)</td><td></td><td><math>89 \text{ g mol}^{-1}</math></td></tr><tr><td>(c)</td><td></td><td><math>90 \text{ g mol}^{-1}</math></td></tr><tr><td>(d)</td><td></td><td><math>90 \text{ g mol}^{-1}</math></td></tr></table>	(a)	$\text{NH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2$	$88 \text{ g mol}^{-1}$	(b)		$89 \text{ g mol}^{-1}$	(c)		$90 \text{ g mol}^{-1}$	(d)		$90 \text{ g mol}^{-1}$
(a)	$\text{NH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2$	$88 \text{ g mol}^{-1}$											
(b)		$89 \text{ g mol}^{-1}$											
(c)		$90 \text{ g mol}^{-1}$											
(d)		$90 \text{ g mol}^{-1}$											

<b>2022</b> <b>Section 1</b> <b>Question 21</b>  <b>Properties and structure of organic materials</b>	How many isomers are there for a molecule with the formula $C_3H_6Cl_2$ ?  (a) 5 (b) 4 (c) 3 (d) 2
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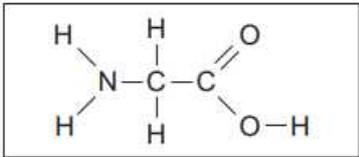
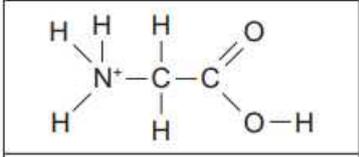
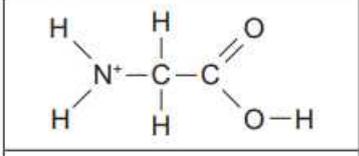
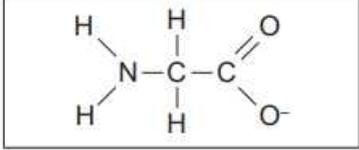
<b>2022</b> <b>Section 1</b> <b>Question 23</b>  <b>Properties and structure of organic materials</b>	In the following diagram, determine the molecular formulae of substances X and Y.   <p style="text-align: center;"> <table border="0"> <thead> <tr> <th style="padding-right: 20px;">X</th> <th>Y</th> </tr> </thead> <tbody> <tr> <td>(a) <math>C_5H_{12}</math></td> <td><math>C_5H_{13}Br</math></td> </tr> <tr> <td>(b) <math>C_5H_{10}</math></td> <td><math>C_5H_{11}Br</math></td> </tr> <tr> <td>(c) <math>C_5H_{10}</math></td> <td><math>C_5H_{10}Br_2</math></td> </tr> <tr> <td>(d) <math>C_5H_8</math></td> <td><math>C_5H_9Br</math></td> </tr> </tbody> </table> </p>	X	Y	(a) $C_5H_{12}$	$C_5H_{13}Br$	(b) $C_5H_{10}$	$C_5H_{11}Br$	(c) $C_5H_{10}$	$C_5H_{10}Br_2$	(d) $C_5H_8$	$C_5H_9Br$
X	Y										
(a) $C_5H_{12}$	$C_5H_{13}Br$										
(b) $C_5H_{10}$	$C_5H_{11}Br$										
(c) $C_5H_{10}$	$C_5H_{10}Br_2$										
(d) $C_5H_8$	$C_5H_9Br$										

<b>2022</b> <b>Section 1</b> <b>Question 24</b>  <b>Properties and structure of organic materials</b>	Which of the following is the correct IUPAC name for the molecule below?   <p>(a) <i>trans</i>-but-2-ene          (b) 1,4-dimethylbutene          (c) <i>cis</i>-but-2-ene          (d) methylprop-1-ene</p>
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<p><b>2021</b> <b>Section 1</b> <b>Question 4</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which of the following characteristics influence how a particular polymer might be used?</p> <p>(i) The amount of cross-linking between the hydrogen atoms in the polymer.  (ii) The length of the carbon chains in the polymer.  (iii) The functional groups present in the monomer used to synthesise the polymer.  (iv) The melting point of the polymer.</p> <p>(a) ii, iii and iv only  (b) i and ii only  (c) ii and iii only  (d) i, ii and iv only</p>
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<p><b>2021</b> <b>Section 1</b> <b>Question 5</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Nylon 46 is a polymer that can withstand very large forces without breaking. Its structural formula is shown below.</p> $\left( \begin{array}{cccccccccccc} & \text{H} & \text{H} & & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & & \\ &   &   & &   &   &   &   &   &   & & \\ \text{C} & - & \text{C} & - & \text{C} & - & \text{C} & - & \text{N} & - & \text{C} & - & \text{N} \\    &   &   &    &   &   &   &   &   &   &   &   &   &   &   &   &   &   &   &   \\ \text{O} & \text{H} & \text{H} & \text{O} & \text{H} \end{array} \right)_n$ <p>The intermolecular forces contributing the most to the strength of Nylon 46 is/are</p> <p>(a) covalent network bonding.  (b) dispersion forces.  (c) hydrogen bonding.  (d) dipole-dipole forces.</p>
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<p><b>2021</b> <b>Section 1</b> <b>Question 7</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which of the following structures represents glycine in acidic conditions?</p> <p>(a) </p> <p>(b) </p> <p>(c) </p> <p>(d) </p>
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<p><b>2021</b> <b>Section 1</b> <b>Question 11</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which of the following shows an <math>\alpha</math>-amino acid?</p> <div style="border: 1px solid black; padding: 5px;"> <p>(i) <math display="block">\begin{array}{c} \text{NH}_2 \\   \\ \text{H}-\text{C}-\text{COOH} \\   \\ \text{H} \end{array}</math></p> <p>(ii) <math display="block">\begin{array}{c} \text{NH}_2 \\   \\ \text{H}-\text{C}-\text{CH}_2-\text{COOH} \\   \\ \text{H} \end{array}</math></p> <p>(iii) <math display="block">\begin{array}{c} \text{NH}_2 \\   \\ \text{H}-\text{C}-\text{COOH} \\   \\ \text{CH}_2\text{CH}_3 \end{array}</math></p> <p>(iv) <math display="block">\begin{array}{c} \text{NH}_2 \\   \\ \text{H}-\text{C}-\text{CH}_2-\text{CH}_2-\text{COOH} \\   \\ \text{H} \end{array}</math></p> </div> <p>(a) i and iii only (b) i only (c) ii, iii and iv only (d) i, ii, iii and iv</p>
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<p><b>2021</b> <b>Section 1</b> <b>Question 16</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Two isomeric forms of a saturated hydrocarbon</p> <p>(a) contain different types of atoms. (b) have the same structural formula. (c) have the same molecular formula. (d) react vigorously with one another.</p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 4</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>The number of possible isomers of <math>\text{C}_2\text{H}_2\text{F}_2</math> is</p> <p>(a) 1 (b) 2 (c) 3 (d) 4</p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 9</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Consider the molecule shown below.</p> <div style="text-align: center;"> </div> <p>This molecule shows</p> <p>(a) an anionic detergent which contains a sulfonate group. (b) a monomer that can be used to synthesise a condensation polymer. (c) a carboxylic acid which can be used to synthesise a soap. (d) an aromatic hydrocarbon which has donated an electron.</p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 10</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which of these statements regarding organic molecules are correct?</p> <p>(i) Organic molecules have hydrocarbon skeletons.  (ii) Functional groups consist of groups of atoms or a particular type of bond.  (iii) Functional groups influence the chemical properties of organic molecules.  (iv) Functional groups influence the physical properties of organic molecules.</p> <p>(a) i and iii only  (b) ii and iv only  (c) i, ii and iii only  (d) i, ii, iii and iv</p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 11</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which of the following pairs of molecules can form peptide bonds with each other?</p> <table border="1" style="width: 100%; text-align: center;"> <tr> <td style="width: 5%; vertical-align: middle;">(i)</td> <td style="width: 45%;"> <math display="block">\begin{array}{cccc} \text{H} &amp; \text{H} &amp; \text{H} &amp; \text{H} \\   &amp;   &amp;   &amp;   \\ \text{HO}-\text{C} &amp; -\text{C} &amp; -\text{C} &amp; -\text{C}-\text{OH} \\   &amp;   &amp;   &amp;   \\ \text{H} &amp; \text{H} &amp; \text{H} &amp; \text{H} \end{array}</math> <p>butan-1,4-diol</p> </td> <td style="width: 45%;"> <math display="block">\begin{array}{cccc} \text{H} &amp; \text{H} &amp; \text{H} &amp; \text{H} \\   &amp;   &amp;   &amp;   \\ \text{H}_2\text{N}-\text{C} &amp; -\text{C} &amp; -\text{C} &amp; -\text{C}-\text{NH}_2 \\   &amp;   &amp;   &amp;   \\ \text{H} &amp; \text{H} &amp; \text{H} &amp; \text{H} \end{array}</math> <p>butan-1,4-diamine</p> </td> </tr> <tr> <td style="vertical-align: middle;">(ii)</td> <td> <math display="block">\begin{array}{c} \text{CH}_2-\text{C}_6\text{H}_4-\text{OH} \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}</math> <p>tyrosine</p> </td> <td> <math display="block">\begin{array}{c} \text{CH}_2-\text{C}_6\text{H}_4-\text{OH} \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}</math> <p>tyrosine</p> </td> </tr> <tr> <td style="vertical-align: middle;">(iii)</td> <td> <math display="block">\begin{array}{c} \text{CH}_3-\text{CH}-\text{CH}_3 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}</math> <p>valine</p> </td> <td> <math display="block">\begin{array}{c} \text{CH}_2-\text{C}_6\text{H}_5 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}</math> <p>phenylalanine</p> </td> </tr> <tr> <td style="vertical-align: middle;">(iv)</td> <td> <math display="block">\begin{array}{ccc} \text{H} &amp; \text{H} &amp; \\   &amp;   &amp; \\ \text{H}-\text{C} &amp; -\text{C} &amp; -\text{O}-\text{H} \\   &amp;   &amp; \\ \text{H} &amp; \text{H} &amp; \end{array}</math> <p>ethanol</p> </td> <td> <math display="block">\begin{array}{ccc} \text{H} &amp; \text{H} &amp; \text{O} \\   &amp;   &amp; // \\ \text{H}-\text{C} &amp; -\text{C} &amp; -\text{C} \\   &amp;   &amp; \backslash \\ \text{H} &amp; \text{H} &amp; \text{O}-\text{H} \end{array}</math> <p>butanoic acid</p> </td> </tr> </table> <p>(a) i and iv only  (b) ii and iii only  (c) i, ii and iii only  (d) i, ii, iii and iv</p>	(i)	$\begin{array}{cccc} \text{H} & \text{H} & \text{H} & \text{H} \\   &   &   &   \\ \text{HO}-\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{OH} \\   &   &   &   \\ \text{H} & \text{H} & \text{H} & \text{H} \end{array}$ <p>butan-1,4-diol</p>	$\begin{array}{cccc} \text{H} & \text{H} & \text{H} & \text{H} \\   &   &   &   \\ \text{H}_2\text{N}-\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{NH}_2 \\   &   &   &   \\ \text{H} & \text{H} & \text{H} & \text{H} \end{array}$ <p>butan-1,4-diamine</p>	(ii)	$\begin{array}{c} \text{CH}_2-\text{C}_6\text{H}_4-\text{OH} \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$ <p>tyrosine</p>	$\begin{array}{c} \text{CH}_2-\text{C}_6\text{H}_4-\text{OH} \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$ <p>tyrosine</p>	(iii)	$\begin{array}{c} \text{CH}_3-\text{CH}-\text{CH}_3 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$ <p>valine</p>	$\begin{array}{c} \text{CH}_2-\text{C}_6\text{H}_5 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$ <p>phenylalanine</p>	(iv)	$\begin{array}{ccc} \text{H} & \text{H} & \\   &   & \\ \text{H}-\text{C} & -\text{C} & -\text{O}-\text{H} \\   &   & \\ \text{H} & \text{H} & \end{array}$ <p>ethanol</p>	$\begin{array}{ccc} \text{H} & \text{H} & \text{O} \\   &   & // \\ \text{H}-\text{C} & -\text{C} & -\text{C} \\   &   & \backslash \\ \text{H} & \text{H} & \text{O}-\text{H} \end{array}$ <p>butanoic acid</p>
(i)	$\begin{array}{cccc} \text{H} & \text{H} & \text{H} & \text{H} \\   &   &   &   \\ \text{HO}-\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{OH} \\   &   &   &   \\ \text{H} & \text{H} & \text{H} & \text{H} \end{array}$ <p>butan-1,4-diol</p>	$\begin{array}{cccc} \text{H} & \text{H} & \text{H} & \text{H} \\   &   &   &   \\ \text{H}_2\text{N}-\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{NH}_2 \\   &   &   &   \\ \text{H} & \text{H} & \text{H} & \text{H} \end{array}$ <p>butan-1,4-diamine</p>											
(ii)	$\begin{array}{c} \text{CH}_2-\text{C}_6\text{H}_4-\text{OH} \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$ <p>tyrosine</p>	$\begin{array}{c} \text{CH}_2-\text{C}_6\text{H}_4-\text{OH} \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$ <p>tyrosine</p>											
(iii)	$\begin{array}{c} \text{CH}_3-\text{CH}-\text{CH}_3 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$ <p>valine</p>	$\begin{array}{c} \text{CH}_2-\text{C}_6\text{H}_5 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$ <p>phenylalanine</p>											
(iv)	$\begin{array}{ccc} \text{H} & \text{H} & \\   &   & \\ \text{H}-\text{C} & -\text{C} & -\text{O}-\text{H} \\   &   & \\ \text{H} & \text{H} & \end{array}$ <p>ethanol</p>	$\begin{array}{ccc} \text{H} & \text{H} & \text{O} \\   &   & // \\ \text{H}-\text{C} & -\text{C} & -\text{C} \\   &   & \backslash \\ \text{H} & \text{H} & \text{O}-\text{H} \end{array}$ <p>butanoic acid</p>											

<p><b>2020</b> <b>Section 1</b> <b>Question 13</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which of the following alcohols would you expect to have the highest boiling point?</p> <p>(a) pentan-1-ol  (b) pentan-2-ol  (c) pentan-3-ol  (d) 2-methylbutan-2-ol</p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 14</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>The Protein Data Bank contains information relating to the structures of proteins. The structure of a protein is important because it is related closely to its</p> <p>(a) equilibrium constant.  (b) bonding capacity.  (c) nutritional value.  (d) function.</p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 21</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Polyacrylonitrile fibres can be used to make blankets and carpets. The structural formula of a segment of this polymer is shown below.</p> $\left( \begin{array}{ccccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\   &   &   &   &   &   &   \\ \text{C} & - \text{C} \\   &   &   &   &   &   &   \\ \text{H} & \text{CN} & \text{H} & \text{CN} & \text{H} & \text{CN} & \text{H} \end{array} \right)_n$ <p>The structural formula of the monomer used to make polyacrylonitrile is:</p> <table border="1" style="width: 100%; text-align: center;"> <tr> <td>(a)</td> <td><math display="block">\begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ \text{H}-\text{C}=\text{C}-\text{C}-\text{H} \\   \quad   \\ \text{CN} \quad \text{H} \end{array}</math></td> </tr> <tr> <td>(b)</td> <td><math display="block">\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\   \quad   \quad   \\ \text{CN} \quad \text{H} \quad \text{CN} \end{array}</math></td> </tr> <tr> <td>(c)</td> <td><math display="block">\begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ \text{H}-\text{C}=\text{C}-\text{CN} \end{array}</math></td> </tr> <tr> <td>(d)</td> <td><math display="block">\begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ \text{H}-\text{C}-\text{C}-\text{CN} \\   \quad   \\ \text{H} \quad \text{H} \end{array}</math></td> </tr> </table>	(a)	$\begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ \text{H}-\text{C}=\text{C}-\text{C}-\text{H} \\   \quad   \\ \text{CN} \quad \text{H} \end{array}$	(b)	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\   \quad   \quad   \\ \text{CN} \quad \text{H} \quad \text{CN} \end{array}$	(c)	$\begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ \text{H}-\text{C}=\text{C}-\text{CN} \end{array}$	(d)	$\begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ \text{H}-\text{C}-\text{C}-\text{CN} \\   \quad   \\ \text{H} \quad \text{H} \end{array}$
(a)	$\begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ \text{H}-\text{C}=\text{C}-\text{C}-\text{H} \\   \quad   \\ \text{CN} \quad \text{H} \end{array}$								
(b)	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\   \quad   \quad   \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\   \quad   \quad   \\ \text{CN} \quad \text{H} \quad \text{CN} \end{array}$								
(c)	$\begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ \text{H}-\text{C}=\text{C}-\text{CN} \end{array}$								
(d)	$\begin{array}{c} \text{H} \quad \text{H} \\   \quad   \\ \text{H}-\text{C}-\text{C}-\text{CN} \\   \quad   \\ \text{H} \quad \text{H} \end{array}$								

<p><b>2019</b> <b>Section 1</b> <b>Question 9</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which one of the following is an alpha amino acid?</p> <table border="1" style="width: 100%; text-align: center;"> <tr> <td>(a)</td> <td><math display="block">\begin{array}{c} \text{H}-\text{Se}-\text{CH}-\text{COOH} \\   \\ \text{NH}_2 \end{array}</math></td> <td>(b)</td> <td><math display="block">\begin{array}{c} \text{OH} \\   \\ \text{H}_2\text{N}-\text{CH}-\text{CH}_2-\text{COOH} \end{array}</math></td> </tr> <tr> <td>(c)</td> <td><math display="block">\begin{array}{c} \text{H}_2\text{N}-\text{CH}_2-\text{CH}_2-\text{COOH} \\   \\ \text{CH}-\text{COOH} \end{array}</math></td> <td>(d)</td> <td><math display="block">\begin{array}{c} \text{O} \\    \\ \text{H}_2\text{N}-\text{C}-\text{NH}_2 \\   \\ \text{Se}-\text{CH}_2-\text{COOH} \end{array}</math></td> </tr> </table>		(a)	$\begin{array}{c} \text{H}-\text{Se}-\text{CH}-\text{COOH} \\   \\ \text{NH}_2 \end{array}$	(b)	$\begin{array}{c} \text{OH} \\   \\ \text{H}_2\text{N}-\text{CH}-\text{CH}_2-\text{COOH} \end{array}$	(c)	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}_2-\text{CH}_2-\text{COOH} \\   \\ \text{CH}-\text{COOH} \end{array}$	(d)	$\begin{array}{c} \text{O} \\    \\ \text{H}_2\text{N}-\text{C}-\text{NH}_2 \\   \\ \text{Se}-\text{CH}_2-\text{COOH} \end{array}$
(a)	$\begin{array}{c} \text{H}-\text{Se}-\text{CH}-\text{COOH} \\   \\ \text{NH}_2 \end{array}$	(b)	$\begin{array}{c} \text{OH} \\   \\ \text{H}_2\text{N}-\text{CH}-\text{CH}_2-\text{COOH} \end{array}$							
(c)	$\begin{array}{c} \text{H}_2\text{N}-\text{CH}_2-\text{CH}_2-\text{COOH} \\   \\ \text{CH}-\text{COOH} \end{array}$	(d)	$\begin{array}{c} \text{O} \\    \\ \text{H}_2\text{N}-\text{C}-\text{NH}_2 \\   \\ \text{Se}-\text{CH}_2-\text{COOH} \end{array}$							

<p><b>2019</b> <b>Section 1</b> <b>Question 14</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which one of the following properties exhibited by octanol is <b>not</b> related to the dispersion forces between the molecules?</p> <p>(a) combustibility (b) melting point (c) solubility in octane (d) solubility in water</p>
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<b>2019</b> <b>Section 1</b> <b>Question</b> <b>15</b>  <b>Properties</b> <b>and</b> <b>structure of</b> <b>organic</b> <b>materials</b>	Which one of the following compounds will <b>not</b> exhibit geometric (cis-trans) isomerism?  (a) 1,2-difluoro-1-butene (b) 1,1-difluoro-1-butene (c) 1,2-difluoro-2-butene (d) 1,4-difluoro-2-butene
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<b>2019</b> <b>Section 1</b> <b>Question</b> <b>22</b>  <b>Properties</b> <b>and</b> <b>structure of</b> <b>organic</b> <b>materials</b>	Between which of the following pairs of substances can dispersion forces exist?  (i) $\text{CH}_3\text{Cl}$ and $\text{H}_2\text{O}$ (ii) $\text{CH}_3\text{CH}_2\text{CHO}$ and $\text{HBr}$ (iii) $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$ and $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$ (iv) $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ and $\text{NH}_3$  (a) i and ii only (b) i, ii and iii only (c) iii only (d) i, ii, iii and iv
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<b>2019</b> <b>Section 1</b> <b>Question</b> <b>23</b>  <b>Properties</b> <b>and</b> <b>structure of</b> <b>organic</b> <b>materials</b>	Which one of the following is an isomer of pentanoic acid?  (a) $\text{CH}_3\text{CHCH-O-CH}_2\text{CHO}$ (b) $\text{CH}_2\text{CHCH}_2\text{-O-CH}_2\text{CH}_2\text{OH}$ (c) $\text{OHCCH}_2\text{CH}_2\text{CH}_2\text{CHO}$ (d) $\text{CH}_3\text{CHCHCH}_2\text{COOH}$
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<b>2019</b> <b>Section 1</b> <b>Question</b> <b>25</b>  <b>Properties</b> <b>and</b> <b>structure of</b> <b>organic</b> <b>materials</b>	How many isomers does the compound $\text{C}_2\text{H}_3\text{Br}_3$ have?  (a) 1 (b) 2 (c) 3 (d) 4
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2022  
Section 2  
Question  
27

Properties  
and  
structure of  
organic  
materials

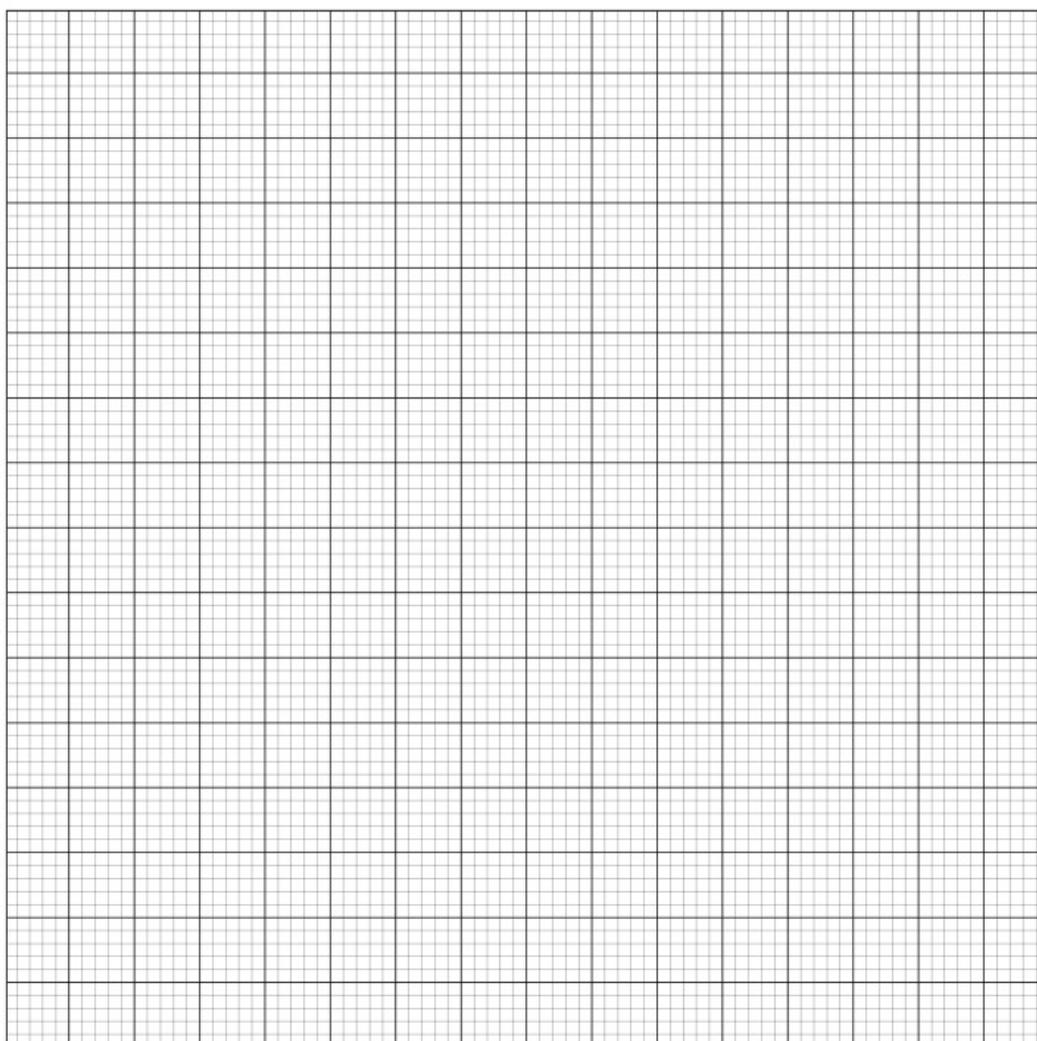
The information in the table below shows the boiling temperature for a range of primary amines.

Amine	Boiling temperature (°C)
Ethanamine	16.6
Propan-1-amine	47.8
Butan-1-amine	78.0
Hexan-1-amine	131
Heptan-1-amine	155

(a) Draw the structure of butan-1-amine showing all atoms and bonds. (2 marks)



(b) Use the data in the table on the previous page to graph the boiling temperature of amines versus the number of carbons in the amines on the grid below. The x-axis has been labelled for you. (5 marks)





(ii) State the condition that is required for zwitterions of  $\alpha$ -amino acids to form in aqueous solution. (1 mark)

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(b) The strength of hair keratin is attributed to a relatively high content of the  $\alpha$ -amino acid cysteine.

(i) State which interaction is possible in proteins due to the presence of cysteine. (1 mark)

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(ii) Define 'protein tertiary structure' and describe how it is formed. (3 marks)

Definition:

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Description:

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(c) Proteins are distinguished at the level of the primary structure. Describe this level of protein structure. (2 marks)

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The  $\alpha$ -helix is a common secondary structure observed in keratins.

(d) Draw dotted lines (.....) on the diagram below to show the position of at least **two** hydrogen bond interactions that stabilise the helical shape. (1 mark)

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The nature of the  $\alpha$ -amino acid side chain or R-group in the helical part of keratins is critical to the overall structure. In certain positions the side chains are non-polar.

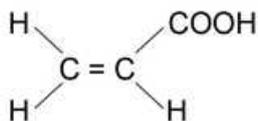
(e) Identify **one**  $\alpha$ -amino acid from the Data booklet with a non-polar side chain. (1 mark)

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2022  
Section 2  
Question  
31

Properties  
and  
structure of  
organic  
materials

Polyacrylic acid is a polymer that is formed from the monomer propenoic acid (also known as acrylic acid). The monomer propenoic acid is shown below.



(a) Draw the structure of the polymer polyacrylic acid showing at least three repeating units. (2 marks)

When reacted with sodium hydroxide, polyacrylic acid becomes polyacrylate. Polyacrylate is a powder that swells when water is added and can absorb up to 180 times its weight in water. It is used for applications such as disposable nappies.

(b) A child's nappy contains approximately 3.97 g of polyacrylate, and a particular company state that their nappies are at least 97.4% efficient at absorbing water. After thorough testing it was demonstrated that this brand of nappies could absorb 691 g of water. Use a calculation to determine whether the claims of the company that manufacture the nappies are true. (3 marks)

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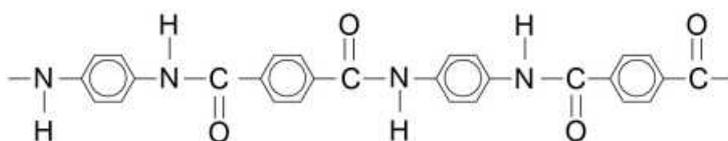
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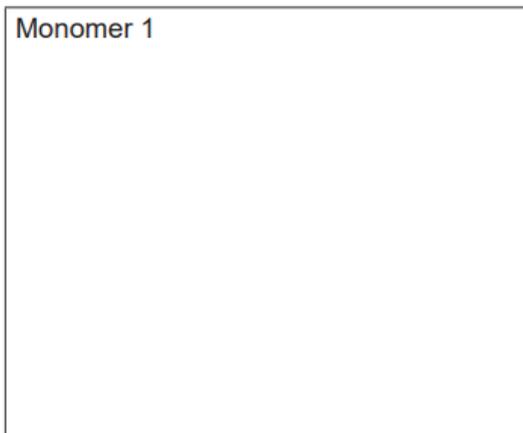
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Kevlar is a polymer that is formed through a condensation reaction that releases water during the polymerisation of its monomers. A section of the Kevlar polymer is shown below.

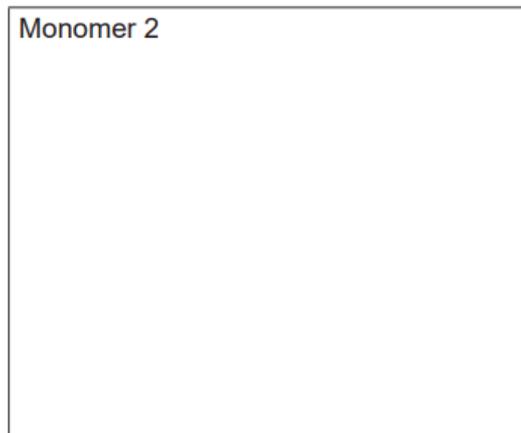


(c) Draw the structure of the **two** monomers from which Kevlar is made. (2 marks)

Monomer 1



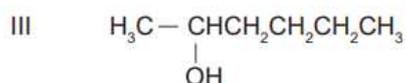
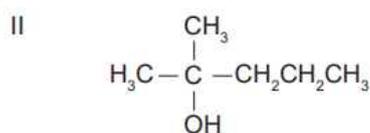
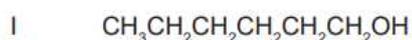
Monomer 2



2022  
Section 2  
Question  
32

Properties  
and  
structure of  
organic  
materials

Consider the following three isomers of C<sub>6</sub>H<sub>14</sub>O:



(a) State the IUPAC name for each isomer. (3 marks)

Isomer	IUPAC name
I	
II	
III	

(b) Propose a chemical test and state the expected observations for each isomer that could be used to distinguish between isomer I and isomer II. (3 marks)

Chemical test:

Isomer I:

Isomer II:

**2022**  
**Section 2**  
**Question**  
**33**

**Properties**  
**and**  
**structure of**  
**organic**  
**materials**

Esters are chemical compounds derived from a carboxylic acid and an alcohol during esterification. An ethyl ester is synthesised using ethanol as the alcohol.

(a) Two methods of producing ethanol industrially include fermentation of glucose and hydrolysis of ethene. Write a chemical equation for each process and state any conditions that are required. (8 marks)

Chemical formula for glucose:  $C_6H_{12}O_6$

Fermentation of glucose:

Conditions:

Hydrolysis of ethene:

Conditions:

(b) The ethanol produced was added to pentanoic acid along with a few drops of concentrated sulfuric acid. This mixture was then heated. Draw the structure and state the IUPAC name of the ester that is formed in this reaction. Include **all** atoms. (3 marks)

Structure:

IUPAC name: \_\_\_\_\_

**2021  
Section 2  
Question  
27**

**Properties  
and  
structure of  
organic  
materials**

Alcohols exhibit a variety of different chemical properties. For example, some alcohols react with acidified permanganate ions while others do not.

(a) The alcohols in the following table were each heated with excess acidified potassium permanganate solution. Name all organic products formed **during** this process. If there is no reaction, indicate this by writing 'no reaction'. (4 marks)

Name of alcohol	Name(s) of organic compound(s) formed
2-methylpentan-2-ol	
pentan-1-ol	
pentan-2-ol	

(b) Write a balanced overall ionic equation showing the formation of **one** of the organic compounds named in part (a). Only the alcohols listed in the table and acidified potassium permanganate solution can be used. Show your working. (4 marks)

(c) The same type of reaction occurs if alcohols are mixed with acidified potassium dichromate solution.

(i) Name this type of reaction. (1 mark)

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(ii) State how the reaction observations are different when limited acidified potassium dichromate solution is used instead of limited acidified potassium permanganate solution. (2 marks)

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**2021  
Section 2  
Question  
26**

**Properties  
and  
structure of  
organic  
materials**

A student was given the task of naming and/or drawing the structural formula of some organic compounds. The student, however, made some errors.

(a) For each of the following organic compounds, state why the name given by the student is incorrect and rename it using IUPAC nomenclature. (4 marks)

Structural formula and name given by student	Reason for name being incorrect	IUPAC name
$  \begin{array}{ccccccc}  & \text{H} & \text{H} & \text{H} & \text{O} & \text{H} & \\  &   &   &   &    &   & \\  \text{H} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{H} \\  &   &   &   & &   & \\  & \text{H} & \text{H} & \text{H} & & \text{H} & \\  \end{array}  $ <p>pentan-4-one</p>		
$  \begin{array}{cccc}  & \text{H} & \text{H} & \text{O} \\  &   &   &    \\  \text{H} & -\text{C} & -\text{C} & -\text{C} & -\text{NH}_2 \\  &   &   & & \\  & \text{H} & \text{H} & & \\  \end{array}  $ <p>1-aminopropanone</p>		

(b) Circle an error in each structural formula and state the reason why it is an error. (4 marks)

Student's structural formula	Reason
$  \begin{array}{cccc}  & \text{H} & \text{H} & \text{H} & \text{H} \\  &   &   &   &   \\  \text{H} & -\text{C} & -\text{C} & =\text{C} & -\text{C} & -\text{H} \\  &   &   & &   \\  & \text{H} & \text{H} & & \text{H}  \end{array}  $	
$  \begin{array}{cccc}  & \text{H} & \text{H} & \text{H} \\  &   &   &   \\  \text{H} & -\text{C} & -\text{C} & -\text{C} & -\text{O} \\  &   &   &   \\  & \text{H} & \text{H} & \text{H}  \end{array}  $	

2020  
Section 2  
Question  
26

Properties  
and  
structure of  
organic  
materials

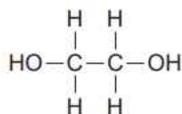
Complete this table by giving the IUPAC name or full structural formula of the indicated organic compounds. All hydrogen atoms must be shown.

Full structural formula	IUPAC name
$\begin{array}{ccccccc} & \text{H} & \text{H} & \text{H} & \text{H} & & \text{H} \\ &   &   &   &   & & / \\ \text{H} & - \text{C} & - \text{N} \\ &   &   &   &   & \parallel & \backslash \\ & \text{H} & \text{H} & \text{H} & \text{H} & \text{O} & \text{H} \end{array}$	
$\begin{array}{ccc} \text{H}_3\text{C} & & \text{CH}_3 \\ & \diagdown & / \\ & \text{C} = \text{C} & \\ & / & \diagdown \\ \text{H}_3\text{C} & & \text{CH}_3 \end{array}$	
	heptan-2-amine
	hexan-3-one

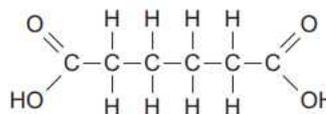
**2020**  
**Section 2**  
**Question**  
**28**

**Properties**  
**and**  
**structure of**  
**organic**  
**materials**

Poly(ethylene adipate) is an inexpensive, biodegradable polymer. It is formed when ethylene glycol and adipic acid react. The structural formulae of these two monomers are shown below.



ethylene glycol



adipic acid

(a) Draw the structural formula of poly(ethylene adipate). Show two repeating units. (2 marks)

(b) Classify poly(ethylene adipate) according to the:

(i) functional group or groups present in its structure. (1 mark)

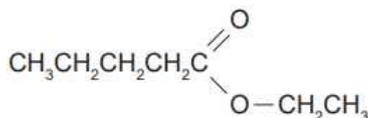
(ii) type of reaction resulting in its formation. (1 mark)

(c) Identify a different type of reaction that results in the formation of a polymer. (1 mark)

2020  
Section 2  
Question  
33

Properties  
and  
structure of  
organic  
materials

A chemist wanted to add a fruity fragrance to an air freshener that he was developing. A colleague suggested the compound ethyl pentanoate which has an apple-like fragrance. The structure for ethyl pentanoate is shown below.



The chemist wanted to check the fragrance of this compound to make sure that it was suitable but there was no ethyl pentanoate in the chemist's laboratory. The only organic substances that the chemist had were a:

- commercial gas cylinder containing ethene
- bottle of pentan-2-one
- bottle of pentan-1-ol
- bottle of pentanal.

Ethyl pentanoate can be synthesised from one or more of the organic substances in the above list in **three** steps.

Describe the steps that will allow the chemist to synthesise ethyl pentanoate. Include balanced equations for all reactions that occur, using molecular formulae for organic compounds. Any inorganic compounds deemed necessary can be used in the procedure. It is not necessary to specify how the products of a particular reaction will be isolated before use in another reaction.

Step One:

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Step Two:

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	Step Three:

<b>2019 Section 2 Question 30</b>  <b>Properties and structure of organic materials</b>	Salvarsan is an organic compound that contains the elements: carbon (C), hydrogen (H), arsenic (As), chlorine (Cl), nitrogen (N) and oxygen (O). It was one of the first drugs used in chemotherapy and for treating sleeping sickness.
	The empirical formula of this compound can be determined in a series of analyses. One process involves the reaction of a known mass of Salvarsan with excess strong acid to convert all the chlorine into aqueous chloride ions.
	(a) Describe the laboratory process involved in determining the mass of chlorine in this sample of Salvarsan once it has been treated with the acid. You should reference any chemicals used and include a balanced equation in your answer. (6 marks)



**2019  
Section 2  
Question  
33**

**Properties  
and  
structure of  
organic  
materials**

Organic molecules have a hydrocarbon skeleton and can contain functional groups that are responsible for the molecules' characteristic chemical properties.

Complete the following tables by

- (i) writing the structural formula of each compound listed
- (ii) writing the structural formula of the organic product from the reaction
- (iii) naming the organic product from the reaction.

When writing the structural formula, show the bonds between carbon atoms and within any functional group e.g.  $\text{CH}_3\text{—CH}_2\text{—C—CH}_3$



Name of compound		Structural formula of compound
pent-2-ene		
Reacts with $\text{Br}_2(\text{aq})$	Structural formula of organic product	
	Name of organic product	

Name of compound		Structural formula of compound
ethanal		
Reacts with $\text{KMnO}_4(\text{aq}) / \text{H}^+(\text{aq})$	Structural formula of organic product	
	Name of organic product	
Name of compound		Structural formula of compound
butanoic acid		
Reacts with $\text{Na}_2\text{CO}_3(\text{aq})$	Structural formula of organic product	
	Name of organic product	









(c) The hydrocarbon has three straight-chain isomers (no branching). Complete the table below by drawing the structure of and naming the three isomers. Show all atoms and bonds in each structure. (9 marks)

If you were unable to determine an answer to part (b) use  $C_5H_{10}$  as the molecular formula for the remaining parts of this question.

Structure	IUPAC Name

(d) State which isomer reacts with water to produce a primary alcohol. Write an equation for this reaction. (3 marks)

Isomer:

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The alcohol produced in part (d) (*above*) can be fully oxidised by acidified potassium dichromate solution.

(e) (i) Write an ionic equation for this reaction. (3 marks)

(ii) Describe fully the observations for this reaction. (2 marks)

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(f) (i) Write an equation for the reaction between the organic products from parts (d) and (e). (2 marks)

(ii) Name the organic product of this reaction. (1 mark)

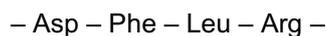
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**2021  
Section 3  
Question  
34**

**Properties  
and  
structure of  
organic  
materials**

Keratin 86 is a protein found in human fingernails. A small section of the amino acid sequence of Keratin 86 is shown below:



(a) Draw the full structural formula of this small section of Keratin 86. (3 marks)

The amino acid chains in Keratin 86 form  $\alpha$ -helices, with two  $\alpha$ -helices twisting around each other to form what is called a 'coiled coil' that is held together by disulfide bridges.

(b) Circle the protein structural level represented by an  $\alpha$ -helix. (1 mark)

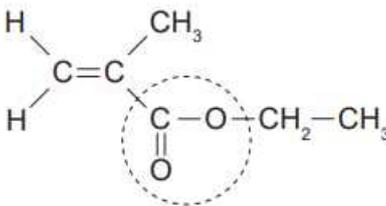
primary      secondary      tertiary

(c) What does the presence of disulfide bridges indicate about the primary structure of Keratin 86? (1 mark)

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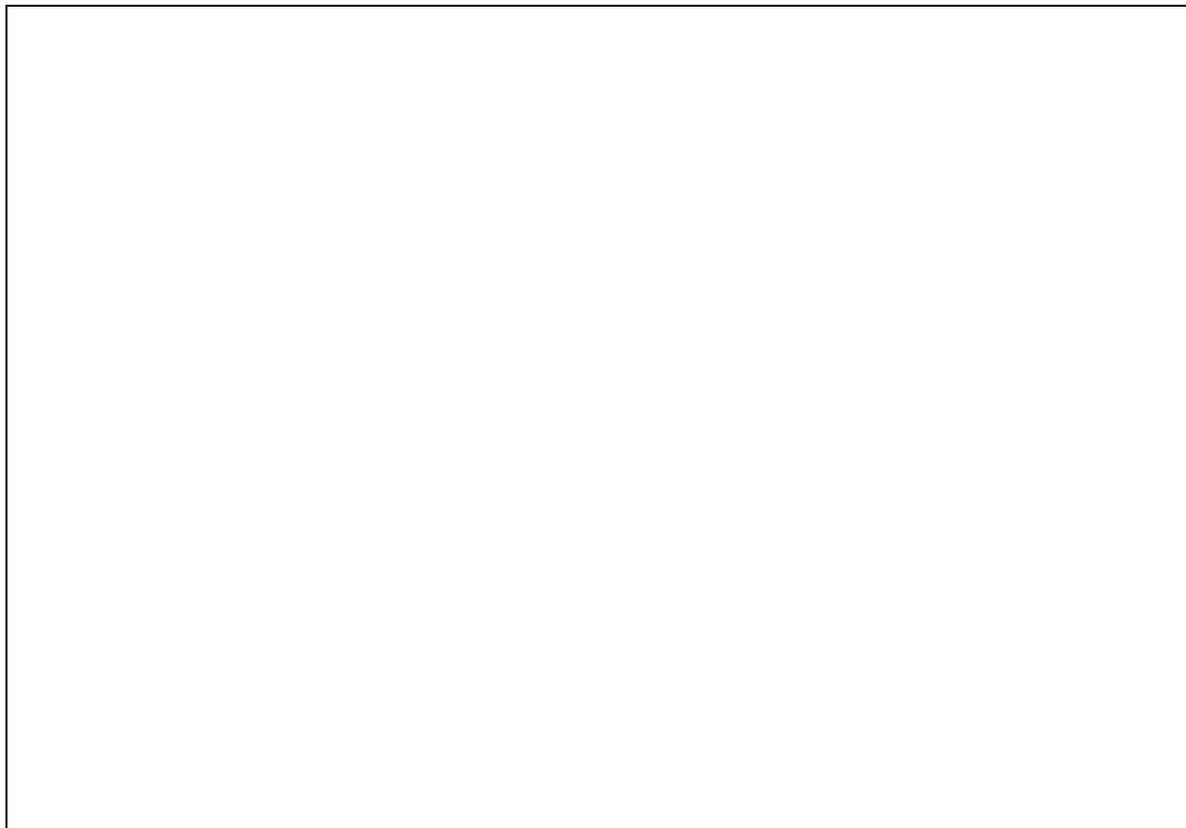
Synthetic fingernails are a popular fashion accessory. They are made in industrial laboratories from polymers. A monomer that can be used to make a polymer suitable for synthetic fingernails is shown below.



(d) Name the circled functional group in this monomer. (1 mark)

(e) Give the IUPAC name of the alcohol needed to make this monomer. (1 mark)

(f) Draw three repeating units of the polymer made from this monomer. (2 marks)



The protein which makes natural fingernails, Keratin 86, is also a polymer.

(g) What type of polymerisation reaction produces Keratin 86 and what type produces synthetic fingernails? (2 marks)

Polymer	Type of polymerisation reaction
Keratin 86	
Synthetic fingernail polymer	

	(h) State two differences between the polymerisation reaction types identified in part (g). (2 marks)
	One:
	Two:

<b>2021 Section 3 Question 36</b>  <b>Properties and structure of organic materials</b>	<p>Glycoluril is an organic compound composed of carbon, hydrogen, nitrogen and oxygen atoms. It is used in paper making and water disinfection. A chemist was given the task of determining the empirical formula and also the molecular formula of glycoluril.</p> <p>To do this, the chemist combusted 2.30 g of glycoluril in excess air, producing 2.85 g of carbon dioxide and 0.874 g of water.</p> <p>The chemist then used the Kjeldahl Method to determine the nitrogen content of another 2.30 g sample of the compound. This involved converting all of the nitrogen atoms in the sample into ammonia with the ammonia then distilled into 25.0 mL of 1.35 mol L<sup>-1</sup> sulfuric acid, which was in excess. The reaction between ammonia and sulfuric acid is:</p> $2 \text{NH}_3(\text{g}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow (\text{NH}_4)_2\text{SO}_4(\text{aq})$ <p>The excess sulfuric acid needed 15.40 mL of 0.186 mol L<sup>-1</sup> sodium hydroxide for complete reaction. The reaction equation is:</p> $2 \text{NaOH}(\text{aq}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{Na}_2\text{SO}_4(\text{aq}) + 2 \text{H}_2\text{O}(\text{l})$ <p>(a) Determine the empirical formula of glycoluril. (12 marks)</p>

(b) Another 2.30 g sample of glycoluril was vapourised at 242.0 kPa and 865.0 °C. The total volume of the resulting gas was 633.0 mL. Determine the molecular formula of glycoluril. (5 marks)

2021  
Section 3  
Question  
39

Properties  
and  
structure of  
organic  
materials

The oil extracted from the seeds of a particular Australian tree contains tripalmitin. The presence of tripalmitin, which is a triglyceride, means that this oil can be used to make ethyl palmitate, a type of biodiesel. The condensed structural formulae of tripalmitin and ethyl palmitate are given below.

Tripalmitin (a type of triglyceride)	Ethyl palmitate (a type of biodiesel)
$\begin{array}{c} \text{H}_2\text{COOC}(\text{CH}_2)_{14}\text{CH}_3 \\   \\ \text{HCOOC}(\text{CH}_2)_{14}\text{CH}_3 \\   \\ \text{H}_2\text{COOC}(\text{CH}_2)_{14}\text{CH}_3 \end{array}$	$\text{CH}_3(\text{CH}_2)_{14}\text{COOCH}_2\text{CH}_3$

(a) Demonstrate, by using a series of balanced reaction equations, how ethyl palmitate can be synthesised from tripalmitin. Your synthesis method **must** use ethene and lipase. You can also use water and any common laboratory acids.

Use condensed structural formulae to represent organic compounds. State symbols are only required for inorganic substances. (8 marks)

A chemist investigated the synthesis step involving lipase referred to in part (a). The results obtained by the chemist are shown in the following table.

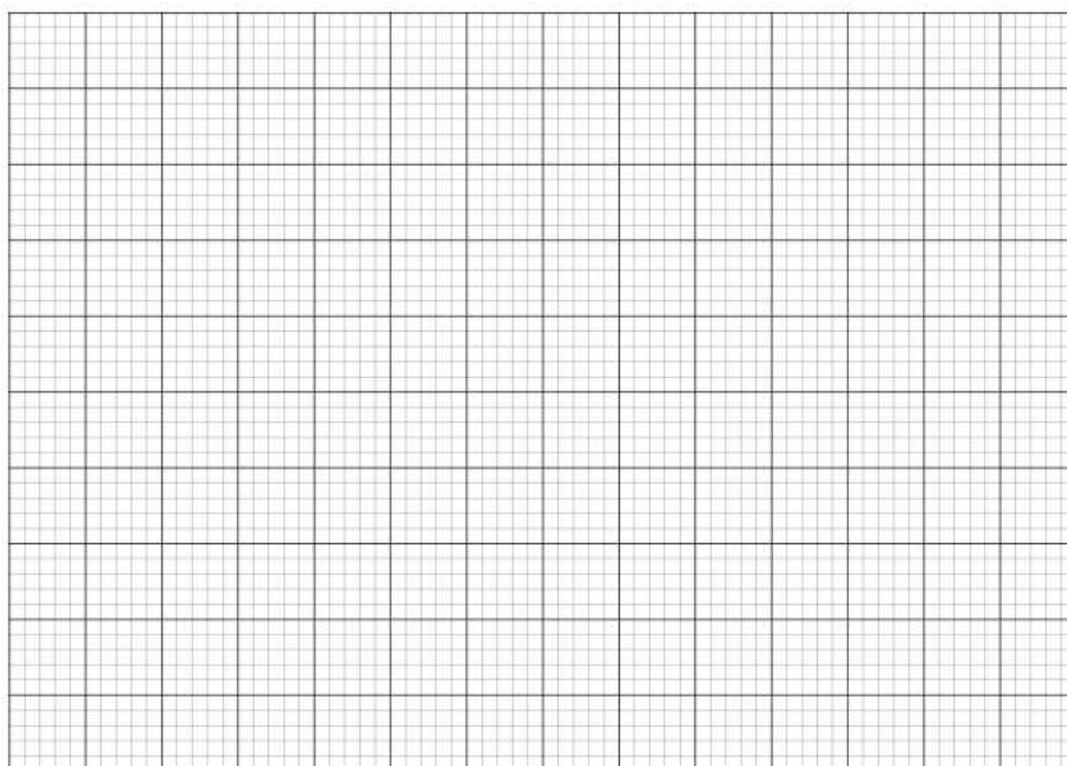
Temperature of reaction system (°C)	Biodiesel yield (%)
20	65
30	78
35	85
40	88
50	91
55	92
60	85
65	75

(b) Construct a question that the chemist might be trying to answer in this investigation. (1 mark)

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(c) Graph the data presented in the table on the following grid. (5 marks)



	(d) Describe the relationship observed in the graph. (2 marks)
	(e) Explain how the use of lipase in the synthesis contributes to the relationship described in part (d). (2 marks)

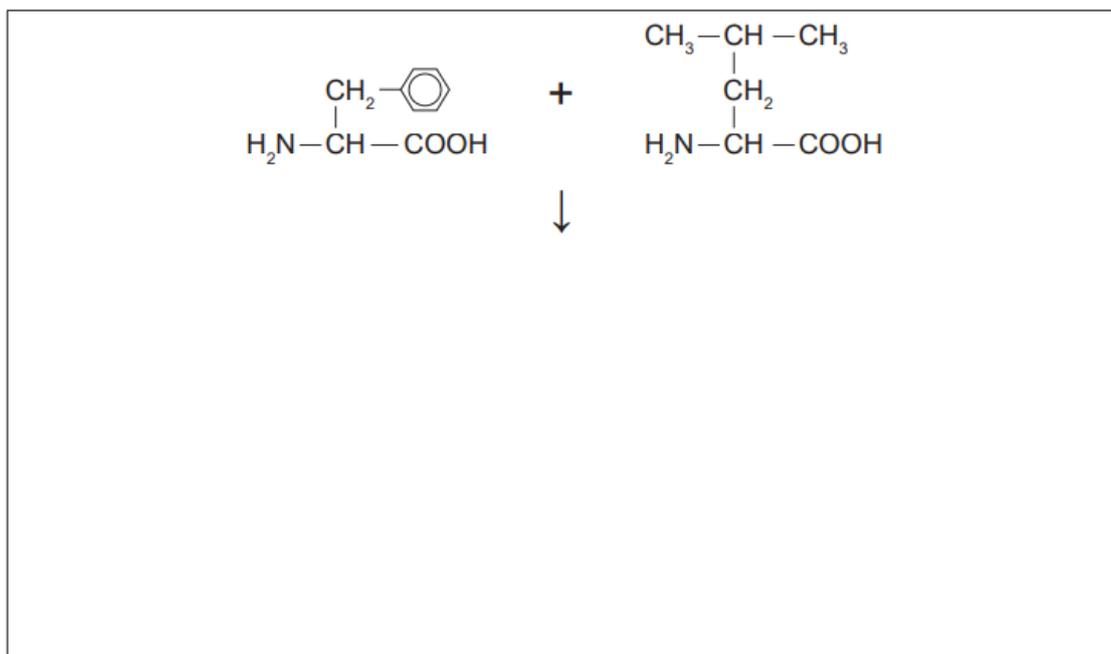
<b>2020 Section 3 Question 35</b>  <b>Properties and structure of organic materials</b>	<p>Cytochrome C is a protein found in the cells of many organisms. A biochemist analysed the Cytochrome C from a human and a grey whale to establish their respective <math>\alpha</math>-amino acid sequences.</p>
	<p>(a) What protein structure level does the <math>\alpha</math>-amino acid sequence represent? (1 mark)</p>



(d) The biochemist found that both human and grey whale Cytochrome C contain several alpha helices but no beta-pleated sheets. What protein structure level do alpha helices and beta-pleated sheets represent? (1 mark)

Further analysis of human Cytochrome C showed that there was a segment where two other  $\alpha$ -amino acids (phenylalanine and leucine) were adjacent to each other. The biochemist obtained pure samples of each of these amino acids and set up an experiment to facilitate their reaction with each other.

(e) Write a balanced equation, using condensed structural formulae, for a reaction that occurs between phenylalanine and leucine. (2 marks)



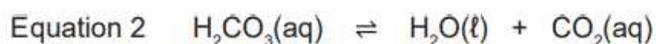
(f) The biochemist decided to examine how the structure of leucine changes with solution pH. Complete the following table by drawing the structural formula of leucine at the indicated pH. (2 marks)

Structural formula of leucine	pH
	acidic
	alkaline





Carbonic acid further reacts to form water and carbon dioxide as shown in Equation 2.



(c) Combine Equations 1 and 2, to create an overall equation that shows the relationship between  $\text{HCO}_3^-(\text{aq})$  and  $\text{CO}_2(\text{aq})$ . (2 marks)

(d) Identify the effect on the blood's pH when each of the following components are removed: carbon dioxide and hydrogencarbonate ions. (2 marks)

Component removed	Effect on pH (circle your answer)		
carbon dioxide	increase	decrease	no effect
hydrogencarbonate ions	increase	decrease	no effect

The buffering capacity of the carbonic acid-hydrogencarbonate is greatest when the pH is between 5.1 and 7.1.

(e) State **two** conditions in terms of concentration that are necessary for this buffering capacity to be optimal. (2 marks)

One:

Two:

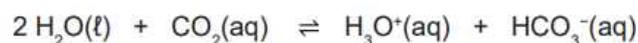
When the pH of the blood is too high, the kidneys can remove hydrogencarbonate ions,  $\text{HCO}_3^-$ , from the blood.

(f) Use Le Châtelier's Principle to demonstrate that the kidneys' action can help to prevent excessively high blood pH. (3 marks)

When inhaling, oxygen is taken into the lungs and transferred to the blood; when exhaling, carbon dioxide is expelled.

During hyperventilation (very rapid and deep breathing) more carbon dioxide is being expelled from the body than it can produce. This upsets the oxygen/carbon dioxide balance and can cause dizziness and fainting. Hyperventilating results in lowering the carbon dioxide concentration in the blood, which can affect the pH of the blood.

The equation shown below illustrates the formation of hydronium ions within the blood system.



A first-aid treatment for hyperventilation is the 'paper-bag treatment' whereby the patient breathes into a paper bag and so breathes back in the expelled breath, which contains a higher concentration of carbon dioxide.

(g) State the effect of the 'paper-bag treatment' on the pH of the blood and explain why it is an effective treatment for hyperventilation. (3 marks)

Another contributor to a potential imbalance of blood pH is the formation of lactic acid. The chemical name for lactic acid is 2-hydroxypropanoic acid, C<sub>3</sub>H<sub>6</sub>O<sub>3</sub>.

(h) Draw the structural formula for lactic acid with **all** its functional groups circled and labelled. (4 marks)

**2019  
Section 3  
Question  
38**

**Properties  
and  
structure of  
organic  
materials**

Polymethyl methacrylate and polycarbonate are two polymers that are used as alternatives to glass. Polymethyl methacrylate is more commonly known as Perspex or plexiglass and is an addition polymer, while polycarbonate is a type of condensation polymer.

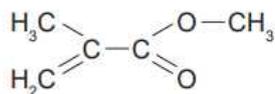
Both polymers are transparent to visible light and have other properties as listed below.

Polymethyl methacrylate	Polycarbonate
lightweight	moderate chemical resistance
moderate UV resistance	high heat resistance
low impact strength	high impact strength
low chemical resistance	low scratch resistance
low heat resistance	low UV resistance

(a) For the following uses as an alternative to glass, identify which polymer would be the more appropriate. Justify your choice of polymer by comparing the effect of **two** relevant properties as listed for both polymers. (4 marks)

Use	Choice of polymer	Justification
Skylight		
Safety glasses		

The monomer, methyl methacrylate, can be formed from the esterification of methanol and methacrylic acid (2-methylprop-2-enoic acid). The structural formula of methyl methacrylate is shown below



(b) Write a balanced equation for the esterification of methanol and methacrylic acid. Show the full structural formula of each species in the equation. (4 marks)

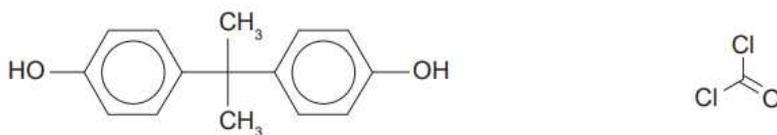
Methyl methacrylate can undergo addition polymerisation to form polymethyl methacrylate.

(c) Draw a section of a polymethyl methacrylate showing **all** atoms and at least **three** repeating units of the monomer. (3 marks)



Polycarbonates are condensation-type polymers for which the by-product is hydrogen chloride instead of water.

The two monomers for polycarbonate are shown below.



(e) Why is polymethyl methacrylate classified as an addition polymer, while polycarbonate is classified as a condensation polymer? (2 marks)

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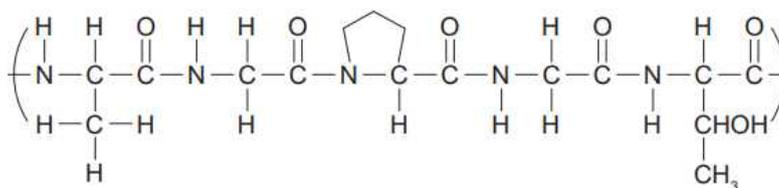
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**2019  
Section 3  
Question  
41**

**Properties  
and  
structure of  
organic  
materials**

When insects touch a spider's web they become stuck and therefore, easy prey for the spider. The insects become stuck because the web is coated with a glue-like substance produced by the spider. The 'spider glue' consists of water, proteins, ionic salts and polar carbon compounds.

The structural formula given below shows a small section of a spider glue protein.



(a) List the names of the amino acids in the order in which they were drawn in the section of the protein given above. Do **not** use abbreviations. (3 marks)

(b) Circle **one** peptide bond in the above structure. (1 mark)

(c) What is the difference between the primary structure and the secondary structure of a protein? (2 marks)

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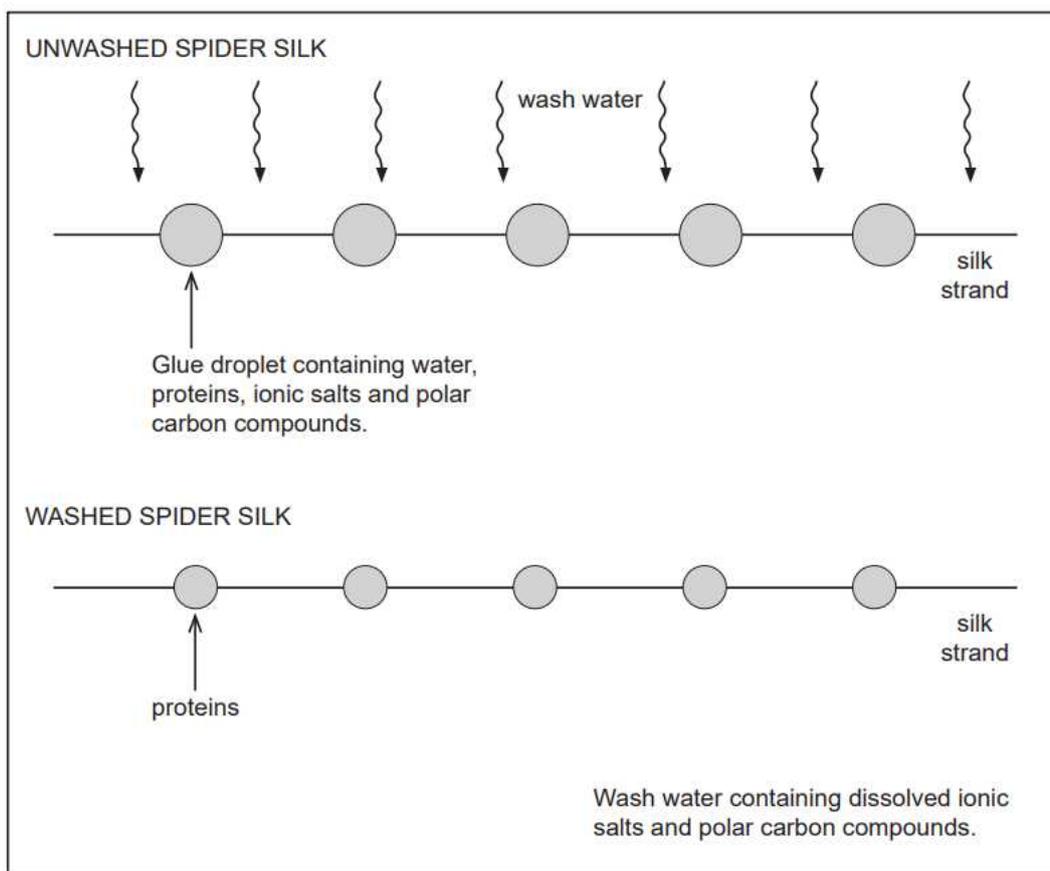
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When spider glue is washed with water, the ionic salts and polar carbon compounds dissolve. The proteins do not dissolve and remain on the silk strand. The following diagram shows what happens.



(d) Explain why the polar carbon compounds dissolve in water but the proteins do not. Illustrate your answer with the aid of a labelled diagram. (6 marks)

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## Marking Guide – Section 1

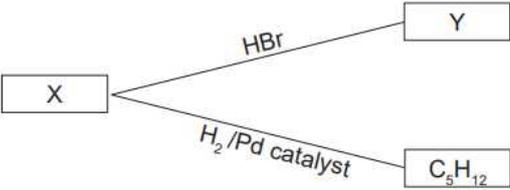
<p><b>2023</b> <b>Section 1</b> <b>Question 2</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which of the following formulae represents an amide?</p> <p>(a) <math>\text{CH}_3\text{CH}(\text{NH}_2)\text{CH}_3</math>            (b) <math>\text{CH}_3\text{COOCH}_3</math>  <b>(c) <math>\text{CH}_3\text{CONHCH}_3</math> – Answer</b>            (d) <math>\text{CH}_3\text{COCH}_2\text{NH}_2</math></p>
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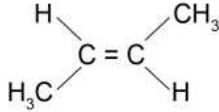
<p><b>2023</b> <b>Section 1</b> <b>Question 16</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Identify the monomer for the polymer shown below.</p> <div style="text-align: center;"> </div> <p>(a) <math>\text{CH}_3\text{CH}_2\text{CH}_3</math>            (b) <math>\text{CH}_2\text{CHCH}_3</math>            (c) <math>\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3</math>  <b>(d) <math>\text{CH}_3\text{CHCHCH}_3</math> – Answer</b></p>
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<p><b>2022</b> <b>Section 1</b> <b>Question 18</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>The presence of a carboxylic acid functional group in an unknown organic compound may be identified by observing a reaction with which of the following?</p> <p>(a) <math>\text{Cr}_2\text{O}_7^{2-}(\text{aq})</math>            (b) <math>\text{Br}_2(\text{aq})</math>            (c) <math>\text{Na}_2\text{SO}_4(\text{s})</math>            (d) <math>\text{Na}_2\text{CO}_3(\text{s})</math></p> <p><b>Answer is D.</b></p>
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<p><b>2022</b> <b>Section 1</b> <b>Question 19</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>The following compounds have similar molar masses and polar functional groups. Which compound is expected to have the highest melting point?</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 5%; text-align: center;">(a)</td> <td style="width: 45%; text-align: center;"><math>\text{NH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2</math></td> <td style="width: 50%; text-align: center;">88 g mol<sup>-1</sup></td> </tr> <tr> <td style="text-align: center;">(b)</td> <td style="text-align: center;"> <math display="block">\begin{array}{c} \text{CH}_3 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}</math> </td> <td style="text-align: center;">89 g mol<sup>-1</sup></td> </tr> <tr> <td style="text-align: center;">(c)</td> <td style="text-align: center;"> <math display="block">\begin{array}{c} \text{O} \\    \\ \text{HO}-\text{C}-\text{CH}_2\text{CH}_2\text{OH} \end{array}</math> </td> <td style="text-align: center;">90 g mol<sup>-1</sup></td> </tr> <tr> <td style="text-align: center;">(d)</td> <td style="text-align: center;"> <math display="block">\begin{array}{c} \text{O} \quad \text{O} \\    \quad    \\ \text{HO}-\text{C}-\text{C}-\text{OH} \end{array}</math> </td> <td style="text-align: center;">90 g mol<sup>-1</sup></td> </tr> </table> <p><b>Answer is b.</b></p>	(a)	$\text{NH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2$	88 g mol <sup>-1</sup>	(b)	$\begin{array}{c} \text{CH}_3 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$	89 g mol <sup>-1</sup>	(c)	$\begin{array}{c} \text{O} \\    \\ \text{HO}-\text{C}-\text{CH}_2\text{CH}_2\text{OH} \end{array}$	90 g mol <sup>-1</sup>	(d)	$\begin{array}{c} \text{O} \quad \text{O} \\    \quad    \\ \text{HO}-\text{C}-\text{C}-\text{OH} \end{array}$	90 g mol <sup>-1</sup>
(a)	$\text{NH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2$	88 g mol <sup>-1</sup>											
(b)	$\begin{array}{c} \text{CH}_3 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$	89 g mol <sup>-1</sup>											
(c)	$\begin{array}{c} \text{O} \\    \\ \text{HO}-\text{C}-\text{CH}_2\text{CH}_2\text{OH} \end{array}$	90 g mol <sup>-1</sup>											
(d)	$\begin{array}{c} \text{O} \quad \text{O} \\    \quad    \\ \text{HO}-\text{C}-\text{C}-\text{OH} \end{array}$	90 g mol <sup>-1</sup>											

<b>2022</b> <b>Section 1</b> <b>Question 21</b>  <b>Properties and structure of organic materials</b>	How many isomers are there for a molecule with the formula $C_3H_6Cl_2$ ?  (a) 5 <b>(b) 4 – Answer</b> (c) 3 (d) 2
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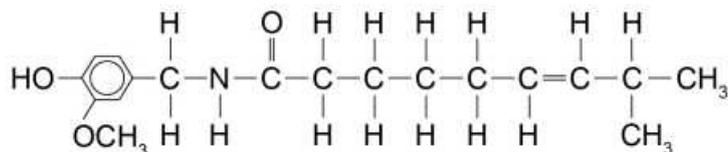
<b>2022</b> <b>Section 1</b> <b>Question 23</b>  <b>Properties and structure of organic materials</b>	In the following diagram, determine the molecular formulae of substances X and Y.   <p style="text-align: center;"> <table border="0"> <thead> <tr> <th style="padding: 0 20px;">X</th> <th>Y</th> </tr> </thead> <tbody> <tr> <td>(a) <math>C_5H_{12}</math></td> <td><math>C_5H_{13}Br</math></td> </tr> <tr> <td>(b) <math>C_5H_{10}</math></td> <td><math>C_5H_{11}Br</math></td> </tr> <tr> <td>(c) <math>C_5H_{10}</math></td> <td><math>C_5H_{10}Br_2</math></td> </tr> <tr> <td>(d) <math>C_5H_8</math></td> <td><math>C_5H_9Br</math></td> </tr> </tbody> </table> </p> <p><b>Answer is b.</b></p>	X	Y	(a) $C_5H_{12}$	$C_5H_{13}Br$	(b) $C_5H_{10}$	$C_5H_{11}Br$	(c) $C_5H_{10}$	$C_5H_{10}Br_2$	(d) $C_5H_8$	$C_5H_9Br$
X	Y										
(a) $C_5H_{12}$	$C_5H_{13}Br$										
(b) $C_5H_{10}$	$C_5H_{11}Br$										
(c) $C_5H_{10}$	$C_5H_{10}Br_2$										
(d) $C_5H_8$	$C_5H_9Br$										

<b>2022</b> <b>Section 1</b> <b>Question 24</b>  <b>Properties and structure of organic materials</b>	Which of the following is the correct IUPAC name for the molecule below?   <p>(a) <b><i>trans</i>-but-2-ene – Answer</b>          (b) 1,4-dimethylbutene          (c) <i>cis</i>-but-2-ene          (d) methylprop-1-ene</p>
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**2022**  
**Section 2**  
**Question**  
**30**

**Properties**  
**and**  
**structure of**  
**organic**  
**materials**

Capsaicin,  $C_{18}H_{27}NO_3$ , is the compound that makes chillies taste hot on the tongue. The molecular structure of capsaicin is shown below.



Drinking milk is effective in reducing the 'hotness' of chillies, by dissolving the capsaicin due to the presence of fats in the milk and removing it from the tongue. Capsaicin does not dissolve in water, and so drinking water does not reduce the effect of the compound when eaten. Explain this observation, using your understanding of intermolecular forces.

Description	Marks
Recognition of the forces of attraction present between the molecules in <ul style="list-style-type: none"> <li>capsaicin are predominantly dispersion</li> <li>fats are predominantly dispersion.</li> </ul>	1
Recognition of the forces of attraction present between the molecules in water are predominantly hydrogen bonds.	1
Recognition that the forces of attraction formed between water and capsaicin are relatively weak compared to the forces of attraction formed between capsaicin and fat	1
Recognition that the energy produced by the forces of attraction formed between capsaicin and fats are sufficient to overcome the existing forces of attraction between the molecules of fats and between the molecules of capsaicin (and so capsaicin dissolves in milk).	1
Recognition that the energy produced between the forces of attraction formed between capsaicin and water is insufficient to overcome the existing forces of attraction between the molecules of capsaicin and between the molecules of water (and so capsaicin does not dissolve in water).	1
<b>Total</b>	<b>5</b>
Also accept a response in terms of strength and number of bonds.	

**2021**  
**Section 1**  
**Question 4**

**Properties**  
**and**  
**structure of**  
**organic**  
**materials**

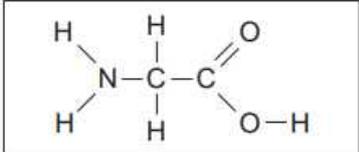
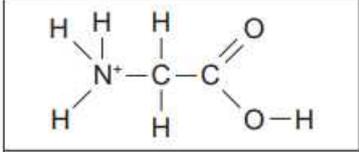
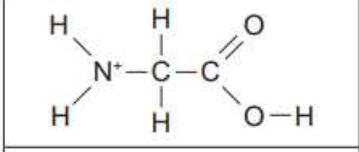
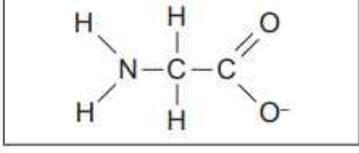
Which of the following characteristics influence how a particular polymer might be used?

- The amount of cross-linking between the hydrogen atoms in the polymer.
- The length of the carbon chains in the polymer.
- The functional groups present in the monomer used to synthesise the polymer.
- The melting point of the polymer.

**(a) ii, iii and iv only – Answer**

- i and ii only
- ii and iii only
- i, ii and iv only

<p><b>2021</b> <b>Section 1</b> <b>Question 5</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Nylon 46 is a polymer that can withstand very large forces without breaking. Its structural formula is shown below.</p> $\left( \begin{array}{cccccccccccc} & \text{H} & \text{H} & & \text{H} \\ &   &   & &   &   &   &   &   &   &   &   \\ \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{N} & - \text{C} & - \text{N} \\    & & &    &   &   &   &   &   &   &   &   \\ \text{O} & \text{H} & \text{H} & \text{O} & \text{H} \end{array} \right)_n$ <p>The intermolecular forces contributing the most to the strength of Nylon 46 is/are</p> <p>(a) covalent network bonding. (b) dispersion forces. <b>(c) hydrogen bonding. – Answer</b> (d) dipole-dipole forces.</p>
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<p><b>2021</b> <b>Section 1</b> <b>Question 7</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which of the following structures represents glycine in acidic conditions?</p> <div style="display: flex; flex-direction: column; align-items: flex-start;"> <div style="margin-bottom: 10px;"> <p>(a) </p> </div> <div style="margin-bottom: 10px;"> <p>(b) </p> </div> <div style="margin-bottom: 10px;"> <p>(c) </p> </div> <div> <p>(d) </p> </div> </div> <p><b>Answer is b.</b></p>
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<p><b>2021</b> <b>Section 1</b> <b>Question 11</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which of the following shows an <math>\alpha</math>-amino acid?</p> <div style="border: 1px solid black; padding: 5px; margin: 5px 0;"> <p>(i) <math display="block">\begin{array}{c} \text{NH}_2 \\   \\ \text{H}-\text{C}-\text{COOH} \\   \\ \text{H} \end{array}</math></p> </div> <div style="border: 1px solid black; padding: 5px; margin: 5px 0;"> <p>(ii) <math display="block">\begin{array}{c} \text{NH}_2 \\   \\ \text{H}-\text{C}-\text{CH}_2-\text{COOH} \\   \\ \text{H} \end{array}</math></p> </div> <div style="border: 1px solid black; padding: 5px; margin: 5px 0;"> <p>(iii) <math display="block">\begin{array}{c} \text{NH}_2 \\   \\ \text{H}-\text{C}-\text{COOH} \\   \\ \text{CH}_2\text{CH}_3 \end{array}</math></p> </div> <div style="border: 1px solid black; padding: 5px; margin: 5px 0;"> <p>(iv) <math display="block">\begin{array}{c} \text{NH}_2 \\   \\ \text{H}-\text{C}-\text{CH}_2-\text{CH}_2-\text{COOH} \\   \\ \text{H} \end{array}</math></p> </div> <p><b>(a) i and iii only – Answer</b>          (b) i only          (c) ii, iii and iv only          (d) i, ii, iii and iv</p>
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<p><b>2021</b> <b>Section 1</b> <b>Question 16</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Two isomeric forms of a saturated hydrocarbon</p> <p>(a) contain different types of atoms.          (b) have the same structural formula.  <b>(c) have the same molecular formula. – Answer</b>          (d) react vigorously with one another.</p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 4</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>The number of possible isomers of <math>\text{C}_2\text{H}_2\text{F}_2</math> is</p> <p>(a) 1          (b) 2  <b>(c) 3 – Answer</b>          (d) 4</p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 9</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Consider the molecule shown below.</p> <div style="text-align: center; margin: 10px 0;"> </div> <p>This molecule shows</p> <p><b>(a) an anionic detergent which contains a sulfonate group. – Answer</b>          (b) a monomer that can be used to synthesise a condensation polymer.          (c) a carboxylic acid which can be used to synthesise a soap.          (d) an aromatic hydrocarbon which has donated an electron.</p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 10</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which of these statements regarding organic molecules are correct?</p> <p>(i) Organic molecules have hydrocarbon skeletons.  (ii) Functional groups consist of groups of atoms or a particular type of bond.  (iii) Functional groups influence the chemical properties of organic molecules.  (iv) Functional groups influence the physical properties of organic molecules.</p> <p>(a) i and iii only  (b) ii and iv only  (c) i, ii and iii only  <b>(d) i, ii, iii and iv – Answer</b></p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 11</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which of the following pairs of molecules can form peptide bonds with each other?</p> <table border="1" style="width: 100%; text-align: center;"> <tr> <td style="width: 5%; vertical-align: middle;">(i)</td> <td style="width: 45%;"> <math display="block">\begin{array}{cccc} \text{H} &amp; \text{H} &amp; \text{H} &amp; \text{H} \\   &amp;   &amp;   &amp;   \\ \text{HO}-\text{C} &amp; -\text{C} &amp; -\text{C} &amp; -\text{C}-\text{OH} \\   &amp;   &amp;   &amp;   \\ \text{H} &amp; \text{H} &amp; \text{H} &amp; \text{H} \end{array}</math> <p>butan-1,4-diol</p> </td> <td style="width: 45%;"> <math display="block">\begin{array}{cccc} \text{H} &amp; \text{H} &amp; \text{H} &amp; \text{H} \\   &amp;   &amp;   &amp;   \\ \text{H}_2\text{N}-\text{C} &amp; -\text{C} &amp; -\text{C} &amp; -\text{C}-\text{NH}_2 \\   &amp;   &amp;   &amp;   \\ \text{H} &amp; \text{H} &amp; \text{H} &amp; \text{H} \end{array}</math> <p>butan-1,4-diamine</p> </td> </tr> <tr> <td style="vertical-align: middle;">(ii)</td> <td> <math display="block">\begin{array}{c} \text{CH}_2 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \\   \\ \text{C}_6\text{H}_4 \\   \\ \text{OH} \end{array}</math> <p>tyrosine</p> </td> <td> <math display="block">\begin{array}{c} \text{CH}_2 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \\   \\ \text{C}_6\text{H}_4 \\   \\ \text{OH} \end{array}</math> <p>tyrosine</p> </td> </tr> <tr> <td style="vertical-align: middle;">(iii)</td> <td> <math display="block">\begin{array}{c} \text{CH}_3-\text{CH}-\text{CH}_3 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}</math> <p>valine</p> </td> <td> <math display="block">\begin{array}{c} \text{CH}_2 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \\   \\ \text{C}_6\text{H}_5 \end{array}</math> <p>phenylalanine</p> </td> </tr> <tr> <td style="vertical-align: middle;">(iv)</td> <td> <math display="block">\begin{array}{cc} \text{H} &amp; \text{H} \\   &amp;   \\ \text{H}-\text{C} &amp; -\text{C}-\text{O}-\text{H} \\   &amp;   \\ \text{H} &amp; \text{H} \end{array}</math> <p>ethanol</p> </td> <td> <math display="block">\begin{array}{ccc} \text{H} &amp; \text{H} &amp; \text{O} \\   &amp;   &amp; // \\ \text{H}-\text{C} &amp; -\text{C} &amp; -\text{C} \\   &amp;   &amp; \backslash \\ \text{H} &amp; \text{H} &amp; \text{O}-\text{H} \end{array}</math> <p>butanoic acid</p> </td> </tr> </table> <p>(a) i and iv only  <b>(b) ii and iii only – Answer</b>  (c) i, ii and iii only  (d) i, ii, iii and iv</p>	(i)	$\begin{array}{cccc} \text{H} & \text{H} & \text{H} & \text{H} \\   &   &   &   \\ \text{HO}-\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{OH} \\   &   &   &   \\ \text{H} & \text{H} & \text{H} & \text{H} \end{array}$ <p>butan-1,4-diol</p>	$\begin{array}{cccc} \text{H} & \text{H} & \text{H} & \text{H} \\   &   &   &   \\ \text{H}_2\text{N}-\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{NH}_2 \\   &   &   &   \\ \text{H} & \text{H} & \text{H} & \text{H} \end{array}$ <p>butan-1,4-diamine</p>	(ii)	$\begin{array}{c} \text{CH}_2 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \\   \\ \text{C}_6\text{H}_4 \\   \\ \text{OH} \end{array}$ <p>tyrosine</p>	$\begin{array}{c} \text{CH}_2 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \\   \\ \text{C}_6\text{H}_4 \\   \\ \text{OH} \end{array}$ <p>tyrosine</p>	(iii)	$\begin{array}{c} \text{CH}_3-\text{CH}-\text{CH}_3 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$ <p>valine</p>	$\begin{array}{c} \text{CH}_2 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \\   \\ \text{C}_6\text{H}_5 \end{array}$ <p>phenylalanine</p>	(iv)	$\begin{array}{cc} \text{H} & \text{H} \\   &   \\ \text{H}-\text{C} & -\text{C}-\text{O}-\text{H} \\   &   \\ \text{H} & \text{H} \end{array}$ <p>ethanol</p>	$\begin{array}{ccc} \text{H} & \text{H} & \text{O} \\   &   & // \\ \text{H}-\text{C} & -\text{C} & -\text{C} \\   &   & \backslash \\ \text{H} & \text{H} & \text{O}-\text{H} \end{array}$ <p>butanoic acid</p>
(i)	$\begin{array}{cccc} \text{H} & \text{H} & \text{H} & \text{H} \\   &   &   &   \\ \text{HO}-\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{OH} \\   &   &   &   \\ \text{H} & \text{H} & \text{H} & \text{H} \end{array}$ <p>butan-1,4-diol</p>	$\begin{array}{cccc} \text{H} & \text{H} & \text{H} & \text{H} \\   &   &   &   \\ \text{H}_2\text{N}-\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{NH}_2 \\   &   &   &   \\ \text{H} & \text{H} & \text{H} & \text{H} \end{array}$ <p>butan-1,4-diamine</p>											
(ii)	$\begin{array}{c} \text{CH}_2 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \\   \\ \text{C}_6\text{H}_4 \\   \\ \text{OH} \end{array}$ <p>tyrosine</p>	$\begin{array}{c} \text{CH}_2 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \\   \\ \text{C}_6\text{H}_4 \\   \\ \text{OH} \end{array}$ <p>tyrosine</p>											
(iii)	$\begin{array}{c} \text{CH}_3-\text{CH}-\text{CH}_3 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$ <p>valine</p>	$\begin{array}{c} \text{CH}_2 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \\   \\ \text{C}_6\text{H}_5 \end{array}$ <p>phenylalanine</p>											
(iv)	$\begin{array}{cc} \text{H} & \text{H} \\   &   \\ \text{H}-\text{C} & -\text{C}-\text{O}-\text{H} \\   &   \\ \text{H} & \text{H} \end{array}$ <p>ethanol</p>	$\begin{array}{ccc} \text{H} & \text{H} & \text{O} \\   &   & // \\ \text{H}-\text{C} & -\text{C} & -\text{C} \\   &   & \backslash \\ \text{H} & \text{H} & \text{O}-\text{H} \end{array}$ <p>butanoic acid</p>											

<p><b>2020</b> <b>Section 1</b> <b>Question 13</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which of the following alcohols would you expect to have the highest boiling point?</p> <p><b>(a) pentan-1-ol – Answer</b>  (b) pentan-2-ol  (c) pentan-3-ol  (d) 2-methylbutan-2-ol</p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 14</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>The Protein Data Bank contains information relating to the structures of proteins. The structure of a protein is important because it is related closely to its</p> <p>(a) equilibrium constant.  (b) bonding capacity.  (c) nutritional value.  <b>(d) function. – Answer</b></p>
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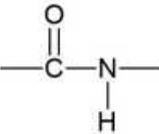
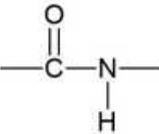
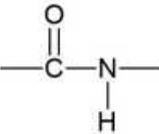
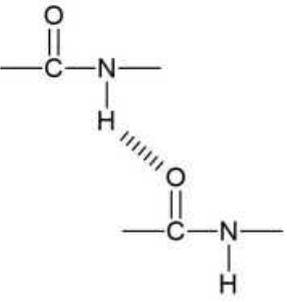
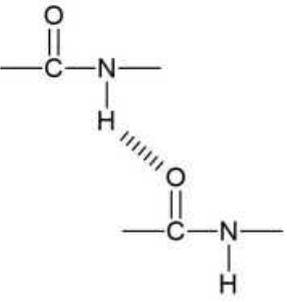
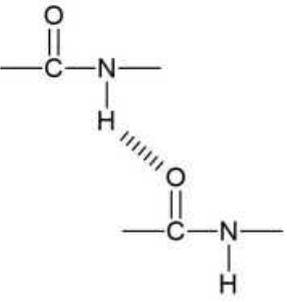
<p><b>2020</b> <b>Section 1</b> <b>Question 21</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Polyacrylonitrile fibres can be used to make blankets and carpets. The structural formula of a segment of this polymer is shown below.</p> $\left( \begin{array}{cccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\   &   &   &   &   &   &   \\ \text{C} & - \text{C} \\   &   &   &   &   &   &   \\ \text{H} & \text{CN} & \text{H} & \text{CN} & \text{H} & \text{CN} & \text{H} \end{array} \right)_n$ <p>The structural formula of the monomer used to make polyacrylonitrile is:</p> <table border="1"> <tr> <td>(a)</td> <td> <math display="block">\begin{array}{c} \text{H} &amp; &amp; \text{H} \\   &amp; &amp;   \\ \text{H}-\text{C} &amp; = &amp; \text{C}-\text{C}-\text{H} \\ &amp; &amp;   &amp;   \\ &amp; &amp; \text{CN} &amp; \text{H} \end{array}</math> </td> </tr> <tr> <td>(b)</td> <td> <math display="block">\begin{array}{c} \text{H} &amp; \text{H} &amp; \text{H} \\   &amp;   &amp;   \\ \text{H}-\text{C} &amp; - &amp; \text{C} &amp; - &amp; \text{C}-\text{H} \\   &amp;   &amp;   \\ \text{CN} &amp; \text{H} &amp; \text{CN} \end{array}</math> </td> </tr> <tr> <td>(c)</td> <td> <math display="block">\begin{array}{c} \text{H} &amp; \text{H} \\   &amp;   \\ \text{H}-\text{C} &amp; = &amp; \text{C}-\text{CN} \end{array}</math> </td> </tr> <tr> <td>(d)</td> <td> <math display="block">\begin{array}{c} \text{H} &amp; \text{H} \\   &amp;   \\ \text{H}-\text{C} &amp; - &amp; \text{C}-\text{CN} \\   &amp;   \\ \text{H} &amp; \text{H} \end{array}</math> </td> </tr> </table> <p><b>Answer is c.</b></p>	(a)	$\begin{array}{c} \text{H} & & \text{H} \\   & &   \\ \text{H}-\text{C} & = & \text{C}-\text{C}-\text{H} \\ & &   &   \\ & & \text{CN} & \text{H} \end{array}$	(b)	$\begin{array}{c} \text{H} & \text{H} & \text{H} \\   &   &   \\ \text{H}-\text{C} & - & \text{C} & - & \text{C}-\text{H} \\   &   &   \\ \text{CN} & \text{H} & \text{CN} \end{array}$	(c)	$\begin{array}{c} \text{H} & \text{H} \\   &   \\ \text{H}-\text{C} & = & \text{C}-\text{CN} \end{array}$	(d)	$\begin{array}{c} \text{H} & \text{H} \\   &   \\ \text{H}-\text{C} & - & \text{C}-\text{CN} \\   &   \\ \text{H} & \text{H} \end{array}$
(a)	$\begin{array}{c} \text{H} & & \text{H} \\   & &   \\ \text{H}-\text{C} & = & \text{C}-\text{C}-\text{H} \\ & &   &   \\ & & \text{CN} & \text{H} \end{array}$								
(b)	$\begin{array}{c} \text{H} & \text{H} & \text{H} \\   &   &   \\ \text{H}-\text{C} & - & \text{C} & - & \text{C}-\text{H} \\   &   &   \\ \text{CN} & \text{H} & \text{CN} \end{array}$								
(c)	$\begin{array}{c} \text{H} & \text{H} \\   &   \\ \text{H}-\text{C} & = & \text{C}-\text{CN} \end{array}$								
(d)	$\begin{array}{c} \text{H} & \text{H} \\   &   \\ \text{H}-\text{C} & - & \text{C}-\text{CN} \\   &   \\ \text{H} & \text{H} \end{array}$								

<p><b>2019</b> <b>Section 1</b> <b>Question 9</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which one of the following is an alpha amino acid?</p> <table border="1"> <tr> <td> <p>(a) <math>\text{H}-\text{Se}-\underset{\text{NH}_2}{\text{CH}}-\text{COOH}</math></p> </td> <td> <p>(b) <math>\text{H}_2\text{N}-\overset{\text{OH}}{\text{CH}}-\text{CH}_2-\text{COOH}</math></p> </td> </tr> <tr> <td> <p>(c) <math>\text{H}_2\text{N}-\underset{\text{CH}-\text{COOH}}{\text{CH}_2}-\text{CH}_2-\text{COOH}</math></p> </td> <td> <p>(d) <math>\text{H}_2\text{N}-\overset{\text{O}}{\parallel}{\text{C}}-\text{NH}_2</math> <math>\text{Se}-\text{CH}_2-\text{COOH}</math></p> </td> </tr> </table> <p><b>Answer is a.</b></p>	<p>(a) <math>\text{H}-\text{Se}-\underset{\text{NH}_2}{\text{CH}}-\text{COOH}</math></p>	<p>(b) <math>\text{H}_2\text{N}-\overset{\text{OH}}{\text{CH}}-\text{CH}_2-\text{COOH}</math></p>	<p>(c) <math>\text{H}_2\text{N}-\underset{\text{CH}-\text{COOH}}{\text{CH}_2}-\text{CH}_2-\text{COOH}</math></p>	<p>(d) <math>\text{H}_2\text{N}-\overset{\text{O}}{\parallel}{\text{C}}-\text{NH}_2</math> <math>\text{Se}-\text{CH}_2-\text{COOH}</math></p>
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<p><b>2019</b> <b>Section 1</b> <b>Question 14</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which one of the following properties exhibited by octanol is <b>not</b> related to the dispersion forces between the molecules?</p> <p>(a) <b>combustibility – Answer</b>          (b) melting point          (c) solubility in octane          (d) solubility in water</p>
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<p><b>2019</b> <b>Section 1</b> <b>Question 15</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which one of the following compounds will <b>not</b> exhibit geometric (cis-trans) isomerism?</p> <p>(a) 1,2-difluoro-1-butene  <b>(b) 1,1-difluoro-1-butene – Answer</b>  (c) 1,2-difluoro-2-butene  (d) 1,4-difluoro-2-butene</p>
<p><b>2019</b> <b>Section 1</b> <b>Question 22</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Between which of the following pairs of substances can dispersion forces exist?</p> <p>(i) <math>\text{CH}_3\text{Cl}</math> and <math>\text{H}_2\text{O}</math>  (ii) <math>\text{CH}_3\text{CH}_2\text{CHO}</math> and <math>\text{HBr}</math>  (iii) <math>\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3</math> and <math>\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3</math>  (iv) <math>\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}</math> and <math>\text{NH}_3</math></p> <p>(a) i and ii only  (b) i, ii and iii only  (c) iii only  <b>(d) i, ii, iii and iv – Answer</b></p>
<p><b>2019</b> <b>Section 1</b> <b>Question 23</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Which one of the following is an isomer of pentanoic acid?</p> <p>(a) <math>\text{CH}_3\text{CHCH-O-CH}_2\text{CHO}</math>  (b) <math>\text{CH}_2\text{CHCH}_2\text{-O-CH}_2\text{CH}_2\text{OH}</math>  (c) <math>\text{OHCCH}_2\text{CH}_2\text{CH}_2\text{CHO}</math>  (d) <math>\text{CH}_3\text{CHCHCH}_2\text{COOH}</math></p> <p><b>Answer is b.</b></p>
<p><b>2019</b> <b>Section 1</b> <b>Question 25</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>How many isomers does the compound <math>\text{C}_2\text{H}_3\text{Br}_3</math> have?</p> <p>(a) 1  <b>(b) 2 – Answer</b>  (c) 3  (d) 4</p>

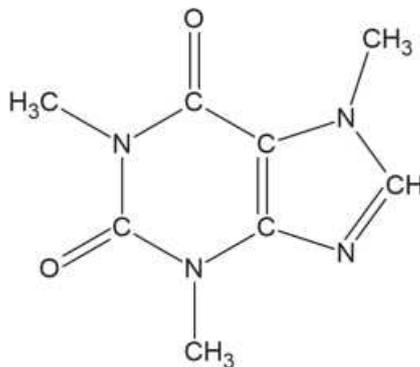
Marking Guide – Section 2

<p><b>2023</b> <b>Section 2</b> <b>Question 31</b></p> <p><b>Properties and structure of organic materials</b></p>	<p>Condensation reactions between <math>\alpha</math>-amino acids form polypeptides called proteins. The function performed by any given protein is determined by its structure, and the structures of proteins are described in terms of levels: primary, secondary and tertiary.</p> <p>(a) Define the primary structure of a protein, including a description and an annotated diagram to explain how the <math>\alpha</math>-amino acid monomers are joined. (4 marks)</p>															
	<table border="1"> <thead> <tr> <th>Description</th> <th>Marks</th> </tr> </thead> <tbody> <tr> <td>Recognition that the primary structure of a protein is the sequence of <math>\alpha</math>-amino acids</td> <td>1</td> </tr> <tr> <td>Recognition that the <math>\alpha</math>-amino acids are joined by peptide or amide bonds</td> <td>1</td> </tr> <tr> <td>Diagram shows a correctly drawn peptide/amide bond</td> <td rowspan="2">1</td> </tr> <tr> <td>  </td> </tr> <tr> <td>Peptide bond is labelled</td> <td>1</td> </tr> <tr> <td style="text-align: right;"><b>Total</b></td> <td><b>4</b></td> </tr> </tbody> </table>	Description	Marks	Recognition that the primary structure of a protein is the sequence of $\alpha$ -amino acids	1	Recognition that the $\alpha$ -amino acids are joined by peptide or amide bonds	1	Diagram shows a correctly drawn peptide/amide bond	1		Peptide bond is labelled	1	<b>Total</b>	<b>4</b>		
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	Peptide bond is labelled	1														
	<b>Total</b>	<b>4</b>														
	<p>(b) Explain the difference between the secondary and tertiary structures of proteins. Include a description of each level of the structure and how it forms in your answer. (5 marks)</p>															
<table border="1"> <thead> <tr> <th>Description</th> <th>Marks</th> </tr> </thead> <tbody> <tr> <td>Recognition that secondary structures result from hydrogen bonding between amide group hydrogen atoms and carbonyl group oxygen atoms. This may include a drawing with a dotted line to show the hydrogen bonding interaction. For example:</td> <td rowspan="2">1</td> </tr> <tr> <td>  </td> </tr> <tr> <td>Recognition that secondary structures are <math>\alpha</math>-helixes and/or <math>\beta</math>-pleated sheets</td> <td>1</td> </tr> <tr> <td>Recognition that <math>\alpha</math>-helix is a secondary structure that results from hydrogen bonding between amide and carbonyl functional groups within a peptide chain and/or</td> <td rowspan="2">1</td> </tr> <tr> <td>Recognition that <math>\beta</math>-pleated sheet is a secondary structure resulting from hydrogen bonding between amide and carbonyl functional groups along adjacent polypeptide chains</td> </tr> <tr> <td>Recognition that the tertiary structure of a protein is a result of folding of the polypeptide chain/overall shape of the protein</td> <td>1</td> </tr> <tr> <td>Recognition that tertiary structure forms due to interactions between side chains of <math>\alpha</math>-amino acids in the polypeptide. Answer to include any one of the following interactions: disulfide bridges, hydrogen bonding, dipole-dipole interactions, dispersion forces and ionic interactions</td> <td>1</td> </tr> <tr> <td style="text-align: right;"><b>Total</b></td> <td><b>5</b></td> </tr> </tbody> </table>	Description	Marks	Recognition that secondary structures result from hydrogen bonding between amide group hydrogen atoms and carbonyl group oxygen atoms. This may include a drawing with a dotted line to show the hydrogen bonding interaction. For example:	1		Recognition that secondary structures are $\alpha$ -helixes and/or $\beta$ -pleated sheets	1	Recognition that $\alpha$ -helix is a secondary structure that results from hydrogen bonding between amide and carbonyl functional groups within a peptide chain and/or	1	Recognition that $\beta$ -pleated sheet is a secondary structure resulting from hydrogen bonding between amide and carbonyl functional groups along adjacent polypeptide chains	Recognition that the tertiary structure of a protein is a result of folding of the polypeptide chain/overall shape of the protein	1	Recognition that tertiary structure forms due to interactions between side chains of $\alpha$ -amino acids in the polypeptide. Answer to include any one of the following interactions: disulfide bridges, hydrogen bonding, dipole-dipole interactions, dispersion forces and ionic interactions	1	<b>Total</b>	<b>5</b>
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2023  
Section 2  
Question  
32

Properties  
and  
structure of  
organic  
materials

Decaffeinated coffee is coffee from which the caffeine has been removed. The structure of caffeine is shown below.



In the decaffeination process, the solvent used should only dissolve caffeine so it can be removed, leaving compounds that are responsible for the flavours of coffee. Using your understanding of intermolecular forces, explain why dichloromethane,  $\text{CH}_2\text{Cl}_2$ , can act as a solvent to remove caffeine. (5 marks)

Description	Marks
Recognition that caffeine contains dipole-dipole and dispersion forces	1
Recognition that dichloromethane contains dipole-dipole and dispersion forces	1
Recognition that the predominant form of bonding between dichloromethane and caffeine is dipole-dipole and dispersion forces	1
Recognition that the energy released in the formation of the forces of attraction between the dichloromethane and caffeine molecules will be sufficient to overcome the forces of attraction between the molecules in caffeine and in dichloromethane	1–2
<b>Total</b>	<b>5</b>

Note: accept explanations relating to strength of intermolecular forces.

2022  
Section 2  
Question  
27

Properties  
and  
structure of  
organic  
materials

The information in the table below shows the boiling temperature for a range of primary amines.

Amine	Boiling temperature ( $^{\circ}\text{C}$ )
Ethanamine	16.6
Propan-1-amine	47.8
Butan-1-amine	78.0
Hexan-1-amine	131
Heptan-1-amine	155

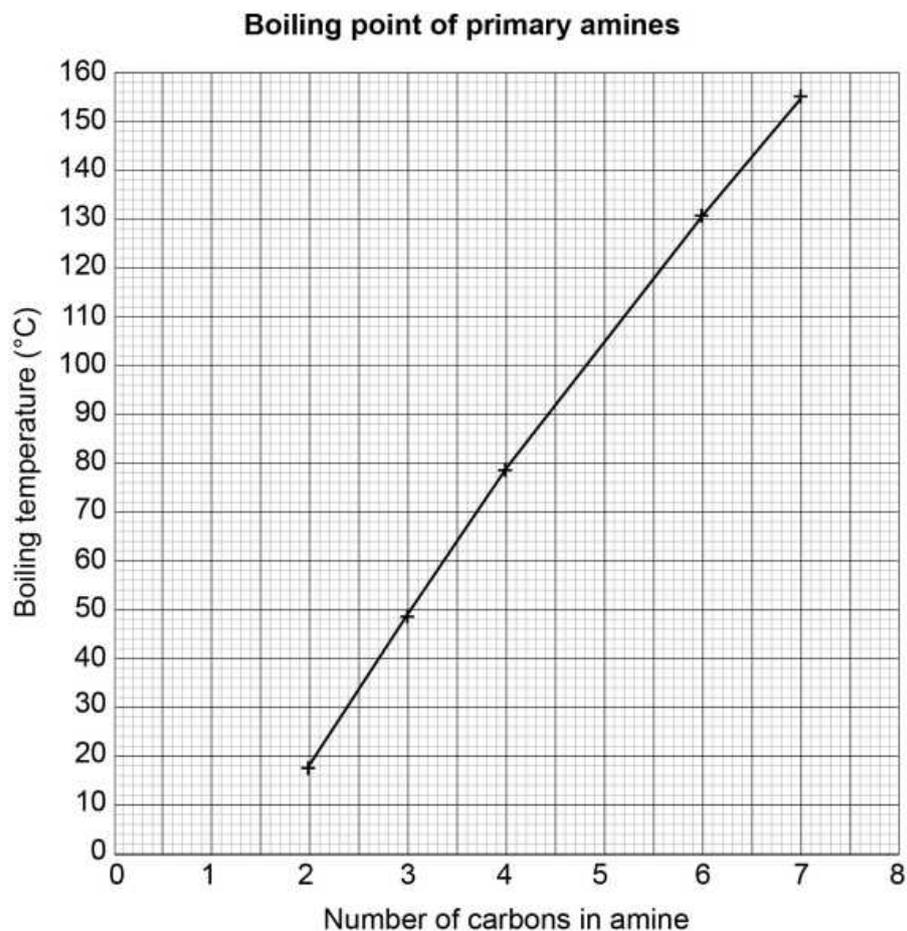
(a) Draw the structure of butan-1-amine showing all atoms and bonds. (2 marks)

Description	Marks
Correct structure 	1–2
<b>Total</b>	<b>2</b>

Maximum 1 mark if minor error, e.g. missing hydrogens.  
Note: condensed structure maximum of one mark.

(b) Use the data in the table on the previous page to graph the boiling temperature of amines versus the number of carbons in the amines on the grid below. The x-axis has been labelled for you. (5 marks)

Description	Marks
appropriate title	1
y-axis labelled with units	1
scales	1
points plotted correctly	1
line/curve of best fit	1
<b>Total</b>	<b>5</b>



(c) Use your graph to predict the boiling temperature of pentan-1-amine. (1 mark)

Description	Marks
104 °C	1
<b>Total</b>	<b>1</b>
Note: Follow through from graph – if student reads graph correctly, award one mark.	

(d) Use your understanding of intermolecular forces to explain the relationship shown in your graph. (4 marks)

Description	Marks
Recognition that all primary amines have $\text{NH}_2$ on terminal carbon so hydrogen bonding/polar forces of attraction is not the determining factor in the increase in boiling temperature.	1
Recognition that the boiling temperature of the primary amines increases as the hydrocarbon chain length increases.	1
Recognition that as chain length increases the magnitude of dispersion forces increases.	1
Recognition that increase in magnitude of dispersion forces requires more energy to overcome and allow the primary amine to boil.	1
<b>Total</b>	<b>4</b>
Note: Also accept increasing number of electrons in answer.	

**2022  
Section 2  
Question  
29**

**Properties  
and  
structure of  
organic  
materials**

Keratin is a substance made up of several different proteins that form the structure of various anatomical features such as human hair and nails.

(a) Keratins are known to contain relatively large amounts of the  $\alpha$ -amino acid valine. A property of  $\alpha$ -amino acids is that they can form zwitterions.

(i) Draw the structure of valine as a zwitterion. (2 marks)

Description	Marks
$\begin{array}{c} \text{H}_3\text{C} - \text{CH} - \text{CH}_3 \\   \\ \text{H}_3\text{N}^+ - \text{CH} - \text{COO}^- \end{array}$	1-2
<b>Total</b>	<b>2</b>
Maximum 1 mark if any minor errors including <ul style="list-style-type: none"> <li>• missing hydrogens</li> <li>• missing charge/incorrect location</li> <li>• missing carbon</li> <li>• incorrect amino acid</li> <li>• incorrect connectivity.</li> </ul>	

(ii) State the condition that is required for zwitterions of  $\alpha$ -amino acids to form in aqueous solution. (1 mark)

Description	Marks
neutral or pH 7 or isoelectric point	1
<b>Total</b>	<b>1</b>

(b) The strength of hair keratin is attributed to a relatively high content of the  $\alpha$ -amino acid cysteine.

(i) State which interaction is possible in proteins due to the presence of cysteine. (1 mark)

Description	Marks
disulfide bridges	1
<b>Total</b>	<b>1</b>

(ii) Define 'protein tertiary structure' and describe how it is formed. (3 marks)

Description	Marks
Definition	
(three-dimensional) shape of a protein/folding of secondary structure	1
<b>Subtotal</b>	<b>1</b>
Description	
<ul style="list-style-type: none"><li>• due to interactions of (<math>\alpha</math>-amino acid) side chains (in the polypeptide)</li><li>• such as hydrogen bonding/dipole-dipole interactions/dispersion forces/ionic interactions/disulfide bridges</li></ul>	1-2
<b>Subtotal</b>	<b>2</b>
<b>Total</b>	<b>3</b>

(c) Proteins are distinguished at the level of the primary structure. Describe this level of protein structure. (2 marks)

Description	Marks
the sequence of	1
( $\alpha$ -)amino acids (in a protein/polypeptide chain)	1
<b>Total</b>	<b>2</b>

The  $\alpha$ -helix is a common secondary structure observed in keratins.

(d) Draw dotted lines (.....) on the diagram below to show the position of at least **two** hydrogen bond interactions that stabilise the helical shape. (1 mark)

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Description	Marks
Two of the correct hydrogen bonding interactions shown below.	1
<b>Total</b>	<b>1</b>

For copyright reasons this diagram cannot be reproduced in the online version of this document.

The nature of the  $\alpha$ -amino acid side chain or R-group in the helical part of keratins is critical to the overall structure. In certain positions the side chains are non-polar.

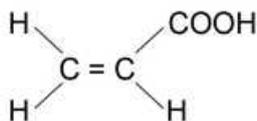
(e) Identify **one**  $\alpha$ -amino acid from the Data booklet with a non-polar side chain. (1 mark)

Description	Marks
One of: alanine, glycine, isoleucine, leucine, methionine, phenylalanine, proline, valine (hydrocarbon or no polar functional groups).	1
<b>Total</b>	<b>1</b>

2022  
Section 2  
Question  
31

Properties  
and  
structure of  
organic  
materials

Polyacrylic acid is a polymer that is formed from the monomer propenoic acid (also known as acrylic acid). The monomer propenoic acid is shown below.



(a) Draw the structure of the polymer polyacrylic acid showing at least three repeating units. (2 marks)

Description	Marks
three correct monomers linked	1
ends are not terminated	1
<b>Total</b>	<b>2</b>

$$\begin{array}{ccccccc} \text{H} & \text{COOH} & \text{H} & \text{COOH} & \text{H} & & \text{H} \\ | & | & | & | & | & & | \\ -\text{C}- & \text{C}- & -\text{C}- & \text{C}- & -\text{C}- & - & \text{C}- \\ | & | & | & | & | & & | \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{COOH} & & \text{H} \end{array}$$
  

Maximum 1 mark if any minor errors, including:

- missing or too many hydrogens
- bond lines connected to wrong atoms.

When reacted with sodium hydroxide, polyacrylic acid becomes polyacrylate. Polyacrylate is a powder that swells when water is added and can absorb up to 180 times its weight in water. It is used for applications such as disposable nappies.

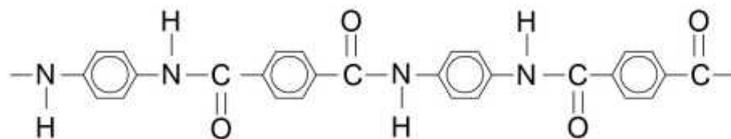
(b) A child's nappy contains approximately 3.97 g of polyacrylate, and a particular company state that their nappies are at least 97.4% efficient at absorbing water. After thorough testing it was demonstrated that this brand of nappies could absorb 691 g of water. Use a calculation to determine whether the claims of the company that manufacture the nappies are true. (3 marks)

Description	Marks
Nappy should absorb $3.97 \times 180$ = 715 g of water.	1
At 97.4% efficiency nappies hold $715 \times 0.974$ = 696 g	1
$696 \text{ g} > 691 \text{ g}$ therefore the company's claims are not true	1
<b>Total</b>	<b>3</b>

Accept alternative approaches  
i.e. percent absorbed =  $691/714.6 \times 100 = 96.7\%$   
 $96.7\% < 97.4\%$  therefore false

Kevlar is a polymer that is formed through a condensation reaction that releases water during the polymerisation of its monomers. A section of the Kevlar polymer is shown below.



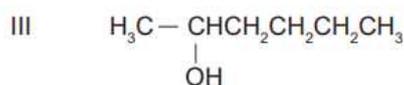
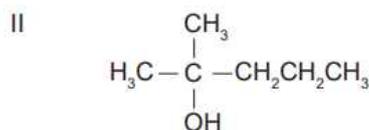
(c) Draw the structure of the **two** monomers from which Kevlar is made. (2 marks)

Description	Marks
	1
	1
<b>Total</b>	<b>2</b>

**2022  
Section 2  
Question  
32**

**Properties  
and  
structure of  
organic  
materials**

Consider the following three isomers of  $C_6H_{14}O$ :



(a) State the IUPAC name for each isomer. (3 marks)

Description		Marks
Correctly names each isomer		1–3
<b>Total</b>		<b>3</b>
Isomer	IUPAC name	
I	hexan-1-ol	
II	2-methylpentan-2-ol	
III	hexan-2-ol	

(b) Propose a chemical test and state the expected observations for each isomer that could be used to distinguish between isomer I and isomer II. (3 marks)

Description	Marks
proposes an appropriate chemical test	1
states the expected observations for isomer 1	1
states the expected observations for isomer 2	1
<b>Total</b>	<b>3</b>

Answers could include:

Chemical test: Addition of (limited amount of) acidified potassium permanganate solution.

Expected observations:

Isomer 1: purple solution decolourised

Isomer 2: solution remains purple/no visible reaction

Chemical test: Addition of (limited amount of) acidified potassium dichromate solution.

Expected observations:

Isomer 1: solution becomes green

Isomer 2: solution remains orange/no visible reaction

Chemical test: Addition of sodium.

Expected observations:

Isomer 1: rapid generation of bubbles

Isomer 2: less rapid/slower generation of bubbles

Accept other correct, relevant answers.

**2022  
Section 2  
Question  
33**

**Properties  
and  
structure of  
organic  
materials**

Esters are chemical compounds derived from a carboxylic acid and an alcohol during esterification. An ethyl ester is synthesised using ethanol as the alcohol.

(a) Two methods of producing ethanol industrially include fermentation of glucose and hydrolysis of ethene. Write a chemical equation for each process and state any conditions that are required. (8 marks)

Chemical formula for glucose:  $C_6H_{12}O_6$

Description	Marks
<b>Process: Fermentation of glucose</b>	
$C_6H_{12}O_6(aq) \rightarrow 2 CH_3CH_2OH(aq) + 2 CO_2(g)$	
correct products	1
correct balancing	1
Zymase/yeast used as a catalyst	1
Conditions – any one of:	1
• temperature stated (range 25 °C – 37 °C)	
• pH range 3–5	
• atmospheric pressure.	
<b>Subtotal</b>	<b>4</b>
<b>Process: Hydrolysis of ethene</b>	
$CH_2CH_2(g) + H_2O(g) \rightleftharpoons CH_3CH_2OH(g)$	
correct reactants	1
correct products	1
acid catalyst ( $H^+/H_3PO_4/H_2SO_4$ )	1
Conditions – any one of:	1
• temperature of 300 °C/moderate temperature	
• pressure of 6000–7000 kPa/high pressure	
• water in the gas state.	
<b>Subtotal</b>	<b>4</b>
<b>Total</b>	<b>8</b>
Accept other correct, relevant answers for conditions.	

(b) The ethanol produced was added to pentanoic acid along with a few drops of concentrated sulfuric acid. This mixture was then heated. Draw the structure and state the IUPAC name of the ester that is formed in this reaction. Include **all** atoms. (3 marks)

Description	Marks
$  \begin{array}{ccccccc}  & H & H & & & & \\  &   &   & & & & \\  H & -C & -C & -O & & & \\  &   &   & & & & \\  & H & H & & & & \\  & & & & O & H & H & H & H \\  & & & &    &   &   &   &   \\  & & & & C & -C & -C & -C & -C & -H \\  & & & & &   &   &   &   \\  & & & & & H & H & H & H  \end{array}  $	1–2
Ethyl pentanoate	1
<b>Total</b>	<b>3</b>
Maximum one mark for structure if any minor errors including:	
<ul style="list-style-type: none"> <li>• missing hydrogens</li> <li>• if pentyl ethanoate is drawn.</li> </ul>	

2021  
Section 2  
Question  
27

Properties  
and  
structure of  
organic  
materials

Alcohols exhibit a variety of different chemical properties. For example, some alcohols react with acidified permanganate ions while others do not.

(a) The alcohols in the following table were each heated with excess acidified potassium permanganate solution. Name all organic products formed **during** this process. If there is no reaction, indicate this by writing 'no reaction'. (4 marks)

Description	Marks
Errors circled correctly	1–2
Correct reasons for errors identified	1–2
<b>Total</b>	<b>4</b>

Note:

- Accept other correct responses.

Student's structural formula	Reason
$  \begin{array}{cccc}  \text{H} & \text{H} & \text{H} & \text{H} \\    &   &   &   \\  \text{H}-\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{H} \\    &   &   &   \\  \text{H} & \text{H} & \text{H} & \\  \end{array}  $	Recognition that carbon should only have four bonds, e.g. each carbon atom can only form four bonds
$  \begin{array}{ccc}  \text{H} & \text{H} & \text{H} \\    &   &   \\  \text{H}-\text{C} & -\text{C} & -\text{C}-\text{O} \\    &   &   \\  \text{H} & \text{H} & \text{H}  \end{array}  $	Recognition that oxygen must have two single bonds, e.g. H atom missing from oxygen

Note: for first structure, also accept one of the extra Hs circled.

(b) Write a balanced overall ionic equation showing the formation of **one** of the organic compounds named in part (a). Only the alcohols listed in the table and acidified potassium permanganate solution can be used. Show your working. (4 marks)

Description	Marks
Oxidation half-equation <ul style="list-style-type: none"> <li>correct species</li> <li>correct balancing</li> </ul>	1 1
Overall redox equation <ul style="list-style-type: none"> <li>correct species</li> <li>correct balancing</li> </ul>	1 1
<b>Total</b>	<b>4</b>
<p><b>Option 1</b> (pentan-1-ol reacting to form pentanal)</p> <ul style="list-style-type: none"> <li>Oxidation: <math>C_5H_{12}O(l) \rightarrow C_5H_{10}O(l) + 2 H^+(aq) + 2 e^-</math></li> <li>Reduction: <math>MnO_4^-(aq) + 8 H^+(aq) + 5 e^- \rightarrow Mn^{2+}(aq) + 4 H_2O(l)</math></li> <li>Overall: <math>5 C_5H_{12}O(l) + 2 MnO_4^-(aq) + 6 H^+(aq) \rightarrow 5 C_5H_{10}O(l) + 2 Mn^{2+}(aq) + 8 H_2O(l)</math></li> </ul> <p>or</p> <p><b>Option 2</b> (pentan-1-ol reacting to form pentanoic acid)</p> <ul style="list-style-type: none"> <li>Oxidation: <math>C_5H_{12}O(l) + H_2O(l) \rightarrow C_5H_{10}O_2(aq) + 4 H^+(aq) + 4 e^-</math></li> <li>Reduction: <math>MnO_4^-(aq) + 8 H^+(aq) + 5 e^- \rightarrow Mn^{2+}(aq) + 4 H_2O(l)</math></li> <li>Overall: <math>5 C_5H_{12}O(l) + 4 MnO_4^-(aq) + 12 H^+(aq) \rightarrow 5 C_5H_{10}O_2(aq) + 4 Mn^{2+}(aq) + 11 H_2O(l)</math></li> </ul> <p>or</p> <p><b>Option 3</b> (pentan-2-ol reacting to form pentan-2-one)</p> <ul style="list-style-type: none"> <li>Oxidation: <math>C_5H_{12}O(l) \rightarrow C_5H_{10}O(l) + 2 H^+(aq) + 2 e^-</math></li> <li>Reduction: <math>MnO_4^-(aq) + 8 H^+(aq) + 5 e^- \rightarrow Mn^{2+}(aq) + 4 H_2O(l)</math></li> <li>Overall: <math>5 C_5H_{12}O(l) + 2 MnO_4^-(aq) + 6 H^+(aq) \rightarrow 5 C_5H_{10}O(l) + 2 Mn^{2+}(aq) + 8 H_2O(l)</math></li> </ul> <p>Note:</p> <ul style="list-style-type: none"> <li>No marks allocated for the reduction half equation because it is given in data booklet.</li> <li>Equation must use one of the alcohols from part (a) and permanganate ions.</li> <li>State symbols are not required for full marks.</li> </ul>	

(c) The same type of reaction occurs if alcohols are mixed with acidified potassium dichromate solution.

(i) Name this type of reaction. (1 mark)

Description	Marks
Oxidation and reduction/redox	1
<b>Total</b>	<b>1</b>
<p>Note:</p> <ul style="list-style-type: none"> <li>Accept oxidation (of alcohols).</li> </ul>	

(ii) State how the reaction observations are different when limited acidified potassium dichromate solution is used instead of limited acidified potassium permanganate solution. (2 marks)

Description	Marks
Instead of the reaction colour change being from purple to pale pink/colourless when using acidified permanganate ions.	1
The colour change when using acidified dichromate ions is from orange to deep green.	1
<b>Total</b>	<b>2</b>

2021  
Section 2  
Question  
26

Properties  
and  
structure of  
organic  
materials

A student was given the task of naming and/or drawing the structural formula of some organic compounds. The student, however, made some errors.

(a) For each of the following organic compounds, state why the name given by the student is incorrect and rename it using IUPAC nomenclature. (4 marks)

Description	Marks
Correct reason for errors	1–2
Correct IUPAC names	1–2
<b>Total</b>	<b>4</b>

Structural formula and name given by student	Reason for name being incorrect	IUPAC name
$  \begin{array}{ccccccc}  & \text{H} & \text{H} & \text{H} & \text{O} & \text{H} & \\  &   &   &   &    &   & \\  \text{H} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{H} \\  &   &   &   & &   & \\  & \text{H} & \text{H} & \text{H} & & \text{H} & \\  \text{pentan-4-one}  \end{array}  $	Number the chain to give functional group the lowest possible number/incorrect numbering.	pentan-2-one
$  \begin{array}{cccc}  & \text{H} & \text{H} & \text{O} \\  &   &   &    \\  \text{H} & -\text{C} & -\text{C} & -\text{C} & -\text{NH}_2 \\  &   &   & & \\  & \text{H} & \text{H} & & \\  \text{1-aminopropanone}  \end{array}  $	Incorrect functional groups identified.	propanamide

(b) Circle an error in each structural formula and state the reason why it is an error. (4 marks)

Description	Marks
Errors circled correctly	1–2
Correct reasons for errors identified	1–2
<b>Total</b>	<b>4</b>

Note:

- Accept other correct responses.

Student's structural formula	Reason
$  \begin{array}{cccc}  & \text{H} & \text{H} & \text{H} & \text{H} \\  &   &   &   &   \\  \text{H} & -\text{C} & -\text{C} & =\text{C} & -\text{C} & -\text{H} \\  &   &   & &   \\  & \text{H} & \text{H} & & \text{H}  \end{array}  $	Recognition that carbon should only have four bonds, e.g. each carbon atom can only form four bonds
$  \begin{array}{cccc}  & \text{H} & \text{H} & \text{H} \\  &   &   &   \\  \text{H} & -\text{C} & -\text{C} & -\text{C} & -\text{O} \\  &   &   &   \\  & \text{H} & \text{H} & \text{H}  \end{array}  $	Recognition that oxygen must have two single bonds, e.g. H atom missing from oxygen

Note: for first structure, also accept one of the extra Hs circled.

2020  
Section 2  
Question  
26

Properties  
and  
structure of  
organic  
materials

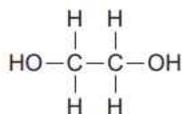
Complete this table by giving the IUPAC name or full structural formula of the indicated organic compounds. All hydrogen atoms must be shown.

Full structural formula	IUPAC name	Marks
$  \begin{array}{ccccccc}  & \text{H} & \text{H} & \text{H} & \text{H} & & \text{H} \\  &   &   &   &   & & / \\  \text{H} & - \text{C} & - \text{N} \\  &   &   &   &   & & \backslash \\  & \text{H} & \text{H} & \text{H} & \text{H} & \text{O} & \text{H}  \end{array}  $	<p><b>Answer</b> pentanamide</p>	1
$  \begin{array}{ccc}  \text{H}_3\text{C} & & \text{CH}_3 \\  & \diagdown & / \\  & \text{C} = \text{C} & \\  & / & \diagdown \\  \text{H}_3\text{C} & & \text{CH}_3  \end{array}  $	<p><b>Answer</b> 2,3-dimethylbut-2-ene</p> <p>Accept 2,3-dimethyl-2-butene dimethylbut-2-ene dimethyl-2-butene</p>	1
<p><b>Answer</b></p> $  \begin{array}{ccccccc}  & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\  &   &   &   &   &   &   \\  \text{H} & - \text{C} - \text{H} \\  &   &   &   &   &   &   \\  & \text{H} & \text{N} & \text{H} & \text{H} & \text{H} & \text{H} \\  & / & \backslash & & & & \\  & \text{H} & \text{H} & & & &   \end{array}  $	heptan-2-amine	1
<p><b>Answer</b></p> $  \begin{array}{ccccccc}  & \text{H} & \text{H} & \text{O} & \text{H} & \text{H} & \text{H} \\  &   &   &    &   &   &   \\  \text{H} & - \text{C} - \text{H} \\  &   &   & &   &   &   \\  & \text{H} & \text{H} & & \text{H} & \text{H} & \text{H}  \end{array}  $	hexan-3-one	1
<b>Total</b>		<b>4</b>
<p>Note:</p> <ul style="list-style-type: none"> <li>• Structural formula must have all hydrogen atoms for the mark to be allocated.</li> <li>• Condensed structures are also accepted.</li> <li>• All structures require numbers except those which would have a 1.</li> </ul>		

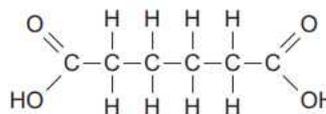
2020  
Section 2  
Question  
28

Properties  
and  
structure of  
organic  
materials

Poly(ethylene adipate) is an inexpensive, biodegradable polymer. It is formed when ethylene glycol and adipic acid react. The structural formulae of these two monomers are shown below.



ethylene glycol



adipic acid

(a) Draw the structural formula of poly(ethylene adipate). Show two repeating units. (2 marks)

Description	Marks
$\begin{array}{cccccccccccccccccccc} & \text{H} & \text{H} & & \text{O} & \text{H} & \text{H} & \text{H} & \text{H} & \text{O} & & \text{H} & \text{H} & & \text{O} & \text{H} & \text{H} & \text{H} & \text{H} & \text{O} \\ &   &   & &    &   &   &   &   &    & &   &   & &    &   &   &   &   &    \\ -\text{O}- & \text{C} & -\text{C} & -\text{O}- & \text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{O}- & \text{C} & -\text{C} & -\text{O}- & \text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{O}- \\ &   &   & & &   &   &   &   & &   &   & &   &   &   &   &   &   & \\ & \text{H} & \text{H} & & & \text{H} & \text{H} & \text{H} & \text{H} & & \text{H} & \text{H} & & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \\ \hline & \text{repeating unit} & & & & \text{repeating unit} & & & & & & & & & & & & & & & \end{array}$ <p>(one minor error is 1 mark only)</p>	1-2
<b>Total</b>	<b>2</b>
<p>Note:</p> <ul style="list-style-type: none"> <li>If only one repeating unit is shown allocate a maximum of one mark only.</li> <li>Minor errors include missing hydrogens or terminating the ends of the polymer.</li> <li>Incorrect or missing ester links is a major error, allocate 0 marks.</li> </ul>	

(b) Classify poly(ethylene adipate) according to the:

(i) functional group or groups present in its structure. (1 mark)

Description	Marks
ester/polyester	1
<b>Total</b>	<b>1</b>

(ii) type of reaction resulting in its formation. (1 mark)

Description	Marks
condensation (polymerisation/reaction)/esterification	1
<b>Total</b>	<b>1</b>

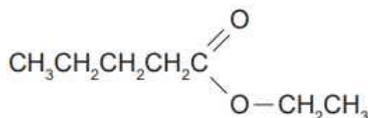
(c) Identify a different type of reaction that results in the formation of a polymer. (1 mark)

Description	Marks
addition (polymerisation/reaction)	1
<b>Total</b>	<b>1</b>

2020  
Section 2  
Question  
33

Properties  
and  
structure of  
organic  
materials

A chemist wanted to add a fruity fragrance to an air freshener that he was developing. A colleague suggested the compound ethyl pentanoate which has an apple-like fragrance. The structure for ethyl pentanoate is shown below.



The chemist wanted to check the fragrance of this compound to make sure that it was suitable but there was no ethyl pentanoate in the chemist's laboratory. The only organic substances that the chemist had were a:

- commercial gas cylinder containing ethene
- bottle of pentan-2-one
- bottle of pentan-1-ol
- bottle of pentanal.

Ethyl pentanoate can be synthesised from one or more of the organic substances in the above list in **three** steps.

Describe the steps that will allow the chemist to synthesise ethyl pentanoate. Include balanced equations for all reactions that occur, using molecular formulae for organic compounds. Any inorganic compounds deemed necessary can be used in the procedure. It is not necessary to specify how the products of a particular reaction will be isolated before use in another reaction.

Description	Marks
<p><b>Ethanol Synthesis</b></p> <ul style="list-style-type: none"> <li>• Add steam (or water and heat) and a</li> <li>• suitable catalyst (e.g. sulfuric acid) (to some gas from the cylinder (which has already been transferred to a suitable reaction vessel)).</li> <li>• Equation: <math>\text{C}_2\text{H}_4 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_6\text{O}</math></li> </ul>	<p>1</p> <p>1</p> <p>1</p>
<p><b>Pentanoic Acid Synthesis</b></p> <ul style="list-style-type: none"> <li>• Add permanganate solution or dichromate solution or another suitable oxidising agent, plus a suitable catalyst (e.g. concentrated sulfuric acid) to some pentanal or pentan-1-ol (which has already been transferred to another suitable reaction vessel).</li> <li>• Equation using species identified in candidate's procedure: Pentanal and permanganate: <math>5 \text{C}_5\text{H}_{10}\text{O} + 2 \text{MnO}_4^- + 6 \text{H}^+ \rightarrow 5 \text{C}_5\text{H}_{10}\text{O}_2 + 2 \text{Mn}^{2+} + 3 \text{H}_2\text{O}</math> <b>or</b> Pentanal and dichromate <math>3 \text{C}_5\text{H}_{10}\text{O} + \text{Cr}_2\text{O}_7^{2-} + 8 \text{H}^+ \rightarrow 3 \text{C}_5\text{H}_{10}\text{O}_2 + 2 \text{Cr}^{3+} + 4 \text{H}_2\text{O}</math> <b>or</b> pentan-1-ol and permanganate <math>5 \text{C}_5\text{H}_{12}\text{O} + 4 \text{MnO}_4^- + 12 \text{H}^+ \rightarrow 5 \text{C}_5\text{H}_{10}\text{O}_2 + 4 \text{Mn}^{2+} + 11 \text{H}_2\text{O}</math> <b>or</b> pentan-1-ol and dichromate <math>3 \text{C}_5\text{H}_{12}\text{O} + 2 \text{Cr}_2\text{O}_7^{2-} + 16 \text{H}^+ \rightarrow 3 \text{C}_5\text{H}_{10}\text{O}_2 + 4 \text{Cr}^{3+} + 11 \text{H}_2\text{O}</math></li> </ul>	<p>1</p> <p>1–2</p>
<ul style="list-style-type: none"> <li>• Combine the substances in the two reaction vessels, add some more concentrated sulfuric acid (and heat) to produce ethyl pentanoate</li> <li>• Equation: <math>\text{C}_2\text{H}_6\text{O} + \text{C}_5\text{H}_{10}\text{O}_2 \rightarrow \text{C}_7\text{H}_{14}\text{O}_2 + \text{H}_2\text{O}</math></li> </ul>	<p>1</p> <p>1–2</p>
<b>Total</b>	<b>9</b>
<p><b>Note:</b></p> <ul style="list-style-type: none"> <li>• Equations must be balanced but state symbols are not required.</li> <li>• Equations, where two marks are allocated for each, there is one mark for correct species and one mark for correct balancing (equation must have merit).</li> <li>• Accept equations written with full structural or condensed molecular formulae without any penalty.</li> </ul>	

**2019  
Section 2  
Question  
30**

**Properties  
and  
structure of  
organic  
materials**

Salvarsan is an organic compound that contains the elements: carbon (C), hydrogen (H), arsenic (As), chlorine (Cl), nitrogen (N) and oxygen (O). It was one of the first drugs used in chemotherapy and for treating sleeping sickness.

The empirical formula of this compound can be determined in a series of analyses. One process involves the reaction of a known mass of Salvarsan with excess strong acid to convert all the chlorine into aqueous chloride ions.

(a) Describe the laboratory process involved in determining the mass of chlorine in this sample of Salvarsan once it has been treated with the acid. You should reference any chemicals used and include a balanced equation in your answer. (6 marks)

Description	Marks
Step 1: React the resultant solution with excess (1) silver nitrate (silver ion) solution (1)	1-2
Step 2: Filter off the precipitate and wash	1
Step 3: Dry the precipitate	1
Step 4: Weigh precipitate	1
One mark for the equation	
Example of a one mark response: $\text{Ag}^+(\text{aq}) + \text{Cl}^-(\text{aq}) \rightarrow \text{AgCl}(\text{s})$	1
<b>Total</b>	<b>6</b>

**Note:**

- Accept alternative answers such as redox titrations, precipitations or answers that show the appropriate chemistry.

The results of these analyses using 5.22 g samples determined that it contained:

- 32.83% carbon by mass
- 3.21% hydrogen by mass
- 1.78 g of arsenic
- 16.18% of chlorine by mass
- 6.38% of nitrogen by mass.

(b) Use this information to calculate the empirical formula of Salvarsan. Show **all** workings. (9 marks)

Description	Marks																												
Identifying the mass in 100 g (%) for C, H, Cl and N <b>or</b> converting % to mass in 5.22 g for C, H, Cl and N	1																												
Converting mass of arsenic in 5.22 g sample to 34.1%	1																												
Determining the % of oxygen	1																												
Conversion of % by mass to moles	1-4																												
Determining simplest ratio by dividing all by the factor of 0.455 or 0.456	1																												
Writing the empirical formula $\text{C}_6\text{H}_7\text{AsClNO}$	1																												
<b>Total</b>	<b>9</b>																												
Example of a nine mark response:																													
	<table border="1"> <thead> <tr> <th></th> <th>C</th> <th>H</th> <th>As</th> <th>Cl</th> <th>N</th> <th>O</th> </tr> </thead> <tbody> <tr> <td>% (mass in 100g)</td> <td>32.83</td> <td>3.21</td> <td><math>1.78 \times 100 / 5.22 = 34.1</math></td> <td>16.18</td> <td>6.38</td> <td><math>100 - (32.83 + 3.21 + 34.1 + 6.38) = 7.3</math></td> </tr> <tr> <td>n</td> <td><math>32.83 / 12.01 = 2.73</math></td> <td><math>3.21 / 1.008 = 3.18</math></td> <td><math>34.1 / 74.92 = 0.455</math></td> <td><math>16.18 / 35.45 = 0.456</math></td> <td><math>6.38 / 14.01 = 0.455</math></td> <td><math>7.3 / 16.0 = 0.456</math></td> </tr> <tr> <td>ratio (/0.455)</td> <td>6</td> <td>7</td> <td>1</td> <td>1</td> <td>1</td> <td>1</td> </tr> </tbody> </table>		C	H	As	Cl	N	O	% (mass in 100g)	32.83	3.21	$1.78 \times 100 / 5.22 = 34.1$	16.18	6.38	$100 - (32.83 + 3.21 + 34.1 + 6.38) = 7.3$	n	$32.83 / 12.01 = 2.73$	$3.21 / 1.008 = 3.18$	$34.1 / 74.92 = 0.455$	$16.18 / 35.45 = 0.456$	$6.38 / 14.01 = 0.455$	$7.3 / 16.0 = 0.456$	ratio (/0.455)	6	7	1	1	1	1
	C	H	As	Cl	N	O																							
% (mass in 100g)	32.83	3.21	$1.78 \times 100 / 5.22 = 34.1$	16.18	6.38	$100 - (32.83 + 3.21 + 34.1 + 6.38) = 7.3$																							
n	$32.83 / 12.01 = 2.73$	$3.21 / 1.008 = 3.18$	$34.1 / 74.92 = 0.455$	$16.18 / 35.45 = 0.456$	$6.38 / 14.01 = 0.455$	$7.3 / 16.0 = 0.456$																							
ratio (/0.455)	6	7	1	1	1	1																							
Empirical formula: $\text{C}_6\text{H}_7\text{AsClNO}$																													

**2019  
Section 2  
Question  
33**

**Properties  
and  
structure of  
organic  
materials**

Organic molecules have a hydrocarbon skeleton and can contain functional groups that are responsible for the molecules' characteristic chemical properties.

Complete the following tables by

- (i) writing the structural formula of each compound listed
- (ii) writing the structural formula of the organic product from the reaction
- (iii) naming the organic product from the reaction.

Description		Marks
<b>Pent-2-ene reacting with Br<sub>2</sub>(aq)</b>		
Structural formula of original compound	$\text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3$	1
Structural formula of organic product		
One mark for correct hydrocarbon chain		1
One mark for correct placement of Br atoms		1
Example of a two mark response:	$\begin{array}{ccccccc} \text{CH}_3 & - & \text{CH} & - & \text{CH} & - & \text{CH}_2 & - & \text{CH}_3 \\ & &   & &   & & & & \\ & & \text{Br} & & \text{Br} & & & & \end{array}$	
Name of organic product	2,3-dibromopentane	1
<b>Ethanal reacting with KMnO<sub>4</sub>(aq)/H<sup>+</sup>(aq)</b>		
Structural formula of original compound	$\text{CH}_3 - \overset{\text{O}}{\parallel}{\text{C}} - \text{H}$	1
Structural formula of organic product		
One mark for correct hydrocarbon chain		1
One mark for correct placement of oxygen atoms		1
Example of a two mark response:	$\begin{array}{c} \text{O} \\ \parallel \\ \text{CH}_3 - \text{C} \\   \\ \text{OH} \end{array}$	
Name of organic product	Acetic acid (ethanoic acid)	1
<b>Butanoic acid(aq) reacting with Na<sub>2</sub>CO<sub>3</sub>(aq)</b>		
Structural formula of original compound	$\begin{array}{ccccccc} & & & & \text{O} & & \\ & & & & \parallel & & \\ \text{H}_3\text{C} & - & \text{CH}_2 & - & \text{CH}_2 & - & \text{C} & - & \text{OH} \end{array}$	1
Structural formula of organic product		
One mark for correct hydrocarbon chain		1
One mark for correct placement of oxygen atoms		1
Example of a two mark response:	$\begin{array}{ccccccc} & & & & \text{O} & & \\ & & & & \parallel & & \\ \text{H}_3\text{C} & - & \text{CH}_2 & - & \text{CH}_2 & - & \text{C} & - & \text{O}^- & (\text{Na}^+) \end{array}$	
Name of organic product	butanoate ion/sodium butanoate	1
		<b>Total</b>
		<b>12</b>

Marking Guide – Section 3

2023  
Section 3  
Question  
36

Properties  
and  
structure of  
organic  
materials

The molecular structures of alanine and lactic acid are shown below with their molecular formulae and melting points. Alanine is an  $\alpha$ -amino acid while lactic acid may be classified as an  $\alpha$ -hydroxy acid.

Compound name	Alanine	Lactic acid
Molecular structure	$\begin{array}{c} \text{O} \quad \text{H} \\ \parallel \quad   \\ \text{HO}-\text{C}-\text{C}-\text{NH}_2 \\   \\ \text{CH}_3 \end{array}$	$\begin{array}{c} \text{O} \quad \text{H} \\ \parallel \quad   \\ \text{HO}-\text{C}-\text{C}-\text{OH} \\   \\ \text{CH}_3 \end{array}$
Molecular formula	$\text{C}_3\text{H}_7\text{NO}_2$	$\text{C}_3\text{H}_6\text{O}_3$
Melting point	297 °C (decomposes)	16.8 °C

Lactic acid is the active constituent in a popular brand of liquid toilet cleaner. A chemist transferred a 10.00 mL sample of the toilet cleaner into a beaker and found it weighed 11.218 g. To confirm the amount of lactic acid in the toilet cleaner, a volumetric analysis on this sample was completed as follows. The liquid sample was diluted with water to 100.0 mL in a volumetric flask and 10.00 mL aliquots titrated against standardised sodium hydroxide solution with a concentration of  $9.861 \times 10^{-3} \text{ mol L}^{-1}$ . The average titre for this analysis was 22.74 mL.

(a) Describe the procedure for transferring the sample to the volumetric flask and diluting it for this analysis. (4 marks)

Description	Marks
Recognition that the entire sample of liquid toilet cleaner must be transferred from the beaker to the volumetric flask	1
Recognition that the complete transfer of the liquid sample occurs by thoroughly rinsing the beaker with (distilled) water and all the rinsing liquid is transferred to the volumetric flask	1
Recognition that the volumetric flask is filled to the mark	1
Recognition that the solution should be mixed thoroughly in the volumetric flask	1
<b>Total</b>	<b>4</b>

(b) Calculate the concentration of lactic acid in the toilet cleaner, in  $\text{g L}^{-1}$ . (5 marks)

Description	Marks
$n(\text{NaOH}) = 9.861 \times 10^{-3} \times 2.274 \times 10^{-2} = 2.242 \times 10^{-4} \text{ mol}$	1
Recognition that $n(\text{NaOH}) = n(\text{CH}_3\text{CH}(\text{OH})\text{COOH}) = 2.242 \times 10^{-4} \text{ mol}$	1
$m(\text{CH}_3\text{CH}(\text{OH})\text{COOH}) \text{ acid in } 10 \text{ mL aliquot} = 2.242 \times 10^{-4} \text{ mol} \times 90.078 = 2.020 \times 10^{-2} \text{ g}$	1
$m(\text{CH}_3\text{CH}(\text{OH})\text{COOH}) \text{ acid in } 100 \text{ mL solution} = 2.020 \times 10^{-2} \times 10 = 0.202 \text{ g}$	1
$c(\text{CH}_3\text{CH}(\text{OH})\text{COOH}) = \frac{0.202}{0.01} = 20.20 \text{ g L}^{-1}$	1
<b>Total</b>	<b>5</b>

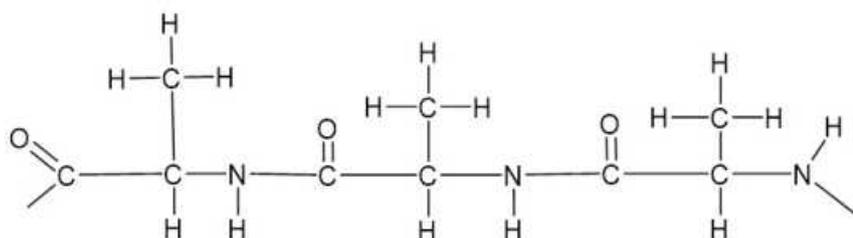
(c) Account for the large difference in melting points between alanine and lactic acid. (4 marks)

Description	Marks
Recognition that alanine is an amino acid which exists as a zwitterion in the solid state (alanine zwitterion structure may be drawn)	1
Recognition that the predominant force of attraction for lactic acid is hydrogen bonding and forces of attraction for alanine are ionic bonds	1
Recognition that the strength of attractive forces between alanine zwitterions are much stronger than those between lactic acid molecules	1
Recognition that the much higher melting point for alanine is because greater energy is required to overcome the attractive forces between the zwitterions to melt the solid	1
<b>Total</b>	<b>4</b>

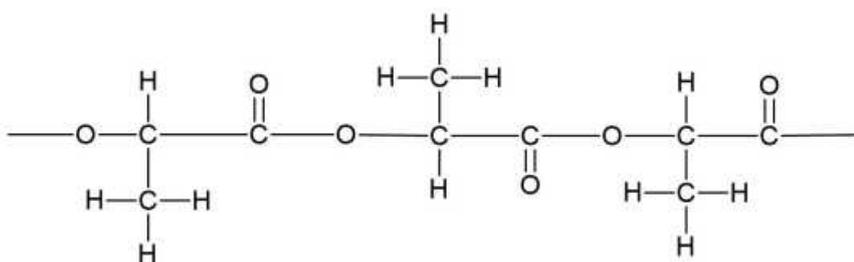
(d) Under certain conditions, both alanine and lactic acid form condensation polymers which produce water molecules. Draw the structures of each polymer, showing all atoms and bonds. Each polymer should contain three repeating units. (5 marks)

Description	Marks
Correct structure for polymer formed from alanine	1–2
Correct structure for polylactic acid	1–2
Each contains three repeating units	1
<b>Total</b>	<b>5</b>

Polymer formed from alanine



Polymer formed from lactic acid



Note: award 1 mark for structures with minor errors, including:

- terminating ends
- missing atoms
- incorrect linkage of monomers.

**2023  
Section 3  
Question  
37**

**Properties  
and  
structure of  
organic  
materials**

A 2.31 g sample of a hydrocarbon was combusted, and 7.25 g of carbon dioxide and 2.97 g of water were produced.

(a) Determine the empirical formula of the hydrocarbon. (4 marks)

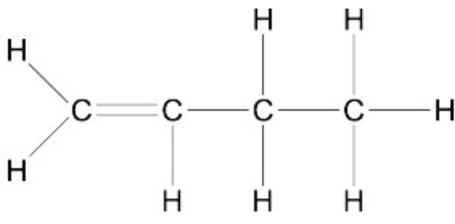
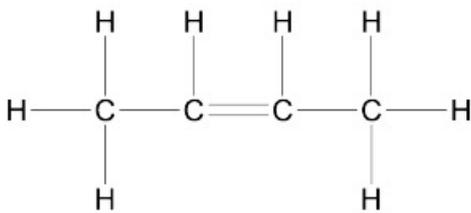
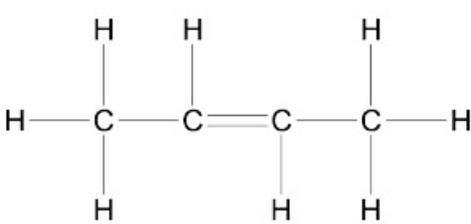
Description			Marks
$n(\text{C}) = n(\text{CO}_2) = 7.25/44.01$ $= 0.165 \text{ mol}$			1
$n(\text{H}) = 2 \times n(\text{H}_2\text{O}) = 2 \times 2.97/18.016$ $= 0.3297$			1
	C	H	1–2
	0.165	0.3297	
Ratio ÷ 0.165	0.165/0.165	0.3297/0.165	
	1	2	
EF = CH <sub>2</sub>			
<b>Total</b>			<b>4</b>

(b) A second 4.67 g sample of the hydrocarbon was vaporised and found to occupy 1.42 L at 150°C and 205 kPa. Calculate the molar mass of the compound and determine its molecular formula. (5 marks)

Description	Marks
$n(\text{sample}) = 1.42 \times 205 / (8.314 \times 423.15)$ $= 8.27 \times 10^{-2} \text{ mol}$	1
$M = 4.67 / 8.27 \times 10^{-2}$ $= 56.4$	1
$\text{EFM} = 12.01 + (2 \times 1.008)$ $= 14.016$	1
Ratio $M/\text{EFM} = 56.4/14.016$ $= 4$	1
MF = C <sub>4</sub> H <sub>8</sub>	1
<b>Total</b>	<b>5</b>

(c) The hydrocarbon has three straight-chain isomers (no branching). Complete the table below by drawing the structure of and naming the three isomers. Show all atoms and bonds in each structure. (9 marks)

If you were unable to determine an answer to part (b) use  $C_5H_{10}$  as the molecular formula for the remaining parts of this question.

Description	Marks
	1-2
But-1-ene	1
	1-2
Cis but-2-ene	1
	1-2
Trans but-2-ene	1
<b>Total</b>	<b>9</b>

(d) State which isomer reacts with water to produce a primary alcohol. Write an equation for this reaction. (3 marks)

Description	Marks
But-1-ene	1
Correct reactants	1
Correct products	1
<b>Total</b>	<b>3</b>
$C_4H_8 + H_2O \rightarrow CH_3CH_2CH_2CH_2OH$	
Note: equation must show primary alcohol.	

The alcohol produced in part (d) (*above*) can be fully oxidised by acidified potassium dichromate solution.

(e) (i) Write an ionic equation for this reaction. (3 marks)

Description	Marks
Correct reactants	1
Correct products	1
Correctly balanced	1
<b>Total</b>	<b>3</b>
$2 \text{Cr}_2\text{O}_7^{2-} + 16 \text{H}^+ + 3 \text{CH}_3(\text{CH}_2)_2\text{CH}_2\text{OH} \rightarrow 4 \text{Cr}^{3+} + 3 \text{CH}_3(\text{CH}_2)_2\text{COOH} + 11 \text{H}_2\text{O}$	
Note: award maximum 1 mark, if only correct $\frac{1}{2}$ equations are given.	

(ii) Describe fully the observations for this reaction. (2 marks)

Description	Marks
orange solution added to colourless solution/liquid	1
(deep) green solution formed	1
<b>Total</b>	<b>2</b>

(f) (i) Write an equation for the reaction between the organic products from parts (d) and (e). (2 marks)

Description	Marks
Correct reactants	1
Correct products	1
<b>Total</b>	<b>2</b>
$\text{CH}_3(\text{CH}_2)_2\text{CH}_2\text{OH} + \text{CH}_3(\text{CH}_2)_2\text{COOH} \rightleftharpoons \text{CH}_3(\text{CH}_2)_2\text{COOCH}_2(\text{CH}_2)_2\text{CH}_3 + \text{H}_2\text{O}$	

(ii) Name the organic product of this reaction. (1 mark)

Description	Marks
Butyl butanoate	1
<b>Total</b>	<b>1</b>

\*Alternative marking key for Question 37(c)–(f)(ii) if  $\text{C}_5\text{H}_{10}$  is used.

(c) The hydrocarbon has three straight-chain isomers (no branching). Complete the table below by drawing the structure of and naming the three isomers. Show all atoms and bonds in each structure. (9 marks)

If you were unable to determine an answer to part (b) use  $C_5H_{10}$  as the molecular formula for the remaining parts of this question.

Description	Marks
	1-2
Pent-1-ene	1
	1-2
Cis pent-2-ene	1
	1-2
Trans pent-2-ene	1
<b>Total</b>	<b>9</b>

(d) State which isomer reacts with water to produce a primary alcohol. Write an equation for this reaction. (3 marks)

Description	Marks
Pent-1-ene	1
Correct reactants	1
Correct products	1
<b>Total</b>	<b>3</b>
$C_5H_{10} + H_2O \rightarrow CH_3CH_2CH_2CH_2CH_2OH$	
Note: equation must show primary alcohol.	

The alcohol produced in part (d) (*above*) can be fully oxidised by acidified potassium dichromate solution.

(e) (i) Write an ionic equation for this reaction. (3 marks)

Description	Marks
Correct reactants	1
Correct products	1
Correctly balanced	1
<b>Total</b>	<b>3</b>
$2 \text{Cr}_2\text{O}_7^{2-} + 16 \text{H}^+ + 3 \text{CH}_3(\text{CH}_2)_3\text{CH}_2\text{OH} \rightarrow 4 \text{Cr}^{3+} + 3 \text{CH}_3(\text{CH}_2)_3\text{COOH} + 11 \text{H}_2\text{O}$	
Note: award maximum 1 mark, if only correct $\frac{1}{2}$ equations are given.	

(ii) Describe fully the observations for this reaction. (2 marks)

Description	Marks
orange solution added to colourless solution/liquid	1
green solution formed	1
<b>Total</b>	<b>2</b>

(f) (i) Write an equation for the reaction between the organic products from parts (d) and (e). (2 marks)

Description	Marks
Correct reactants	1
Correct products	1
<b>Total</b>	<b>2</b>
$\text{CH}_3(\text{CH}_2)_3\text{CH}_2\text{OH} + \text{CH}_3(\text{CH}_2)_3\text{COOH} \rightleftharpoons \text{CH}_3(\text{CH}_2)_3\text{COOCH}_2(\text{CH}_2)_3\text{CH}_3 + \text{H}_2\text{O}$	

(ii) Name the organic product of this reaction. (1 mark)

Description	Marks
Pentyl pentanoate	1
<b>Total</b>	<b>1</b>

**2022**  
**Section 3**  
**Question**  
**34**

**Properties**  
**and**  
**structure of**  
**organic**  
**materials**

Fluconazole is an antifungal medication that contains carbon, hydrogen, fluorine, nitrogen and oxygen.

A 3.42 g sample of fluconazole was combusted and produced 6.39 g of carbon dioxide and 1.21 g of water. All of the nitrogen in a second 0.422 g sample of fluconazole was converted into nitric acid, which was neutralised by 16.5 mL of a 0.500 mol L<sup>-1</sup> solution of sodium hydroxide. The second sample was also found to contain 0.0525 g of fluorine.

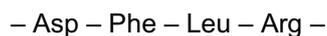
Determine the empirical formula of fluconazole.

Description						Marks
$m(\text{C}) = \frac{6.39}{44.01} \times 12.01$ $= 1.744 \text{ g}$						1
$\%(\text{C}) = \frac{1.744}{3.42} \times 100$ $= 51.0\%$						1
$m(\text{H}) = \frac{1.21}{18.016} \times 2 \times 1.008$ $= 0.1354 \text{ g}$						1
$\%\text{H} = \frac{0.1354}{3.42} \times 100$ $= 3.96\%$						1
$\%\text{F} = \frac{0.0525}{0.422} \times 100$ $= 12.4\%$						1
$n(\text{OH}^-) = 0.0165(0.500)$ $= 8.25 \times 10^{-3} \text{ mol}$ $= n(\text{H}^+)$ $= n(\text{N})$						1
$m(\text{N}) = (8.25 \times 10^{-3}) \times 14.01$ $= 0.1156 \text{ g}$						1
$\%\text{N} = \frac{0.1156}{0.422} \times 100$ $= 27.4\%$						1
$\%\text{O} = 100 - (51.0 + 3.96 + 12.4 + 27.4)$ $= 5.24\%$						1
	<b>C</b>	<b>H</b>	<b>F</b>	<b>N</b>	<b>O</b>	1
M in 100 g	51.0	3.96	12.4	27.4	5.24	
n	$\frac{51.0}{12.01}$ $= 4.25$	$\frac{3.96}{1.008}$ $= 3.93$	$\frac{12.4}{19.00}$ $= 0.653$	$\frac{27.4}{14.01}$ $= 1.96$	$\frac{5.24}{16.00}$ $= 0.328$	
ratio	$\frac{4.25}{0.328}$ $= 13$	$\frac{3.93}{0.328}$ $= 12$	$\frac{0.653}{0.328}$ $= 2$	$\frac{1.96}{0.328}$ $= 6$	$\frac{0.328}{0.328}$ $= 1$	1
Empirical Formula is C <sub>13</sub> H <sub>12</sub> F <sub>2</sub> N <sub>6</sub> O						1
<b>Total</b>						<b>12</b>
Accept alternative methods, e.g. proportions.						

2021  
Section 3  
Question  
34

Properties  
and  
structure of  
organic  
materials

Keratin 86 is a protein found in human fingernails. A small section of the amino acid sequence of Keratin 86 is shown below:



(a) Draw the full structural formula of this small section of Keratin 86. (3 marks)

Description	Marks
The four amino acids are correctly represented in the appropriate order	1
Peptide linkages are correctly drawn	1
Peptide chain not terminated at either end	1
<b>Total</b>	<b>3</b>

Note:

- Showing abbreviations of the amino acids under the structure is not required.

The amino acid chains in Keratin 86 form  $\alpha$ -helices, with two  $\alpha$ -helices twisting around each other to form what is called a 'coiled coil' that is held together by disulfide bridges.

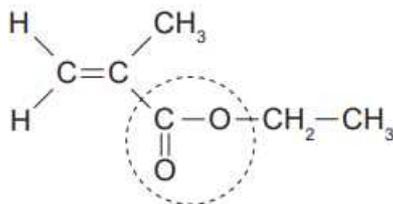
(b) Circle the protein structural level represented by an  $\alpha$ -helix. (1 mark)

Description	Marks
secondary	1
<b>Total</b>	<b>1</b>

(c) What does the presence of disulfide bridges indicate about the primary structure of Keratin 86? (1 mark)

Description	Marks
(The amino acid) cysteine is present.	1
<b>Total</b>	<b>1</b>

Synthetic fingernails are a popular fashion accessory. They are made in industrial laboratories from polymers. A monomer that can be used to make a polymer suitable for synthetic fingernails is shown below.



(d) Name the circled functional group in this monomer. (1 mark)

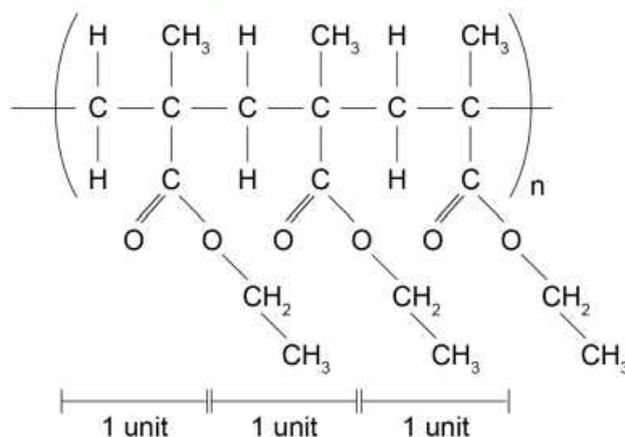
Description	Marks
ester	1
<b>Total</b>	<b>1</b>

(e) Give the IUPAC name of the alcohol needed to make this monomer. (1 mark)

Description	Marks
ethanol	1
<b>Total</b>	<b>1</b>

(f) Draw three repeating units of the polymer made from this monomer. (2 marks)

Description	Marks
The three monomers are correctly represented	1
Monomers are correctly linked	1
<b>Total</b>	<b>2</b>



Minor errors include:

- terminating either end of the chain
- missing or too many hydrogen atoms
- bond lines connecting to wrong atom (e.g. to a hydrogen instead of a carbon)

Note:

- 1 mark for minor error

The protein which makes natural fingernails, Keratin 86, is also a polymer.

(g) What type of polymerisation reaction produces Keratin 86 and what type produces synthetic fingernails? (2 marks)

Polymer	Type of polymerisation reaction	Marks
Keratin 86	condensation	1
Synthetic fingernail polymer	addition	1
<b>Total</b>		<b>2</b>

(h) State two differences between the polymerisation reaction types identified in part (g). (2 marks)

Description	Marks
Any <b>two</b> relevant points. Answers could include: <ul style="list-style-type: none"><li>• Condensation polymerisation produces small molecules such as water, addition does not.</li><li>• Addition polymerisation involves the conversion of a C=C double bond to a single bond, condensation does not.</li><li>• Condensation polymerisation can result in the formation of, for example, polyamides or polyesters, addition does not.</li><li>• Condensation polymerisation involves the reaction of monomers with different functional groups to form bonds in the polymer, addition does not.</li><li>• Addition polymerisation produces a polymer which has the same empirical formula as its monomer, this is not the case in condensation polymerisation.</li></ul>	1–2
<b>Total</b>	<b>2</b>
Note: <ul style="list-style-type: none"><li>• Each difference needs to refer to both condensation and addition to be allocated the mark.</li></ul>	

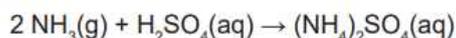
**2021  
Section 3  
Question  
36**

**Properties  
and  
structure of  
organic  
materials**

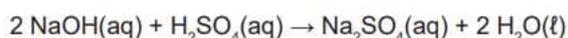
Glycoluril is an organic compound composed of carbon, hydrogen, nitrogen and oxygen atoms. It is used in paper making and water disinfection. A chemist was given the task of determining the empirical formula and also the molecular formula of glycoluril.

To do this, the chemist combusted 2.30 g of glycoluril in excess air, producing 2.85 g of carbon dioxide and 0.874 g of water.

The chemist then used the Kjeldahl Method to determine the nitrogen content of another 2.30 g sample of the compound. This involved converting all of the nitrogen atoms in the sample into ammonia with the ammonia then distilled into 25.0 mL of 1.35 mol L<sup>-1</sup> sulfuric acid, which was in excess. The reaction between ammonia and sulfuric acid is:



The excess sulfuric acid needed 15.40 mL of 0.186 mol L<sup>-1</sup> sodium hydroxide for complete reaction. The reaction equation is:



(a) Determine the empirical formula of glycoluril. (12 marks)

Description	Marks																									
<b>Carbon dioxide</b> <ul style="list-style-type: none"> <li><math>n(\text{CO}_2) = 2.85/44.01 = 0.06476 \text{ mol CO}_2</math></li> <li><math>n(\text{C}) = 0.06476 \text{ mol}</math></li> <li><math>m(\text{C}) = 0.06476 \times 12.01 = 0.7777 \text{ g}</math></li> </ul>	1																									
<b>Water</b> <ul style="list-style-type: none"> <li><math>n(\text{H}_2\text{O}) = 0.874/18.016 = 0.04851 \text{ mol H}_2\text{O}</math></li> <li><math>n(\text{H}) = 2 \times 0.04851 = 0.09702 \text{ mol of H}</math></li> <li><math>m(\text{H}) = 0.09702 \times 1.008 = 0.09780 \text{ g}</math></li> </ul>	1 1																									
<b>Nitrogen</b> <ul style="list-style-type: none"> <li><math>n(\text{H}_2\text{SO}_4, \text{ total}) = 1.35 \times 0.025 = 0.03375 \text{ mol}</math></li> <li><math>n(\text{NaOH}) = 0.186 \times 0.01540 = 0.002864 \text{ mol}</math></li> <li><math>n(\text{H}_2\text{SO}_4 \text{ that reacted with NaOH}) = \frac{1}{2} \times 0.00286 = 0.001432 \text{ mol}</math></li> <li><math>n(\text{H}_2\text{SO}_4 \text{ reacted with NH}_3) = 0.03375 - 0.001432 = 0.03232 \text{ mol}</math></li> <li><math>n(\text{NH}_3) = 2 \times 0.03232 = 0.06464 \text{ mol} = n(\text{N from glycoluril})</math></li> <li><math>m(\text{N from glycoluril sample}) = 0.06464 \times 14.01 = 0.9056 \text{ g}</math></li> </ul>	1–6																									
<b>Oxygen</b> <ul style="list-style-type: none"> <li><math>2.30 - (0.7777 + 0.09780 + 0.9056) = 0.5189 \text{ g}</math></li> <li><math>n(\text{O}) = 0.5189/16.00 = 0.03243 \text{ mol}</math></li> </ul>	1																									
<b>Mole ratio</b> <table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th></th> <th style="text-align: center;">C</th> <th style="text-align: center;">H</th> <th style="text-align: center;">N</th> <th style="text-align: center;">O</th> </tr> </thead> <tbody> <tr> <td>Calculated moles</td> <td style="text-align: center;">0.06476</td> <td style="text-align: center;">0.09702</td> <td style="text-align: center;">0.06464</td> <td style="text-align: center;">0.03243</td> </tr> <tr> <td colspan="5">Divide all numbers for smallest figure 0.03243</td> </tr> <tr> <td>Mole ratio</td> <td style="text-align: center;">1.997</td> <td style="text-align: center;">2.992</td> <td style="text-align: center;">1.993</td> <td style="text-align: center;">1.00</td> </tr> <tr> <td>Simplified</td> <td style="text-align: center;">2</td> <td style="text-align: center;">3</td> <td style="text-align: center;">2</td> <td style="text-align: center;">1</td> </tr> </tbody> </table>		C	H	N	O	Calculated moles	0.06476	0.09702	0.06464	0.03243	Divide all numbers for smallest figure 0.03243					Mole ratio	1.997	2.992	1.993	1.00	Simplified	2	3	2	1	1
	C	H	N	O																						
Calculated moles	0.06476	0.09702	0.06464	0.03243																						
Divide all numbers for smallest figure 0.03243																										
Mole ratio	1.997	2.992	1.993	1.00																						
Simplified	2	3	2	1																						
Empirical formula is C <sub>2</sub> H <sub>3</sub> N <sub>2</sub> O	1																									
<b>Total</b>	<b>12</b>																									
<b>Note:</b> % C in glycoluril = $(0.778/2.3) \times 100 = 33.81\%$ % H in glycoluril = $(0.0978/2.3) \times 100 = 4.25\%$ % N in glycoluril = $(0.906/2.3) \times 100 = 39.37\%$ % O in glycoluril = $(100 - 33.81 - 4.25 - 39.37) = 22.57\%$																										

(b) Another 2.30 g sample of glycoluril was vapourised at 242.0 kPa and 865.0 °C. The total volume of the resulting gas was 633.0 mL. Determine the molecular formula of glycoluril. (5 marks)

Description	Marks
$T = 865.0 + 273.15 = 1138.15 \text{ K}$ $n = PV/RT = 242.0 \times 0.633/8.314 \times 1138.15 = 0.01619 \text{ mol}$	1
$M \text{ (molecular)} = 2.30/0.01619 = 142.081 \text{ g mol}^{-1}$	1
$M \text{ (empirical)} = 71.064 \text{ g mol}^{-1}$	1
Ratio of molecular to empirical: $142.081/71.064 = 1.999 = 2$	1
Molecular formula of glycoluril is $2 \times \text{C}_2\text{H}_3\text{N}_2\text{O} = \text{C}_4\text{H}_6\text{N}_4\text{O}_2$	1
<b>Total</b>	<b>5</b>

**2021  
Section 3  
Question  
39**

**Properties  
and  
structure of  
organic  
materials**

The oil extracted from the seeds of a particular Australian tree contains tripalmitin. The presence of tripalmitin, which is a triglyceride, means that this oil can be used to make ethyl palmitate, a type of biodiesel. The condensed structural formulae of tripalmitin and ethyl palmitate are given below.

Tripalmitin (a type of triglyceride)	Ethyl palmitate (a type of biodiesel)
$\begin{array}{c} \text{H}_2\text{COOC}(\text{CH}_2)_{14}\text{CH}_3 \\   \\ \text{HCOOC}(\text{CH}_2)_{14}\text{CH}_3 \\   \\ \text{H}_2\text{COOC}(\text{CH}_2)_{14}\text{CH}_3 \end{array}$	$\text{CH}_3(\text{CH}_2)_{14}\text{COOCH}_2\text{CH}_3$

(a) Demonstrate, by using a series of balanced reaction equations, how ethyl palmitate can be synthesised from tripalmitin. Your synthesis method **must** use ethene and lipase. You can also use water and any common laboratory acids.

Use condensed structural formulae to represent organic compounds. State symbols are only required for inorganic substances. (8 marks)

Description	Marks
<p>Alcohol synthesis:</p> $\text{CH}_2\text{CH}_2 + \text{H}_2\text{O} (\text{g}) \xrightarrow{\text{H}^+} \text{CH}_3\text{CH}_2\text{OH}$ <ul style="list-style-type: none"> <li>1 mark for reactants</li> <li>1 mark for products</li> <li>1 mark for specifying a suitable catalyst (e.g. <math>\text{H}_2\text{SO}_4/\text{H}_3\text{PO}_4</math>) which can be written above the arrow or as a separate statement</li> <li>1 mark for correctly having <math>\text{H}_2\text{O}</math> in gas state</li> </ul>	1–4
<p>Biodiesel synthesis:</p> $\begin{array}{c} \text{H}_2\text{COOC}(\text{CH}_2)_{14}\text{CH}_3 \\   \\ \text{HCOOC}(\text{CH}_2)_{14}\text{CH}_3 + 3 \text{CH}_3\text{CH}_2\text{OH} \\   \\ \text{H}_2\text{COOC}(\text{CH}_2)_{14}\text{CH}_3 \end{array} \xrightarrow{\text{Lipase}} 3 \text{CH}_3(\text{CH}_2)_{14}\text{COOCH}_2\text{CH}_3 + \begin{array}{c} \text{CH}_2\text{OH} \\   \\ \text{CHOH} \\   \\ \text{CH}_2\text{OH} \end{array}$ <ul style="list-style-type: none"> <li>1 mark for reactants</li> <li>1 mark for products</li> <li>1 mark for correct balancing</li> <li>1 mark for having lipase as the catalyst, written above the arrow or as a separate statement</li> </ul>	1–4
<b>Total</b>	<b>8</b>

A chemist investigated the synthesis step involving lipase referred to in part (a). The results obtained by the chemist are shown in the following table.

Temperature of reaction system (°C)	Biodiesel yield (%)
20	65
30	78
35	85
40	88
50	91
55	92
60	85
65	75

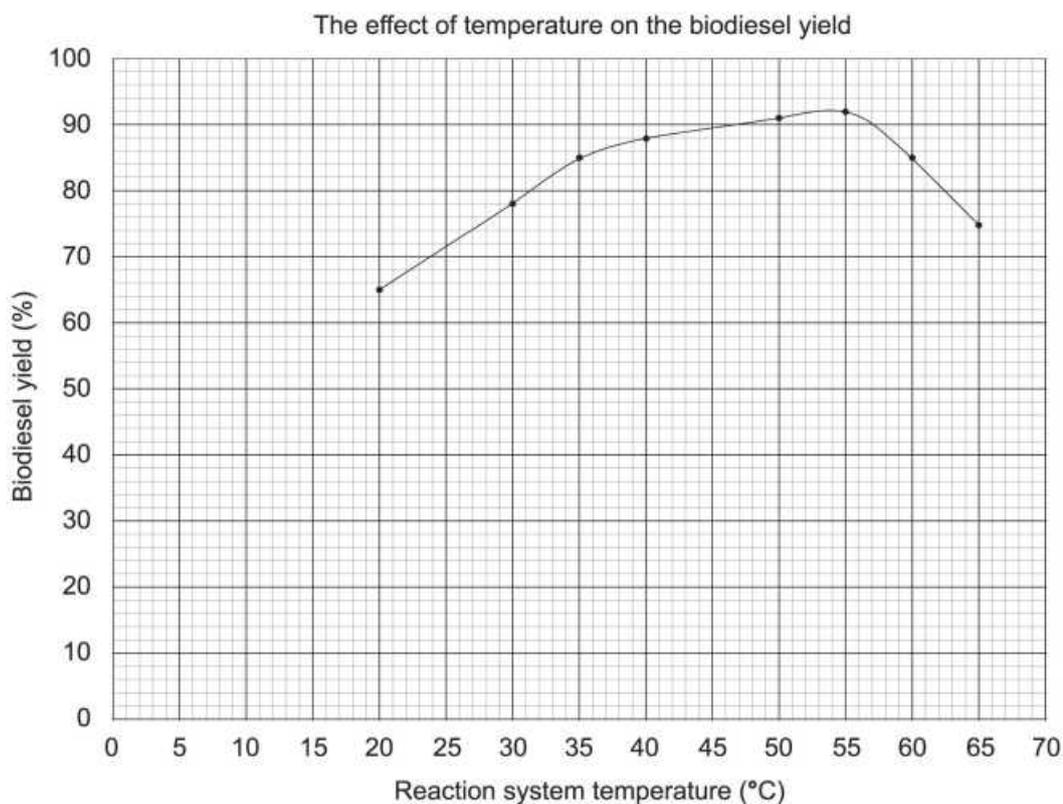
(b) Construct a question that the chemist might be trying to answer in this investigation. (1 mark)

Description	Marks
A question recognising that the relationship between temperature and biodiesel yield is being investigated.	1
<b>Total</b>	<b>1</b>

Note:  
Any reasonable relevant question accepted.  
E.g.

- What is the optimum temperature required to maximise the yield of biodiesel using lipase?
- What is the effect of temperature on the yield of biodiesel?
- Does temperature affect the yield of biodiesel?

(c) Graph the data presented in the table on the following grid. (5 marks)



Description	Marks
Suitable title linking yield to temperature	1
Suitable scales on both axes	1
x-axis labelled as temperature (°C), y-axis labelled as biodiesel yield (%)	1
Plotting data correctly	1
Curve of best fit	1
<b>Total</b>	<b>5</b>
<b>Note:</b>	
<ul style="list-style-type: none"> <li>Must have correct identification of both axes and units to be awarded the mark.</li> </ul>	

(d) Describe the relationship observed in the graph. (2 marks)

Description	Marks
The graph shows that the biodiesel yield increases (steadily) as the temperature increases, reaching a maximum at 55 °C.	1
The yield decreases at higher temperatures.	1
<b>Total</b>	<b>2</b>

(e) Explain how the use of lipase in the synthesis contributes to the relationship described in part (d). (2 marks)

Description	Marks
Lipase is an enzyme/protein.	1
Any one of <ul style="list-style-type: none"> <li>Enzymes/proteins are deactivated/denatured at higher temperatures (and lose their effectiveness hence the lower biodiesel yield at higher temperatures).</li> <li>Lipase will not contribute to the relationship as a catalyst increase rate of forward and reverse reaction equally/does not affect yield.</li> </ul>	1
<b>Total</b>	<b>2</b>

2020  
Section 3  
Question  
35

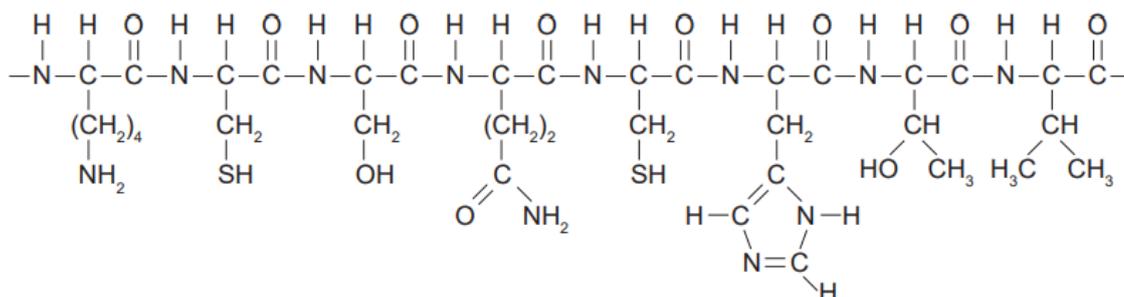
Properties  
and  
structure of  
organic  
materials

Cytochrome C is a protein found in the cells of many organisms. A biochemist analysed the Cytochrome C from a human and a grey whale to establish their respective  $\alpha$ -amino acid sequences.

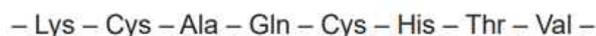
(a) What protein structure level does the  $\alpha$ -amino acid sequence represent? (1 mark)

Description	Marks
primary	1
<b>Total</b>	<b>1</b>

The structural formula of a small segment of human Cytochrome C, as written by the biochemist in her notebook, is shown below.



The biochemist wrote the sequence of  $\alpha$ -amino acids in the corresponding grey whale Cytochrome C segment in an abbreviated form:



(b) Identify **one** similarity and **one** difference between the given  $\alpha$ -amino acid sequences of human and grey whale Cytochrome C. (2 marks)

Description	Marks
Accept anything reasonable, e.g. There are five $\alpha$ -amino acids that are common to both types of Cytochrome C. They both contain lysine.	1
The third amino acid is different. The only difference is that in the position where human Cytochrome C has serine, grey whale Cytochrome C has alanine (the third amino acid in their respective sequences).	1
<b>Total</b>	<b>2</b>

The biochemist examined the overall three-dimensional folded shape of grey whale Cytochrome C. The biochemist did this by identifying the predominant types of interactions occurring between the side chains of  $\alpha$ -amino acids located near each other in grey whale Cytochrome C. Three of the  $\alpha$ -amino acid pairs considered by the biochemist are shown in the following table.

(c) Complete the following table by identifying the predominant side chain interaction for each  $\alpha$ -amino acid pair. (3 marks)

Description	Marks
Ala and Val = dispersion forces	1
Gln and His = hydrogen bonding	1
Cys and Cys = disulfide bridge (disulfide bond/covalent bond and dipole-dipole also acceptable)	1
<b>Total</b>	<b>3</b>

(d) The biochemist found that both human and grey whale Cytochrome C contain several alpha helices but no beta-pleated sheets. What protein structure level do alpha helices and beta-pleated sheets represent? (1 mark)

Description	Marks
secondary	1
<b>Total</b>	<b>1</b>

Further analysis of human Cytochrome C showed that there was a segment where two other  $\alpha$ -amino acids (phenylalanine and leucine) were adjacent to each other. The biochemist obtained pure samples of each of these amino acids and set up an experiment to facilitate their reaction with each other.

(e) Write a balanced equation, using condensed structural formulae, for a reaction that occurs between phenylalanine and leucine. (2 marks)

Description	Marks
$  \begin{array}{c}  \text{CH}_2-\text{C}_6\text{H}_5 \\    \\  \text{H}_2\text{N}-\text{CH}-\text{COOH}  \end{array}  +  \begin{array}{c}  \text{CH}_3-\text{CH}-\text{CH}_3 \\    \\  \text{CH}_2 \\    \\  \text{H}_2\text{N}-\text{CH}-\text{COOH}  \end{array}  $ <p style="text-align: center;">↓</p> $  \begin{array}{c}  \text{CH}_3-\text{CH}-\text{CH}_3 \\    \\  \text{CH}_2 \\    \\  \text{H}_2\text{N}-\text{CH}-\text{CONH}-\text{CH}-\text{COOH} \\    \qquad \qquad   \\  \text{CH}_2-\text{C}_6\text{H}_5 \qquad \text{CH}_2  \end{array}  + \text{H}_2\text{O}  $ <p>Or</p> $  \begin{array}{c}  \text{CH}_3-\text{CH}-\text{CH}_3 \\    \\  \text{CH}_2 \\    \\  \text{H}_2\text{N}-\text{CH}-\text{CONH}-\text{CH}-\text{COOH} \\    \qquad \qquad   \\  \text{CH}_2-\text{C}_6\text{H}_5 \qquad \text{CH}_2  \end{array}  + \text{H}_2\text{O}  $	1-2
<b>Total</b>	<b>2</b>
<b>Note:</b> <ul style="list-style-type: none"> <li>• One minor error maximum one mark e.g. no water, single transcription error.</li> <li>• Out of two possible organic products, only one is required.</li> <li>• Zwitterion form is also accepted.</li> </ul>	

(f) The biochemist decided to examine how the structure of leucine changes with solution pH. Complete the following table by drawing the structural formula of leucine at the indicated pH. (2 marks)

Description		Marks
Structural formula of leucine	pH	
$  \begin{array}{c}  \text{H}_3\text{C}-\text{CH}-\text{CH}_3 \\    \\  \text{CH}_2 \\    \\  \text{H}_3\text{N}^+-\text{CH}-\text{COOH}  \end{array}  $	acidic	1
$  \begin{array}{c}  \text{H}_3\text{C}-\text{CH}-\text{CH}_3 \\    \\  \text{CH}_2 \\    \\  \text{H}_2\text{N}-\text{CH}-\text{COO}^-  \end{array}  $	alkaline	1
<b>Total</b>		<b>2</b>
<b>Note:</b> Wrong amino acid, maximum 1 mark.		

**2020  
Section 3  
Question  
38**

**Properties  
and  
structure of  
organic  
materials**

Skunks are animals that are perhaps best known for the pungent odour they produce. Several organic compounds are responsible for this odour. One of these compounds contains carbon, hydrogen, sulfur and oxygen.

Combustion of a 5.00 g sample of this compound produced 6.46 g of carbon dioxide and 2.68 g of water. There was also enough sulfur (as sulfur dioxide) to make 10 L of 0.00371 mol L<sup>-1</sup> sulfuric acid.

(a) Determine the empirical formula of the compound. (12 marks)

Description	Marks
Carbon • $n(\text{CO}_2) = n(\text{C}) = 6.46/44.01 = 0.147$ mol carbon in 5.00 g • $m(\text{C}) = 0.147 \times 12.01 = 1.76$ g in 5.00 g	1 1
Hydrogen • $n(\text{H}_2\text{O}) = 2.68/18.016 = 0.149$ mol • $n(\text{H}) = 2 \times 0.149 = 0.298$ mol • $m(\text{H}) = 0.296 \times 1.008 = 0.300$ g in 5.00 g	1 1 1
Sulfur • $n(\text{H}_2\text{SO}_4) = cV = 10 \times 0.00371 = 0.0371$ mol • $n(\text{S}) = 0.0371$ mol • $m(\text{S}) = 0.0371 \times 32.06 = 1.19$ g in 5.00 g	1 1 1
Oxygen • $5.00 - 1.76 - 0.300 - 1.19 = 1.75$ g of oxygen • $n(\text{O}) = 1.75/16.00 = 0.109$ mol	1 1
Atom ratio • carbon          hydrogen          sulfur          oxygen 0.147              0.300              0.0371          0.109 • Divide all by 0.0371 to get atom ratio 3.96              8.02              1.00              2.94 4                  8                  1                  3	1
Empirical formula = <b>C<sub>4</sub>H<sub>8</sub>SO<sub>3</sub></b>	1
<b>Total</b>	<b>12</b>
Accept any other methods that have consistent logic to achieve a correct answer.	

When another 5.00 g sample was vaporised it was found to occupy a total volume of 637 mL at 150 kPa and 40 °C.

(b) Determine the molecular formula of the compound. (4 marks)

Description	Marks
Empirical formula mass = 136.164	1
Actual molar mass • $PV = nRT$ • $150 \times 0.637 = n \times 8.314 \times 313.15$ • $n = 0.0367$ • $n = m/M$ , so $M = m/n = 5.00/0.036700 = 136$	1 1
• (Molar mass = empirical mass) • Thus, the molecular formula is C <sub>4</sub> H <sub>8</sub> SO <sub>3</sub>	1
<b>Total</b>	<b>4</b>
Note: • If Empirical formula mass is not calculated – maximum of 2 marks.	

2019  
Section 3  
Question  
36

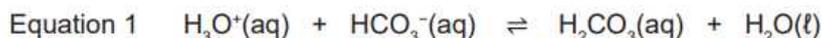
Properties  
and  
structure of  
organic  
materials

The ideal pH of human blood is 7.4. If the pH of a person's blood varies too much from this value, a serious condition can develop. If the pH is too low, it is called acidosis; if the pH is too high, it is called alkalosis. Death may occur if the pH drops below 6.8 or rises above 7.8.

One buffer system for maintaining acid-base balance in blood is the carbonic acid-hydrogencarbonate buffer.

During exercise, the muscles need more oxygen to produce energy. They produce carbon dioxide,  $\text{CO}_2$ , and hydronium ions,  $\text{H}_3\text{O}^+$ , which move from the muscles to the blood.

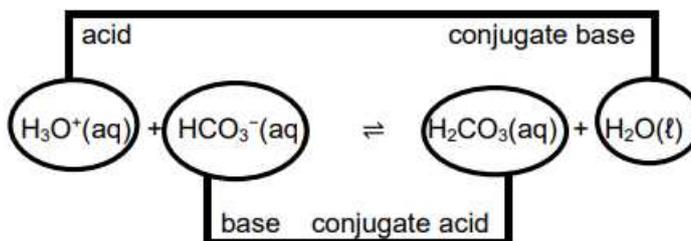
The relevant equilibrium equations for the carbonic acid-hydrogencarbonate buffer system are shown as follows.



(a) Identify the **two** conjugate acid-base pairs on Equation 1 above, indicating clearly which is the acid and which is the base in each pairing. (2 marks)

Description	Marks
$\text{H}_3\text{O}^+(\text{aq})$ - acid / $\text{H}_2\text{O}(\ell)$ - (conjugate) base	1
$\text{HCO}_3^-(\text{aq})$ - base / $\text{H}_2\text{CO}_3(\text{aq})$ - (conjugate) acid	1
<b>Total</b>	<b>2</b>

Example of a two mark response:



**Note:**

- The pairs may be expressed in various ways.
- Full marks may be awarded if the pairing and identification of acid and base is clear.
- One mark may be awarded if one pair is correct or there is ambiguity but chemical worth.

(b) Write the equilibrium constant expression for Equation 1. (2 marks)

Description	Marks
One mark for including 'K =' in the expression	1
One mark for correct structure of the concentration expression	1
<b>Total</b>	<b>2</b>

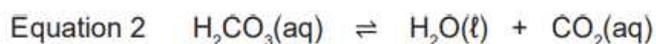
Example of a two mark response:

$$K = \frac{[\text{H}_2\text{CO}_3]}{[\text{H}_3\text{O}^+][\text{HCO}_3^-]}$$

**Note:**

- One mark may be allocated if there is only one minor error eg: one charge sign left off.

Carbonic acid further reacts to form water and carbon dioxide as shown in Equation 2.



(c) Combine Equations 1 and 2, to create an overall equation that shows the relationship between  $\text{HCO}_3^-(\text{aq})$  and  $\text{CO}_2(\text{aq})$ . (2 marks)

Description	Marks
One mark each for:	
• correct products and reactants	1
• correct balancing.	1
<b>Total</b>	<b>2</b>
Example of a two mark response:	
$\text{H}_3\text{O}^+(\text{aq}) + \text{HCO}_3^-(\text{aq}) \rightleftharpoons 2 \text{H}_2\text{O}(\ell) + \text{CO}_2(\text{aq})$	

(d) Identify the effect on the blood's pH when each of the following components are removed: carbon dioxide and hydrogencarbonate ions. (2 marks)

Description	Marks
carbon dioxide      increase      decrease      no effect	1
hydrogencarbonate ions      increase      decrease      no effect	1
<b>Total</b>	<b>2</b>

The buffering capacity of the carbonic acid-hydrogencarbonate is greatest when the pH is between 5.1 and 7.1.

(e) State **two** conditions in terms of concentration that are necessary for this buffering capacity to be optimal. (2 marks)

Description	Marks
	1
	1
<b>Total</b>	<b>2</b>

When the pH of the blood is too high, the kidneys can remove hydrogencarbonate ions,  $\text{HCO}_3^-$ , from the blood.

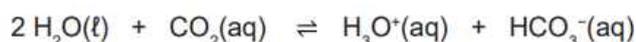
(f) Use Le Châtelier's Principle to demonstrate that the kidneys' action can help to prevent excessively high blood pH. (3 marks)

Description	Marks
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	1
	1
<b>Total</b>	<b>3</b>

When inhaling, oxygen is taken into the lungs and transferred to the blood; when exhaling, carbon dioxide is expelled.

During hyperventilation (very rapid and deep breathing) more carbon dioxide is being expelled from the body than it can produce. This upsets the oxygen/carbon dioxide balance and can cause dizziness and fainting. Hyperventilating results in lowering the carbon dioxide concentration in the blood, which can affect the pH of the blood.

The equation shown below illustrates the formation of hydronium ions within the blood system.



A first-aid treatment for hyperventilation is the 'paper-bag treatment' whereby the patient breathes into a paper bag and so breathes back in the expelled breath, which contains a higher concentration of carbon dioxide.

(g) State the effect of the 'paper-bag treatment' on the pH of the blood and explain why it is an effective treatment for hyperventilation. (3 marks)

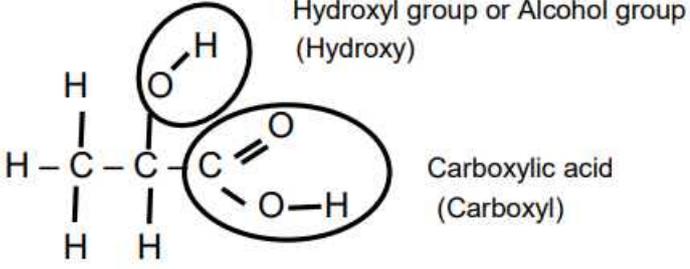
Description	Marks
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	1
	1
<b>Total</b>	<b>3</b>

**Note:**

- No specific mark is allocated for the equation,  $2 \text{H}_2\text{O}(\ell) + \text{CO}_2(\text{aq}) \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{HCO}_3^-(\text{aq})$ , stated in question.
- Le Châtelier's Principle (predicting tool) cannot be used to explain the effect.
- No reference to the re-establishing the oxygen/carbon dioxide balance is required.

Another contributor to a potential imbalance of blood pH is the formation of lactic acid. The chemical name for lactic acid is 2-hydroxypropanoic acid,  $C_3H_6O_3$ .

(h) Draw the structural formula for lactic acid with **all** its functional groups circled and labelled. (4 marks)

Description	Marks
Drawing of diagram:	
• one mark for correct carbon chain	1
• one mark for correct positions of oxygen atoms	1
• one mark for correctly circling and naming the hydroxyl group	1
• one mark for correctly circling and naming the carboxylic acid.	1
<b>Total</b>	<b>4</b>
Example of a four mark response:	
 <p>The diagram shows the structural formula of lactic acid: <math>CH_3-CH(OH)-COOH</math>. The hydroxyl group (OH) on the second carbon is circled and labeled "Hydroxyl group or Alcohol group (Hydroxy)". The carboxyl group (COOH) on the third carbon is circled and labeled "Carboxylic acid (Carboxyl)".</p>	

2019  
Section 3  
Question  
38

Properties  
and  
structure of  
organic  
materials

Polymethyl methacrylate and polycarbonate are two polymers that are used as alternatives to glass. Polymethyl methacrylate is more commonly known as Perspex or plexiglass and is an addition polymer, while polycarbonate is a type of condensation polymer.

Both polymers are transparent to visible light and have other properties as listed below.

Polymethyl methacrylate	Polycarbonate
lightweight	moderate chemical resistance
moderate UV resistance	high heat resistance
low impact strength	high impact strength
low chemical resistance	low scratch resistance
low heat resistance	low UV resistance

(a) For the following uses as an alternative to glass, identify which polymer would be the more appropriate. Justify your choice of polymer by comparing the effect of **two** relevant properties as listed for both polymers. (4 marks)

Description	Marks
Skylight:	
• justification	1-2
Safety glasses:	
• justification	1-2
<b>Total</b>	<b>4</b>

Example of a four mark response:

Use	Choice of polymer	Justification (sample answers)
Skylight	polymethyl methacrylate	<ul style="list-style-type: none"> <li>• moderate UV resistance is more desirable than low UV resistance as it serves to provide protection from harmful UV radiation</li> <li>• lightweight is more desirable as it minimises added weight to the roof structure</li> </ul>
Safety glasses	polycarbonate	<ul style="list-style-type: none"> <li>• in order to protect eyes, it must have at least moderate chemical resistance to withstand chemical splashes, the low chemical resistance of polymethacrylate would be insufficient.</li> <li>• higher heat resistance is required to avoid melting and burning the wearer when protection from heat or sparks is required.</li> </ul>

**Note:**

No marks are awarded to the choice of polymer as the choice is implied in the justification. The justification must be reasonable and match the polymer chosen for a mark to allocated. The focus of this question is that candidates can identify and reasonably link desirable properties to usage.

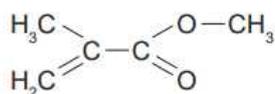
Skylight

- Polycarbonate as the choice for use as a skylight may be awarded marks if the justifications given reasonably support that argument. For example, it could be argued that its relatively higher:
  - impact strength offers greater protection against hailstorm damage.
  - heat resistance offers longevity as it is in the sunshine all day.
  - chemical resistance offers more protection against; 'acid rain'.

Safety glasses

- Marks are only awarded for polycarbonate in use as safety glasses.

The monomer, methyl methacrylate, can be formed from the esterification of methanol and methacrylic acid (2-methylprop-2-enoic acid). The structural formula of methyl methacrylate is shown below



(b) Write a balanced equation for the esterification of methanol and methacrylic acid. Show the full structural formula of each species in the equation. (4 marks)

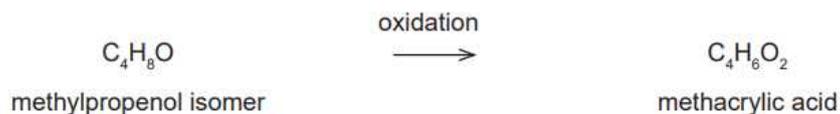
Description	Marks
Equation shows correct:	
• methanol structure	1
• carboxylic acid structure	1
• structure of the ester	1
• balancing (needs to include water).	1
<b>Total</b>	<b>4</b>
Example of a four mark response:	
$\begin{array}{c} \text{HO} \\   \\ \text{CH}_3 \end{array} + \begin{array}{c} \text{H}_3\text{C} \\ \diagdown \\ \text{C} \\ \diagup \\ \text{H}_2\text{C} \end{array} = \begin{array}{c} \text{OH} \\ \diagup \\ \text{C} \\ \diagdown \\ \text{O} \end{array} \rightleftharpoons \begin{array}{c} \text{H}_3\text{C} \\ \diagdown \\ \text{C} \\ \diagup \\ \text{H}_2\text{C} \end{array} = \begin{array}{c} \text{O}-\text{CH}_3 \\ \diagup \\ \text{C} \\ \diagdown \\ \text{O} \end{array} + \text{H}_2\text{O}$	

Methyl methacrylate can undergo addition polymerisation to form polymethyl methacrylate.

(c) Draw a section of a polymethyl methacrylate showing **all** atoms and at least **three** repeating units of the monomer. (3 marks)

Description	Marks
Continuing chain - no terminating ends	1
Correct repeating units (monomer)	1-2
<b>Total</b>	<b>3</b>
Example of a three mark response:	
$\left( \begin{array}{cccccc} \text{H} & \text{CH}_3 & \text{H} & \text{CH}_3 & \text{H} & \text{CH}_3 \\   &   &   &   &   &   \\ \text{---C---} & \text{---C---} & \text{---C---} & \text{---C---} & \text{---C---} & \text{---C---} \\   &   &   &   &   &   \\ \text{H} & \text{CO}_2\text{CH}_3 & \text{H} & \text{CO}_2\text{CH}_3 & \text{H} & \text{CO}_2\text{CH}_3 \end{array} \right)_n$	
<b>Note:</b>	
• No marks for opening and adding into C=O double bonds.	

One method for the production of methacrylic acid is by the following oxidation.

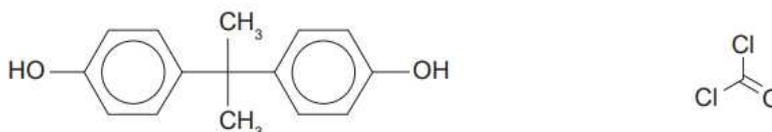


(d) Suggest an assumption that must be made regarding the mole ratios of product to reactant for this reaction and then determine the mass of the methylpropenol isomer required to produce 1.50 tonne of methacrylic acid if the efficiency of this oxidation is 65%. (Note: 1 tonne = 1000 kg.) (5 marks)

Description	Marks
Assumption: $n(\text{C}_4\text{H}_8\text{O}) = n(\text{C}_4\text{H}_6\text{O}_2)$	1
Calculation:	
$n(\text{C}_4\text{H}_6\text{O}_2) = 1.50 \times 10^6 / 86.088$ $= 1.742 \times 10^4 \text{ mol}$	1
$m(\text{C}_4\text{H}_8\text{O}) = 72.104 \times 1.742 \times 10^4$ $= 1.256 \times 10^6 \text{ g}$ represents 65% efficiency	1
$m(\text{C}_4\text{H}_8\text{O}) = 100/65 \times 1.256 \times 10^6$ $= 1.93 \times 10^6 \text{ g}$ represents 100% efficiency	1
Correct molar masses	1
<b>Total</b>	<b>5</b>

Polycarbonates are condensation-type polymers for which the by-product is hydrogen chloride instead of water.

The two monomers for polycarbonate are shown below.



(e) Why is polymethyl methacrylate classified as an addition polymer, while polycarbonate is classified as a condensation polymer? (2 marks)

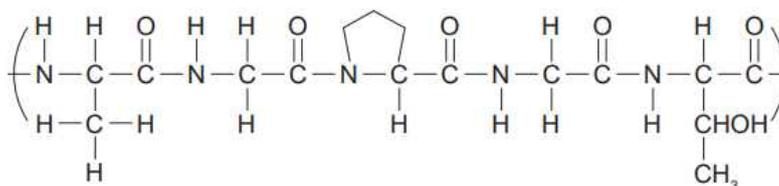
Description	Marks
Polymethyl methacrylate is produced from: <ul style="list-style-type: none"> <li>one type of monomer (methyl methacrylate) that</li> <li>contains a double bond across which two species are added.</li> </ul>	1
Polycarbonate is produced from: <ul style="list-style-type: none"> <li>monomers with two different (reactive) functional groups.</li> <li>(Hydrogen chloride is the by-product and so it is classified as a condensation polymer.)</li> </ul>	1
<b>Total</b>	<b>2</b>

2019  
Section 3  
Question  
41

Properties  
and  
structure of  
organic  
materials

When insects touch a spider's web they become stuck and therefore, easy prey for the spider. The insects become stuck because the web is coated with a glue-like substance produced by the spider. The 'spider glue' consists of water, proteins, ionic salts and polar carbon compounds.

The structural formula given below shows a small section of a spider glue protein.



(a) List the names of the amino acids in the order in which they were drawn in the section of the protein given above. Do **not** use abbreviations. (3 marks)

Description	Marks
Has the five amino acids in correct order	2
Has a minimum of three amino acids in correct order	1
Amino acid names written in full	1
<b>Total</b>	<b>3</b>
A three mark response:	
Alanine – Glycine – Proline – Glycine – Threonine	

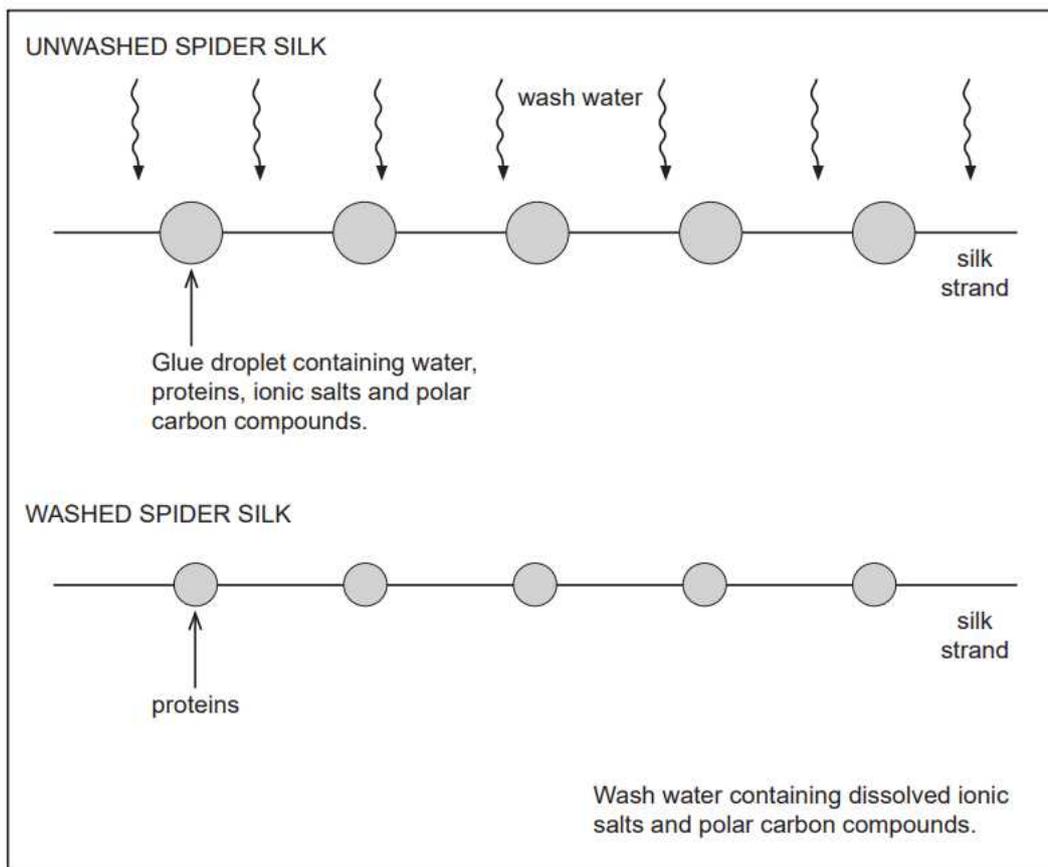
(b) Circle **one** peptide bond in the above structure. (1 mark)

Description	Marks
One peptide bond is circled	1
<b>Total</b>	<b>1</b>
Possible peptide bonds are circled below:	

(c) What is the difference between the primary structure and the secondary structure of a protein? (2 marks)

Description	Marks
The primary structure of a protein is the sequence of alpha amino acids	1
The secondary structure is:	1
<ul style="list-style-type: none"> <li>how the amide and carbonyl groups in a protein chain interact to form alpha helices and beta pleated sheets.</li> </ul>	
or	
Secondary structure results from:	1
<ul style="list-style-type: none"> <li>interactions (hydrogen bonding) between amide and carboxyl groups</li> </ul>	
or	
<ul style="list-style-type: none"> <li>interactions in the protein chain to form alpha helices and beta pleated sheets.</li> </ul>	2
<b>Total</b>	

When spider glue is washed with water, the ionic salts and polar carbon compounds dissolve. The proteins do not dissolve and remain on the silk strand. The following diagram shows what happens.



(d) Explain why the polar carbon compounds dissolve in water but the proteins do not. Illustrate your answer with the aid of a labelled diagram. (6 marks)

Description	Marks
An explanation includes a recognition that:	
<ul style="list-style-type: none"> <li>the sum of the forces of attraction (dispersion forces, <b>dipole-dipole and H-Bonding</b>) that exist <b>between</b> the molecules of the polar carbon compounds and water</li> </ul>	1
<ul style="list-style-type: none"> <li>are sufficient in strength to overcome</li> </ul>	1
<ul style="list-style-type: none"> <li>the sum of the forces of attraction (dispersion forces, <b>dipole-dipole and H-Bonding</b>) that exist between the molecules <b>within each</b> of the polar carbon compounds and water (and so dissolve)</li> </ul>	1
<ul style="list-style-type: none"> <li>being large molecules, the dispersion forces of attraction between protein molecules is large</li> </ul>	1
<ul style="list-style-type: none"> <li>the sum of attractive forces (dispersion forces, dipole-dipole and H-bonding) exerted by water molecules are insufficient in strength to disrupt the dispersion forces between the protein molecules (and so do not dissolve in water)</li> </ul>	1
<ul style="list-style-type: none"> <li>an appropriately labelled diagram that shows the interactions within and/or between the molecules of polar carbon compounds and water.</li> </ul>	1
<b>Total</b>	<b>6</b>

## Unit 4 – Chemical synthesis

### Section 1

<p>2023 Section 1 Question 22</p> <p>Chemical synthesis</p>	<p>The table below shows some properties of a variety of polymers.</p> <table border="1"><thead><tr><th>Polymer</th><th>Properties</th></tr></thead><tbody><tr><td>Polyvinyl chloride</td><td>hard brittle electrically insulating</td></tr><tr><td>Polypropene</td><td>low density tough</td></tr><tr><td>Polyethylene terephthalate</td><td>strong chemical resistant</td></tr><tr><td>Polytetrafluoroethene</td><td>high melting point chemically stable low friction</td></tr></tbody></table> <p>From the properties given above, which of the polymers would be the <b>best</b> to use to create a non-stick coating on pans?</p> <p>(a) polyvinyl chloride (b) polypropene (c) polyethylene terephthalate (d) polytetrafluoroethene</p>	Polymer	Properties	Polyvinyl chloride	hard brittle electrically insulating	Polypropene	low density tough	Polyethylene terephthalate	strong chemical resistant	Polytetrafluoroethene	high melting point chemically stable low friction
Polymer	Properties										
Polyvinyl chloride	hard brittle electrically insulating										
Polypropene	low density tough										
Polyethylene terephthalate	strong chemical resistant										
Polytetrafluoroethene	high melting point chemically stable low friction										
<p>2023 Section 1 Question 25</p> <p>Chemical synthesis</p>	<p>Which of the following statements best differentiates the cleaning action of soaps and detergents?</p> <p>(a) Soaps contain a long, non-polar hydrocarbon tail, whereas detergents contain a carboxylate head that dissolves in grease. (b) Detergents form micelles on agitation, whereas the anionic head of soap dissolves in grease. (c) Detergents do not form precipitates with divalent ions found in water, whereas soaps will precipitate out in similar conditions. (d) Soaps contain a sulfonate group that dissolves in water, whereas detergents contain a carboxylate group that dissolves in water.</p>										
<p>2022 Section 1 Question 4</p> <p>Chemical synthesis</p>	<p>Which of the following is a saponification reaction?</p> <p>(a) condensation of <math>\alpha</math>-amino acids (b) oxidation of primary alcohols (c) acid-catalysed reaction of alcohols and carboxylic acids (d) base hydrolysis of fats</p>										

<p><b>2022</b> <b>Section 1</b> <b>Question 6-8</b></p> <p><b>Chemical synthesis</b></p>	<p>Questions 6 to 8 refer to the following reaction at equilibrium in a closed reaction vessel.</p> $2 \text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2 \text{SO}_3(\text{g}) \quad \Delta H = -196 \text{ kJ mol}^{-1}$ <p>6. The equilibrium constant for this reaction at 298 K is <math>4.0 \times 10^{-24}</math>. What information does this provide about the reaction mixture at this temperature? The partial</p> <p>(a) pressure of the products is greater than that of the reactants.          (b) pressures of all species are the same.          (c) pressures of the reactants are greater than that of the products.          (d) pressures of both sulfur oxides are greater than that of oxygen.</p> <p>7. Which of the following changes will initially decrease the rate at which <math>\text{SO}_2(\text{g})</math> is consumed?</p> <p>(a) decrease the volume of the reaction vessel          (b) decrease the partial pressure of <math>\text{O}_2(\text{g})</math>          (c) heat the reaction vessel          (d) add an appropriate catalyst</p> <p>8. Which of the following changes will increase the yield of <math>\text{SO}_3(\text{g})</math> in the reaction?</p> <p>(a) remove <math>\text{O}_2(\text{g})</math> from the reaction vessel          (b) add an inert gas to the reaction vessel          (c) increase the volume of the reaction vessel          (d) decrease the temperature of the reaction vessel</p>
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<p><b>2022</b> <b>Section 1</b> <b>Question 22</b></p> <p><b>Chemical synthesis</b></p>	<p>How many moles of oxygen will be consumed in the complete combustion of 1 mole of ethanol? The unbalanced equation for this reaction is shown below.</p> $\text{C}_2\text{H}_6\text{O}(\text{l}) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{g})$ <p>(a) 1 mol          (b) 2 mol          (c) 3 mol          (d) 4 mol</p>
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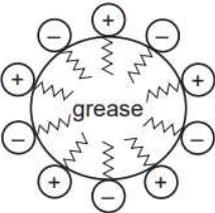
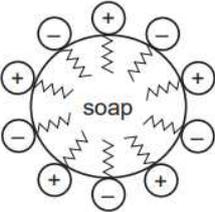
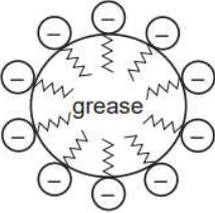
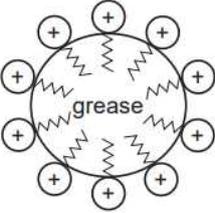
<p><b>2022</b> <b>Section 1</b> <b>Question 25</b></p> <p><b>Chemical synthesis</b></p>	<p>Which set of conditions below would optimise the yield of methanol in the following industrial process?</p> $\text{CO}(\text{g}) + 2 \text{H}_2(\text{g}) \rightleftharpoons \text{CH}_3\text{OH}(\text{g}) \quad \Delta H = -90 \text{ kJ mol}^{-1}$ <p>(a) low pressure, high temperature          (b) high pressure, high temperature, catalyst          (c) low pressure, low temperature, catalyst          (d) high pressure, low temperature</p>
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<p><b>2021</b> <b>Section 1</b> <b>Question 2</b></p> <p><b>Chemical synthesis</b></p>	<p>Chlorine gas is bubbled for several minutes through a sample of pent-1-ene. Which of the following statements identifies the type of reaction that occurs and the colour of the solution in the flask after the reaction is complete, assuming the chlorine gas is the limiting reagent?</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th>Type of reaction</th> <th>Solution colour after complete reaction</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>substitution</td> <td>colourless</td> </tr> <tr> <td>(b)</td> <td>addition</td> <td>colourless</td> </tr> <tr> <td>(c)</td> <td>addition</td> <td>green</td> </tr> <tr> <td>(d)</td> <td>substitution</td> <td>green</td> </tr> </tbody> </table>		Type of reaction	Solution colour after complete reaction	(a)	substitution	colourless	(b)	addition	colourless	(c)	addition	green	(d)	substitution	green
	Type of reaction	Solution colour after complete reaction														
(a)	substitution	colourless														
(b)	addition	colourless														
(c)	addition	green														
(d)	substitution	green														

<p><b>2021</b> <b>Section 1</b> <b>Question 6</b></p> <p><b>Chemical synthesis</b></p>	<p>Which of the following is <b>least</b> likely to be a characteristic of a process classified as green chemistry?</p> <p>(a) is energy intensive (b) utilises renewable feedstocks (c) produces less waste (d) utilises fewer toxic solvents</p>
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<p><b>2021</b> <b>Section 1</b> <b>Question 19</b></p> <p><b>Chemical synthesis</b></p>	<p>In which of the following reactions would there be no visible reaction at 25 °C?</p> <p>(a) A solid iron strip is placed in a solution of 1.00 mol L<sup>-1</sup> copper(II) sulfate. (b) Bromine water and 2,3-dimethylbut-2-ene are shaken together. (c) Chlorine gas is bubbled through a solution of 1.00 mol L<sup>-1</sup> potassium iodide. (d) 1.00 mol L<sup>-1</sup> potassium dichromate and 1.00 mol L<sup>-1</sup> acetic acid are mixed together.</p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 22</b></p> <p><b>Chemical synthesis</b></p>	<p>When cleaning greasy/dirty objects in hard water, it is <b>best</b> to use</p> <p>(a) a soap, because it forms a precipitate with the ions causing water hardness, thereby removing these ions from solution. (b) a detergent, because it does not react with the ions causing water hardness. (c) a detergent, because it forms a precipitate with the ions causing water hardness, thereby removing these ions from solution. (d) a soap, because it does not react with the ions causing water hardness.</p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 23</b></p> <p><b>Chemical synthesis</b></p>	<p>Which of the following diagrams represents the micelle that forms in water when soap is used to remove grease from dirty dishes?</p> <p>(a) </p> <p>(b) </p> <p>(c) </p> <p>(d) </p>
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<p><b>2019</b> <b>Section 1</b> <b>Question 11</b></p> <p><b>Chemical synthesis</b></p>	<p>Which one of the following statements about catalysis in the production of biodiesel is correct?</p> <p>(a) Base catalysis generally has a higher reaction rate but, unlike lipase catalysis, can cause saponification, which decreases the biodiesel yield.</p> <p>(b) The sodium hydroxide and potassium hydroxide used in base catalysis are readily available and relatively cheap, but lipase catalysis produces more toxic waste water.</p> <p>(c) Base catalysis involves only one step, while lipase catalysis involves many steps in its synthesis sequence, which in turn adds to the cost of the process.</p> <p>(d) Base catalysis typically has a lower rate and yield of biodiesel but lipase catalysis is sensitive to alcohols, such as methanol, and has higher energy costs.</p>
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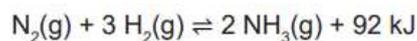
<p><b>2019</b> <b>Section 1</b> <b>Question 13</b></p> <p><b>Chemical synthesis</b></p>	<p>One method of producing biodiesel is by a transesterification reaction where triglycerides are converted into simpler methyl esters (the biodiesel) of the fatty acids. Which one of the following is a reactant of this transesterification reaction?</p>
<p>(a)</p> $  \begin{array}{c}  \text{H} \quad \quad \text{O} \\    \quad \quad    \\  \text{H}-\text{C}-\text{O}-\text{C}-\text{R} \\    \\  \text{H}  \end{array}  $	<p>(b)</p> $  \begin{array}{c}  \text{H} \\    \\  \text{H}-\text{C}-\text{OH} \\    \\  \text{H}-\text{C}-\text{OH} \\    \\  \text{H}-\text{C}-\text{OH} \\    \\  \text{H}  \end{array}  $
<p>(c)</p> $  \begin{array}{c}  \text{H} \quad \quad \text{O} \\    \quad \quad    \\  \text{H}-\text{C}-\text{O}-\text{C}-\text{R} \\    \\  \text{H}-\text{C}-\text{O}-\text{C}-\text{R} \\    \\  \text{H}-\text{C}-\text{O}-\text{C}-\text{R} \\    \\  \text{H}  \end{array}  $	<p>(d)</p> $  \begin{array}{c}  \text{H} \quad \quad \text{O} \\    \quad \quad    \\  \text{H}-\text{C}-\text{C}-\text{OH} \\    \\  \text{H}-\text{C}-\text{C}-\text{OH} \\    \\  \text{H}-\text{C}-\text{C}-\text{OH} \\    \\  \text{H}  \end{array}  $



2020  
Section 2  
Question  
34

Chemical  
synthesis

The Haber process is used to make ammonia. The balanced equation for the process is:



The Haber process provides challenges for industrial operators in relation to the rate of ammonia production and the ammonia yield. This is reflected in the following quotation taken from *Chemistry and Engineering News*:

**Copyright restrictions prohibit the release of this SCSA exam material.**

(a) State whether you agree with the claims about the effects of temperature on the yield of ammonia. Justify your statement using Le Châtelier's Principle. (4 marks)

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(b) State whether you agree with the claims about the effects of temperature on the rate of the Haber process. Justify your statement using collision theory. (6 marks)

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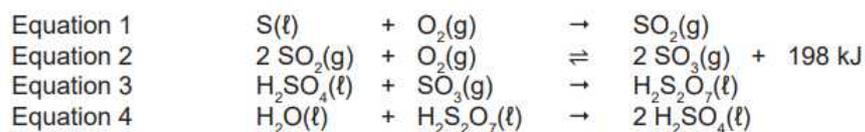
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**2019**  
**Section 2**  
**Question**  
**29**

**Chemical**  
**synthesis**

Sulfuric acid is a very useful chemical that is produced industrially by a multi-stepped process. These steps are summarised by the following equations.



When dihydrogen sulfate,  $\text{H}_2\text{SO}_4(\ell)$ , is mixed with water, it produces sulfuric acid,  $\text{H}_2\text{SO}_4(\text{aq})$ .

(a) Combine these equations to produce an overall equation for the production of dihydrogen sulfate,  $\text{H}_2\text{SO}_4(\ell)$ , from sulfur dioxide,  $\text{SO}_2(\text{g})$ . (2 marks)

(b) Complete the following table by listing the advantages and disadvantages of using high temperatures and high pressures for the reaction represented by Equation 2 above. Consider yield, rate, cost and safety. (6 marks)

	Advantage/s	Disadvantage/s
High temperature		
High pressure		



### Section 3

**2023**  
**Section 3**  
**Question**  
**39**

**Chemical**  
**synthesis**

Ethanol can be produced either from plant materials or from petrochemical sources.

(a) When ethanol is produced from plant sources, the material is ground up. The starches and cellulose in the material are then converted into sugars. Yeast or zymase is mixed with the sugars at 25 to 37°C and a pH of between 3 and 5 at atmospheric pressure. The products of the fermentation process are ethanol and carbon dioxide.

(i) Justify the conditions used for fermentation. (2 marks)

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(ii) Write an equation for the fermentation process, using  $C_6H_{12}O_6$  as the sugar. Use condensed structures in your equation. (2 marks)

Ethanol can also be produced by the endothermic hydration of ethene. This is carried out at 250 to 300 °C and 6000 to 7000 kPa in the presence of an acid catalyst.

(b) (i) Write an equation for the hydration of ethene. Use condensed structures in your equation. (3 marks)

(ii) Justify the temperature and pressure used for the hydration of ethene. (5 marks)

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	(c) State <b>three</b> reasons why the fermentation process to produce ethanol is more common than the hydration of ethene. (3 marks)
	One:
	Two:
	Three:

<b>2022</b> <b>Section 3</b> <b>Question</b> <b>36</b>  <b>Chemical</b> <b>synthesis</b>	Compare soaps and detergents in terms of the following:
	(a) structure (2 marks)
	(b) cleaning action; include a labelled diagram to illustrate the cleaning action(s) (7 marks)
	(c) properties in hard water. (3 marks)


2020  
Section 3  
Question  
39

Chemical  
synthesis

Fluorescent lights are glass tubes which are coated on the inside with rare earth metal phosphates (such as cerium, lanthanum and terbium phosphates) that provide light. Cerium, lanthanum and terbium are expensive, so are recovered once the fluorescent light is no longer functional.

The key steps in one method proposed for recovery of these rare earth metals are summarised below:

- **Step 1:** Physical separation of the rare earth metal phosphates from the glass and any metallic components. This gives an impure powder consisting of cerium, lanthanum and terbium phosphates.
- **Step 2:** Add excess solid sodium carbonate to the powder and heat, completely converting each rare earth metal phosphate to its corresponding oxide, as shown by the following balanced equations:  
$$2 \text{LaPO}_4(\text{s}) + 3 \text{Na}_2\text{CO}_3(\text{s}) \rightarrow \text{La}_2\text{O}_3(\text{s}) + 2 \text{Na}_3\text{PO}_4(\text{s}) + 3 \text{CO}_2(\text{g})$$
$$4 \text{CePO}_4(\text{s}) + 6 \text{Na}_2\text{CO}_3(\text{s}) + \text{O}_2(\text{g}) \rightarrow 4 \text{CeO}_2(\text{s}) + 4 \text{Na}_3\text{PO}_4(\text{s}) + 6 \text{CO}_2(\text{g})$$
$$2 \text{TbPO}_4(\text{s}) + 3 \text{Na}_2\text{CO}_3(\text{s}) \rightarrow \text{Tb}_2\text{O}_3(\text{s}) + 2 \text{Na}_3\text{PO}_4(\text{s}) + 3 \text{CO}_2(\text{g})$$
- **Step 3:** Wash the product from Step 2 with water.
- **Step 4:** Add hydrochloric acid to the washed product from Step 3 to leach (dissolve) only the rare earth metal oxides.
- **Step 5:** Use solvent extraction to separate the different rare earth metals from each other and create separate solutions of each of them.
- **Step 6:** Add oxalic acid to the separated solutions to precipitate the rare earth metal ions as oxalate salts.
- **Step 7:** Heat the oxalate salts to recover the rare earth metals as pure oxides, namely  $\text{La}_2\text{O}_3$ ,  $\text{Tb}_4\text{O}_7$  and  $\text{CeO}_2$ .

A chemist used the above procedure to determine the percentage by mass of lanthanum, terbium and cerium in some fluorescent lights and, after completing Step 1, had recovered 1.20 kg of the coating chemicals.

(a) At the completion of Step 2, the mass of the mixture had decreased by 11.3 g. Calculate the mass of sodium carbonate that reacted with the rare earth metal phosphates. (3 marks)

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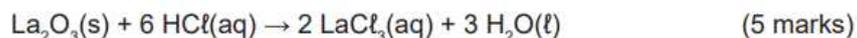
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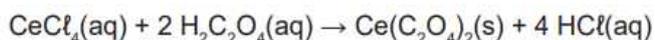
The mass of the solid sent from Step 3 to Step 4 was 1.16 kg. This solid was leached with 6.00 mol L<sup>-1</sup> HCl at a solid to liquid ratio of 150 g per litre. Analysis of the solution at the end of leaching showed that it contained lanthanum, terbium and cerium, with its lanthanum concentration being 8.65 x 10<sup>-3</sup> mol L<sup>-1</sup>.

(b) Calculate the percentage, by mass, of lanthanum in the fluorescent light coating chemical, given that the leaching efficiency for lanthanum was 86%.

Note that the balanced equation for the leaching of lanthanum with hydrochloric acid is:



Analysis of the cerium-containing solution produced in Step 5 showed that its cerium concentration was 0.146 mol L<sup>-1</sup>. This solution, which had a volume of 424 mL, was added to 110 mL of aqueous 1.15 mol L<sup>-1</sup> oxalic acid during Step 6, resulting in the precipitation of cerium oxalate, Ce(C<sub>2</sub>O<sub>4</sub>)<sub>2</sub>. The balanced equation for this reaction is:



(c) Did the chemist add enough oxalic acid solution to precipitate all of the cerium? Use calculations to support your answer. (4 marks)

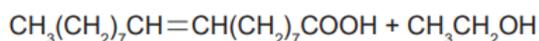




(b) Lipase is a protein that can be used to catalyse the reaction between triolein and ethanol. To which class of biological chemicals (other than proteins) does lipase belong? (1 mark)

The free fatty acids found in vegetable oil waste will react with the ethanol that was intended for biodiesel synthesis, establishing an equilibrium.

(c) Complete the following equation to show the equilibrium that is established between oleic acid and ethanol. Represent all organic substances as condensed structural formulae and assume acidic conditions. (2 marks)



In an industrial setting, reaction conditions are adjusted to favour the forward direction of the oleic acid/ethanol equilibrium.

(d) Identify **two** different actions that can be carried out to favour the forward direction of this equilibrium. (2 marks)

One:

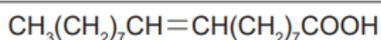
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Two:

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The base sodium hydroxide can also catalyse the reaction between triolein and ethanol. The free fatty acids in the vegetable oil waste also react with the base.

(e) (i) Write a balanced equation showing the reaction of oleic acid with sodium hydroxide. Represent all organic substances as condensed structural formulae. (2 marks)



(ii) To which class of compounds does the organic product of this reaction belong? (1 mark)

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(f) Which of the catalysts, lipase or sodium hydroxide, is more likely to be the industrially preferred catalyst when using vegetable oil waste to make biodiesel? Justify your answer. (3 marks)

(g) Other than the recycling of vegetable oil waste, give two different reasons why the production of biodiesel from vegetable oil waste is an example of green chemistry but the production of diesel from fossil fuels is not. Each of your reasons needs to contrast biodiesel and fossil fuel diesel. (2 marks)

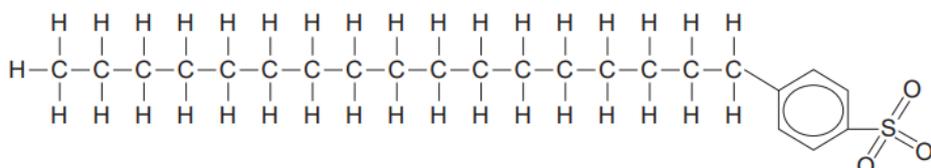
One:

Two:

**2019  
Section 3  
Question  
37**

**Chemical  
synthesis**

Detergents and soaps are both used as cleaning agents. The general structure of a detergent is given below.



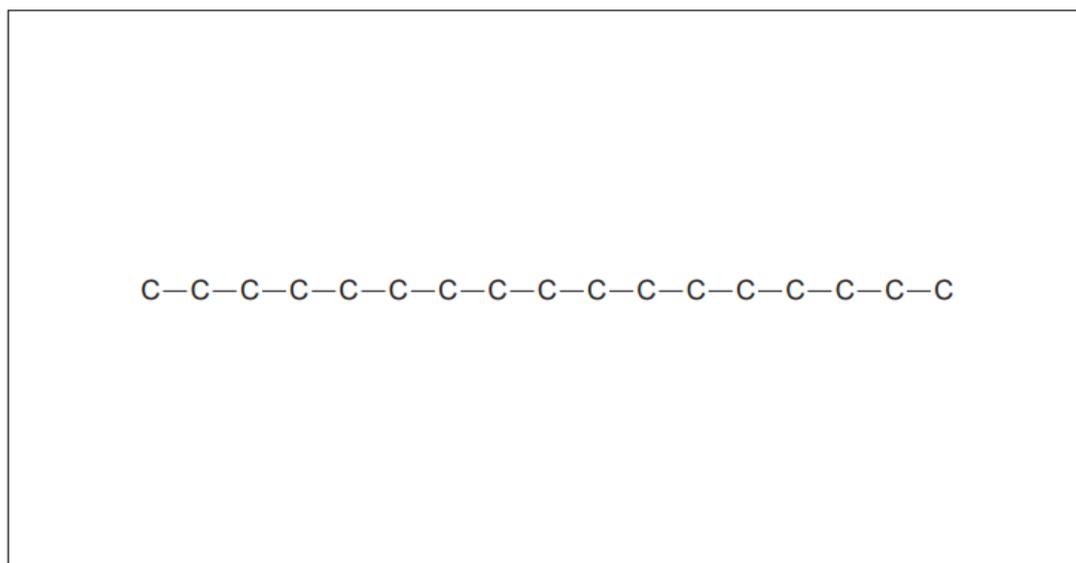
(a) Explain how detergents are able to remove grease from a surface by referring to the intermolecular forces present. Include a labelled diagram to illustrate your answer. (7 marks)

Detergents are considered to be more versatile cleaners than soap.

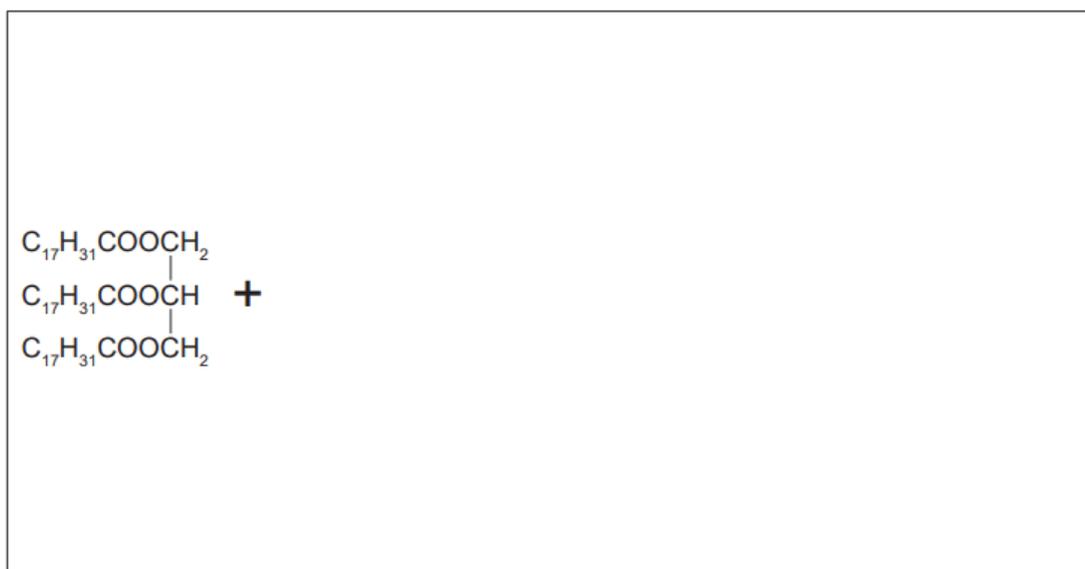
(b) Explain why soaps are generally less effective than detergents as cleaning agents in hard water. Include a relevant equation in your answer. (4 marks)

Alkenes can also form soaps.

(c) Draw a structural diagram for the soap ion,  $C_{17}H_{31}CO_2^-$  – using the incomplete structure below. Show **all** atoms and bonds. (2 marks)



(d) Write an equation showing the formation of this soap from the fat (triglyceride) shown below. (3 marks)



The formation of soap is both an endothermic and equilibrium reaction.

(e) Predict and explain the conditions that would result in the highest yield of soap in the shortest amount of time. (8 marks)

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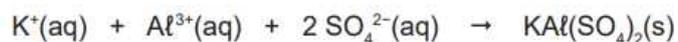
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To remove the remaining  $\text{Al}^{3+}$  ions from the leach solution, the chemist added 2.63 L of a  $0.0550 \text{ mol L}^{-1}$   $\text{K}_2\text{SO}_4$  solution, with the result being the precipitation of potassium alum as shown in the equation below.



The sulfate ions remained in excess due to the initial addition of sulfuric acid.

(b) Was sufficient  $\text{K}_2\text{SO}_4$  solution added to precipitate all of the  $\text{Al}^{3+}$  ions remaining in the leach solution? Justify your answer with relevant calculations. (4 marks)



## Marking Guide – Section 1

<b>2023</b> <b>Section 1</b> <b>Question 22</b>  <b>Chemical synthesis</b>	<p>The table below shows some properties of a variety of polymers.</p> <table border="1"><thead><tr><th>Polymer</th><th>Properties</th></tr></thead><tbody><tr><td>Polyvinyl chloride</td><td>hard brittle electrically insulating</td></tr><tr><td>Polypropene</td><td>low density tough</td></tr><tr><td>Polyethylene terephthalate</td><td>strong chemical resistant</td></tr><tr><td>Polytetrafluoroethene</td><td>high melting point chemically stable low friction</td></tr></tbody></table> <p>From the properties given above, which of the polymers would be the <b>best</b> to use to create a non-stick coating on pans?</p> <p>(a) polyvinyl chloride (b) polypropene (c) polyethylene terephthalate <b>(d) polytetrafluoroethene – Answer</b></p>	Polymer	Properties	Polyvinyl chloride	hard brittle electrically insulating	Polypropene	low density tough	Polyethylene terephthalate	strong chemical resistant	Polytetrafluoroethene	high melting point chemically stable low friction
Polymer	Properties										
Polyvinyl chloride	hard brittle electrically insulating										
Polypropene	low density tough										
Polyethylene terephthalate	strong chemical resistant										
Polytetrafluoroethene	high melting point chemically stable low friction										
<b>2023</b> <b>Section 1</b> <b>Question 25</b>  <b>Chemical synthesis</b>	<p>Which of the following statements best differentiates the cleaning action of soaps and detergents?</p> <p>(a) Soaps contain a long, non-polar hydrocarbon tail, whereas detergents contain a carboxylate head that dissolves in grease. (b) Detergents form micelles on agitation, whereas the anionic head of soap dissolves in grease. <b>(c) Detergents do not form precipitates with divalent ions found in water, whereas soaps will precipitate out in similar conditions. – Answer</b> (d) Soaps contain a sulfonate group that dissolves in water, whereas detergents contain a carboxylate group that dissolves in water.</p>										
<b>2022</b> <b>Section 1</b> <b>Question 4</b>  <b>Chemical synthesis</b>	<p>Which of the following is a saponification reaction?</p> <p>(a) condensation of <math>\alpha</math>-amino acids (b) oxidation of primary alcohols (c) acid-catalysed reaction of alcohols and carboxylic acids <b>(d) base hydrolysis of fats – Answer</b></p>										

<p><b>2022</b> <b>Section 1</b> <b>Question</b> <b>6-8</b></p> <p><b>Chemical synthesis</b></p>	<p>Questions 6 to 8 refer to the following reaction at equilibrium in a closed reaction vessel.</p> $2 \text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2 \text{SO}_3(\text{g}) \quad \Delta H = -196 \text{ kJ mol}^{-1}$ <p>6. The equilibrium constant for this reaction at 298 K is <math>4.0 \times 10^{-24}</math>. What information does this provide about the reaction mixture at this temperature? The partial</p> <p>(a) pressure of the products is greater than that of the reactants.          (b) pressures of all species are the same.  <b>(c) pressures of the reactants are greater than that of the products. – Answer</b>          (d) pressures of both sulfur oxides are greater than that of oxygen.</p> <p>7. Which of the following changes will initially decrease the rate at which <math>\text{SO}_2(\text{g})</math> is consumed?</p> <p>(a) decrease the volume of the reaction vessel  <b>(b) decrease the partial pressure of <math>\text{O}_2(\text{g})</math> – Answer</b>          (c) heat the reaction vessel          (d) add an appropriate catalyst</p> <p>8. Which of the following changes will increase the yield of <math>\text{SO}_3(\text{g})</math> in the reaction?</p> <p>(a) remove <math>\text{O}_2(\text{g})</math> from the reaction vessel          (b) add an inert gas to the reaction vessel          (c) increase the volume of the reaction vessel  <b>(d) decrease the temperature of the reaction vessel – Answer</b></p>
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<p><b>2022</b> <b>Section 1</b> <b>Question</b> <b>22</b></p> <p><b>Chemical synthesis</b></p>	<p>How many moles of oxygen will be consumed in the complete combustion of 1 mole of ethanol? The unbalanced equation for this reaction is shown below.</p> $\text{C}_2\text{H}_6\text{O}(\text{l}) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{g})$ <p>(a) 1 mol          (b) 2 mol  <b>(c) 3 mol – Answer</b>          (d) 4 mol</p>
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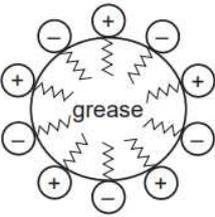
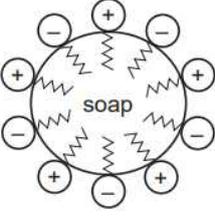
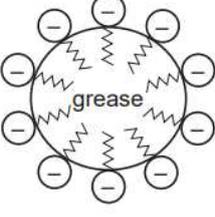
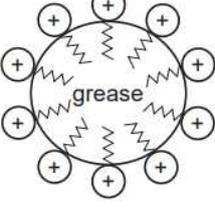
<p><b>2022</b> <b>Section 1</b> <b>Question</b> <b>25</b></p> <p><b>Chemical synthesis</b></p>	<p>Which set of conditions below would optimise the yield of methanol in the following industrial process?</p> $\text{CO}(\text{g}) + 2 \text{H}_2(\text{g}) \rightleftharpoons \text{CH}_3\text{OH}(\text{g}) \quad \Delta H = -90 \text{ kJ mol}^{-1}$ <p>(a) low pressure, high temperature          (b) high pressure, high temperature, catalyst          (c) low pressure, low temperature, catalyst  <b>(d) high pressure, low temperature – Answer</b></p>
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<p><b>2021</b> <b>Section 1</b> <b>Question 2</b></p> <p><b>Chemical synthesis</b></p>	<p>Chlorine gas is bubbled for several minutes through a sample of pent-1-ene. Which of the following statements identifies the type of reaction that occurs and the colour of the solution in the flask after the reaction is complete, assuming the chlorine gas is the limiting reagent?</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th>Type of reaction</th> <th>Solution colour after complete reaction</th> </tr> </thead> <tbody> <tr> <td>(a)</td> <td>substitution</td> <td>colourless</td> </tr> <tr> <td>(b)</td> <td>addition</td> <td>colourless</td> </tr> <tr> <td>(c)</td> <td>addition</td> <td>green</td> </tr> <tr> <td>(d)</td> <td>substitution</td> <td>green</td> </tr> </tbody> </table> <p><b>Answer is b.</b></p>		Type of reaction	Solution colour after complete reaction	(a)	substitution	colourless	(b)	addition	colourless	(c)	addition	green	(d)	substitution	green
	Type of reaction	Solution colour after complete reaction														
(a)	substitution	colourless														
(b)	addition	colourless														
(c)	addition	green														
(d)	substitution	green														

<p><b>2021</b> <b>Section 1</b> <b>Question 6</b></p> <p><b>Chemical synthesis</b></p>	<p>Which of the following is <b>least</b> likely to be a characteristic of a process classified as green chemistry?</p> <p><b>(a) is energy intensive – Answer</b>            (b) utilises renewable feedstocks            (c) produces less waste            (d) utilises fewer toxic solvents</p>
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<p><b>2021</b> <b>Section 1</b> <b>Question 19</b></p> <p><b>Chemical synthesis</b></p>	<p>In which of the following reactions would there be no visible reaction at 25 °C?</p> <p>(a) A solid iron strip is placed in a solution of 1.00 mol L<sup>-1</sup> copper(II) sulfate.            (b) Bromine water and 2,3-dimethylbut-2-ene are shaken together.            (c) Chlorine gas is bubbled through a solution of 1.00 mol L<sup>-1</sup> potassium iodide.            (d) 1.00 mol L<sup>-1</sup> potassium dichromate and 1.00 mol L<sup>-1</sup> acetic acid are mixed together.</p> <p><b>Answer is d.</b></p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 22</b></p> <p><b>Chemical synthesis</b></p>	<p>When cleaning greasy/dirty objects in hard water, it is <b>best</b> to use</p> <p>(a) a soap, because it forms a precipitate with the ions causing water hardness, thereby removing these ions from solution.  <b>(b) a detergent, because it does not react with the ions causing water hardness. – Answer</b>            (c) a detergent, because it forms a precipitate with the ions causing water hardness, thereby removing these ions from solution.            (d) a soap, because it does not react with the ions causing water hardness.</p>
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<p><b>2020</b> <b>Section 1</b> <b>Question 23</b></p> <p><b>Chemical synthesis</b></p>	<p>Which of the following diagrams represents the micelle that forms in water when soap is used to remove grease from dirty dishes?</p> <p>(a) </p> <p>(b) </p> <p>(c) </p> <p>(d) </p> <p><b>Answer is c.</b></p>
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<p><b>2019</b> <b>Section 1</b> <b>Question 11</b></p> <p><b>Chemical synthesis</b></p>	<p>Which one of the following statements about catalysis in the production of biodiesel is correct?</p> <p><b>(a) Base catalysis generally has a higher reaction rate but, unlike lipase catalysis, can cause saponification, which decreases the biodiesel yield. – Answer</b></p> <p>(b) The sodium hydroxide and potassium hydroxide used in base catalysis are readily available and relatively cheap, but lipase catalysis produces more toxic waste water.</p> <p>(c) Base catalysis involves only one step, while lipase catalysis involves many steps in its synthesis sequence, which in turn adds to the cost of the process.</p> <p>(d) Base catalysis typically has a lower rate and yield of biodiesel but lipase catalysis is sensitive to alcohols, such as methanol, and has higher energy costs.</p>
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<p><b>2019</b> <b>Section 1</b> <b>Question 13</b></p> <p><b>Chemical synthesis</b></p>	<p>One method of producing biodiesel is by a transesterification reaction where triglycerides are converted into simpler methyl esters (the biodiesel) of the fatty acids. Which one of the following is a reactant of this transesterification reaction?</p> <table border="1" style="width: 100%; text-align: center;"> <tr> <td style="width: 50%; vertical-align: middle;"> <p>(a)</p> <math display="block">\begin{array}{c} \text{H} \quad \quad \text{O} \\   \quad \quad    \\ \text{H}-\text{C}-\text{O}-\text{C}-\text{R} \\   \\ \text{H} \end{array}</math> </td> <td style="width: 50%; vertical-align: middle;"> <p>(b)</p> <math display="block">\begin{array}{c} \text{H} \\   \\ \text{H}-\text{C}-\text{OH} \\   \\ \text{H}-\text{C}-\text{OH} \\   \\ \text{H}-\text{C}-\text{OH} \\   \\ \text{H} \end{array}</math> </td> </tr> <tr> <td style="width: 50%; vertical-align: middle;"> <p>(c)</p> <math display="block">\begin{array}{c} \text{H} \quad \quad \text{O} \\   \quad \quad    \\ \text{H}-\text{C}-\text{O}-\text{C}-\text{R} \\   \\ \text{H}-\text{C}-\text{O}-\text{C}-\text{R} \\   \\ \text{H}-\text{C}-\text{O}-\text{C}-\text{R} \\   \\ \text{H} \end{array}</math> </td> <td style="width: 50%; vertical-align: middle;"> <p>(d)</p> <math display="block">\begin{array}{c} \text{H} \quad \text{O} \\   \quad    \\ \text{H}-\text{C}-\text{C}-\text{OH} \\   \\ \text{H}-\text{C}-\text{C}-\text{OH} \\   \\ \text{H}-\text{C}-\text{C}-\text{OH} \\   \\ \text{H} \end{array}</math> </td> </tr> </table> <p><b>Answer is c.</b></p>	<p>(a)</p> $\begin{array}{c} \text{H} \quad \quad \text{O} \\   \quad \quad    \\ \text{H}-\text{C}-\text{O}-\text{C}-\text{R} \\   \\ \text{H} \end{array}$	<p>(b)</p> $\begin{array}{c} \text{H} \\   \\ \text{H}-\text{C}-\text{OH} \\   \\ \text{H}-\text{C}-\text{OH} \\   \\ \text{H}-\text{C}-\text{OH} \\   \\ \text{H} \end{array}$	<p>(c)</p> $\begin{array}{c} \text{H} \quad \quad \text{O} \\   \quad \quad    \\ \text{H}-\text{C}-\text{O}-\text{C}-\text{R} \\   \\ \text{H}-\text{C}-\text{O}-\text{C}-\text{R} \\   \\ \text{H}-\text{C}-\text{O}-\text{C}-\text{R} \\   \\ \text{H} \end{array}$	<p>(d)</p> $\begin{array}{c} \text{H} \quad \text{O} \\   \quad    \\ \text{H}-\text{C}-\text{C}-\text{OH} \\   \\ \text{H}-\text{C}-\text{C}-\text{OH} \\   \\ \text{H}-\text{C}-\text{C}-\text{OH} \\   \\ \text{H} \end{array}$
<p>(a)</p> $\begin{array}{c} \text{H} \quad \quad \text{O} \\   \quad \quad    \\ \text{H}-\text{C}-\text{O}-\text{C}-\text{R} \\   \\ \text{H} \end{array}$	<p>(b)</p> $\begin{array}{c} \text{H} \\   \\ \text{H}-\text{C}-\text{OH} \\   \\ \text{H}-\text{C}-\text{OH} \\   \\ \text{H}-\text{C}-\text{OH} \\   \\ \text{H} \end{array}$				
<p>(c)</p> $\begin{array}{c} \text{H} \quad \quad \text{O} \\   \quad \quad    \\ \text{H}-\text{C}-\text{O}-\text{C}-\text{R} \\   \\ \text{H}-\text{C}-\text{O}-\text{C}-\text{R} \\   \\ \text{H}-\text{C}-\text{O}-\text{C}-\text{R} \\   \\ \text{H} \end{array}$	<p>(d)</p> $\begin{array}{c} \text{H} \quad \text{O} \\   \quad    \\ \text{H}-\text{C}-\text{C}-\text{OH} \\   \\ \text{H}-\text{C}-\text{C}-\text{OH} \\   \\ \text{H}-\text{C}-\text{C}-\text{OH} \\   \\ \text{H} \end{array}$				

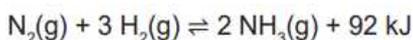
Marking Guide – Section 2

<p><b>2021</b> <b>Section 2</b> <b>Question</b> <b>33</b></p> <p><b>Chemical</b> <b>synthesis</b></p>	<p>Ethanol (C<sub>2</sub>H<sub>5</sub>OH) dissolves readily in water, while decan-1-ol (C<sub>10</sub>H<sub>21</sub>OH) has very limited solubility. Explain, with the aid of labelled diagrams, why ethanol is able to dissolve in water and decan-1-ol is not.</p>	
	<b>Description</b>	<b>Marks</b>
	<p>A detailed, coherent response consisting of the majority of the points below:</p> <p><b>Energy response</b></p> <ul style="list-style-type: none"> <li>• In order for a solute to dissolve in a solvent the energy released in the formation of the intermolecular forces between the solute and solvent are sufficient to overcome the existing intermolecular forces between the solute molecules and the solvent molecules.</li> <li>• Both alcohols form dispersion forces and hydrogen bonds with water.</li> <li>• Ethanol and water both have hydrogen bonding as their predominant type of intermolecular force.</li> <li>• The energy required to disrupt the hydrogen bonds in the ethanol and water are comparable to the energy released during the formation of the hydrogen bonds between the ethanol and water molecules and so dissolution occurs.</li> <li>• The predominant type of intermolecular force in decan-1-ol is dispersion forces.</li> <li>• The energy released during the formation of dispersion forces with water and decan-1-ol is not sufficient to disrupt the dispersion forces between the decan-1-ol molecules and so dissolving does not occur.</li> </ul> <p style="text-align: center;"><b>or</b></p> <p><b>Strength of attraction response</b></p> <ul style="list-style-type: none"> <li>• In order for a substance to dissolve, the strength of intermolecular forces formed must be sufficient to disrupt the intermolecular forces between the solute molecules and between the solvent molecules.</li> <li>• Both alcohols form dispersion forces and hydrogen bonds with water.</li> <li>• When ethanol dissolves in water, hydrogen bonds are their predominant forces of attraction between the water and the ethanol molecules.</li> <li>• The strength of the hydrogen bonds formed are sufficient to overcome the hydrogen bonds between the water molecules and the hydrogen bonds between the ethanol molecules and so dissolution occurs.</li> <li>• The predominant type of intermolecular force in decan-1-ol is dispersion forces.</li> <li>• The strength of the dispersion forces formed between decan-1-ol molecules and water is insufficient to disrupt the dispersion forces between the (much larger) decan-1-ol molecules and so dissolving does not occur.</li> </ul>	1–6
	<p>Appropriate labelled diagrams showing interactions between solute and solvent, for example</p> <ul style="list-style-type: none"> <li>• Diagram showing the hydrogen bonding between the ethanol and water molecules.</li> <li>• Diagram showing the dispersion forces between decan-1-ol.</li> </ul>	1–2
<b>Total</b>	<b>8</b>	

2020  
Section 2  
Question  
34

Chemical  
synthesis

The Haber process is used to make ammonia. The balanced equation for the process is:



The Haber process provides challenges for industrial operators in relation to the rate of ammonia production and the ammonia yield. This is reflected in the following quotation taken from *Chemistry and Engineering News*:

**Copyright restrictions prohibit the release of this SCSA exam material.**

(a) State whether you agree with the claims about the effects of temperature on the yield of ammonia. Justify your statement using Le Châtelier's Principle. (4 marks)

Description	Marks
Applying Le Châtelier's Principle to this system, if the temperature is raised (goes from low to high temperature) then the reverse reaction is favoured <b>or</b> Applying Le Châtelier's Principle to this system, if the temperature is reduced (goes from high to low temperature) the forward reaction is favoured.	1
This is because the reverse reaction uses heat (it is endothermic) decreasing the temperature of the system <b>or</b> This is because the forward reaction produces heat (it is exothermic) increasing the temperature of the system.	1
The result is that less ammonia is made (yield decreases) at higher temperatures <b>or</b> The result is that more ammonia is made (yield increases) at lower temperatures.	1
The quote's claims about the effect of temperature on the yield of ammonia are, therefore, correct.	1
<b>Total</b>	<b>4</b>
Note:	
<ul style="list-style-type: none"> <li>Agreement/disagreement without any justification is not worth any marks.</li> </ul>	

(b) State whether you agree with the claims about the effects of temperature on the rate of the Haber process. Justify your statement using collision theory. (6 marks)

Description	Marks
<p><b>Option One</b> (from the perspective of low temperature):</p> <ul style="list-style-type: none"> <li>lower temperatures decrease the average kinetic energy of the particles</li> <li>fewer collisions will have energy higher than the activation energy.</li> <li>a smaller <u>proportion</u> of the collisions are, therefore, successful</li> <li>particles are also moving slower so collide less <u>frequently</u></li> <li>the result is that the reaction rate decreases as the temperature decreases</li> <li>the quote's claim about the effect of temperature on the rate of the reaction is thus correct.</li> </ul> <p><b>or</b></p> <p><b>Option Two</b> (from the perspective of high temperature):</p> <ul style="list-style-type: none"> <li>higher temperatures increase the average kinetic energy of the particles</li> <li>more collisions have energy higher than the activation energy</li> <li>a greater <u>proportion</u> of the collisions are, therefore, successful</li> <li>particles are also moving faster so collide more <u>frequently</u></li> <li>the result is that the reaction rate increases as the temperature increases</li> <li>the quote's claim about the effect of temperature on the rate of the reaction is thus correct.</li> </ul>	1–6
<b>Total</b>	<b>6</b>
Note:	
<ul style="list-style-type: none"> <li>Agreement/disagreement without any justification is not worth any marks.</li> <li>For both approaches, allocate one mark for each dot point.</li> </ul>	



**2019  
Section 2  
Question  
32**

**Chemical  
synthesis**

From a measuring cylinder, 34.0 mL of 0.114 mol L<sup>-1</sup> nitric acid, HNO<sub>3</sub> (aq), is added to a flask containing 44.5 mL of 0.0556 mol L<sup>-1</sup> solution of calcium hydroxide, Ca(OH)<sub>2</sub> (aq). Determine the pH of the final solution.

Description	Marks
n(H <sup>+</sup> ) = 0.034 x 0.114 = 3.876 x 10 <sup>-3</sup> mol	1
shows ratio of either H <sup>+</sup> to OH <sup>-</sup> or HNO <sub>3</sub> to Ca(OH) <sub>2</sub>	1
n(OH <sup>-</sup> ) = 0.0445 x 0.0556 x 2 = 4.9484 x 10 <sup>-3</sup> mol	1
As n(H <sup>+</sup> ) : n(OH <sup>-</sup> ) is 1:1,	1
H <sup>+</sup> is the limiting reagent due to smaller number of moles (or other justification)	1
n(OH <sup>-</sup> excess) = 4.9484 x 10 <sup>-3</sup> - 3.876 x 10 <sup>-3</sup> mol = 1.0724 x 10 <sup>-3</sup> mol	1
[OH <sup>-</sup> ] = 1.072 x 10 <sup>-3</sup> / 0.0785 = 0.01366 mol L <sup>-1</sup>	1
[H <sup>+</sup> ] = 1 x 10 <sup>-14</sup> / 0.01366 = 7.32 x 10 <sup>-13</sup> mol L <sup>-1</sup>	1
pH = -log 7.32 x 10 <sup>-13</sup> = 12.1	1
<b>Total</b>	<b>9</b>

Marking Guide – Section 3

2023  
Section 3  
Question  
39  
  
Chemical  
synthesis

Ethanol can be produced either from plant materials or from petrochemical sources.

(a) When ethanol is produced from plant sources, the material is ground up. The starches and cellulose in the material are then converted into sugars. Yeast or zymase is mixed with the sugars at 25 to 37°C and a pH of between 3 and 5 at atmospheric pressure. The products of the fermentation process are ethanol and carbon dioxide.

(i) Justify the conditions used for fermentation. (2 marks)

Description	Marks
Recognition that yeast/zymase are enzymes	1
Recognition that enzymes are only effective in a narrow pH band and temperature band or Recognition that without the enzymes, reaction either does not proceed or is too slow to be viable	1
<b>Total</b>	<b>2</b>

(ii) Write an equation for the fermentation process, using C<sub>6</sub>H<sub>12</sub>O<sub>6</sub> as the sugar. Use condensed structures in your equation. (2 marks)

Description	Marks
Correct reactants and products	1
Correct balancing	1
<b>Total</b>	<b>2</b>
C <sub>6</sub> H <sub>12</sub> O <sub>6</sub> → 2 CH <sub>3</sub> CH <sub>2</sub> OH + 2 CO <sub>2</sub>	

Ethanol can also be produced by the endothermic hydration of ethene. This is carried out at 250 to 300 °C and 6000 to 7000 kPa in the presence of an acid catalyst.

(b) (i) Write an equation for the hydration of ethene. Use condensed structures in your equation. (3 marks)

Description	Marks
Correct reactants	1
Correct products	1
Uses condensed structures in equation	1
<b>Total</b>	<b>3</b>
CH <sub>2</sub> CH <sub>2</sub> + H <sub>2</sub> O ⇌ CH <sub>3</sub> CH <sub>2</sub> OH	

(ii) Justify the temperature and pressure used for the hydration of ethene. (5 marks)

Response for the reaction being endothermic.

Description	Marks
Recognition that high pressure increases rate of reaction as there are more particles per unit volume, therefore a greater frequency of collisions	1
Recognition that high pressure also increases yield due to it favouring the direction with the fewer number of gas particles which is the product side of the reaction	1
Recognition that high temperature will increase rate as the particles are moving more rapidly and collide more often, as well as more particles having sufficient energy for successful collision, so greater proportion of collisions will be successful	1
Recognition that because hydration of ethene is endothermic, high temperature will favour the formation of the products	1
Recognition that, although high temperature favours both rate and yield, a moderate temperature will produce economical/safe yield	1
<b>Total</b>	<b>5</b>

Alternative response for the reaction being exothermic.

Description	Marks
Recognition that high pressure increases rate of reaction as there are more particles per unit volume, therefore a greater frequency of collisions	1
Recognition that high pressure also increases yield due to it favouring the direction with the fewer number of gas particles which is the product side of the reaction	1
Recognition that high temperature will increase rate as the particles are moving more rapidly and collide more often, as well as more particles having sufficient energy for successful collision, so greater proportion of collisions will be successful	1
Recognition that because hydration of ethene is exothermic, high temperature will favour the formation of the reactants	1
Recognition that, high temperature favours rate and a low temperature favours yield, a moderate temperature will be an appropriate compromise.	1
<b>Total</b>	<b>5</b>

(c) State **three** reasons why the fermentation process to produce ethanol is more common than the hydration of ethene. (3 marks)

Description	Marks
Any three of	
<ul style="list-style-type: none"> <li>fermentation requires less energy input than hydration of ethene</li> <li>fermentation costs less than hydration of ethene</li> <li>fermentation is a 'greener' process than hydration of ethene</li> <li>fermentation uses a renewable feedstock while hydration of ethene does not.</li> </ul>	1–3
<b>Total</b>	<b>3</b>
Accept other relevant answers.	

2022  
Section 3  
Question  
36

Chemical  
synthesis

Compare soaps and detergents in terms of the following:

(a) structure (2 marks)

Description	Marks
Recognition that soaps and detergents both contain a long (non-polar) hydrocarbon chain.	1
Recognition that soaps contain a carboxylate group whereas detergents contain a sulfonate group.	1
<b>Total</b>	<b>2</b>

(b) cleaning action; include a labelled diagram to illustrate the cleaning action(s) (7 marks)

Description	Marks
Recognition that soaps and detergents have the same cleaning action.	1
Labelled drawing of a micelle with correct orientation of charged group and non-polar chain, e.g.	1–2
Recognition that charged groups are soluble in water through ion-dipole attraction.	1
Recognition that chains are non-polar (and aggregate together).	1
Recognition that non-polar grease/dirt aggregates with the hydrocarbon chains within the micelle through dispersion forces.	1
Recognition that grease/dirt becomes 'soluble'/suspended in water and washed away via agitation.	1
<b>Total</b>	<b>7</b>
Accept labelled diagrams showing the non-polar ends sticking into the grease and the polar/charged ends outwards from the grease	

(c) properties in hard water. (3 marks)

Description	Marks
Recognition that cleaning action of soap is diminished in hard water whereas detergents are effective.	1
Recognition that hard water contains (divalent) cations such as $\text{Ca}^{2+}/\text{Mg}^{2+}$ .	1
Recognition that the $\text{Ca}^{2+}$ salts of soaps are insoluble in water and precipitate to form 'soap scum' and the $\text{Ca}^{2+}$ salts of detergents are soluble in water.	1
<b>Total</b>	<b>3</b>

**2020  
Section 3  
Question  
39**

**Chemical  
synthesis**

Fluorescent lights are glass tubes which are coated on the inside with rare earth metal phosphates (such as cerium, lanthanum and terbium phosphates) that provide light. Cerium, lanthanum and terbium are expensive, so are recovered once the fluorescent light is no longer functional.

The key steps in one method proposed for recovery of these rare earth metals are summarised below:

- **Step 1:** Physical separation of the rare earth metal phosphates from the glass and any metallic components. This gives an impure powder consisting of cerium, lanthanum and terbium phosphates.
- **Step 2:** Add excess solid sodium carbonate to the powder and heat, completely converting each rare earth metal phosphate to its corresponding oxide, as shown by the following balanced equations:  
$$2 \text{LaPO}_4(\text{s}) + 3 \text{Na}_2\text{CO}_3(\text{s}) \rightarrow \text{La}_2\text{O}_3(\text{s}) + 2 \text{Na}_3\text{PO}_4(\text{s}) + 3 \text{CO}_2(\text{g})$$
$$4 \text{CePO}_4(\text{s}) + 6 \text{Na}_2\text{CO}_3(\text{s}) + \text{O}_2(\text{g}) \rightarrow 4 \text{CeO}_2(\text{s}) + 4 \text{Na}_3\text{PO}_4(\text{s}) + 6 \text{CO}_2(\text{g})$$
$$2 \text{TbPO}_4(\text{s}) + 3 \text{Na}_2\text{CO}_3(\text{s}) \rightarrow \text{Tb}_2\text{O}_3(\text{s}) + 2 \text{Na}_3\text{PO}_4(\text{s}) + 3 \text{CO}_2(\text{g})$$
- **Step 3:** Wash the product from Step 2 with water.
- **Step 4:** Add hydrochloric acid to the washed product from Step 3 to leach (dissolve) only the rare earth metal oxides.
- **Step 5:** Use solvent extraction to separate the different rare earth metals from each other and create separate solutions of each of them.
- **Step 6:** Add oxalic acid to the separated solutions to precipitate the rare earth metal ions as oxalate salts.
- **Step 7:** Heat the oxalate salts to recover the rare earth metals as pure oxides, namely  $\text{La}_2\text{O}_3$ ,  $\text{Tb}_4\text{O}_7$  and  $\text{CeO}_2$ .

A chemist used the above procedure to determine the percentage by mass of lanthanum, terbium and cerium in some fluorescent lights and, after completing Step 1, had recovered 1.20 kg of the coating chemicals.

(a) At the completion of Step 2, the mass of the mixture had decreased by 11.3 g. Calculate the mass of sodium carbonate that reacted with the rare earth metal phosphates. (3 marks)

Description	Marks
$n(\text{CO}_2) = 11.3/44.01 = 0.257 \text{ mol}$	1
$n(\text{CO}_2) = n(\text{C}) = n(\text{Na}_2\text{CO}_3) = 0.257 \text{ mol}$	1
$m(\text{Na}_2\text{CO}_3) = 0.257 \times 105.99 = 27.2 \text{ g}$	1
<b>Total</b>	<b>3</b>

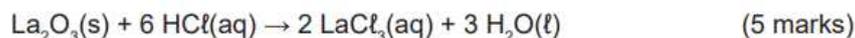
Note:

- Mass loss is due to  $\text{CO}_2(\text{g})$ .

The mass of the solid sent from Step 3 to Step 4 was 1.16 kg. This solid was leached with 6.00 mol L<sup>-1</sup> HCl at a solid to liquid ratio of 150 g per litre. Analysis of the solution at the end of leaching showed that it contained lanthanum, terbium and cerium, with its lanthanum concentration being 8.65 x 10<sup>-3</sup> mol L<sup>-1</sup>.

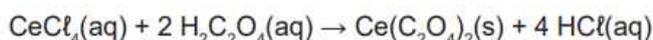
(b) Calculate the percentage, by mass, of lanthanum in the fluorescent light coating chemical, given that the leaching efficiency for lanthanum was 86%.

Note that the balanced equation for the leaching of lanthanum with hydrochloric acid is:



Description	Marks
Volume of HCl used: 1160/150 = 7.73 L	1
$n(\text{La}) = cV = 8.65 \times 10^{-3} \times 7.73 = 0.0669 \text{ mol La in solution}$	1
Taking into account the leaching efficiency, $n(\text{La in the solid that was leached}) = 0.0669/0.86 = 0.0778$	1
$m(\text{La in the solid that was leached}) = 0.0778 \times 138.9 = 10.8 \text{ g}$	1
$\% \text{ La in the coating chemical} = (10.8/1200) \times 100 = 0.900\%$	1
<b>Total</b>	<b>5</b>

Analysis of the cerium-containing solution produced in Step 5 showed that its cerium concentration was 0.146 mol L<sup>-1</sup>. This solution, which had a volume of 424 mL, was added to 110 mL of aqueous 1.15 mol L<sup>-1</sup> oxalic acid during Step 6, resulting in the precipitation of cerium oxalate, Ce(C<sub>2</sub>O<sub>4</sub>)<sub>2</sub>. The balanced equation for this reaction is:



(c) Did the chemist add enough oxalic acid solution to precipitate all of the cerium? Use calculations to support your answer. (4 marks)

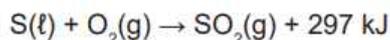
Description	Marks
$n(\text{cerium}) = 0.146 \times 0.424 = 0.0619 \text{ mol}$	1
$n(\text{oxalic acid needed to react with cerium})$ $= 2 \times 0.0619$ $= 0.124 \text{ mol}$	1
$n(\text{oxalic acid available}) = 0.110 \times 1.15 = 0.127 \text{ mol}$	1
comparison of the moles of oxalic acid shows that enough oxalic acid was added	1
<b>Total</b>	<b>4</b>

**2021  
Section 3  
Question  
38**

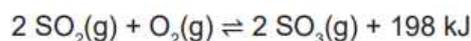
**Chemical  
synthesis**

Sulfuric acid is manufactured by the Contact process, the steps of which are outlined below.

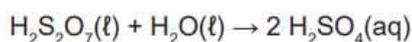
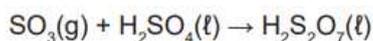
Step One: Molten sulfur is burned in air at approximately 1000 °C:



Step Two: The resulting sulfur dioxide is converted to sulfur trioxide as shown in the following equilibrium reaction. It is conducted at a temperature of about 450 °C with a V<sub>2</sub>O<sub>5</sub> catalyst at a pressure of between 100 and 200 kPa:



Step Three: The resulting sulfur trioxide is absorbed into sulfuric acid, producing oleum ( $\text{H}_2\text{S}_2\text{O}_7$ ). Water is added to the oleum, producing 18 mol  $\text{L}^{-1}$  sulfuric acid:



Use your understanding of collision theory and chemical equilibrium to discuss the reaction conditions for Steps 1 and 2 of the Contact process, given that the aim is to produce the greatest yield in the shortest time. In your discussion, also address economic concerns where appropriate.

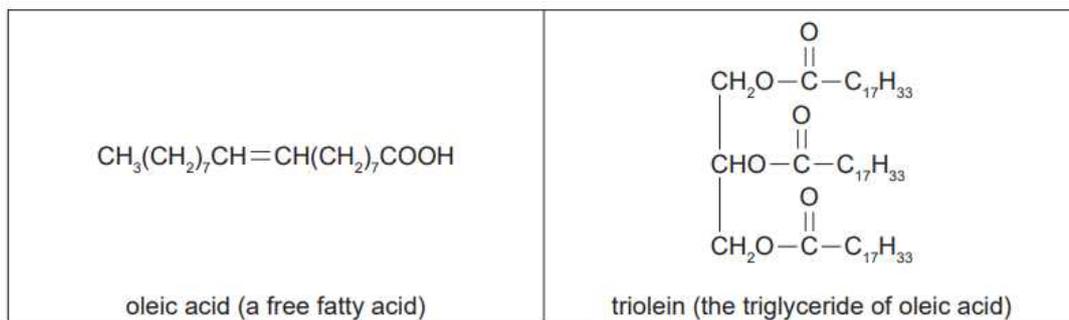
Description	Marks
<p><b>Rates</b></p> <ul style="list-style-type: none"> <li>High temperature increases the average kinetic energy of the particles, which means that the particles collide more frequently.</li> <li>Also, more of these collisions will have energy higher than the activation energy, which means a greater proportion of collisions are successful, and the reaction rate increases.</li> <li>The vanadium catalyst increases the rate of the forward reaction (and also the rate of the reverse reaction to an equal extent) as it provides an alternative pathway with a lower activation energy.</li> <li>(Therefore, a greater proportion of the particles will have sufficient energy to react when they collide.)</li> <li>High pressure (concentration) has more particles per unit volume and so there is a higher frequency of collisions, and the reaction rate increases.</li> <li>As Step 1 is a combustion reaction, it essentially goes to completion at the high temperature (and does not require a catalyst or high pressure).</li> <li>For Step 2, high temperature, high pressure and catalyst would favour high rate.</li> </ul>	1–6
<p><b>Equilibrium</b> Only considered for Step 2</p> <ul style="list-style-type: none"> <li>High temperature favours the reverse reaction because it is endothermic, and this decreases the <math>\text{SO}_3(\text{g})</math> yield (which is not desired).</li> <li>A low temperature decreases the rate of reaction (which is also not desired).</li> <li>A high pressure favours the forward reaction because there are a greater number of moles of gas reactants, (increasing the <math>\text{SO}_3(\text{g})</math> yield which is desired).</li> </ul>	1–3
<p><b>Economics</b> High pressures are costly (and dangerous).</p>	1
<p><b>Compromise</b></p> <ul style="list-style-type: none"> <li>For Step 2, a compromise is required between the high temperature for rate and the low temperature for yield.</li> <li>A compromise is also required between the cost of higher pressures and the pressure that allows a satisfactory yield and rate.</li> </ul>	1–2
<b>Total</b>	<b>12</b>

**2020  
Section 3  
Question  
40**

**Chemical  
synthesis**

Thousands of fast-food outlets across Australia use vegetable oil in cooking. Large volumes of vegetable oil waste are thus produced and need to be disposed of. A disposal option is turning the vegetable oil waste into biodiesel.

Vegetable oil waste is a mixture of free fatty acids and triglycerides. Triolein, the triglyceride of the free fatty acid oleic acid, is typically present in large amounts. The condensed structural formulae of oleic acid and triolein are shown below.



(a) Write a balanced equation, using condensed structural formulae, to show the formation of biodiesel from triolein and ethanol. Assume that a suitable catalyst is present. (3 marks)

Description	Marks
$\begin{array}{c} \text{O} \\    \\ \text{CH}_2\text{O}-\text{C}-\text{C}_{17}\text{H}_{33} \\   \\ \text{O} \\    \\ \text{CHO}-\text{C}-\text{C}_{17}\text{H}_{33} \\   \\ \text{O} \\    \\ \text{CH}_2\text{O}-\text{C}-\text{C}_{17}\text{H}_{33} \end{array} + 3 \text{CH}_3\text{CH}_2\text{OH} \rightarrow 3 \text{C}_{17}\text{H}_{33}\text{COOCH}_2\text{CH}_3 + \begin{array}{c} \text{CH}_2-\text{OH} \\   \\ \text{CH}-\text{OH} \\   \\ \text{CH}_2-\text{OH} \end{array}$	
glycerol (glycerin) is shown as a reaction product	1
biodiesel formula is correct and shown as a reaction product	1
equation balanced correctly	1
<b>Total</b>	<b>3</b>
<b>Note:</b> <ul style="list-style-type: none"> <li>Do not deduct marks if full structural formulae are drawn for any or all substances involved in the reaction.</li> </ul>	

(b) Lipase is a protein that can be used to catalyse the reaction between triolein and ethanol. To which class of biological chemicals (other than proteins) does lipase belong? (1 mark)

Description	Marks
enzyme	1
<b>Total</b>	<b>1</b>

The free fatty acids found in vegetable oil waste will react with the ethanol that was intended for biodiesel synthesis, establishing an equilibrium.

(c) Complete the following equation to show the equilibrium that is established between oleic acid and ethanol. Represent all organic substances as condensed structural formulae and assume acidic conditions. (2 marks)

Description	Marks
Reaction products: $\text{CH}_3(\text{CH}_2)_7\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOCH}_2\text{CH}_3 + \text{H}_2\text{O}$	
the ester product formula is correct	1
water is shown as a reaction product	1
<b>Total</b>	<b>2</b>
Note: <ul style="list-style-type: none"> <li>Do not deduct marks if full structural formulae are drawn for any or all substances involved in the reaction.</li> </ul>	

In an industrial setting, reaction conditions are adjusted to favour the forward direction of the oleic acid/ethanol equilibrium.

(d) Identify **two** different actions that can be carried out to favour the forward direction of this equilibrium. (2 marks)

Description	Marks
Removing the biodiesel/ester as it forms	1
Removing water as it forms	1
<b>Total</b>	<b>2</b>
Note: Also accept <ul style="list-style-type: none"> <li>decrease the temperature of the reaction</li> <li>increase concentration of ethanol</li> <li>increase the concentration of oleic acid.</li> </ul>	

The base sodium hydroxide can also catalyse the reaction between triolein and ethanol. The free fatty acids in the vegetable oil waste also react with the base.

(e) (i) Write a balanced equation showing the reaction of oleic acid with sodium hydroxide. Represent all organic substances as condensed structural formulae. (2 marks)

Description	Marks
$\text{CH}_3(\text{CH}_2)_7\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH} + \text{NaOH} \rightarrow$ $\text{CH}_3(\text{CH}_2)_7\text{CH}=\text{CH}(\text{CH}_2)_7\text{COO}^-\text{Na}^+ + \text{H}_2\text{O}$	
the formula of the soap product is correct	1
water is shown as a reaction product	1
<b>Total</b>	<b>2</b>
Note: <ul style="list-style-type: none"> <li>Do not deduct marks if full structural formulae are drawn for any or all substances involved in the reaction.</li> <li>Na is not required for full marks i.e. accept ionic equation.</li> <li>+/- on soap product is not required for full marks.</li> </ul>	

(ii) To which class of compounds does the organic product of this reaction belong? (1 mark)

Description	Marks
soaps/salts/carboxylate/alkene	1
<b>Total</b>	<b>1</b>

(f) Which of the catalysts, lipase or sodium hydroxide, is more likely to be the industrially preferred catalyst when using vegetable oil waste to make biodiesel? Justify your answer. (3 marks)

**No mark is allocated for the choice of catalyst.**

Description	Marks
Sodium hydroxide is most likely preferred in industrial settings	
Any three of the following: <ul style="list-style-type: none"><li>• can operate at high temperatures making conversion quicker</li><li>• cost effective</li><li>• sodium hydroxide cheaper</li><li>• higher yield</li><li>• more readily available</li><li>• not pH or temperature sensitive.</li></ul>	1–3
<b>Total</b>	<b>3</b>
Accept other relevant answers.	

or

Description	Marks
Lipase is most likely preferred in industrial settings	
Any three of the following: <ul style="list-style-type: none"><li>• this is to avoid contaminating the biodiesel with soap</li><li>• requires less energy</li><li>• can be reused many times</li><li>• operates at a lower temperature</li><li>• catalyst less harmful.</li></ul>	1–3
<b>Total</b>	<b>3</b>
Accept other relevant answers.	
Note: <ul style="list-style-type: none"><li>• Stating only 'environmentally friendly' without reasoning is too vague.</li></ul>	

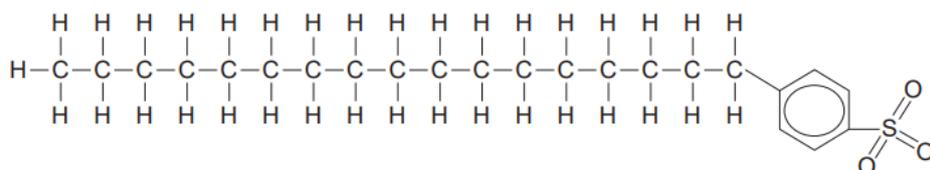
(g) Other than the recycling of vegetable oil waste, give two different reasons why the production of biodiesel from vegetable oil waste is an example of green chemistry but the production of diesel from fossil fuels is not. Each of your reasons needs to contrast biodiesel and fossil fuel diesel. (2 marks)

Description	Marks
Any two of the following: <ul style="list-style-type: none"><li>• it uses a renewable feed stock (plants, as the ultimate source of its raw materials) but fossil fuel diesel (uses resources that take millions of years to form/) are non-renewable</li><li>• the synthesis of biodiesel from vegetable oil waste does not require as much expensive/complex equipment as is the case for using fossil fuels</li><li>• the synthesis of biodiesel from vegetable oil waste does not require the use of high temperatures, unlike the production from fossil fuels. This means that the carbon footprint of biodiesel is less.</li></ul>	1–2
<b>Total</b>	<b>2</b>
Accept other relevant reasons.	
Note: <ul style="list-style-type: none"><li>• To be awarded the mark, each reason must mention biodiesel vs fossil fuel diesel.</li></ul>	

2019  
Section 3  
Question  
37

Chemical  
synthesis

Detergents and soaps are both used as cleaning agents. The general structure of a detergent is given below.



(a) Explain how detergents are able to remove grease from a surface by referring to the intermolecular forces present. Include a labelled diagram to illustrate your answer. (7 marks)

Description	Marks
Recognition that:	
• that the non-polar tail of the detergent ion exhibits dispersion forces	1
• which are similar in strength to, and so can overcome, the dispersion forces that exist between the oil molecules and so will dissolve in them	1
Recognition that:	
• that the charged head of the detergent ion exhibits stronger ion-dipole forces of attraction (and hydrogen bonds) with water molecules	1
• and so overcoming the hydrogen bonding between the water molecules dissolves preferentially in water	1
Demonstrates an understanding that	
• the grease/oil micelles formed remain suspended in the water and with agitation, can be removed	1
Labelled diagram illustrates:	
• 'tail – grease' interaction (dispersion- dispersion) interaction	1
• 'head– water' (ion-dipole) interaction.	1
For copyright reasons this text cannot be reproduced in the online version of this document, but may be viewed at the link listed on the acknowledgements page.	
<b>Total</b>	<b>7</b>
<b>Note:</b>	
• Can be answered in terms of having sufficient energy to overcome the forces of attraction.	
• Maximum one mark if diagram not clearly labelled.	

Detergents are considered to be more versatile cleaners than soap.

(b) Explain why soaps are generally less effective than detergents as cleaning agents in hard water. Include a relevant equation in your answer. (4 marks)

Description	Marks
Detergents do not combine with the ions present in hard water (e.g. $\text{Ca}^{2+}$ or $\text{Mg}^{2+}$ ) to form insoluble precipitates	1
When the precipitate forms with soap (scum) the soap ions are no longer available to form micelles/not available to act as a cleaning agent	1
Equation:	
One mark for valid products and reactants with $n > 12$	1
One mark for correct balancing	1
Example: $\text{Ca}^{2+}(\text{aq}) + 2 \text{CH}_3(\text{CH}_2)_n\text{COO}^-(\text{aq}) \rightarrow \text{Ca}(\text{CH}_3(\text{CH}_2)_n\text{COO})_2(\text{s})$	
<b>Total</b>	<b>4</b>
<b>Note:</b>	
• Any soap molecule is acceptable.	

Alkenes can also form soaps.

(c) Draw a structural diagram for the soap ion,  $C_{17}H_{31}CO_2^-$  – using the incomplete structure below. Show **all** atoms and bonds. (2 marks)

Description	Marks
Structural diagram includes:	
• $COO^-$	1
• all bonds including both double bonds.	1
<b>Total</b>	<b>2</b>
Example of a two mark response:	
$  \begin{array}{cccccccccccccccccccc}  & H & & H & H & H & H & H & H & H & H & H & H & H & H & & H & O^- \\  &   & &   &   &   &   &   &   &   &   &   &   &   &   & &   &   \\  H & - C & - C & = C & - C & - C & - C & - C & - C & - C & - C & - C & - C & - C & - C & = C & - C & - C = O \\  &   &   & &   &   &   &   &   &   &   &   &   &   & &   &   \\  & H & H & & H & H & H & H & H & H & H & H & H & H & & H & H  \end{array}  $	
<b>Note:</b>	
• One triple bond instead of two double bonds is acceptable.	

(d) Write an equation showing the formation of this soap from the fat (triglyceride) shown below. (3 marks)

Description	Marks
Equation has:	
• a hydroxide with the fat	1
• correct products	1
• correct balancing.	1
<b>Total</b>	<b>3</b>
Example of a three mark response:	
$  \begin{array}{ccccccc}  C_{17}H_{31}COOCH_2 & & & & & & CH_2OH \\    & & & & & &   \\  C_{17}H_{31}COOCH & + & 3 OH^-(aq) & \rightleftharpoons & 3 C_{17}H_{31}COO^- & + & CHOH \\    & & & & & &   \\  C_{17}H_{31}COOCH_2 & & & & & & CH_2OH  \end{array}  $	
<b>Note:</b>	
• No mark penalty for using molecular versions with KOH or NaOH.	

The formation of soap is both an endothermic and equilibrium reaction.

(e) Predict and explain the conditions that would result in the highest yield of soap in the shortest amount of time. (8 marks)

Description	Marks
Predicts high temperature	1
Explains high temperature and higher rate due to:	
<ul style="list-style-type: none"> <li>a greater proportion of particles having sufficient energy to react when they collide</li> </ul>	1
<ul style="list-style-type: none"> <li>a higher frequency of collision as the average kinetic energy of the particles is higher.</li> </ul>	1
<ul style="list-style-type: none"> <li>higher yield as the forward rate will increase more than the reverse rate when temperature is increased.</li> </ul>	1
Predicts high concentration of (sodium/potassium) hydroxide solution	1
Explains high concentration of sodium hydroxide solution and higher rate due to:	
<ul style="list-style-type: none"> <li>(more particles present in same volume, therefore) greater frequency of collisions and so greater number of successful collisions</li> </ul>	1
<ul style="list-style-type: none"> <li>higher yield as forward reaction will be faster than reverse reaction until equilibrium re-established.</li> </ul>	1
States agitation or removal	
Agitation will increase the surface area, increasing the contact/collisions between reacting particles and hence rate (will have no impact on yield) <b>or</b> Removal of product (soap/glycerol) as produced to minimise/inhibit reverse reaction	1
<b>Total</b>	<b>8</b>
<p><b>Note:</b></p> <ul style="list-style-type: none"> <li>In order to achieve full marks, students must refer to the collision theory and reference both rate and yield for temperature and concentration of sodium hydroxide.</li> <li>Pressure changes do not affect this reaction.</li> <li>Oil/grease does not have a concentration and should not be referred to.</li> <li>Catalysts are not used in saponification. No penalty if a catalyst is referenced. Candidates do not need to state that catalysts have no effect on yield.</li> </ul>	

**2019  
Section 3  
Question  
40**

**Chemical  
synthesis**

A chemist was developing a new method for extracting lithium metal from ores rich in the mineral lepidolite. The procedure being proposed by the chemist is as follows:

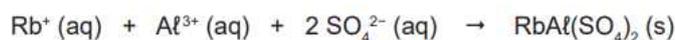
Step 1	crush and grind the ore
Step 2 (Leach)	add sulfuric acid to the crushed ore to dissolve lepidolite (and other soluble ore constituents)
Step 3	add reagents to the leach solution that will precipitate unwanted soluble species
Step 4	recover lithium as lithium carbonate.

In a test of Step 2, performed by the chemist, 5.0 L of sulfuric acid, which was in excess, was added to a crushed and ground sample of a lepidolite-containing ore.

The leach solution was analysed and found to contain sulfate ions and hydrogen ions from the sulfuric acid and the ions stated in the table below.

Ions present	Concentration
Li <sup>+</sup>	2.13 g L <sup>-1</sup>
Rb <sup>+</sup>	1.30 g L <sup>-1</sup>
Al <sup>3+</sup>	1.86 g L <sup>-1</sup>
Fe (as Fe <sup>2+</sup> and Fe <sup>3+</sup> )	1.27 g L <sup>-1</sup>

The chemist tried to remove the rubidium and aluminium ions from the leach solution by cooling the solution to 5.00 °C so as to precipitate them as rubidium alum, RbAl(SO<sub>4</sub>)<sub>2</sub>. The equation is shown below.



The chemist found that, while all of the Rb<sup>+</sup> precipitated, there was a considerable quantity of Al<sup>3+</sup> ions still dissolved in the leach solution.

(a) Calculate the concentration of Al<sup>3+</sup> ions remaining in the 5.0 L of leach solution. Give your answer in grams per litre (g L<sup>-1</sup>) to the appropriate number of significant figures. (9 marks)

Description	Marks
In 5.0 L m(Rb <sup>+</sup> ) = 1.30 x 5.0 = 6.5 g	1
n(Rb <sup>+</sup> ) = m/M = 6.5 / 85.47 = 0.07605 mol	1
n(Al <sup>3+</sup> ) reacting = n(Rb <sup>+</sup> ) = 0.07605 mol	1
m(Al <sup>3+</sup> ) initially present in 5.0 L = 1.86 x 5.0 = 9.3 g	1
n(Al <sup>3+</sup> ) initially present in 5.0 L = 9.3 / 26.98 = 0.34469 mol	1
n(Al <sup>3+</sup> ) left in 5.0 L = 0.34469 – 0.07605 = 0.26864 mol	1
c(Al <sup>3+</sup> ) = 0.26864 / 5.0 = 0.05372 mol L <sup>-1</sup>	1
= 0.05372 x 26.98 = 1.44963 g L <sup>-1</sup>	1
= 1.4 g L <sup>-1</sup> (correct to two significant figures)	1
<b>Total</b>	<b>9</b>
<b>Note:</b>	
• Allow for follow-through marks.	

To remove the remaining  $\text{Al}^{3+}$  ions from the leach solution, the chemist added 2.63 L of a  $0.0550 \text{ mol L}^{-1}$   $\text{K}_2\text{SO}_4$  solution, with the result being the precipitation of potassium alum as shown in the equation below.



The sulfate ions remained in excess due to the initial addition of sulfuric acid.

(b) Was sufficient  $\text{K}_2\text{SO}_4$  solution added to precipitate all of the  $\text{Al}^{3+}$  ions remaining in the leach solution? Justify your answer with relevant calculations. (4 marks)

Description	Marks
$n(\text{K}_2\text{SO}_4) \text{ added} = c(\text{K}_2\text{SO}_4) \times v(\text{K}_2\text{SO}_4)$ $= 2.63 \times 0.055$ $= 0.14465 \text{ mol}$	1
$n(\text{K}^+) \text{ added} = 2 \times 0.14465$ $= 0.2893 \text{ mol}$	1
From equation $n(\text{K}^+) \text{ required} = n(\text{Al}^{3+})$ $= 0.26864 \text{ mol (from Part a)}$	1
$n(\text{K}^+) \text{ added (0.2893 mol)} > n(\text{K}^+) \text{ required (0.26864 mol)}$ Therefore sufficient $\text{K}_2\text{SO}_4$ added to precipitate all the $\text{Al}^{3+}$	1
<b>Total</b>	<b>4</b>
<b>Note:</b>	
<ul style="list-style-type: none"> <li>Allow for follow-through marks, from part (a) and also in part (b).</li> </ul>	

The final purification step was the removal of iron from the leach solution. To do this the chemist added a suitable oxidant ( $1.00 \text{ mol L}^{-1}$  hydrogen peroxide) to convert all of the  $\text{Fe}^{2+}$  ions to  $\text{Fe}^{3+}$  ions. The chemist then added excess sodium hydroxide solution to precipitate all of the iron (now present as  $\text{Fe}^{3+}$  ions) as  $\text{Fe}(\text{OH})_3$ . This precipitate, and the alum precipitates formed earlier, were removed by filtration.

(c) Write a balanced overall equation to show the conversion of  $\text{Fe}^{2+}$  to  $\text{Fe}^{3+}$  by hydrogen peroxide. (3 marks)

Description	Marks
<ul style="list-style-type: none"> <li>correct reactants</li> </ul>	1
<ul style="list-style-type: none"> <li>correct products</li> </ul>	1
<ul style="list-style-type: none"> <li>correct balancing</li> </ul>	1
<b>Total</b>	<b>3</b>
Overall equation:  $\text{H}_2\text{O}_2(\text{aq}) + 2 \text{H}^+(\text{aq}) + 2 \text{Fe}^{2+}(\text{aq}) \rightarrow 2 \text{Fe}^{3+}(\text{aq}) + 2 \text{H}_2\text{O}(\ell)$	
<b>Note:</b>	
<ul style="list-style-type: none"> <li>The overall equation is gained from:</li> </ul> $\begin{array}{l} \text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow 2\text{H}_2\text{O}(\ell) \\ 2 \times (\text{Fe}^{2+}(\text{aq}) \rightarrow \text{Fe}^{3+}(\text{aq}) + \text{e}^-) \\ \text{or} \quad 2 \text{Fe}^{2+}(\text{aq}) \rightarrow 2\text{Fe}^{3+}(\text{aq}) + 2\text{e}^- \end{array}$	

The leach solution, now free from rubidium, aluminium and iron, was heated and evaporated to dryness, yielding a lithium-rich residue. The residue was further treated to produce lithium carbonate suitable for use in lithium-ion battery manufacture, with the mass of lithium carbonate recovered being equal to 46.7 g.

(d) Calculate the percentage yield of lithium carbonate,  $\text{Li}_2\text{CO}_3$ , based on the theoretical amount that should have been recovered. Use the concentration of  $\text{Li}^+(\text{aq})$  in the table on page 42 (*start of this question*). (6 marks)

Description	Marks
$n(\text{Li}_2\text{CO}_3)$ recovered = $46.7 / 73.89$ = 0.63202 mol	1
leach solution contains $[\text{Li}^+] = 2.13 \text{ g L}^{-1}$ so, in 5.0 L there will be $2.13 \times 5.0 = 10.65 \text{ g Li}^+$	1
$n(\text{Li}^+) = 10.65 / 6.94$ = 1.53458 moles	1
$n(\text{Li}_2\text{CO}_3) = \frac{1}{2} \times 1.534582 \text{ moles}$ = 0.76729 moles	1
$\% \text{ yield} = (0.63202 / 0.76729) \times 100$ = 82.37031	1
= 82% yield	1
<b>Total</b>	<b>6</b>

## Unit 3 and 4 – Science Inquiry Skills

### Section 1

2023  
Section 1  
Question  
6-13  
  
Science  
Inquiry  
Skills

Questions 6 to 13 refer to the following information.

A student set up an experiment to investigate the relationship between the temperature of an acid and the rate of carbon dioxide production when reacted with a base. In each trial the student timed how long in seconds it took to produce 100 mL of carbon dioxide in a gas syringe. The results are shown below.

Temperature of acid (°C)	Time taken to produce 100 mL of carbon dioxide (s)
30	91
40	65
50	64
60	21

6. Which of the following is an appropriate hypothesis for this investigation?

- (a) How does temperature affect the rate of carbon dioxide production?
- (b) If 100 mL of carbon dioxide is produced, then the acid is at a low temperature.
- (c) Increasing the temperature of the acid will decrease the time taken to produce 100 mL of carbon dioxide.
- (d) Decreased volumes of carbon dioxide will be produced if the acid temperature is increased.

7. Which of the following is the dependent variable?

- (a) temperature of the acid
- (b) time to heat the acid
- (c) volume of carbon dioxide produced
- (d) time to produce 100 mL of carbon dioxide

8. Which of the following are control variables in this investigation?

- (i) volume of carbon dioxide produced
  - (ii) temperature of the acid
  - (iii) volume of the acid
  - (iv) amount of base used
  - (v) concentration of the acid
- (a) i, iii and v
  - (b) i, ii and v
  - (c) ii, iii and iv
  - (d) iii, iv and v

9. Which of the following substances would be the base used in this investigation?

- (a) sodium hydroxide
- (b) magnesium
- (c) calcium carbonate
- (d) copper oxide

	<p>10. Which of the following would improve the reliability of the data produced in this investigation?</p> <p>(i) conduct multiple trials for each temperature  (ii) change the concentration of the acid  (iii) use a range of bases to react with the acid  (iv) increase the range of temperatures investigated</p> <p>(a) ii, iii and iv  (b) i, ii and iii  (c) iii and iv only  (d) i and iv only</p> <p>11. Which of the following would be classified as a random error?</p> <p>(a) judging when 100 mL of carbon dioxide is produced  (b) heating the acid in a water bath  (c) using the same balance to weigh out the base  (d) an error in the stopwatch calibration</p> <p>12. Which of the following would be classified as a systematic error?</p> <p>(a) judging when 100 mL of carbon dioxide is produced  (b) heating the acid in a water bath  (c) using the same balance to weigh out the base  (d) an error in the stopwatch calibration</p> <p>13. Which of the following statements <b>best</b> describes the relationship between the dependent and independent variables?</p> <p>(a) The volume of carbon dioxide is decreased as the temperature decreases.  (b) As the temperature of the acid increases, the time taken to produce 100 mL of carbon dioxide decreases.  (c) The rate at which carbon dioxide is produced decreases as the temperature increases.  (d) The change in temperature has no effect on the rate of production of carbon dioxide.</p> <p>14. Identify the type of structure from the following description: An organic molecule containing a carboxylic acid group, a side chain and an amine group bound to the same carbon atom.</p> <p>(a) polyester  (b) soap  (c) <math>\alpha</math>-amino acid  (d) biodiesel</p>
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<p><b>2021</b>  <b>Section 1</b>  <b>Question</b>  <b>17</b></p> <p><b>Science</b>  <b>Inquiry</b>  <b>Skills</b></p>	<p>A chemist performed a series of titrations and published the results in a scientific journal. From the point of view of the chemist, the titration data is</p> <p>(a) primary.  (b) secondary.  (c) personal.  (d) investigative.</p>
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## Section 2

### 2020 Section 2 Question 32

#### Science Inquiry Skills

Some students were asked to identify the 'best' cleaning solvent for the removal of graffiti from concrete. They were given black spray paint and five different cleaning solvents.

The students sprayed five different 10 cm by 10 cm areas of a concrete wall with the black paint and allowed the paint to dry for 24 hours. They then used 100 mL of cleaning solvent to try to remove the black paint, with a different cleaning solvent being used for each square. The students subsequently ranked the cleaning solvents from 1 to 5 based on their ability to dissolve the black paint with 1 being the best and 5 being the worst.

The results of the students' investigation, plus some information about the composition of each cleaning solvent, are shown in the table below.

Solvent	Investigation ranking	Composition of cleaning solvent
distilled water	5	water
turpentine	2	straight-chain hydrocarbons containing ten carbon atoms and one double bond
acetone	3	propanone
white spirit	1	straight-chain hydrocarbons C7 to C12
methylated spirits	4	5% methanol, 95% ethanol

(a) Identify the independent and dependent variables in the students' investigation. (2 marks)

Independent variable	
Dependent variable	

(b) State two variables that the students needed to control in their investigation. (2 marks)

One:

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Two:

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(c) What could the students do to ensure that their investigation was:

(i) valid? (1 mark)

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(ii) reliable? (1 mark)

(d) Identify two safety risks associated with the students' investigation and state how each risk could be minimised. (4 marks)

Safety risk	How to minimise the risk

(e) Paints contain, among other things, a pigment (which is the paint colour) and a solvent (which dissolves the pigment). When paint dries, the solvent evaporates, leaving the pigment behind.

Use this information, the students' results and your knowledge of chemistry to identify the predominant type of intermolecular force occurring between the pigment molecules in the black paint used by the students. Explain your reasoning. (3 marks)

Section 3

2022  
Section 3  
Question  
39

Science  
Inquiry  
Skills

A student wanted to investigate how changing temperature would influence how rapidly oxalic acid solution would decolourise an acidified potassium permanganate solution.

The student was provided with the following chemicals and equipment:

- 0.1 mol L<sup>-1</sup> acidified potassium permanganate solution
- 0.1 mol L<sup>-1</sup> oxalic acid solution
- 250 mL conical flasks
- Bunsen burner
- tripod and gauze mat
- thermometer
- stop watches
- 5.00 mL, 10.00 mL, 20.00 mL and 25.00 mL pipettes
- distilled water
- 25.0 mL measuring cylinders.

(a) State a hypothesis for this investigation. (2 marks)

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(b) Identify the independent and dependent variables. (2 marks)

Independent variable:

Dependent variable:

(c) Identify **two** control variables. (2 marks)

One:

Two:

(d) Describe a procedure for this investigation. (6 marks)

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(e) Outline the difference between systematic and random errors. Use an example of each from this investigation to support your answer. (4 marks)

**2023  
Section 1  
Question  
6-13**

**Science  
Inquiry  
Skills**

Questions 6 to 13 refer to the following information.

A student set up an experiment to investigate the relationship between the temperature of an acid and the rate of carbon dioxide production when reacted with a base. In each trial the student timed how long in seconds it took to produce 100 mL of carbon dioxide in a gas syringe. The results are shown below.

Temperature of acid (°C)	Time taken to produce 100 mL of carbon dioxide (s)
30	91
40	65
50	64
60	21

6. Which of the following is an appropriate hypothesis for this investigation?

- (a) How does temperature affect the rate of carbon dioxide production?
- (b) If 100 mL of carbon dioxide is produced, then the acid is at a low temperature.
- (c) Increasing the temperature of the acid will decrease the time taken to produce 100 mL of carbon dioxide. – Answer**
- (d) Decreased volumes of carbon dioxide will be produced if the acid temperature is increased.

7. Which of the following is the dependent variable?

- (a) temperature of the acid
- (b) time to heat the acid
- (c) volume of carbon dioxide produced
- (d) time to produce 100 mL of carbon dioxide – Answer**

8. Which of the following are control variables in this investigation?

- (i) volume of carbon dioxide produced
  - (ii) temperature of the acid
  - (iii) volume of the acid
  - (iv) amount of base used
  - (v) concentration of the acid
- (a) i, iii and v – Answer**
- (b) i, ii and v
  - (c) ii, iii and iv
  - (d) iii, iv and v

9. Which of the following substances would be the base used in this investigation?

- (a) sodium hydroxide
- (b) magnesium
- (c) calcium carbonate – Answer**
- (d) copper oxide

	<p>10. Which of the following would improve the reliability of the data produced in this investigation?</p> <p>(i) conduct multiple trials for each temperature  (ii) change the concentration of the acid  (iii) use a range of bases to react with the acid  (iv) increase the range of temperatures investigated</p> <p>(a) ii, iii and iv  (b) i, ii and iii  (c) iii and iv only  <b>(d) i and iv only – Answer</b></p> <p>11. Which of the following would be classified as a random error?</p> <p><b>(a) judging when 100 mL of carbon dioxide is produced – Answer</b>  (b) heating the acid in a water bath  (c) using the same balance to weigh out the base  (d) an error in the stopwatch calibration</p> <p>12. Which of the following would be classified as a systematic error?</p> <p>(a) judging when 100 mL of carbon dioxide is produced  (b) heating the acid in a water bath  (c) using the same balance to weigh out the base  <b>(d) an error in the stopwatch calibration – Answer</b></p> <p>13. Which of the following statements <b>best</b> describes the relationship between the dependent and independent variables?</p> <p>(a) The volume of carbon dioxide is decreased as the temperature decreases.  <b>(b) As the temperature of the acid increases, the time taken to produce 100 mL of carbon dioxide decreases. – Answer</b>  (c) The rate at which carbon dioxide is produced decreases as the temperature increases.  (d) The change in temperature has no effect on the rate of production of carbon dioxide.</p> <p>14. Identify the type of structure from the following description: An organic molecule containing a carboxylic acid group, a side chain and an amine group bound to the same carbon atom.</p> <p>(a) polyester  (b) soap  <b>(c) <math>\alpha</math>-amino acid – Answer</b>  (d) biodiesel</p>
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<p><b>2021</b>  <b>Section 1</b>  <b>Question</b>  <b>17</b></p> <p><b>Science</b>  <b>Inquiry</b>  <b>Skills</b></p>	<p>A chemist performed a series of titrations and published the results in a scientific journal. From the point of view of the chemist, the titration data is</p> <p><b>(a) primary. – Answer</b>  (b) secondary.  (c) personal.  (d) investigative.</p>
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Marking Guide – Section 2

2020  
Section 2  
Question  
32

Science  
Inquiry  
Skills

Some students were asked to identify the ‘best’ cleaning solvent for the removal of graffiti from concrete. They were given black spray paint and five different cleaning solvents.

The students sprayed five different 10 cm by 10 cm areas of a concrete wall with the black paint and allowed the paint to dry for 24 hours. They then used 100 mL of cleaning solvent to try to remove the black paint, with a different cleaning solvent being used for each square. The students subsequently ranked the cleaning solvents from 1 to 5 based on their ability to dissolve the black paint with 1 being the best and 5 being the worst.

The results of the students’ investigation, plus some information about the composition of each cleaning solvent, are shown in the table below.

Solvent	Investigation ranking	Composition of cleaning solvent
distilled water	5	water
turpentine	2	straight-chain hydrocarbons containing ten carbon atoms and one double bond
acetone	3	propanone
white spirit	1	straight-chain hydrocarbons C7 to C12
methylated spirits	4	5% methanol, 95% ethanol

(a) Identify the independent and dependent variables in the students’ investigation. (2 marks)

Description	Marks
Independent variable = identity of the (cleaning) solvent	1
Dependent variable = the amount/extent to which the black spray paint is dissolved/removed	1
<b>Total</b>	<b>2</b>

(b) State two variables that the students needed to control in their investigation. (2 marks)

Description	Marks
Identification of one variable that needs to be controlled.	1
Identification of another (different) variable that needs to be controlled.	1
<b>Total</b>	<b>2</b>
Answers could include: <ul style="list-style-type: none"> <li>• the brand of black spray paint</li> <li>• the concrete/wall the paint is sprayed on</li> <li>• thickness of paint</li> <li>• drying temperature</li> <li>• size of the painted areas</li> <li>• drying time</li> <li>• volume of cleaning solvent used</li> <li>• method used to apply the cleaning solvent.</li> </ul>	

(c) What could the students do to ensure that their investigation was:

(i) valid? (1 mark)

Description	Marks
To make their investigation valid they will need to (either) <ul style="list-style-type: none"><li>design/perform an investigation that compares the effectiveness of different cleaning solvents on the removal of black spray paint from concrete.</li><li>ensure the control variables are controlled.</li></ul>	1
<b>Total</b>	<b>1</b>

(ii) reliable? (1 mark)

Description	Marks
To make their investigation reliable they will need to repeat their investigation several times (if they obtain consistent/reproducible results then their investigation is reliable).	1
<b>Total</b>	<b>1</b>

(d) Identify two safety risks associated with the students' investigation and state how each risk could be minimised. (4 marks)

Description	Marks
Identification of one safety risk	1
States how to minimise that risk	1
Identification of another (different) safety risk	1
States how to minimise that risk	1
<b>Total</b>	<b>4</b>

Answers could include:

- chemicals contacting the eyes, wear safety glasses
- inhalation of fumes, wear suitable mask
- chemicals contacting skin on hands, wear safety gloves
- spilling chemicals on feet, wear enclosed shoes
- spilling chemicals on exposed skin, wear enclosed shoes/gloves and/or lab coat.

Note:

- The risk must be a plausible risk for the investigation detailed in the question.
- For full marks the minimising strategy must match the risk.
- If only minimising risk box is filled in, 0 marks.

(e) Paints contain, among other things, a pigment (which is the paint colour) and a solvent (which dissolves the pigment). When paint dries, the solvent evaporates, leaving the pigment behind.

Use this information, the students' results and your knowledge of chemistry to identify the predominant type of intermolecular force occurring between the pigment molecules in the black paint used by the students. Explain your reasoning. (3 marks)

Description	Marks
The paint's pigment molecules must have dispersion forces as their predominant intermolecular force because the best solvents have dispersion forces as their predominant intermolecular force.	1
<ul style="list-style-type: none"><li>This is because for substances to be soluble in each other they must be able to disrupt the existing intermolecular forces and form new intermolecular forces with each other.</li><li>This can only be done if the intermolecular forces are of similar strength (hence they all need dispersion forces as their predominant intermolecular force).</li></ul>	1-2
<b>Total</b>	<b>3</b>

Marking Guide – Section 3

2022  
Section 3  
Question  
39

Science  
Inquiry  
Skills

A student wanted to investigate how changing temperature would influence how rapidly oxalic acid solution would decolourise an acidified potassium permanganate solution.

The student was provided with the following chemicals and equipment:

- 0.1 mol L<sup>-1</sup> acidified potassium permanganate solution
- 0.1 mol L<sup>-1</sup> oxalic acid solution
- 250 mL conical flasks
- Bunsen burner
- tripod and gauze mat
- thermometer
- stop watches
- 5.00 mL, 10.00 mL, 20.00 mL and 25.00 mL pipettes
- distilled water
- 25.0 mL measuring cylinders.

(a) State a hypothesis for this investigation. (2 marks)

Description	Marks
Writes a hypothesis that gives the relationship between the independent and dependent variables.	2
Writes a hypothesis that includes the independent and dependent variables without giving their relationship.	1
<b>Total</b>	<b>2</b>
Answer could include:	
Increasing the temperature will decrease the time taken for the acidified potassium permanganate to decolourise (change from purple to pale pink/colourless as the rate of reaction increases with increasing temperature).	
Accept other relevant answers.	

(b) Identify the independent and dependent variables. (2 marks)

Description	Marks
independent variable: temperature (of solution)	1
dependent variable: time taken (for potassium permanganate solution/mixture) to decolourise	1
<b>Total</b>	<b>2</b>
Accept other relevant answers.	

(c) Identify **two** control variables. (2 marks)

Description	Marks
Identifies control variables	1–2
<b>Total</b>	<b>2</b>
Answers could include:	
<ul style="list-style-type: none"> <li>• concentration of acidified potassium permanganate solution</li> <li>• concentration of oxalic acid solution</li> <li>• volume of acidified potassium permanganate solution</li> <li>• volume of oxalic acid solution</li> <li>• stopwatch/timer</li> <li>• person timing/observing.</li> </ul>	
Accept other relevant answers.	

(d) Describe a procedure for this investigation. (6 marks)

Description	Marks
Recognition that fixed volumes of oxalic acid and acidified potassium permanganate are used.	1–2
Recognition that temperature must be varied and measured.	1
Recognition that time must be measured from mixing.	1
Any two of the following: <ul style="list-style-type: none"><li>• recognition of appropriate method for determining end point of the reaction (decolourisation) e.g. use a white paper base</li><li>• recognition of the use of trials</li><li>• recognition of the use of appropriate glassware</li><li>• recognition that solutions are mixed in appropriate proportions e.g. 2:5 ratio of solutions.</li></ul>	1–2
<b>Total</b>	<b>6</b>

Accept other relevant answers.

(e) Outline the difference between systematic and random errors. Use an example of each from this investigation to support your answer. (4 marks)

Description	Marks
Recognises that systematic errors produce consistently high or consistently low measurements compared to the true value.	1
Recognises that random errors produce measurements that can be either high or low/fluctuate around the true value.	1
Example of a systematic error. Any one of: <ul style="list-style-type: none"><li>• only heating one solution</li><li>• using an inappropriate proportion of reactants</li><li>• errors in calibration with equipment</li><li>• inappropriate rinsing of glassware.</li></ul>	1
Example of a random error. Any one of: <ul style="list-style-type: none"><li>• parallax (reading of meniscus)</li><li>• judging the end point</li><li>• use of stopwatch</li><li>• reading thermometer</li><li>• not using the same measuring equipment during the reaction</li><li>• using measuring cylinder rather than pipette.</li></ul>	1
<b>Total</b>	<b>4</b>

Accept other correct relevant answers.