



# TAMPINES MERIDIAN JUNIOR COLLEGE

## JC2 PRELIMINARY EXAMINATION

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### H2 CHEMISTRY

Paper 1 Multiple Choice

**9729/01**

**26 September 2019**

**1 hour**

Additional Materials:

Multiple Choice Answer Sheet

Data Booklet

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### READ THESE INSTRUCTIONS FIRST

Write in soft pencil.

Do not use staples, paper clips, glue or correction fluid.

Write your name, class and index number on the Answer Sheet in the spaces provided unless this has been done for you.

There are **thirty** questions on this paper. Answer **all** questions. For each question there are four possible answers **A, B, C** and **D**.

Choose the **one** you consider correct and record your choice in **soft pencil** on the separate Answer Sheet.

Each correct answer will score one mark. A mark will not be deducted for a wrong answer. Any rough working should be done in this booklet.

The use of an approved scientific calculator is expected, where appropriate.

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This document consists of **18** printed pages.



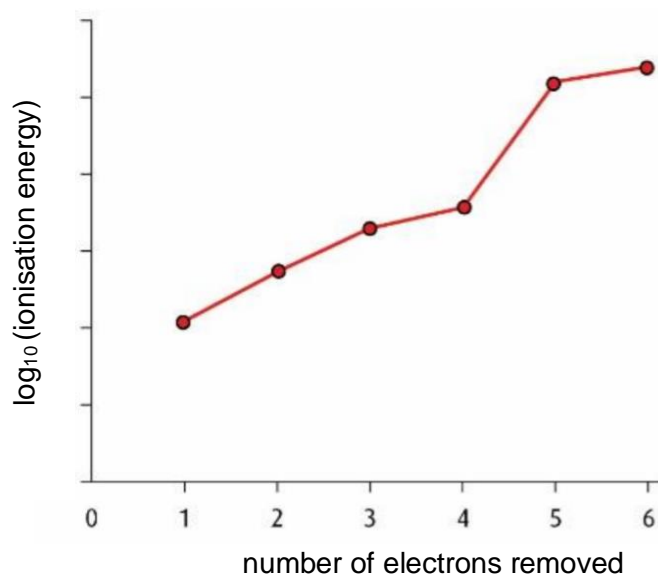
- 1 Some data of the ions of four unknown elements are given in the table below.

	$A^+$	$B^-$	$D^{2-}$	$E^{3-}$
mass number	21	20	20	21
number of protons	–	11	9	–
number of electrons	9	–	–	12

Which of the following correctly shows pairs of isotopic and isoelectronic species?

	isotopic	isoelectronic
<b>A</b>	$D^{2-}, E^{3-}$	$B^-, E^{3-}$
<b>B</b>	$B^-, D^{2-}$	$A^+, B^-$
<b>C</b>	$B^-, D^{2-}$	$B^-, E^{3-}$
<b>D</b>	$D^{2-}, E^{3-}$	$A^+, B^-$

- 2 The first six ionisation energies of element **G** are plotted in the graph below.



Which of the following can be deduced from the graph?

- A** There are 2 quantum shells in element **G**.
- B** Element **G** is from Group 2 in the Periodic Table.
- C** The fifth and sixth electrons are removed from the same subshell.
- D** The identity of element **G** is carbon.

3 For which of the following pairs does the first molecule have a higher polarity than the second molecule?

- 1  $\text{CH}_3\text{OH}$ ,  $\text{CH}_3\text{I}$
- 2  $\text{CF}_4$ ,  $\text{CCl}_4$
- 3 *cis*- $\text{CHF}=\text{CHF}$ , *trans*- $\text{CHF}=\text{CHF}$

- A** 1 only  
**B** 1 and 3  
**C** 2 and 3  
**D** 1, 2 and 3

4 Three substances **H**, **I** and **J** have physical properties shown in the table below.

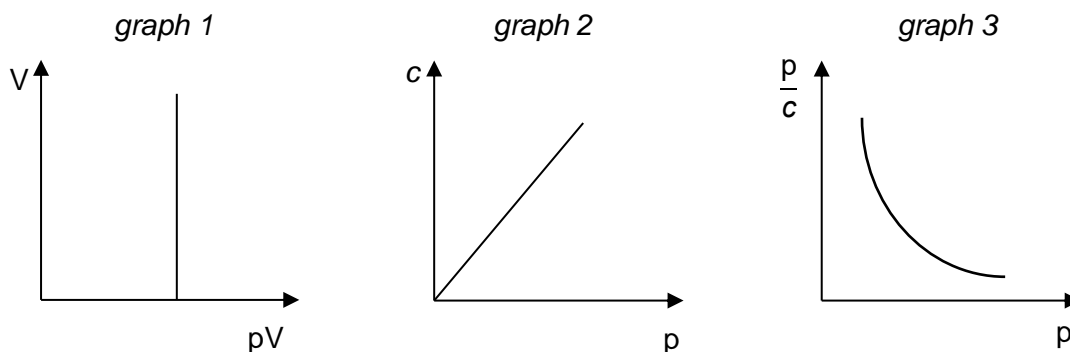
substance	melting point/ °C	boiling point/ °C	electrical conductivity	
			of solid	of liquid
<b>H</b>	801	1413	poor	good
<b>I</b>	2852	3600	poor	good
<b>J</b>	3500 at very high pressure	unable to determine	poor	unable to determine

What are the possible identities for substances **H**, **I** and **J**?

	<b>H</b>	<b>I</b>	<b>J</b>
<b>A</b>	$\text{NaCl}$	$\text{AlCl}_3$	C (diamond)
<b>B</b>	$\text{MgO}$	$\text{AlCl}_3$	C (graphite)
<b>C</b>	$\text{NaCl}$	$\text{MgO}$	C (graphite)
<b>D</b>	$\text{NaCl}$	$\text{MgO}$	C (diamond)

- 5 Which of the following diagrams correctly describe the behaviour of a fixed mass of an ideal gas at constant temperature?

[c is concentration]



- A 2 only  
 B 1 and 2  
 C 2 and 3  
 D 1, 2 and 3
- 6 In which of the following reactions is the underlined reactant acting as a Lewis acid?
- A  $\underline{\text{BF}_3} + \text{F}^- \longrightarrow \text{BF}_4^-$   
 B  $\text{AlCl}_3 + \underline{\text{Cl}_2} \longrightarrow \text{AlCl}_4^- + \text{Cl}^+$   
 C  $\text{Ag}^+ + 2\underline{\text{NH}_3} \longrightarrow [\text{Ag}(\text{NH}_3)_2]^+$   
 D  $\text{H}_2\text{O} + \underline{\text{HSO}_3^-} \longrightarrow \text{H}_2\text{SO}_3 + \text{OH}^-$
- 7 Which of the following statements is true of the Period 3 chlorides, NaCl to  $\text{PCl}_5$ ?
- A The melting points of the chlorides show a continuously decreasing trend.  
 B The pH of the solutions formed when the chlorides are added to water range from alkaline to acidic.  
 C Three of the chlorides have simple molecular structures.  
 D The only chlorides which undergo hydrolysis in water are  $\text{AlCl}_3$  and  $\text{MgCl}_2$ .

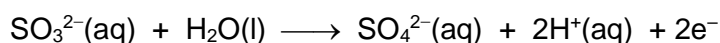
- 8 The relative abundances of the isotopes of a sample of titanium are shown in the table below.

relative isotopic mass	46	47	48
relative abundance	11.2	10.1	z

Given that the relative atomic mass of the sample is 47.862, what is the value of z?

- A 214.2                      B 79.1                      C 78.7                      D 26.6
- 9 A metallic salt was found to react exactly with sulfite ions in a 2 : 1 ratio.

In this reaction, the sulfite ion is oxidised as follows.

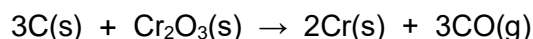


What is the new oxidation number of the metal in the salt if its original oxidation number was +3?

- A +1                      B +2                      C +4                      D +5
- 10 The enthalpy changes for the following reactions are given:



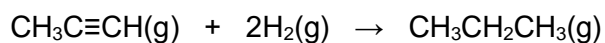
What is the enthalpy change of reaction for the following reaction, in terms of  $\text{kJ mol}^{-1}$ ?



- A - 940                      B - 870                      C + 590                      D + 790



- 11 An experiment was conducted by reacting propyne with hydrogen gas in a shock tube.

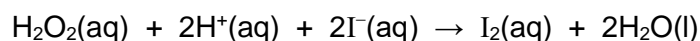


The value of  $\Delta G$  for the reaction is found to be negative at low temperature.

What is the sign of  $\Delta H$  and  $\Delta S$  for the above reaction?

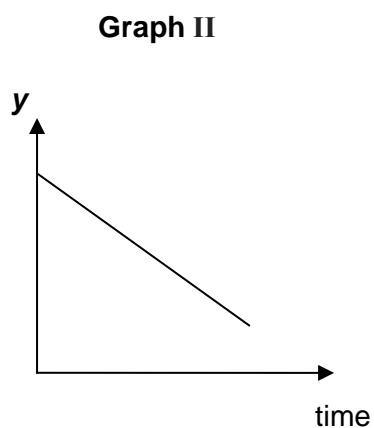
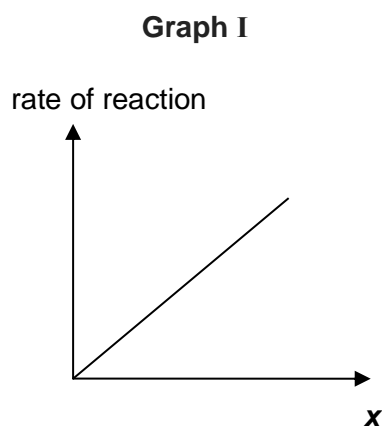
	$\Delta H$	$\Delta S$
<b>A</b>	–	–
<b>B</b>	+	–
<b>C</b>	–	+
<b>D</b>	+	+

- 12 The kinetics of the reaction between hydrogen peroxide and acidified iodide ions were investigated.



The rate equation was found to be:  $\text{rate} = k[\text{H}_2\text{O}_2][\text{I}^-]$

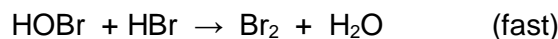
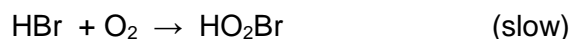
Which of the following shows the correct labelling of the **x**-axis for **Graph I** and **y**-axis for **Graph II**?



	<b>x</b> -axis for <b>Graph I</b>	<b>y</b> -axis for <b>Graph II</b>
<b>A</b>	$[\text{I}^-]$	$[\text{H}_2\text{O}_2][\text{I}^-]$
<b>B</b>	$[\text{H}^+]$	$[\text{I}_2]$
<b>C</b>	$[\text{H}_2\text{O}_2][\text{I}^-]$	$[\text{H}^+]$
<b>D</b>	$[\text{H}_2\text{O}_2][\text{H}^+]$	$[\text{I}^-]$



- 13 The reaction between HBr and O<sub>2</sub> is thought to occur via a multi-step mechanism:



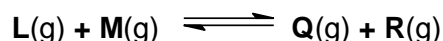
The overall reaction is given to be  $4\text{HBr} + \text{O}_2 \rightarrow 2\text{Br}_2 + 2\text{H}_2\text{O}$ .

Which of the following statements are true?

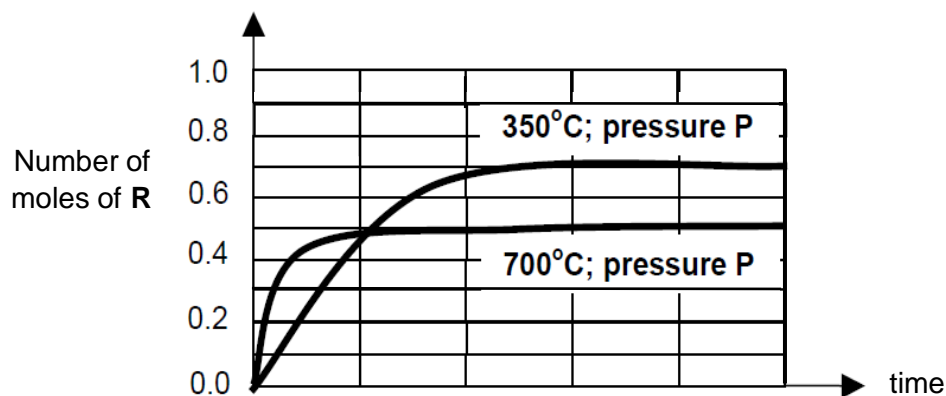
- 1 The overall order of reaction is 2.
- 2 HO<sub>2</sub>Br is the only intermediate in the reaction.
- 3 HOBr acts as a catalyst in the reaction.

**A** 1 only      **B** 3 only      **C** 1 and 2      **D** 1, 2 and 3

- 14 **L** and **M** can react together to reach equilibrium in the reaction below.



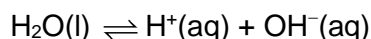
In an experiment, 1.0 mole each of **L** and **M** were reacted at constant pressure **P** and temperature 350 °C. The amount of **R** present in the mixture at intervals of time was recorded. The experiment was repeated at the same pressure **P**, but at a temperature of 700 °C. The results for both experiments are shown below.



Which one of the following information **cannot** be deduced from the graph?

- A** The value of  $K_c$  decreases with an increase in temperature.
- B** The equilibrium is achieved at a faster rate at higher temperatures.
- C** The enthalpy change for the forward reaction is negative.
- D** The activation energy of the forward reaction is high.

- 15 The dissociation constants,  $K_w$ , for the ionisation of water at different temperatures are given below.



temperature / °C	$K_w$ / mol <sup>2</sup> dm <sup>-6</sup>
0	$1.15 \times 10^{-15}$
25	$1.00 \times 10^{-14}$
50	$5.50 \times 10^{-14}$

What can be deduced from this information?

- A Only at 25 °C are  $[\text{H}^+]$  and  $[\text{OH}^-]$  equal.  
 B  $K_w$  is not affected by changes in temperature.  
 C The forward reaction is exothermic.  
 D The pH of water decreases as temperature increases.
- 16 The following tests were performed on an aqueous solution containing chloride and iodide ions.

step	test	observations
1	Add excess $\text{AgNO}_3(\text{aq})$ .	Mixture of white and yellow precipitates is formed.
2	To the mixture from step 1, add excess $\text{NH}_3(\text{aq})$ .	White precipitate dissolves to form a colourless solution. Yellow precipitate is insoluble.
3	Filter the mixture from step 2.	Filtrate was a colourless solution. Residue was a yellow solid.

Which of the following statements are correct?

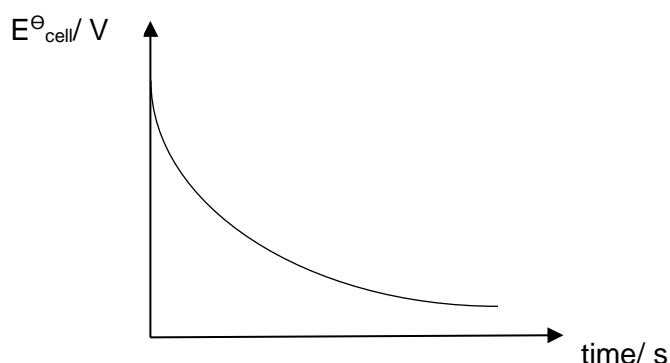
- The  $K_{\text{sp}}$  for  $\text{AgCl}$  is lower than that for  $\text{AgI}$ .
  - There are no  $\text{Ag}^+(\text{aq})$  and  $\text{Cl}^-(\text{aq})$  present in the filtrate formed in Step 3.
  - In step 2, the addition of  $\text{NH}_3(\text{aq})$  results in the formation of  $[\text{Ag}(\text{NH}_3)]_2^+$  that momentarily decreases the ionic product of  $\text{AgCl}$ .
- A 3 only  
 B 1 and 2  
 C 2 and 3  
 D 1, 2 and 3





- 17 An experiment is carried out between the  $\text{Fe}^{2+}/\text{Fe}$  and  $\text{Co}^{2+}/\text{Co}$  half cells.

The following graph of cell potential against time was obtained when a change was continuously made to the half-cell.

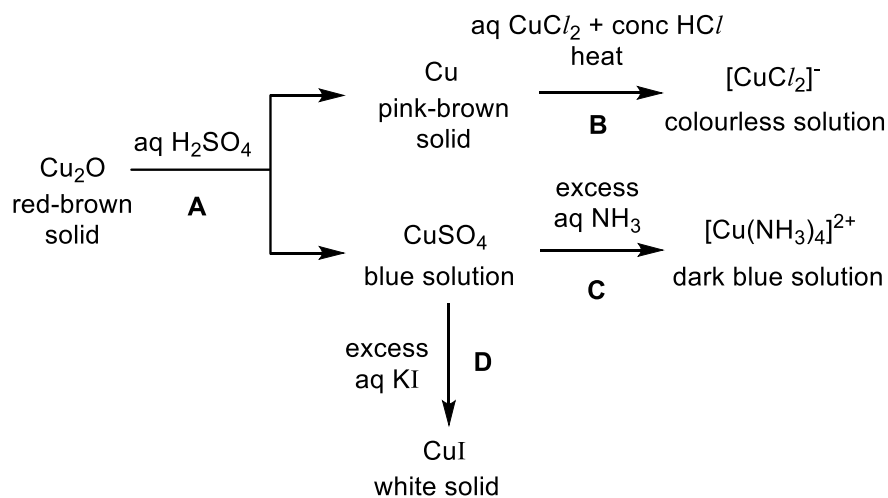


What continuous change could produce this graph?

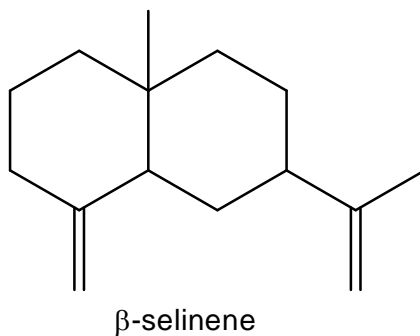
- A add aqueous cobalt(II) ions to the cobalt half-cell
  - B add aqueous ammonia to the cobalt half-cell
  - C add water to the iron half-cell
  - D increase the mass of solid iron immersed in the solution
- 18 Which of the following statements about octahedral complexes is correct?
- A The ratio of hexadentate ligands to the central metal ion is 6:1.
  - B The  $d_{xz}$ ,  $d_{yz}$  and  $d_{xy}$  orbitals are higher in energy than the  $d_{x^2-y^2}$  and  $d_{z^2}$  orbitals.
  - C The d orbitals are split into different energy levels due to different orientation of the orbitals to the ligands.
  - D The same transition metal with different oxidation states displays the same colour with the same ligands.

- 19 The diagram below shows some reactions involving copper and its compounds.

Which reaction involves ligand exchange only?



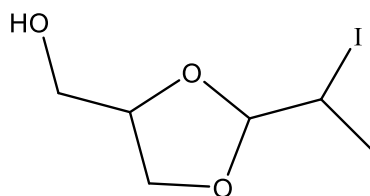
- 20  $\beta$ -selinene is a molecule that can be isolated from plants. It has the following structural formula.



Which of the following statements about this molecule is correct?

- A It has a plane of symmetry.
- B It does not contain any  $sp$  hybridised carbon.
- C It has one chiral centre.
- D It exhibits cis-trans isomerism.

- 21 Iodinated glycerol is used in the symptomatic treatment of patients with chronic obstructive pulmonary disease.



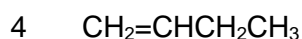
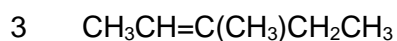
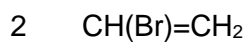
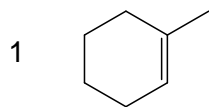
iodinated glycerol

Which of the following correctly shows the product formed when iodinated glycerol is reacted with the given reagents and conditions?

[The C–O–C bond in the structure is inert to the reagents.]

	<i>reagent &amp; conditions</i>	<i>product</i>
<b>A</b>	alcoholic KOH, heat	
<b>B</b>	alcoholic KOH, heat	
<b>C</b>	aqueous KOH, heat	
<b>D</b>	concentrated H <sub>2</sub> SO <sub>4</sub> , heat	

- 22 Which of the following compounds react with HBr in an addition reaction to give a major chiral product?



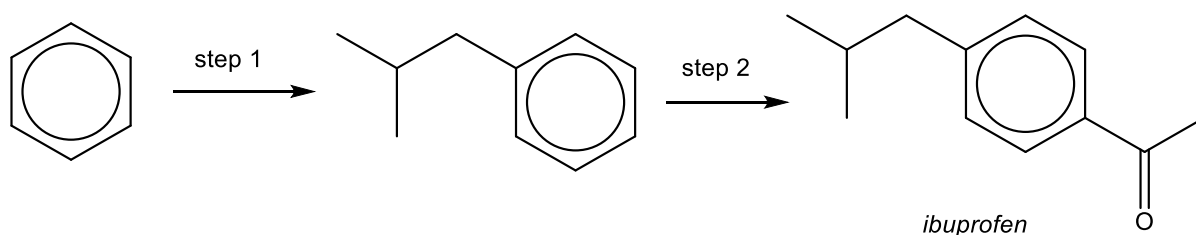
A 1 and 3

B 1 and 4

C 2 and 3

D 4 only

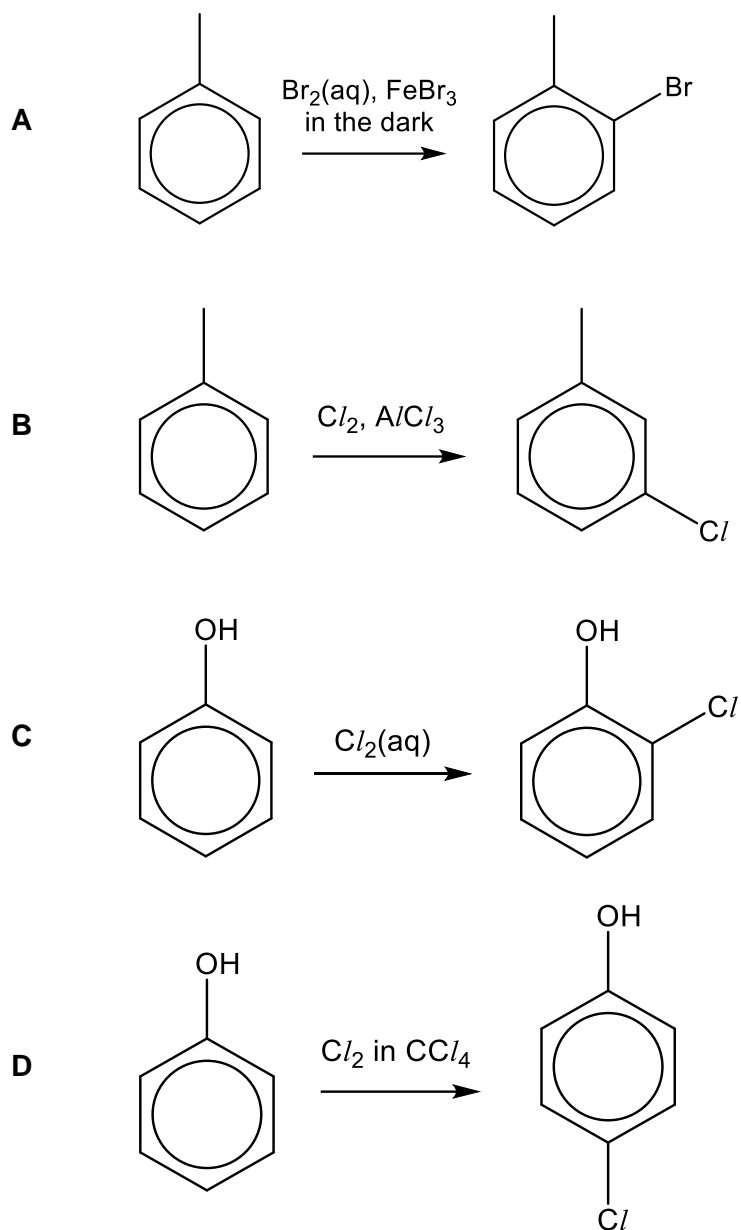
- 23 Two of the steps in the manufacture of the pain-relief drug, *ibuprofen* are shown below.



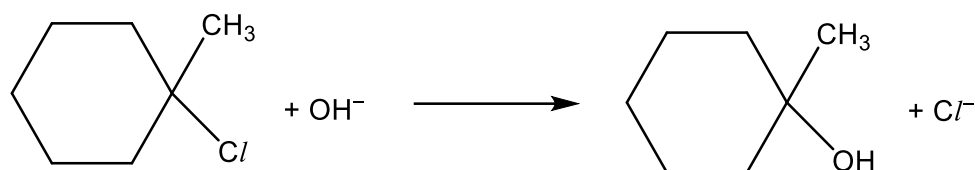
Which statement is correct?

- A Both steps involve the use of catalyst.
- B The sequence of the steps are interchangeable.
- C Both steps involve different types of reaction.
- D Only step 2 involves the use of a halogen-containing reagent.

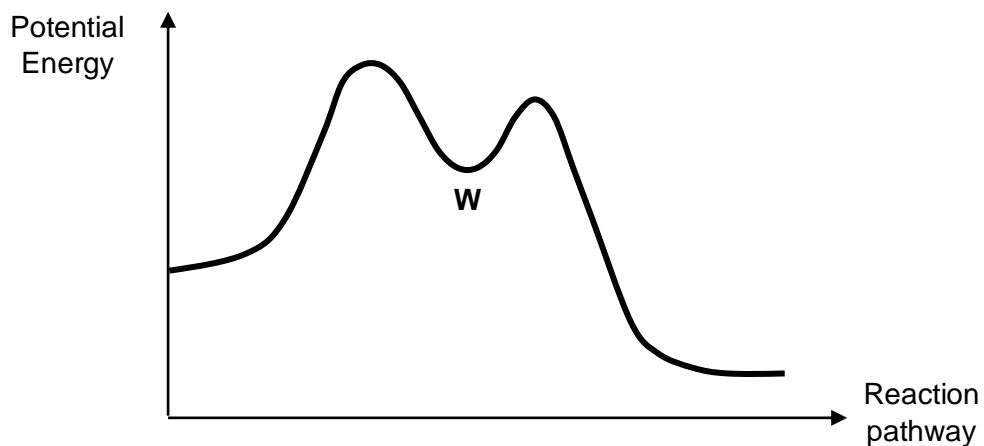
- 24 The reaction conditions for four electrophilic substitution reactions are given below. Which reaction would yield the product stated?



- 25 1-chloro-1-methylcyclohexane is hydrolysed by heating with NaOH(aq).



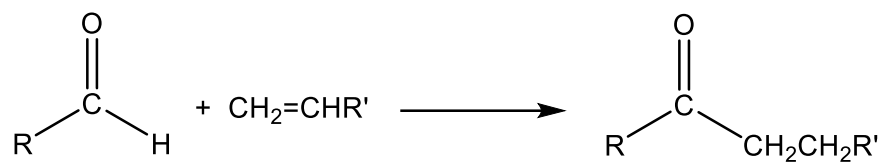
The energy profile diagram for this reaction is shown below.



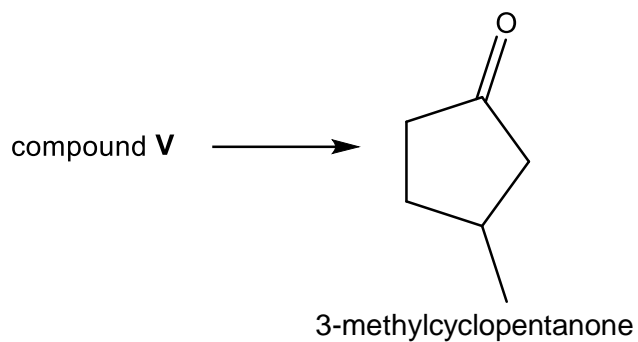
Which statements regarding this reaction are correct?

- 1 The species at point **W** bears a positive charge.
  - 2 The reaction proceeds via  $\text{S}_{\text{N}}2$  mechanism since it is a two-step mechanism.
  - 3 The same energy profile diagram would be obtained if chloromethane undergoes the same reaction.
- A** 1 only  
**B** 1 and 2  
**C** 2 and 3  
**D** 1, 2 and 3

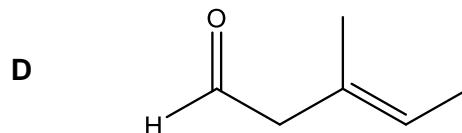
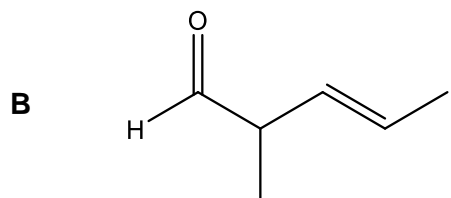
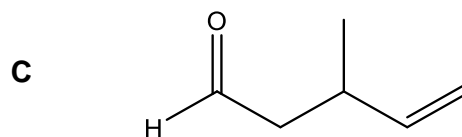
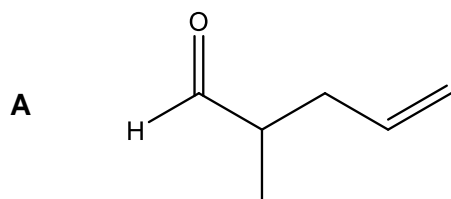
- 26 Hydroacylation is a reaction in which an alkene is 'inserted' into the C–H bond of an aldehyde to form a ketone.



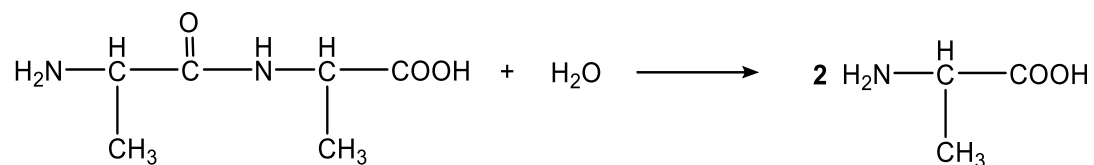
Compound **V** could be converted to 3-methylcyclopentanone using the above reaction.



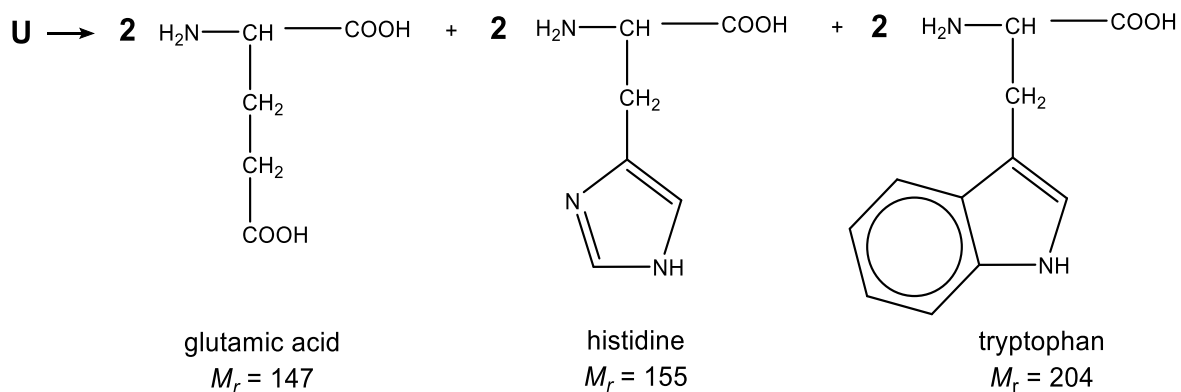
What could compound **V** be?



- 27 Peptidases are enzymes that hydrolyse the peptide bonds that bind amino acids together in the polypeptide chain of a protein.

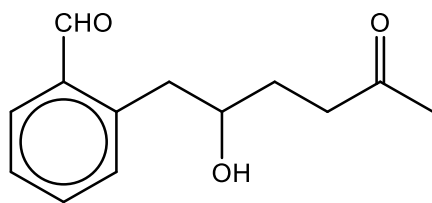


Partial hydrolysis of a small peptide, **U**, by a peptidase, produces the following amino acids.

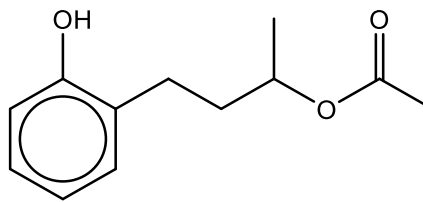


What is the  $M_r$  of the peptide **U**?

- A 904  
B 922  
C 1012  
D 1102
- 28 Which of the following reagents could be used to distinguish between compounds **S** and **T**?



Compound **S**

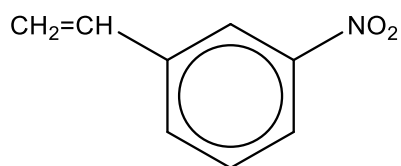


Compound **T**

- A  $\text{I}_2$  in aqueous  $\text{NaOH}$   
B  $\text{Cu}^{2+}$  in alkaline solution  
C aqueous  $\text{NH}_3$  with  $\text{AgNO}_3$   
D acidified potassium dichromate



29 3-nitrostyrene is an aromatic organic compound.

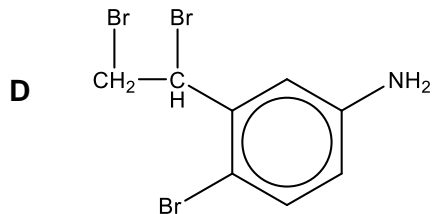
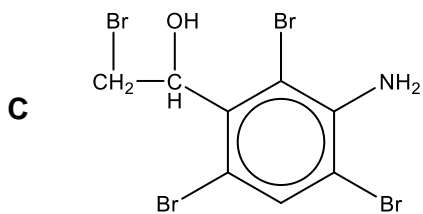
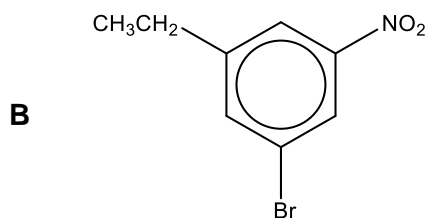
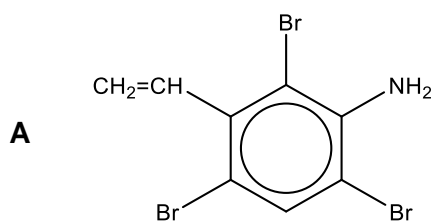


3-nitrostyrene

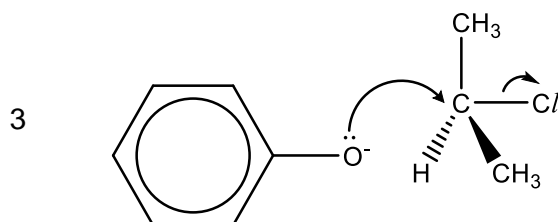
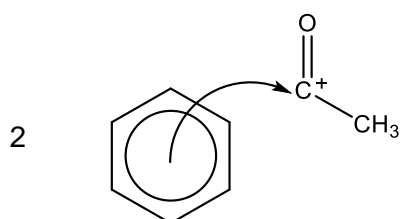
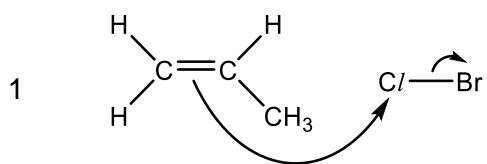
It is subjected to the following reactions:

- heat with Sn in concentrated HCl followed by careful addition of cold NaOH(aq)
- then the addition of Br<sub>2</sub>(aq)

What is the product obtained after the above reactions?



- 30 Which of the following show a correct mechanistic step in the reaction between the reagents?



- A 3 only  
 B 1 and 2  
 C 2 and 3  
 D 1, 2 and 3

**End of Paper 1**



# TAMPINES MERIDIAN JUNIOR COLLEGE

## 2019 JC2 H2 Chemistry Prelim Exam Paper 1

- 1 Some data of the ions of four unknown elements are given in the table below.

	$A^+$	$B^-$	$D^{2-}$	$E^{3-}$
mass number	21	20	20	21
number of protons	–	11	9	–
number of electrons	9	–	–	12

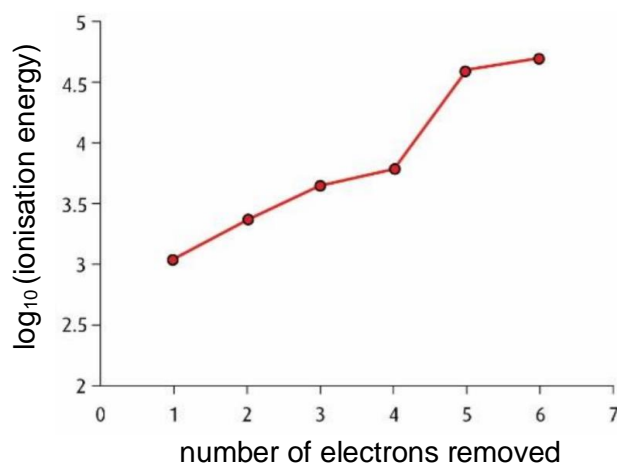
Which of the following correctly shows pairs of isotopic and isoelectronic species?

	isotopic	isoelectronic
A	$D^{2-}, E^{3-}$	$B^-, E^{3-}$
B	$B^-, D^{2-}$	$A^+, B^-$
C	$B^-, D^{2-}$	$B^-, E^{3-}$
D	$D^{2-}, E^{3-}$	$A^+, B^-$

Answer: A

	$A^+$	$B^-$	$D^{2-}$	$E^{3-}$
mass number	21	20	20	21
number of protons	10	11	9	9
			$D^{2-}$ and $E^{3-}$ are isotopic	
number of electrons	9	12	11	12
		$B^-$ and $E^{3-}$ are isoelectronic		

- 2 The first six ionisation energies of element G are plotted in the graph below.



Which of the following can be deduced from the graph?

- A There are 2 quantum shells in element **G**.
- B Element **G** is from Group 2 in the Periodic Table.
- C The fifth and sixth electrons are removed from the same subshell.
- D The identity of element **G** is carbon.

**Answer: C**

With limited information from the graph, it is unclear if the jump from the 4<sup>th</sup> to the 5<sup>th</sup> I.E. is a change in subshell or quantum shell. Hence, options A, B and D cannot be concluded using the graph. Then only conclusion which can be made is that the 5<sup>th</sup> and 6<sup>th</sup> electrons are in the same subshell.

- 3 For which of the following pairs does the first molecule have a higher polarity than the second molecule?

- 1  $\text{CH}_3\text{OH}$ ,  $\text{CH}_3\text{I}$
- 2  $\text{CF}_4$ ,  $\text{CCl}_4$
- 3 *cis*-CHF=CHF, *trans*-CHF=CHF

- A 1 only
- B 1 and 3
- C 2 and 3
- D 1, 2 and 3

**Answer: B**

- 1 Although both  $\text{CH}_3\text{OH}$  and  $\text{CH}_3\text{I}$  are polar,  $\text{CH}_3\text{OH}$  has higher polarity because O is more electronegative than I, hence the C–O bond is more polar than the C–I bond.
- 2 Both  $\text{CF}_4$  and  $\text{CCl}_4$  are non-polar as both have net zero dipole moment.
- 3 *trans*-CHF=CHF is non-polar as both C–F dipole moment cancels out, hence net zero dipole moment. *cis*-CHF=CHF is polar.



- 4 Three substances **H**, **I** and **J** have physical properties shown in the table below.

substance	melting point/ °C	boiling point/ °C	electrical conductivity	
			of solid	of liquid
<b>H</b>	801	1413	poor	good
<b>I</b>	2852	3600	poor	good
<b>J</b>	3500 at very high pressure	unable to determine	poor	unable to determine

What are the possible identities for substances **H**, **I** and **J**?

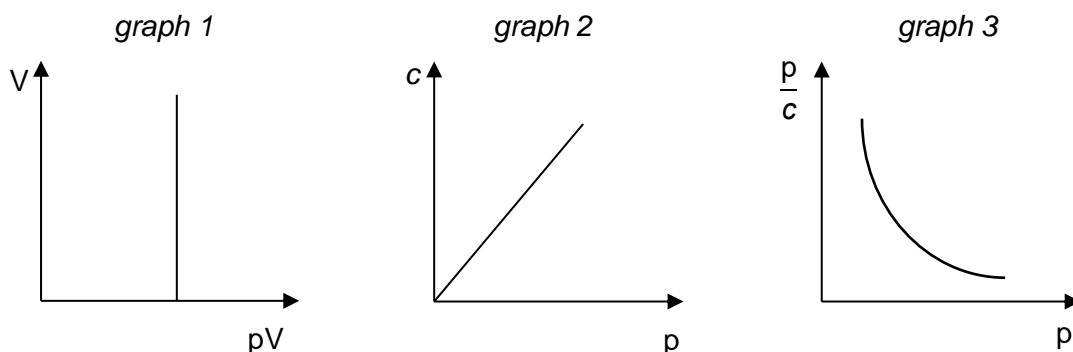
	<b>H</b>	<b>I</b>	<b>J</b>
<b>A</b>	NaCl	AlCl <sub>3</sub>	C (diamond)
<b>B</b>	MgO	AlCl <sub>3</sub>	C (graphite)
<b>C</b>	NaCl	MgO	C (graphite)
<b>D</b>	NaCl	MgO	C (diamond)

**Answer: D**

- Substance **H** should have a **giant ionic structure**, where NaCl or MgO are possible identities.
- Substance **I** should also have a **giant ionic structure but with larger lattice energy** compared to substance **H**. AlCl<sub>3</sub> cannot be substance **H** because it is a simple molecule. Hence, **H** must be MgO.
- Substance **J** should have a **giant molecular structure, which does not conduct electricity**. Hence, **J** must be diamond.


- 5 Which of the following diagrams correctly describe the behaviour of a fixed mass of an ideal gas at constant temperature?

[ $c$  is concentration]



- A 2 only  
 B 1 and 2  
 C 2 and 3  
 D 1, 2 and 3

**Answer: B**

✓	1	$pV = nRT$ $pV = \text{constant}$ ( $T$ is constant) $pV$ plotted on horizontal axis $\Rightarrow$ graph resembles " $x = \text{constant}$ " graph.
✓	2	$pV = nRT$ $pV = \frac{m}{M}RT$ (where $m$ is mass and $M$ is molar mass) $p = \frac{m}{V} \times \text{constant}$ ( $T$ and $M$ are constant) $p = c \times \text{constant}$ $\Rightarrow c = p \times \text{constant} \Rightarrow$ graph resembles " $y = \text{constant} \times x$ " graph.
✗	3	$p = c \times \text{constant}$ $\frac{p}{c} = \text{constant} \Rightarrow$ graph resembles " $y = \text{constant}$ " graph. 

6 In which of the following reactions is the underlined reactant acting as a Lewis acid?

- A  $\underline{\text{BF}_3} + \text{F}^- \longrightarrow \text{BF}_4^-$   
 B  $\text{AlCl}_3 + \underline{\text{Cl}_2} \longrightarrow \text{AlCl}_4^- + \text{Cl}^+$   
 C  $\text{Ag}^+ + 2\underline{\text{NH}_3} \longrightarrow [\text{Ag}(\text{NH}_3)_2]^+$   
 D  $\text{H}_2\text{O} + \underline{\text{HSO}_3^-} \longrightarrow \text{H}_2\text{SO}_3 + \text{OH}^-$

Answer: A

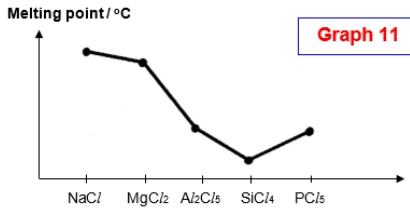
Lewis acid: species (molecule or ion) that can accept a pair of electrons

✓	A	In the formation of $\text{BF}_4^-$ , $\text{F}^-$ donates a pair of electrons for dative bond formation to B in $\text{BF}_3$ (B here is electron-deficient, with only 6 electrons around it).
✗	B	$\text{Cl}$ in $\text{Cl}_2$ donates a pair of electrons for dative bond formation to $\text{Al}$ in $\text{AlCl}_3$ ( $\text{Al}$ here is electron-deficient, with only 6 electrons around it) $\Rightarrow \text{AlCl}_3$ is the Lewis acid.
✗	C	$\text{NH}_3$ donates a pair of electrons for dative bond formation to $\text{Ag}^+$ .
✗	D	$\text{HSO}_3^-$ donates a pair of electrons for dative bond formation to $\text{H}^+$ (from $\text{H}_2\text{O}$ ) $\Rightarrow \text{H}^+$ is the Lewis acid.

7 Which of the following statements is true of the Period 3 chlorides,  $\text{NaCl}$  to  $\text{PCl}_5$ ?

- A The melting points of the chlorides show a continuously decreasing trend.  
 B The pH of the solutions formed when the chlorides are added to water range from alkaline to acidic.  
 C Three of the chlorides have simple molecular structures.  
 D The only chlorides which undergo hydrolysis in water are  $\text{AlCl}_3$  and  $\text{MgCl}_2$ .

Answer: C

✗	A	 <p>(pg 15 of Periodic Table lecture notes)</p>
✗	B	The pH of aqueous $\text{NaCl}$ is 7, not alkaline.
✓	C	$\text{NaCl}$ and $\text{MgCl}_2$ are both ionic while the other 3 chlorides are covalent. The covalent chlorides have simple molecular structure.
✗	D	All the chlorides, except for $\text{NaCl}$ undergo slight or complete hydrolysis.

- 8 The relative abundances of the isotopes of a sample of titanium are shown in the table below.

relative isotopic mass	46	47	48
relative abundance	11.2	10.1	$z$

Given that the relative atomic mass of the sample is 47.862, what is the value of  $z$ ?

- A 214.2                      B 79.1                      C 78.7                      D 26.6

**Answer: A**

$$\frac{(46 \times 11.2) + (47 \times 10.1) + (48 \times z)}{11.2 + 10.1 + z} = 47.862 \quad \Rightarrow z = \underline{214.2}$$

- 9 A metallic salt was found to react exactly with sulfite ions in a 2 : 1 ratio.

In this reaction, the sulfite ion is oxidised as follows.



What is the new oxidation number of the metal in the salt if its original oxidation number was +3?

- A +1                      B +2                      C +4                      D +5

**Answer: B**

Since  $\text{SO}_3^{2-}$  lost  $\text{e}^-$ , the metallic salt gained  $\text{e}^-$ .

Let the moles of  $\text{e}^-$  gained by 1 mole of metallic salt be  $y$

Total moles of  $\text{e}^-$  gained = Total moles of  $\text{e}^-$  lost

$$2 \times y = 1 \times 2$$

$$\Rightarrow y = 1$$

$\Rightarrow$  new ox. state is +2

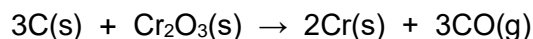




- 10 The enthalpy changes for the following reactions are given:



What is the enthalpy change of reaction for the following reaction, in terms of  $\text{kJ mol}^{-1}$ ?

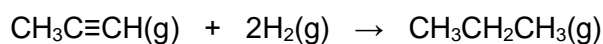


- A**    - 940                      **B**    - 870                      **C**    + 590                      **D**    + 790

**Answer: D**

$$\Delta H_{\text{rxn}} = 3(-110) - (-1120) = \underline{\underline{+790 \text{ kJ mol}^{-1}}}$$

- 11 An experiment was conducted by reacting propyne with hydrogen gas in a shock tube.



The value of  $\Delta G$  for the reaction is found to be negative at low temperature.

What is the sign of  $\Delta H$  and  $\Delta S$  for the above reaction?

	$\Delta H$	$\Delta S$
<b>A</b>	-	-
<b>B</b>	+	-
<b>C</b>	-	+
<b>D</b>	+	+

**Answer: A**

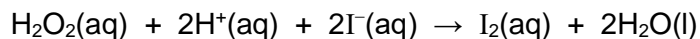
There is a decrease in number of moles of gaseous particles (from 3 moles to 1 mole) after the reaction, thus  $\Delta S$  is negative.

$$\Delta G = \Delta H - T\Delta S$$

Since  $\Delta G$  is negative and  $-T\Delta S$  is positive,  $\Delta H$  should be negative.

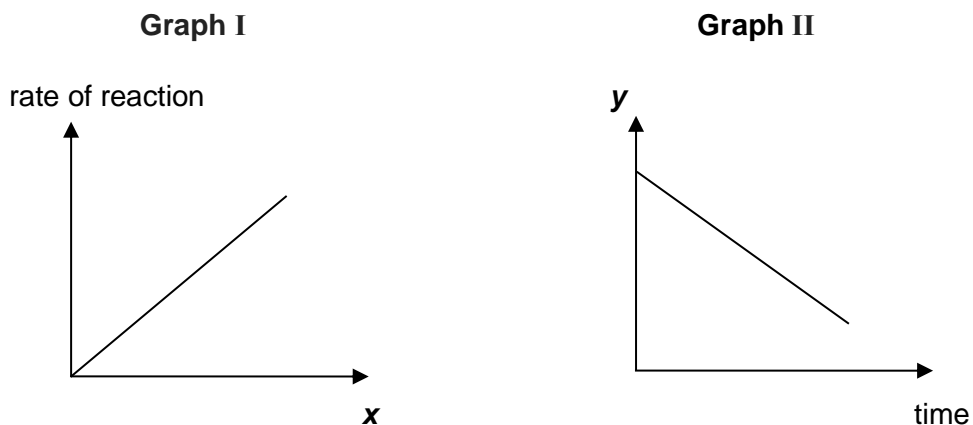


- 12 The kinetics of the reaction between hydrogen peroxide and acidified iodide ions were investigated.



The rate equation was found to be:  $\text{rate} = k[\text{H}_2\text{O}_2][\text{I}^-]$

Which of the following shows the correct labelling of the **x**-axis for **Graph I** and **y**-axis for **Graph II**?



**x**-axis for **Graph I**

**y**-axis for **Graph II**

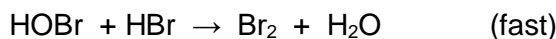
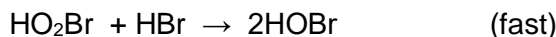
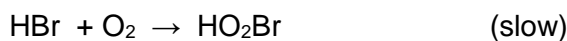
- |          |                                      |                                      |
|----------|--------------------------------------|--------------------------------------|
| <b>A</b> | $[\text{I}^-]$                       | $[\text{H}_2\text{O}_2][\text{I}^-]$ |
| <b>B</b> | $[\text{H}^+]$                       | $[\text{I}_2]$                       |
| <b>C</b> | $[\text{H}_2\text{O}_2][\text{I}^-]$ | $[\text{H}^+]$                       |
| <b>D</b> | $[\text{H}_2\text{O}_2][\text{H}^+]$ | $[\text{I}^-]$                       |

**Answer: C**

**Graph I :**  $\text{Rate} = k \underbrace{[\text{H}_2\text{O}_2]}_y \underbrace{[\text{I}^-]}_x$  (similar to  $y=mx$  graph)

**Graph II :** gradient of the graph shows that rate is independent [reactant]

- 13 The reaction between HBr and O<sub>2</sub> is thought to occur via a multi-step mechanism:



The overall reaction is given to be  $4\text{HBr} + \text{O}_2 \rightarrow 2\text{Br}_2 + 2\text{H}_2\text{O}$ .

Which of the following statements are true?

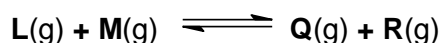
- 1 The overall order of reaction is 2.
  - 2 HO<sub>2</sub>Br is the only intermediate in the reaction.
  - 3 HOBr acts as a catalyst in the reaction.
- A** 1 only  
**B** 3 only  
**C** 1 and 2  
**D** 1, 2 and 3

**Answer: A**

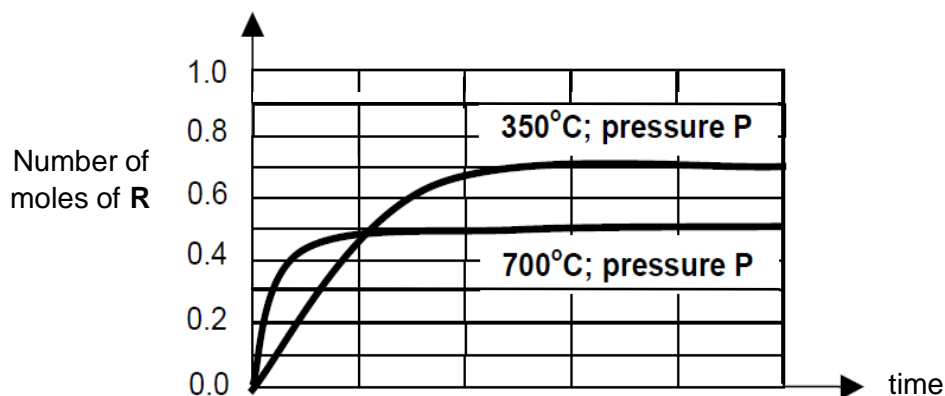
Rate =  $k[\text{HBr}][\text{O}_2] \Rightarrow$  overall order of reaction is 2

HO<sub>2</sub>Br and HOBr are the intermediates in the reaction (they do not appear in the overall equation).

- 14 **L** and **M** can react together to reach equilibrium in the reaction below.



In an experiment, 1.0 mole each of **L** and **M** were reacted at constant pressure **P** and temperature 350 °C. The amount of **R** present in the mixture at intervals of time was recorded. The experiment was repeated at the same pressure **P**, but at a temperature of 700 °C. The results for both experiments are shown below.



Which one of the following information **cannot** be deduced from the graph?

- A The value of  $K_c$  decreases with an increase in temperature.
- B The equilibrium is achieved at a faster rate at higher temperatures.
- C The enthalpy change for the forward reaction is negative.
- D The activation energy of the forward reaction is high.

**Answer: D**

From the graph,

Amount of product R decreases when temperature is increased from 350°C to 700°C  
 $\Rightarrow K_c$  decreases.

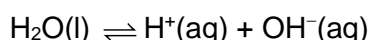
Rate of reaction increases with increase in temperature.

By Le Chatelier's Principle, when temperature increases, equilibrium position shifts towards the endothermic reaction to absorb heat. From graph, equilibrium position shifts to the left.

- $\Rightarrow$  Backward reaction is endothermic
- $\Rightarrow$  Forward reaction is exothermic.
- $\Rightarrow$  Enthalpy change for the forward reaction is negative.

The graph does not provide any information about the activation energy for the reaction.

- 15 The dissociation constants,  $K_w$ , for the ionisation of water at different temperatures are given below.



temperature / °C	$K_w$ / mol <sup>2</sup> dm <sup>-6</sup>
0	$1.15 \times 10^{-15}$
25	$1.00 \times 10^{-14}$
50	$5.50 \times 10^{-14}$

What can be deduced from this information?

- A Only at 25 °C are  $[\text{H}^+]$  and  $[\text{OH}^-]$  equal.
- B  $K_w$  is not affected by changes in temperature.
- C The forward reaction is exothermic.
- D The pH of water decreases as temperature increases.

**Answer: D**

- Option A is incorrect.  $[\text{H}^+]$  and  $[\text{OH}^-]$  are equal at all temperature for pure water.
- Option B is incorrect.  $K_w$  is an equilibrium constant thus it is affected by changes in temperature as shown in the different  $K_w$  values at various temperatures.
- Option C is incorrect. When temperature increases,  $K_w$  increases. This shows that position of equilibrium shifts to the right towards the forward reaction which is endothermic.
- Option D is correct.  $K_w = [\text{H}^+][\text{OH}^-]$ . By inspection, when temperature rises,  $[\text{H}^+]$  increases. Hence, pH of water decreases.



- 16 The following tests were performed on an aqueous solution containing chloride and iodide ions.

step	test	observations
1	Add excess $\text{AgNO}_3(\text{aq})$ .	Mixture of white and yellow precipitates is formed.
2	To the mixture from step 1, add excess $\text{NH}_3(\text{aq})$ .	White precipitate dissolves to form a colourless solution. Yellow precipitate is insoluble.
3	Filter the mixture from step 2.	Filtrate was a colourless solution. Residue was a yellow solid.

Which of the following statements are correct?

- 1 The  $K_{\text{sp}}$  for  $\text{AgCl}$  is lower than that for  $\text{AgI}$ .
  - 2 There are no  $\text{Ag}^+(\text{aq})$  and  $\text{Cl}^-(\text{aq})$  present in the filtrate formed in Step 3.
  - 3 In step 2, the addition of  $\text{NH}_3(\text{aq})$  results in the formation of  $[\text{Ag}(\text{NH}_3)]_2^+$  that momentarily decreases the ionic product of  $\text{AgCl}$ .
- A** 3 only  
**B** 1 and 2  
**C** 2 and 3  
**D** 1, 2 and 3

**Answer: A**

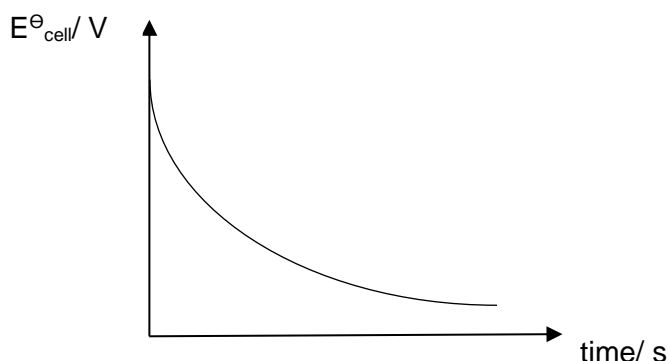
Statement 1 is incorrect as  $K_{\text{sp}}$  for  $\text{AgCl}$  is higher than that for  $\text{AgI}$ .

Statement 2 is incorrect. The filtrate contains saturated solution of  $\text{Ag}^+(\text{aq})$  and  $\text{Cl}^-(\text{aq})$  as well as  $\text{I}^-(\text{aq})$  that is not precipitated.

Statement 3 is correct. The complex formation  $[\text{Ag}(\text{NH}_3)]_2^+$  reduces the concentration of  $\text{Ag}^+(\text{aq})$  which decreases ionic product of  $\text{AgCl}$ .

- 17 An experiment is carried out between the  $\text{Fe}^{2+}/\text{Fe}$  and  $\text{Co}^{2+}/\text{Co}$  half cells.

The following graph of cell potential against time was obtained when a change was continuously made to the half-cell.



What continuous change could produce this graph?

- A add aqueous cobalt(II) ions to the cobalt half-cell
- B add aqueous ammonia to the cobalt half-cell
- C add water to the iron half-cell
- D increase the mass of solid iron immersed in the solution

Answer: **B**

$$E_{\text{cell}} = E_{\text{red}} - E_{\text{oxd}} = E_{\text{Co}^{2+}/\text{Co}} - E_{\text{Fe}/\text{Fe}^{2+}}$$

Option **A** is incorrect.



When cobalt (II) ions is added to the cobalt half-cell,  $[\text{Co}^{2+}]$  increases. Position of eqm shifts right which causes  $E_{\text{Co}^{2+}/\text{Co}}$  ( $E_{\text{red}}$ ) to be more positive. Thus,  $E_{\text{cell}}$  increases.

Option **B** is correct.

When aqueous ammonia is added to the cobalt half-cell, complex  $[\text{Co}(\text{CN})_6]^{2-}$  is formed. This complex formation decreases the concentration of aqueous  $\text{Co}^{2+}$  which causes the position of eqm to shift left leading to  $E_{\text{Co}^{2+}/\text{Co}}$  ( $E_{\text{red}}$ ) becoming less positive. Thus,  $E_{\text{cell}}$  decreases.

Option **C** is incorrect.



When water is added to the iron half-cell,  $[\text{Fe}^{2+}]$  decreases. Position of eqm shift left causing  $E_{\text{Fe}^{2+}/\text{Fe}}$  ( $E_{\text{oxd}}$ ) to be less positive. Thus,  $E_{\text{cell}}$  increases.

Option **D** is incorrect as an increase in the mass of solid iron does not affect E values.



18 Which of the following statements about octahedral complexes is correct?

- A The ratio of hexadentate ligands to the central metal ion is 6:1.
- B The  $d_{xz}$ ,  $d_{yz}$  and  $d_{xy}$  orbitals are higher in energy than the  $d_{x^2-y^2}$  and  $d_{z^2}$  orbitals.
- C The d orbitals are split into different energy levels due to different orientation of the orbitals to the ligands.
- D The same transition metal with different oxidation states displays the same colour with the same ligands.

**Answer: C**

A is not correct as the coordination number of octahedral complexes is 6; as each hexadentate ligands can form 6 dative bonds per ligand, the ratio of hexadentate ligands to complex should thus be 1:1 (not 6:1).

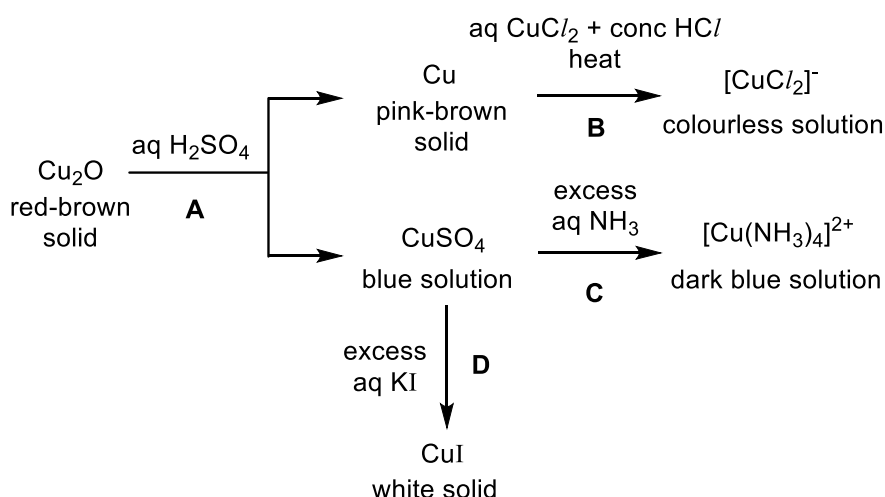
B is not correct as electrons in the d orbitals lying along the bonding axes (ie. x, y and z axes) would experience greater repulsion with the ligands, the  $d_{x^2-y^2}$  and  $d_{z^2}$  orbitals are higher in energy in octahedral complex.

C is correct as the ligand field splitting arises from the repulsion of the electrons in the d orbitals with the ligands and this would be influenced by the orientation of the orbitals and the ligands.

D is not correct as different complexes with the same metal but different oxidation states will have with different d electronic configurations, hence even though the ligands may be same, the colours will be different.

19 The diagram below shows some reactions involving copper and its compounds.

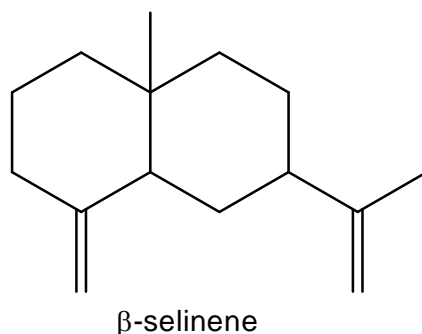
Which reaction involves ligand exchange only?



Answer: C

- **A** is a disproportionation (redox) reaction where  $\text{Cu}_2\text{O}$  (O.S. = +1) forms Cu metal (O.S. = 0) and  $\text{CuSO}_4$  (O.S. = +2).
- **B** is a redox (comproportionation) reaction where Cu metal (O.S. = 0) and  $\text{CuCl}_2$  (O.S. = +2) forms  $[\text{CuCl}_2]^-$  (O.S. = +1).
- **C** is a ligand exchange where  $\text{H}_2\text{O}$  ligands in  $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$  complex is replaced with  $\text{NH}_3$  ligands to form a new complex  $[\text{Cu}(\text{NH}_3)_4]^{2+}$ .
- **D** is a redox reaction involving  $\text{Cu}^{2+}$  (O.S. = +2) reducing to form CuI in the presence of excess  $\text{I}^-$ ;  $2\text{Cu}^{2+} + 4\text{I}^- \rightarrow 2\text{CuI} + \text{I}_2$

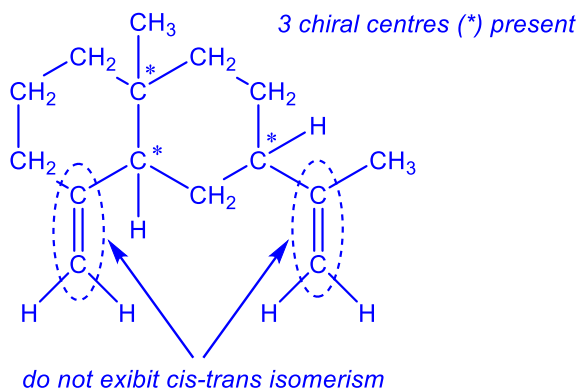
- 20  $\beta$ -selinene is a molecule that can be isolated from plants. It has the following structural formula.



Which of the following statements about this molecule is correct?

- A** It has a plane of symmetry.
- B** It does not contain any  $\text{sp}$  hybridised carbon.
- C** It has one chiral centre.
- D** It exhibits cis-trans isomerism.

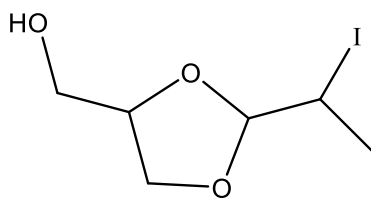
Answer: B



Based on the options, only constitutional isomers possible.



- 21 Iodinated glycerol is used in the symptomatic treatment of patients with chronic obstructive pulmonary disease.



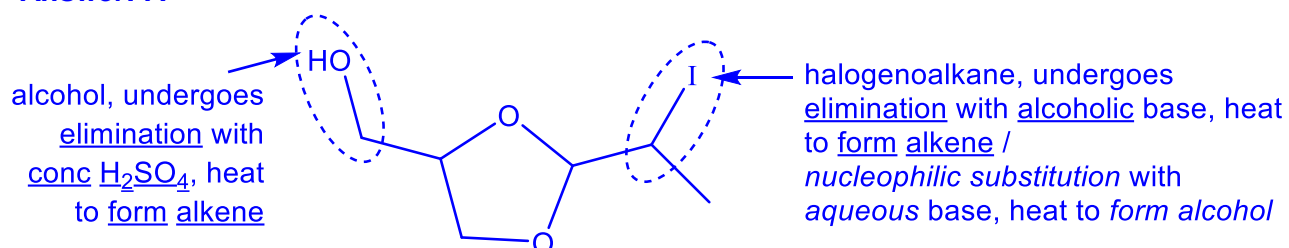
iodinated glycerol

Which of the following correctly shows the product formed when iodinated glycerol is reacted with the given reagents and conditions?

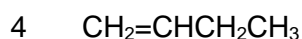
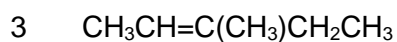
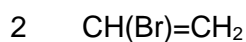
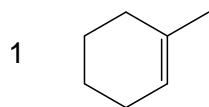
[The C–O–C bond in the structure is inert to the reagents.]

	reagent & conditions	product
<b>A</b>	alcoholic KOH, heat	
<b>B</b>	alcoholic KOH, heat	
<b>C</b>	aqueous KOH, heat	
<b>D</b>	concentrated H <sub>2</sub> SO <sub>4</sub> , heat	

**Answer: A**



- 22 Which of the following compounds react with HBr in an addition reaction to give a major chiral product?



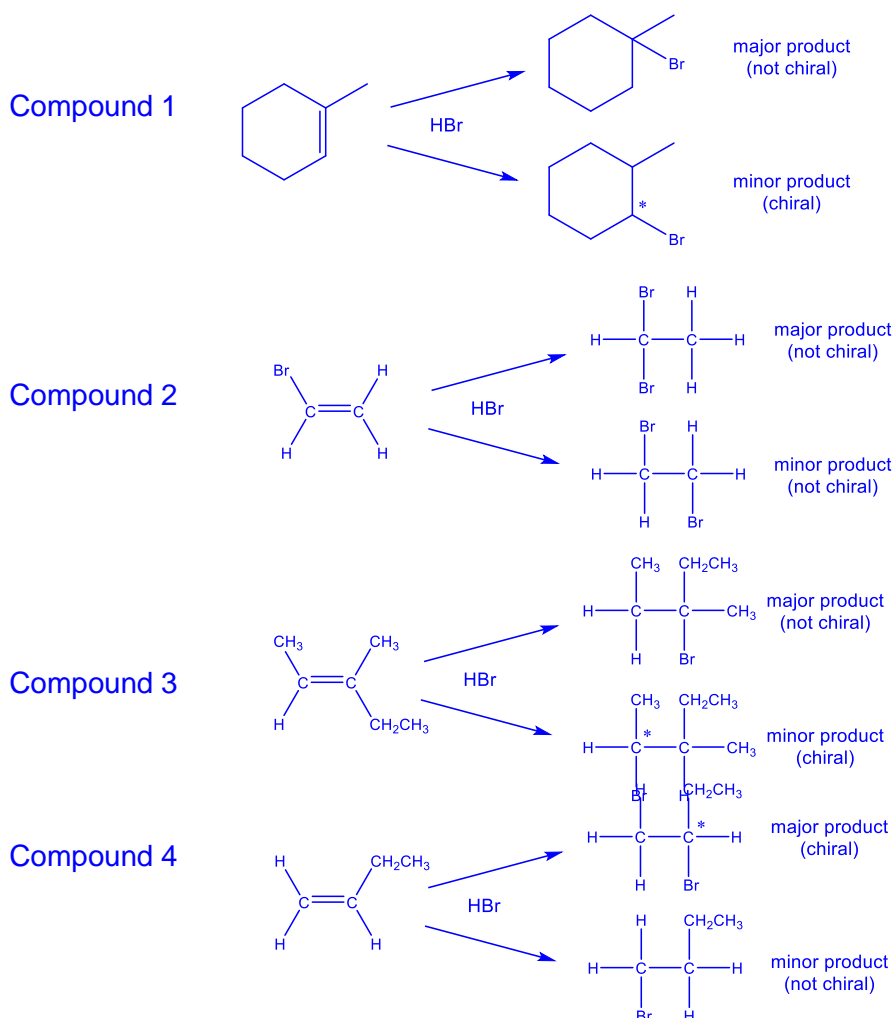
A 1 and 3

B 1 and 4

C 2 and 3

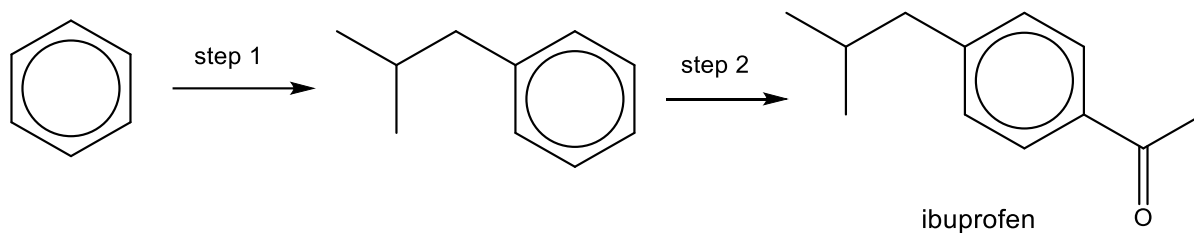
D 4 only

Answer: D



Only Compound 4 gives a major product upon electrophilic addition that is chiral.

- 23 Two of the steps in the manufacture of the pain-relief drug, ibuprofen are shown below.



Which statement is correct?

- A Both steps involve the use of catalyst.
- B The sequence of the steps are interchangeable.
- C Both steps involve different types of reaction.
- D Only step 2 involves the use of a halogen-containing reagent.

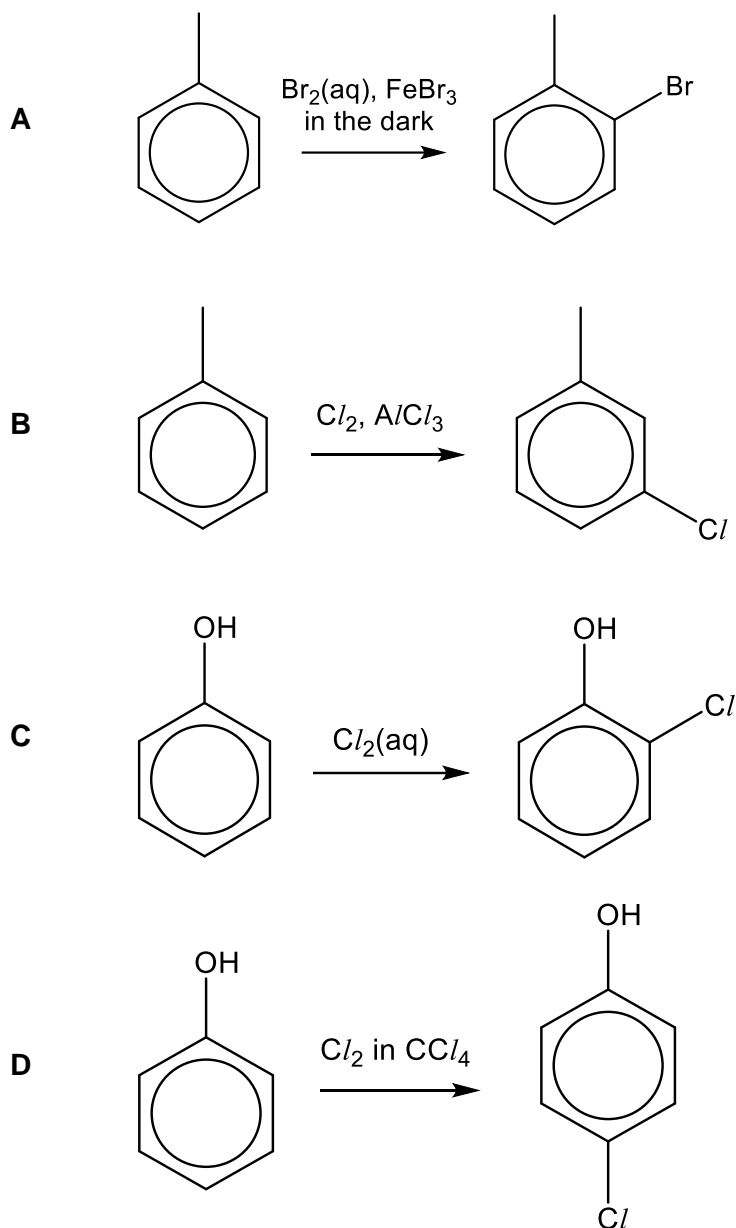
**Answer: A**

Both reactions are electrophilic substitution (Friedel-Crafts Alkylation and Friedel-Crafts Acylation respectively) and both require the use of  $\text{AlCl}_3$  catalyst.

The reagents required for alkylation and acylation are halogenalkane,  $\text{CH}_3\text{CH}(\text{CH}_2\text{Cl})\text{CH}_3$  and acyl chloride,  $\text{CH}_3\text{COCl}$  respectively and both contain halogen.

As the desired product contains a benzene ring that is 1,4-disubstituted, it is necessary to carry out alkylation first followed by acylation as alkyl group is 2,4-directing whereas  $-\text{COCH}_3$  group is 3-directing.

- 24 The reaction conditions for four electrophilic substitution reactions are given below. Which reaction would yield the product stated?



**Answer: D**

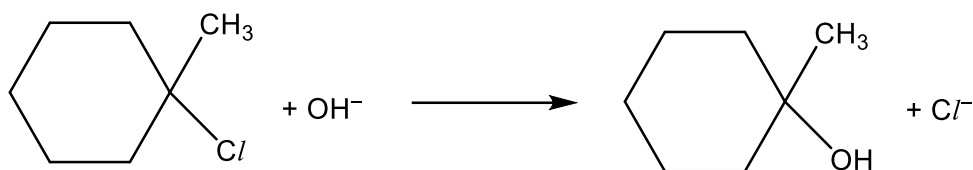
**A:** As aqueous  $\text{Br}_2$  is used,  $\text{FeBr}_3$  may not be formed.

**B:** as  $-\text{CH}_3$  is 2,4-directing thus 3-chloromethylbenzene formed is a minor product

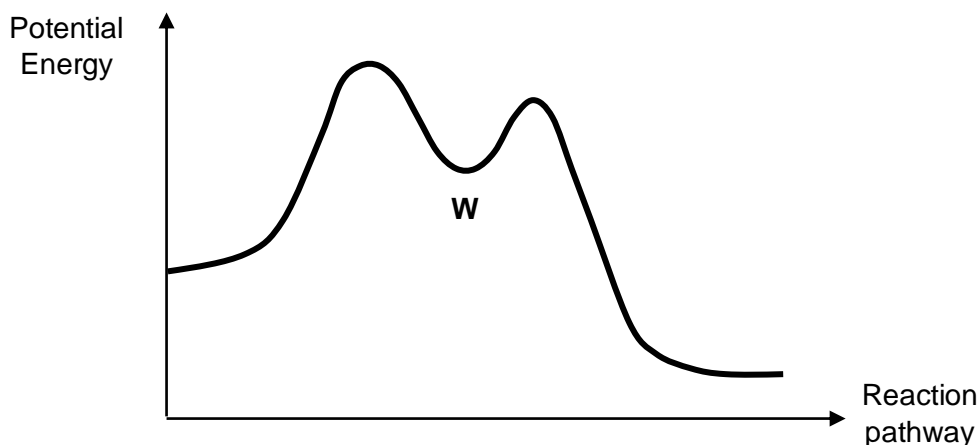
**C:** use of aqueous chlorine should result in a multi-substituted product for phenol

**D:** use of chlorine in organic solvent will result in a mono-substituted product for phenol

- 25 1-chloro-1-methylcyclohexane is hydrolysed by heating with NaOH(aq).



The energy profile diagram for this reaction is shown below.



Which statements regarding this reaction are correct?

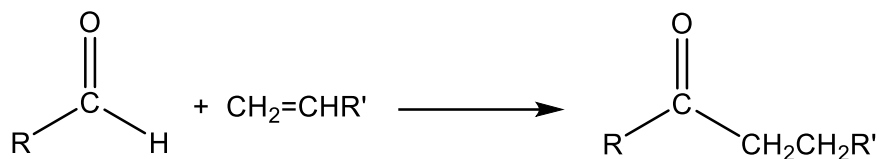
- 1 The species at point **W** bears a positive charge.
  - 2 The reaction proceeds via  $\text{S}_{\text{N}}2$  mechanism since it is a two-step mechanism.
  - 3 The same energy profile diagram would be obtained if chloromethane undergoes the same reaction.
- A** 1 only  
**B** 1 and 2  
**C** 2 and 3  
**D** 1, 2 and 3

**Answer: A**

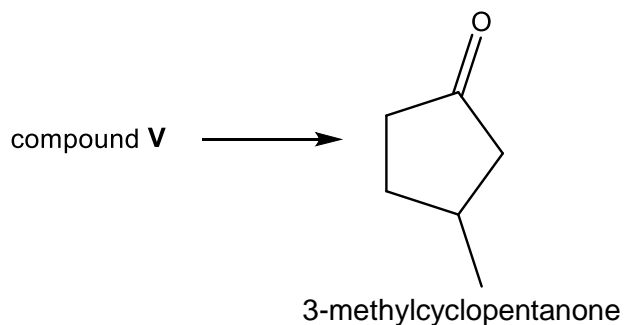
The mechanism shown is  $\text{S}_{\text{N}}1$

- 1 **W** is an intermediate which is a carbocation.
- 2 The energy profile diagram depicts the  $\text{S}_{\text{N}}1$  mechanism which is two-step
- 3 Chloromethane is a primary halogenoalkane and should undergo  $\text{S}_{\text{N}}2$  mechanism.

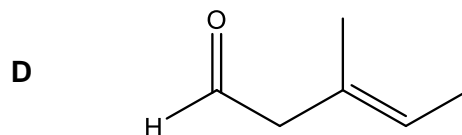
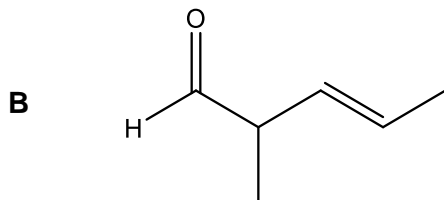
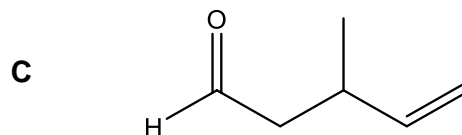
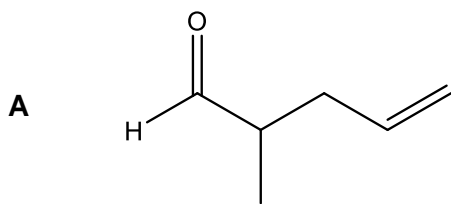
- 26 Hydroacylation is a reaction in which an alkene is 'inserted' into the C–H bond of an aldehyde to form a ketone.



Compound **V** could be converted to 3-methylcyclopentanone using the above reaction.

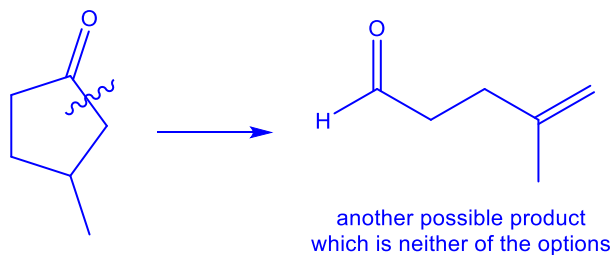
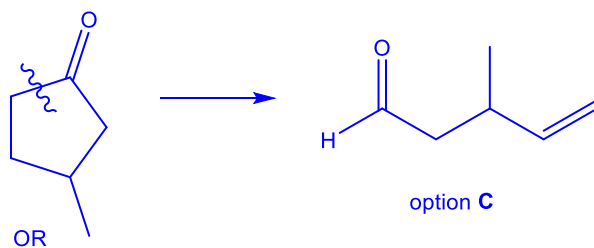


What could compound **V** be?

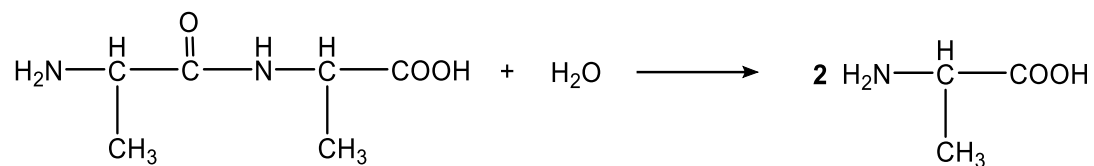


**Answer: C**

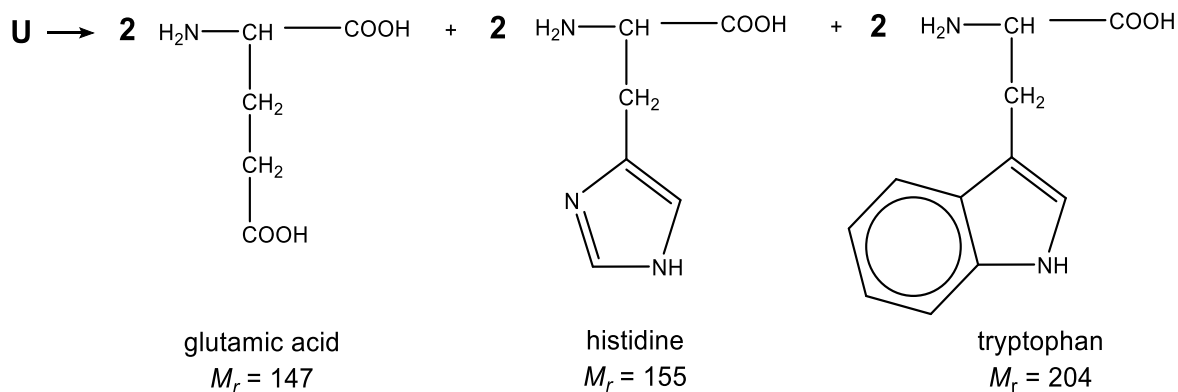
working backwards,



- 27 Peptidases are enzymes that hydrolyse the peptide bonds that bind amino acids together in the polypeptide chain of a protein.



Partial hydrolysis of a small peptide, **U**, by a peptidase, produces the following amino acids.



What is the  $M_r$  of the peptide **U**?

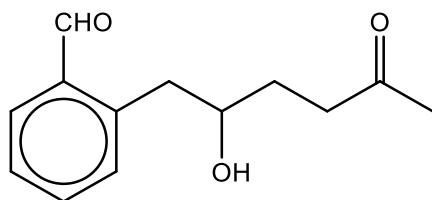
- A 904  
B 922  
C 1012  
D 1102

**Answer: B**

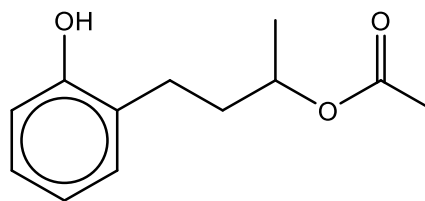
Since there are 6 amino acids, there are  $6 - 1 = 5$  amide bonds

$M_r$  of the peptide **U** =  $(147 \times 2) + (155 \times 2) + (204 \times 2) - \{(6-1) \times 18\} = \underline{922}$

- 28 Which of the following reagents could be used to distinguish between compounds **S** and **T**?



Compound **S**



Compound **T**

- A  $\text{I}_2$  in aqueous NaOH  
B  $\text{Cu}^{2+}$  in alkaline solution  
C aqueous  $\text{NH}_3$  with  $\text{AgNO}_3$   
D acidified potassium dichromate

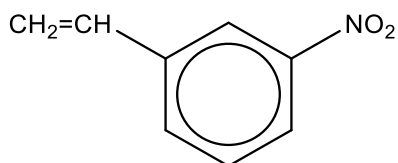
**Answer: C**

Aromatic aldehyde on compound **S** – positive test for Tollens' Reagent. (aqueous  $\text{NH}_3$  with  $\text{AgNO}_3$ )

Both will give a positive test for iodoform test and oxidation reaction.

Both will give a negative test Fehling's solution.

**29** 3-nitrostyrene is an aromatic organic compound.

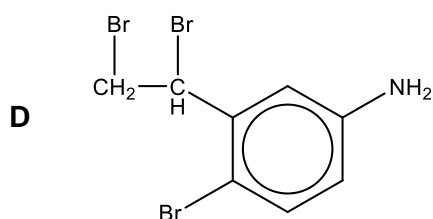
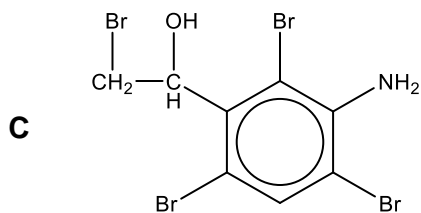
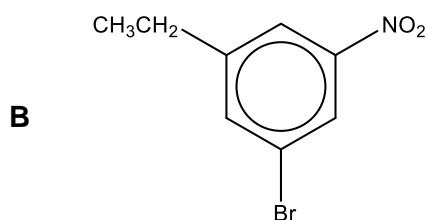
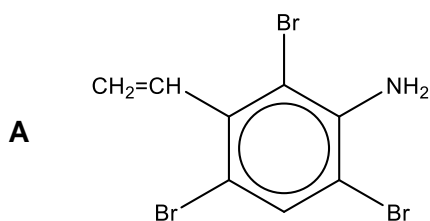


3-nitrostyrene

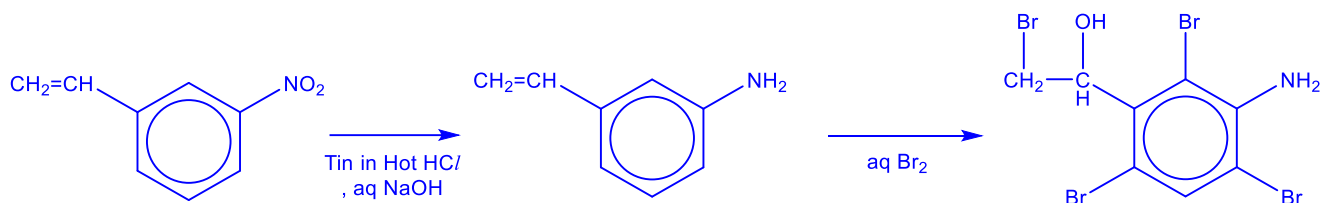
It is subjected to the following reactions:

- heat with Sn in concentrated  $\text{HCl}$  followed by careful addition of cold  $\text{NaOH(aq)}$
- then the addition of  $\text{Br}_2(\text{aq})$

What is the product obtained after the above reactions?

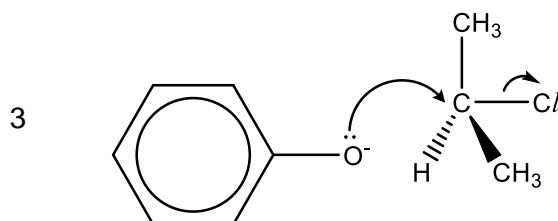
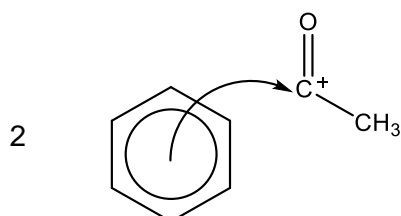
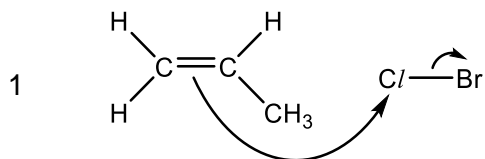


**Answer: C**





- 30 Which of the following show a correct mechanistic step in the reaction between the reagents?



- A 3 only  
B 1 and 2  
C 2 and 3  
D 1, 2 and 3

**Answer: C**

Option 1 is wrong as the alkene should attack the electron poor bromine atom instead.

**Answers**

1	2	3	4	5	6	7	8	9	10
A	C	B	D	B	A	C	A	B	D
11	12	13	14	15	16	17	18	19	20
A	C	A	D	D	A	B	C	C	B
21	22	23	24	25	26	27	28	29	30
A	D	A	D	A	C	B	C	C	C





# TAMPINES MERIDIAN JUNIOR COLLEGE

## JC2 PRELIMINARY EXAMINATION

CANDIDATE  
NAME

CIVICS GROUP

### H2 CHEMISTRY

Paper 2 Structured Questions

**9729/02**

**19 September 2019**

**2 hours**

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

#### READ THESE INSTRUCTIONS FIRST

Write your name and civics group in the spaces at the top of this page.

Write in dark blue or black pen on both sides of the paper.

You may use an HB pencil for any diagrams, graphs or rough working.

Do not use paper clips, glue or correction fluid.

Answer **all** questions in the spaces provided on the Question Paper.

The use of an approved scientific calculator is expected, where appropriate.

The number of marks is given in brackets [ ] at the end of each question or part question.

Examiner's Use		
Paper 1	MCQ	/ 30
Paper 2	Q1	/ 14
	Q2	/ 9
	Q3	/ 13
	Q4	/ 12
	Q5	/ 11
	Q6	/ 16
	/ 75	
Paper 3	/ 80	
Paper 4	/ 55	
Total	/ 100	
Grade		

This document consists of **19** printed pages.



- 1 (a) Carbon forms compounds with Group 16 elements such as oxygen, sulfur and selenium. The properties of some of these compounds are given below.

compound	structure	net dipole moment	boiling point / °C
CO <sub>2</sub>	O=C=O	0	sublimes
CS <sub>2</sub>	S=C=S	0	46
COS	S=C=O	0.71	-50
COSe	Se=C=O	0.73	-22

- (i) Explain, in terms of structure and bonding, the difference in the boiling points of CS<sub>2</sub> and COS.

.....

.....

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.....[2]

- (ii) Explain why
- CO<sub>2</sub> has no net dipole moment.
  - COSe has a greater net dipole moment than COS.

.....

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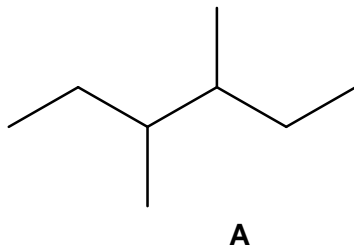
.....

.....[2]



Carbon forms the backbone of organic compounds. Hydrocarbons are the simplest organic compounds that contain carbon and hydrogen.

- (b) Compound **A** is an isomer of the hydrocarbon octane,  $C_8H_{18}$ .



Controlled chlorination of compound **A** in the presence of UV light produces different mono-chlorinated products with a molecular formula of  $C_8H_{17}Cl$ .

- (i) Suggest the total number of constitutional isomers which can be formed from the possible mono-chlorination of compound **A**. Draw the structural formulae of any **two** of these products.

Total number of possible mono-chlorinated products = .....

[3]

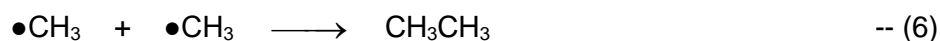
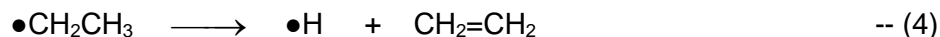
- (ii) Draw the **skeletal** formula of the isomer of octane which could produce **only one** possible mono-chlorinated product if it undergoes free radical substitution.

[1]



- (c) Besides reaction of alkanes with halogens, the process of thermal cracking, in which large alkane molecules are broken down into smaller alkanes and alkenes, proceeds via free radical mechanism.

The following are reactions involved when propane undergoes thermal cracking.



- (i) Reactions (1) and (2) are termed initiation steps. By quoting relevant data from the *Data Booklet*, deduce which one is more likely to occur.

.....  
 .....[1]

- (ii) From reactions (3) to (7), identify those which may be termed propagation steps in the mechanism.

.....[1]

- (iii) Which gas, if detected in the product mixture, would support the occurrence of both reactions (2) and (4)?

.....[1]

- (iv) Suggest why reaction (7) may be termed a *disproportionation* reaction.

.....  
 .....[1]



- (d) Methanoic acid,  $\text{H}_2\text{CO}_2$ , is the simplest carboxylic acid.

Draw a dot-and-cross diagram of methanoic acid. Suggest the shape around the carbon atom in methanoic acid.

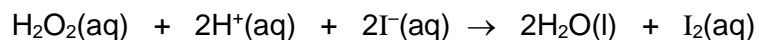
Shape around C atom .....

[2]

[Total: 14]



- 2 Hydrogen peroxide reacts with acidified iodide ions to liberate iodine, according to the following equation:



In investigations of this reaction, the following results were obtained by varying the volumes of hydrogen peroxide and iodide ions.

experiment	volume of $\text{H}_2\text{O}_2$ / $\text{cm}^3$	volume of $\text{I}^-$ / $\text{cm}^3$	volume of $\text{H}_2\text{O}$ / $\text{cm}^3$	initial rate / $\text{mol dm}^{-3} \text{s}^{-1}$
1	20.0	20.0	20.0	$1.2 \times 10^{-2}$
2	20.0	30.0	10.0	$1.8 \times 10^{-2}$
3	50.0	10.0	0.0	$1.5 \times 10^{-2}$

- (a) Explain why water was added to experiments 1 and 2.

.....  
 .....[1]





(b) The reaction was determined to be **zero order** with respect to hydrogen ions.

(i) Sketch the rate-concentration graph for  $\text{H}^+$  ions.

[1]

(ii) Determine the order of reaction with respect to the other two reactants.

Hence, write down the rate equation.

[3]



- (c) In order to further investigate the kinetics of the reaction, experiments 4 and 5 were conducted. The following results were obtained by varying the concentrations of hydrogen peroxide and iodide ions.

experiment	initial $[\text{H}_2\text{O}_2(\text{aq})]$ / $\text{mol dm}^{-3}$	initial $[\text{I}^-(\text{aq})]$ / $\text{mol dm}^{-3}$
4	0.020	0.500
5	0.050	1.000

The half-life of hydrogen peroxide was 9.6 min in experiment 4. Explain and predict the half-life of hydrogen peroxide in experiment 5.

.....  
 .....  
 .....  
 .....[2]

- (d) An alternative method of investigating the rate of the above reaction is by withdrawing aliquots at specified time intervals and titrating the iodine formed in each aliquot with sodium thiosulfate solution.

Suggest how the reaction can be quenched at specified time intervals.

.....  
 .....[1]

- (e) Hydrogen peroxide decomposes easily. Suggest a method whereby the shelf-life of the hydrogen peroxide solution could be increased.

.....  
 .....[1]

[Total: 9]



- 3** Lithium forms various compounds used for a wide range of purposes. For example,  $\text{Li}_2\text{CO}_3$  is used as a mood-stabilising drug and  $\text{LiF}$  is used to record ionising radiation exposure from gamma rays, beta particles and neutrons.

- (a)** Numerical values of the solubility products of some lithium salts at 298 K are given in the table below.

salt	solubility product
$\text{LiF}$	$2.68 \times 10^{-3}$
$\text{Li}_2\text{CO}_3$	$2.14 \times 10^{-2}$
$\text{Li}_3\text{PO}_4$	$3.20 \times 10^{-9}$

- (i)** Write an expression for the solubility product,  $K_{\text{sp}}$ , of lithium phosphate, including its units.

[2]

- (ii)** Using the data above, calculate a value for the solubility of lithium phosphate.

[2]

- (iii)**  $\text{LiF}$  was precipitated when equal volumes of a solution of  $0.050 \text{ mol dm}^{-3} \text{ LiNO}_3$  and a solution of  $\text{KF}$  were mixed.

Calculate the minimum concentration of the  $\text{KF}$  solution required for precipitation to occur.

[2]



- (iv) Describe and explain how the solubility of  $\text{Li}_2\text{CO}_3$  is affected by adding solid  $\text{Na}_2\text{CO}_3$  into the solution.

.....  
 .....  
 .....  
 .....[2]

- (b) When a precipitate is formed,  $\Delta G^\circ_{\text{ppt}}$ , in  $\text{J mol}^{-1}$ , is given by the following expression.

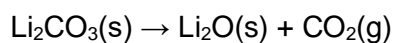
$$\Delta G^\circ_{\text{ppt}} = 2.303 RT \log K_{\text{sp}}$$

For lithium sulfate,  $\text{Li}_2\text{SO}_4$ ,  $K_{\text{sp}} = 128 \text{ mol}^3 \text{ dm}^{-9}$  at 298 K.

Using the above expression, determine whether lithium sulfate is soluble in water at 298 K. Explain your answer.

[2]

- (c) Another use of  $\text{Li}_2\text{CO}_3$  is in the processing of metal oxides. When  $\text{Li}_2\text{CO}_3$  decomposes, it forms  $\text{Li}_2\text{O}$  solid and  $\text{CO}_2$  gas according to the following equation.



- (i) Calculate the standard enthalpy change of reaction for the decomposition of  $\text{Li}_2\text{CO}_3$  using the following standard enthalpy changes of formation,  $\Delta H_f^\circ$ .

compound	$\text{Li}_2\text{CO}_3$	$\text{Li}_2\text{O}$	$\text{CO}_2$
$\Delta H_f^\circ / \text{kJ mol}^{-1}$	-1216	-596	-394

[1]



- (ii) The entropy change for the decomposition reaction is positive. Explain the effect on spontaneity of this decomposition reaction as temperature increases.

[2]

[Total: 13]



4 Use of the Data Booklet is relevant to this question.

- (a) Chemical companies manufacture containers filled with liquid butane for use by campers. The complete combustion of butane produces carbon dioxide and water. The enthalpy change of combustion of butane is  $-3000 \text{ kJ mol}^{-1}$ .

A camper estimates that the liquid butane left in a container would give  $1.2 \text{ dm}^3$  of butane gas (measured at room temperature of  $20^\circ\text{C}$  and pressure of  $1 \text{ atm}$ ).

- (i) Calculate the mass of water at room temperature that could be brought to boiling point at  $100^\circ\text{C}$  by completely burning this mass of butane, given that the process is only 80% efficient.

[3]

- (ii) Suggest a reason why the combustion process is only 80% efficient.

.....

.....[1]

- (b) When burnt in a limited supply of air, butane forms carbon and water. The enthalpy change of this reaction is  $-1400 \text{ kJ mol}^{-1}$ .

- (i) Construct a balanced equation for this reaction.

.....[1]

- (ii) Explain why the enthalpy changes of the two combustion reactions in (a) and (b) are different.

.....[1]

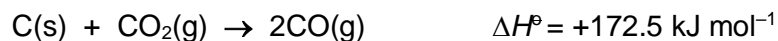
- (iii) State the quantitative information that can be obtained from this difference in enthalpy changes.

.....[1]



- (c) The carbon-oxygen *bond energy* in carbon monoxide, CO, is  $1077 \text{ kJ mol}^{-1}$ .

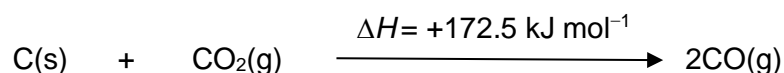
Carbon monoxide can be formed by the following reaction:



- (i) Explain, with the aid of a suitable equation, what is meant by the term *bond energy* of carbon monoxide.

.....  
 .....  
 .....[2]

- (ii) Determine the enthalpy change of atomisation of carbon by using relevant bond energy data from the *Data Booklet* to complete the energy cycle below. Include relevant information in your cycle.



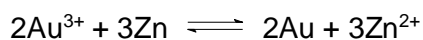
[3]

[Total: 12]



**5** Use of the Data Booklet is relevant to this question.

A student wanted to study the following reaction.



He first sets up an electrochemical cell which comprises of  $\text{Au}^{3+}/\text{Au}$  and  $\text{Zn}^{2+}/\text{Zn}$  half-cells prepared under standard conditions.

- (a)**    **(i)**    Draw a fully labelled diagram of the electrochemical cell under standard conditions.

[2]

- (ii)**    Given that  $E^{\ominus}_{\text{Au}^{3+}/\text{Au}}$  is +1.50 V, calculate the  $E^{\ominus}_{\text{cell}}$  of this cell.

[1]

- (iii)**    Suggest a replacement transition element ion-ion half-cell for the  $\text{Zn}^{2+}/\text{Zn}$  half-cell so that the direction of electron flow is reversed.

.....[1]





- (b) When the reaction in (a) begins,  $[\text{Au}^{3+}]$  starts to decrease while  $[\text{Zn}^{2+}]$  increases. In the study of electrochemical cells, the *Nernst equation*, given below, can be applied to determine the cell potential under non-standard conditions.

$$E_{\text{cell}} = E^{\circ}_{\text{cell}} - \frac{0.0592}{n} \log_{10} Q$$

where  $n$  is the number of moles of electrons transferred and  $Q$  is the reaction quotient given by  $\frac{[\text{Zn}^{2+}]}{[\text{Au}^{3+}]}$ .

- (i) Using your answer in (a)(ii), calculate the new  $E_{\text{cell}}$  using the Nernst equation, when  $[\text{Au}^{3+}]$  and  $[\text{Zn}^{2+}]$  are  $0.02 \text{ mol dm}^{-3}$  and  $2.47 \text{ mol dm}^{-3}$  respectively.

[1]

- (ii) Suggest the value of  $E_{\text{cell}}$  when the reaction goes to completion.

[1]

- (c) The redox reaction in (a) is an example of a spontaneous reaction which proceeds as predicted by the cell potential. However, not every chemical reaction agrees with the theoretical prediction. One example is the reaction between acidified  $\text{K}_2\text{Cr}_2\text{O}_7$  and water.

- (i) Using information from the *Data Booklet*, calculate  $\Delta G^{\circ}$  for the reaction between acidified  $\text{K}_2\text{Cr}_2\text{O}_7$  and water. Based on your value for  $\Delta G^{\circ}$ , comment on the spontaneity of the reaction.

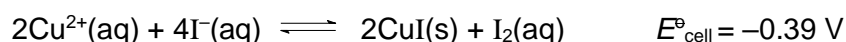
[3]



- (ii) The reaction between water and acidified  $\text{K}_2\text{Cr}_2\text{O}_7$  has an  $E^\ominus_{\text{cell}}$  greater than 0 V under standard conditions, yet the reaction does not proceed. Suggest a reason for this observation.

.....  
 .....[1]

- (iii) Another example of a reaction that does not agree with the theoretical prediction is the reaction between  $\text{Cu}^{2+}$  and  $\text{I}^-$  according to the equation below.



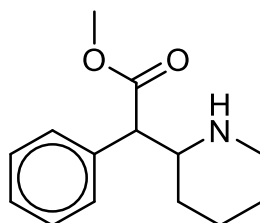
White precipitate of CuI is formed during the reaction. Suggest a reason why the reaction proceeds despite the  $E^\ominus_{\text{cell}}$  being less than 0 V.

.....  
 .....[1]

[Total: 11]

- 6 Adrenaline is a naturally occurring hormone and stimulant released in the body during times of danger or stress. Stimulant drugs that can mimic the effect of adrenaline have been developed for treatment of various conditions.

- (a) Methylphenidate is a stimulant drug commonly used in the treatment of Attention Deficit Hyperactive Disorder (ADHD).




methylphenidate

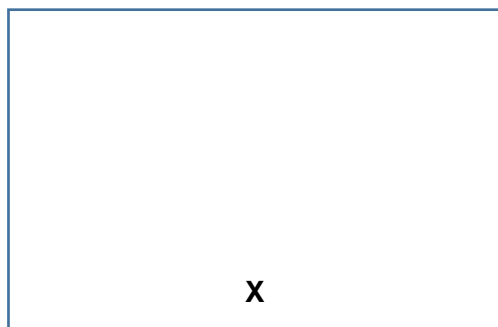
- (i) Draw the structures of the organic products formed when methylphenidate is heated with dilute hydrochloric acid.

[2]

(ii) An isomer of methylphenidate, compound **X**, is neutral and has the following structural properties:

- contains one aromatic six-membered ring
- contains 

Suggest a structure for compound **X** and state its isomeric relationship to methylphenidate.

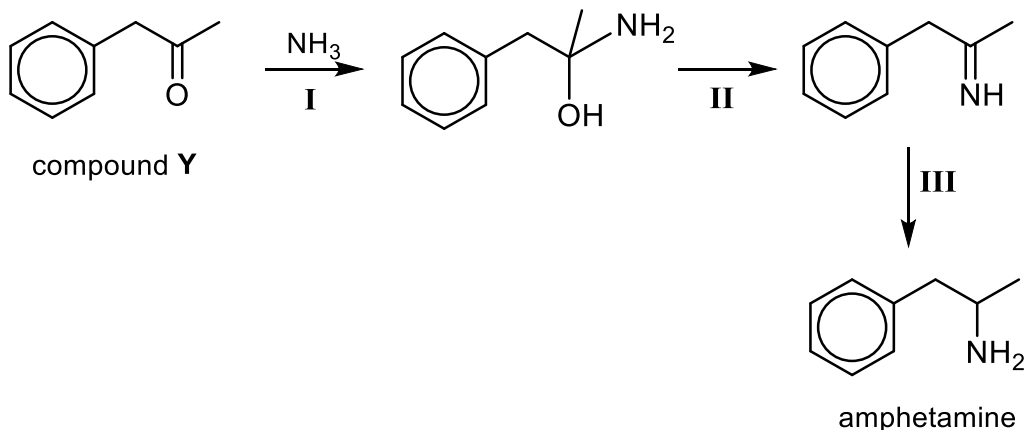


isomeric relationship to methylphenidate:

.....

[2]

(b) Another stimulant, amphetamine, is prepared commercially from compound **Y** as shown below.



(i) Suggest the type of reaction occurring in:

Step **II** .....

Step **III** .....

[2]

(ii) Suggest suitable reagents and conditions for the conversion in step **III**. You may assume the R=NH group reacts in a similar manner to the carbonyl group.

reagents and conditions .....

[1]

- (iii) Reaction I which occurs between compound Y and  $\text{NH}_3$  is a nucleophilic addition reaction.

Draw the mechanism for this reaction, given that in the rate-determining step, the nucleophilic attack by  $\text{NH}_3$ , results in an intermediate species containing both a positive and negative charge.

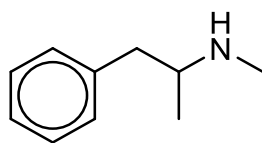
[3]

- (iv) With reference to the mechanism you have drawn in (iii), explain why the product from step I is expected to be optically inactive.

.....  
.....  
.....  
.....[2]



- (c) Methamphetamine is a stimulant which has a structure similar to amphetamine.



methamphetamine

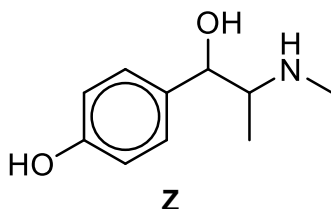
- (i) The hydrochloride salt of methamphetamine exists as colourless crystals.

Methamphetamine is immiscible with water whereas the salt is soluble in water.

With reference to the interactions formed between each of the compounds and water, explain the difference in the solubility of methamphetamine and its salt in water.

.....  
 .....  
 .....  
 .....  
 .....[2]

- (ii) In the human body, methamphetamine can be converted to compound **Z**.



**Z**

Describe a simple chemical test which could be used to distinguish between methamphetamine and compound **Z**.

You should state the reagents and conditions required, together with the expected observations for each compound.

.....  
 .....  
 .....[2]

[Total: 16]

**End of Paper 2**



# TAMPINES MERIDIAN JUNIOR COLLEGE

## 2019 JC2 H2 Chemistry Prelim Exam Paper 2

### (Suggested Answers)

- 1 (a) Carbon forms compounds with Group 16 elements such as oxygen, sulfur and selenium. The properties of some of these compounds are given below.

compound	structure	net dipole moment	boiling point / °C
CO <sub>2</sub>	O=C=O	0	sublimes
CS <sub>2</sub>	S=C=S	0	46
COS	S=C=O	0.71	-50
COSe	Se=C=O	0.73	-22

- (i) Explain, in terms of structure and bonding, the difference in the boiling points of CS<sub>2</sub> and COS.

**CS<sub>2</sub> has a higher boiling point.** Both CS<sub>2</sub> and COS have simple molecular structures.

CS<sub>2</sub> has a larger electron cloud (or larger number of electrons) than COS. More energy is required to overcome the stronger instantaneous dipole-induced dipole interactions (or IMF/Dispersion forces) between CS<sub>2</sub> molecules than the instantaneous dipole-induced dipole interactions between COS molecules.

[2]

- (ii) Explain why

- CO<sub>2</sub> has no net dipole moment.
- COSe has a greater net dipole moment than COS.

CO<sub>2</sub> has not net dipole moment because it is linear and the dipole moments cancel out.

COSe has a greater net dipole moment than COS.

There is a smaller difference between the dipole moment of C=O and C=S in COS than that between C=O and C=Se in COSe since S is more electronegative than Se.

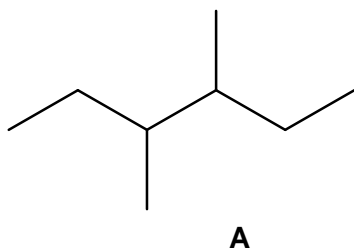
OR polarity of C=S is greater than that of C=Se.

[2]



Carbon forms the backbone of organic compounds. Hydrocarbons are the simplest organic compounds that contain carbon and hydrogen.

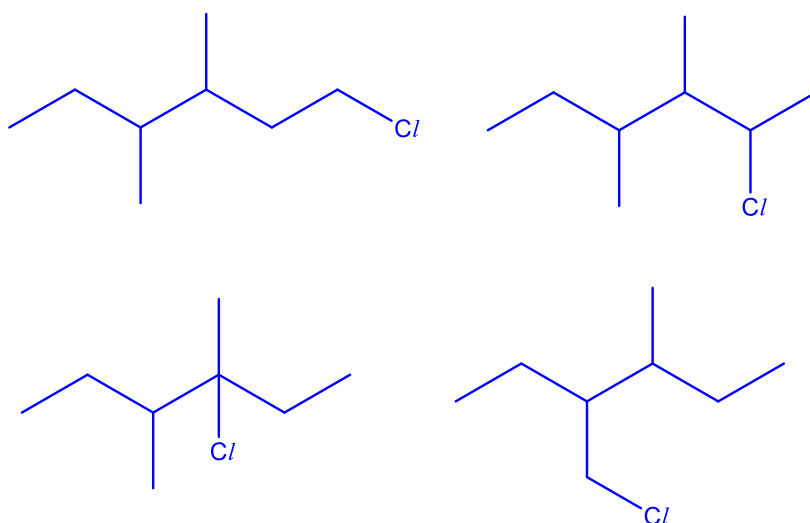
- (b) Compound **A** is an isomer of the hydrocarbon octane,  $C_8H_{18}$ .



Controlled chlorination of compound **A** in the presence of UV light produces different mono-chlorinated products with a molecular formula of  $C_8H_{17}Cl$ .

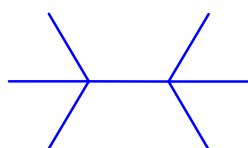
- (i) Suggest the total number of constitutional isomers which can be formed from the possible mono-chlorination of compound **A**. Draw the structural formulae of any **two** of these products.

Total number of possible mono-chlorinated products = 4



[3]

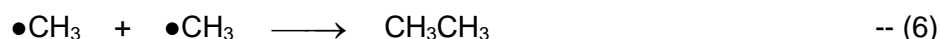
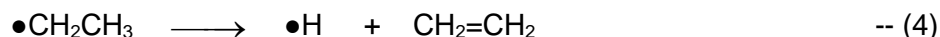
- (ii) Draw the **skeletal** formula of the isomer of octane which could produce **only one** possible mono-chlorinated product if it undergoes free radical substitution.



[1]

- (c) Besides reaction of alkanes with halogens, the process of thermal cracking, in which large alkane molecules are broken down into smaller alkanes and alkenes, proceeds via free radical mechanism.

The following are reactions involved when propane undergoes thermal cracking.



- (i) Reactions (1) and (2) are termed initiation steps. By quoting relevant data from the *Data Booklet*, deduce which one is more likely to occur.

Reaction (1) is more likely to occur as it is easier to break a C-C bond (350 kJ mol<sup>-1</sup>) compared to a C-H bond (410 kJ mol<sup>-1</sup>).

[1]

- (ii) From reactions (3) to (7), identify those which may be termed propagation steps in the mechanism.

Reactions (3), (4) and (5)

[1]

- (iii) Which gas, if detected in the product mixture, would support the occurrence of both reactions (2) and (4)?

Hydrogen

[1]

- (iv) Suggest why reaction (7) may be termed a *disproportionation* reaction.

The  $\bullet\text{CH}_2\text{CH}_3$  radical loses a hydrogen (is oxidised) to form ethene and gains a hydrogen (is reduced) to form ethane.

OR

The oxidation number of carbon in  $\bullet\text{CH}_2\text{CH}_3$  increases -3 from to -2 in ethene and decreases from to -3 to form ethane.

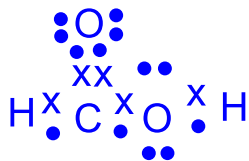
[1]





- (d) Methanoic acid,  $\text{H}_2\text{CO}_2$ , is the simplest carboxylic acid.

Draw a dot-and-cross diagram of methanoic acid. Suggest the shape around the carbon atom in methanoic acid.

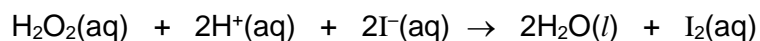


Shape around C atom: Trigonal planar

[2]

[Total: 14]

- 2 Hydrogen peroxide reacts with acidified iodide ions to liberate iodine, according to the following equation:



In investigations of this reaction, the following results were obtained by varying the volumes of hydrogen peroxide and iodide ions.

experiment	volume of $\text{H}_2\text{O}_2$ / $\text{cm}^3$	volume of $\text{I}^-$ / $\text{cm}^3$	volume of $\text{H}_2\text{O}$ / $\text{cm}^3$	initial rate / $\text{mol dm}^{-3} \text{s}^{-1}$
1	20.0	20.0	20.0	$1.2 \times 10^{-2}$
2	20.0	30.0	10.0	$1.8 \times 10^{-2}$
3	50.0	10.0	0.0	$1.5 \times 10^{-2}$

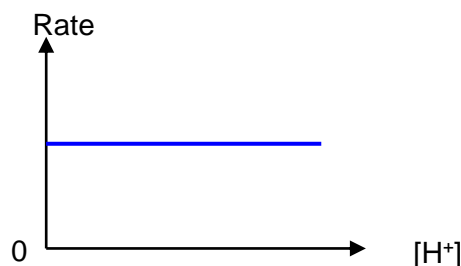
- (a) Explain why water was added to experiments 1 and 2.

To ensure the total volume of the mixture remains constant, so that volume of reactant is directly proportional to [reactant] in the mixture .

[1]

- (b) The reaction was determined to be **zero order** with respect to hydrogen ions.

- (i) Sketch the rate-concentration graph for  $\text{H}^+$  ions.



[1]

- (ii) Determine the order of reaction with respect to the other two reactants.

Hence, write down the rate equation.

$$\text{Let rate} = k[\text{H}_2\text{O}_2(\text{aq})]^m[\text{I}^-(\text{aq})]^n$$

Compare experiments 1 & 2, keeping  $[\text{H}_2\text{O}_2(\text{aq})]$  and total volume constant

$$\frac{1.2 \times 10^{-2}}{1.8 \times 10^{-2}} = \frac{k(20.0)^m(20.0)^n}{k(20.0)^m(30.0)^n} \quad (\text{or use inspection method})$$

$$n = 1$$

Rate of reaction is 1st order with respect to  $\text{I}^-(\text{aq})$ .

Or

Compare experiments 1 & 2, keeping  $[\text{H}_2\text{O}_2(\text{aq})]$  and total volume constant

when  $[\text{I}^-]$  x 3/2, rate of reaction x 3/2

Order of reaction w.r.t.  $\text{I}^- = 1$

Compare experiments 1 & 3, keeping total volume constant

$$\frac{1.2 \times 10^{-2}}{1.5 \times 10^{-2}} = \frac{k(20.0)^m(20.0)^1}{k(50.0)^m(10.0)^1}$$

$$m = 1$$

Rate of reaction is 1st order with respect to  $\text{H}_2\text{O}_2(\text{aq})$ .

Or

Compare experiments 1 & 3, keeping total volume constant

When  $[\text{I}^-]$  x 1/2 and  $[\text{H}_2\text{O}_2]$  x 5/2, rate x 5/4 ( $1/2 \times 5/2$ )

Since the order wrt.  $\text{I}^-$  is 1, order wrt to  $\text{H}_2\text{O}_2$  is 1.

$$\text{rate} = k[\text{H}_2\text{O}_2(\text{aq})][\text{I}^-(\text{aq})]$$

[3]

- (c) In order to further investigate the kinetics of the reaction, experiments 4 and 5 were conducted. The following results were obtained by varying the concentrations of hydrogen peroxide and iodide ions.

experiment	initial $[\text{H}_2\text{O}_2(\text{aq})]$ / $\text{mol dm}^{-3}$	initial $[\text{I}^-(\text{aq})]$ / $\text{mol dm}^{-3}$
4	0.020	0.500
5	0.050	1.000

The half-life of hydrogen peroxide was 9.6 min in experiment 4. Explain and predict the half-life of hydrogen peroxide in experiment 5.

For experiment 4 and 5, since  $[\text{I}^-(\text{aq})] \gg [\text{H}_2\text{O}_2(\text{aq})]$ ,  $[\text{I}^-(\text{aq})]$  is approximately constant.

Thus, rate =  $k'[\text{H}_2\text{O}_2(\text{aq})]$  (a pseudo first order reaction)

where  $k' = k[\text{I}^-(\text{aq})]$

$$t_{1/2} = \frac{\ln 2}{k'} = \frac{\ln 2}{k[\text{I}^-]}$$

$t_{1/2}$  of  $\text{H}_2\text{O}_2$  in experiment 4 = 9.6 min (for  $[\text{I}^-(\text{aq})] = 0.500 \text{ mol dm}^{-3}$ )

$t_{1/2}$  of  $\text{H}_2\text{O}_2$  in experiment 5 = 4.8 min (for  $[\text{I}^-(\text{aq})] = 1.00 \text{ mol dm}^{-3}$ )

[2]



- (d) An alternative method of investigating the rate of the above reaction is by withdrawing aliquots at specified time intervals and titrating the iodine formed in each aliquot with sodium thiosulfate solution.

Suggest how the reaction can be quenched at specified time intervals.

Sudden cooling of the reaction mixture or sudden dilution through the addition of large volume of water.

[1]

- (e) Hydrogen peroxide decomposes easily. Suggest a method whereby the shelf-life of the hydrogen peroxide solution could be increased.

Keep away from light by storing it in a dark-coloured bottle.

or

Ensure purity of the solutions, i.e. no contaminants, especially those that hasten the decomposition of peroxide.

[1]

[Total: 9]

- 3 Lithium forms various compounds used for a wide range of purposes. For example,  $\text{Li}_2\text{CO}_3$  is used as a mood-stabilising drug and  $\text{LiF}$  is used to record ionising radiation exposure from gamma rays, beta particles and neutrons.

- (a) Numerical values of the solubility products of some lithium salts at 298 K are given in the table below.

salt	solubility product
$\text{LiF}$	$2.68 \times 10^{-3}$
$\text{Li}_2\text{CO}_3$	$2.14 \times 10^{-2}$
$\text{Li}_3\text{PO}_4$	$3.20 \times 10^{-9}$

- (i) Write an expression for the solubility product,  $K_{\text{sp}}$ , of lithium phosphate, including its units.

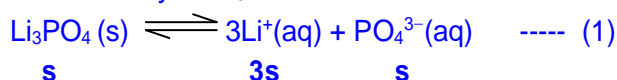
$$K_{\text{sp}} = [\text{Li}^+]^3 [\text{PO}_4^{3-}] \text{ mol}^4 \text{ dm}^{-12}$$

[2]



- (ii) Using the data above, calculate a value for the solubility of lithium phosphate.

Let solubility of  $\text{Li}_3\text{PO}_4$  be  $s \text{ mol dm}^{-3}$



$$\begin{aligned} K_{\text{sp}} &= [\text{Li}^+]^3 [\text{PO}_4^{3-}] \\ &= (3s)^3 (s) \\ &= 27s^4 \end{aligned}$$

$$3.20 \times 10^{-9} = 27s^4$$

$$\text{Solubility of } \text{Li}_3\text{PO}_4 = s = \underline{3.30 \times 10^{-3} \text{ mol dm}^{-3}}$$

[2]

- (iii)  $\text{LiF}$  was precipitated when equal volumes of a solution of  $0.050 \text{ mol dm}^{-3} \text{ LiNO}_3$  and a solution of  $\text{KF}$  were mixed.

Calculate the minimum concentration of the  $\text{KF}$  solution required for precipitation to occur.

Since equal volumes are mixed, new  $[\text{Li}^+] = 0.050 / 2 = 0.025 \text{ mol dm}^{-3}$

Precipitation occurs when Ionic Product  $\geq K_{\text{sp}}$

$$[\text{Li}^+] [\text{F}^-] \geq 2.68 \times 10^{-3}$$

$$0.025 \times [\text{F}^-] \geq 2.68 \times 10^{-3}$$

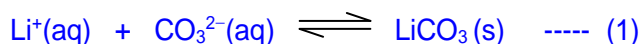
$$[\text{F}^-] \geq 0.1072 \text{ mol dm}^{-3}$$



$$\text{Original concentration of KF} = 0.1072 \times 2 = \underline{0.214 \text{ mol dm}^{-3}}$$

[2]

- (iv) Describe and explain how the solubility of  $\text{Li}_2\text{CO}_3$  is affected by adding solid  $\text{Na}_2\text{CO}_3$  into the solution.



Due to **common ion  $\text{CO}_3^{2-}$** , when  $\text{Na}_2\text{CO}_3$  is added into the solution,  **$[\text{CO}_3^{2-}]$  increases**. By Le Chatelier's Principle, **equilibrium position** (1) shifts to the **right** to **decrease  $[\text{CO}_3^{2-}]$** . Hence, **solubility of  $\text{Li}_2\text{CO}_3$  decreases**.

[2]

- (b) When a precipitate is formed,  $\Delta G^\circ_{\text{ppt}}$ , in  $\text{J mol}^{-1}$ , is given by the following expression.

$$\Delta G^\circ_{\text{ppt}} = 2.303 RT \log K_{\text{sp}}$$

For lithium sulfate,  $\text{Li}_2\text{SO}_4$ ,  $K_{\text{sp}} = 128 \text{ mol}^3 \text{ dm}^{-9}$  at 298 K.

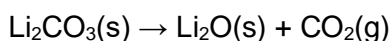
Using the above expression, determine whether lithium sulfate is soluble in water at 298 K. Explain your answer.

$$\begin{aligned} \text{For } \text{Li}_2\text{SO}_4, \Delta G^\circ_{\text{ppt}} &= 2.303RT \log K_{\text{sp}} \\ &= 2.303 \times 8.31 \times 298 \times \log (128) \\ &= \underline{+1.20 \times 10^4 \text{ J mol}^{-1}} \end{aligned}$$

Since  $\Delta G^\circ_{\text{ppt}} > 0$ , it implies that the precipitation of  $\text{Li}_2\text{SO}_4$ , is not feasible. Hence,  $\text{Li}_2\text{SO}_4$ , is soluble in water at 298K.

[2]

- (c) Another use of  $\text{Li}_2\text{CO}_3$  is in the processing of metal oxides. When  $\text{Li}_2\text{CO}_3$  decomposes, it forms  $\text{Li}_2\text{O}$  solid and  $\text{CO}_2$  gas according to the following equation.



- (i) Calculate the standard enthalpy change of reaction for the decomposition of  $\text{Li}_2\text{CO}_3$  using the following standard enthalpy changes of formation,  $\Delta H_f^\circ$ .

compound	$\text{Li}_2\text{CO}_3$	$\text{Li}_2\text{O}$	$\text{CO}_2$
$\Delta H_f^\circ / \text{kJ mol}^{-1}$	-1216	-596	-394

$$\begin{aligned} \Delta H_r^\circ &= \Sigma \Delta H_f^\circ(\text{products}) - \Sigma \Delta H_f^\circ(\text{reactants}) \\ &= \Delta H_f^\circ(\text{CO}_2) + \Delta H_f^\circ(\text{Li}_2\text{O}) - \Delta H_f^\circ(\text{Li}_2\text{CO}_3) \\ &= -394 - 596 - (-1216) \\ &= \underline{+226 \text{ kJ mol}^{-1}} \end{aligned}$$

[1]

- (ii) The entropy change for the decomposition reaction is positive. Explain the effect on spontaneity of this decomposition reaction as temperature increases.

$\Delta H^\circ$  is positive while  $\Delta S^\circ$  is positive. So  $-T\Delta S$  is negative.

As temperature increases,  $-T\Delta S$  becomes more negative so  $\Delta G$  becomes more negative. Thus the decomposition becomes more spontaneous as temperature increases.

OR

At low  $T$ ,

$$|T\Delta S| < |\Delta H|$$

$\Rightarrow$  Hence,  $\Delta G > 0$  (+ve) at low temperatures.

At high  $T$ ,

$$|T\Delta S| > |\Delta H|$$

$\Rightarrow$  Hence,  $\Delta G < 0$  (-ve) at high temperatures.

Thus the decomposition becomes more spontaneous as temperature increases.

[2]

[Total: 13]



4 Use of the Data Booklet is relevant to this question.

- (a) Chemical companies manufacture containers filled with liquid butane for use by campers. The complete combustion of butane produces carbon dioxide and water. The enthalpy change of combustion of butane is  $-3000 \text{ kJ mol}^{-1}$ .

A camper estimates that the liquid butane left in a container would give  $1.2 \text{ dm}^3$  of butane gas (measured at room temperature of  $20^\circ\text{C}$  and pressure of  $1 \text{ atm}$ ).

- (i) Calculate the mass of water at room temperature that could be brought to boiling point at  $100^\circ\text{C}$  by completely burning this mass of butane, given that the process is only 80% efficient.

$$\text{No. of moles of butane present} = \frac{1.2}{24} = 0.0500 \text{ mol}$$

$$\text{Quantity of heat released by combustion, } q' = 3000 \times 0.0500 = 150 \text{ kJ}$$

$$\begin{aligned} \text{Quantity of heat absorbed by water, } q &= 80\% \times q' = 80\% \times 150 = 120 \text{ kJ} \\ q &= m c \Delta T \Rightarrow q = m \times 4.18 \times (100 - 20) \end{aligned}$$

$$\text{Mass of water, } m = \frac{120}{334.4} = \underline{\underline{0.359 \text{ kg (or 359 g)}}} \text{ (3 s.f.)}$$

[3]

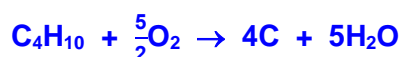
- (ii) Suggest a reason why the combustion process is only 80% efficient.

- Heat is lost to surroundings during combustion.
- Some of the heat is used to vapourise the liquid butane.

[1]

- (b) When burnt in a limited supply of air, butane forms carbon and water. The enthalpy change of this reaction is  $-1400 \text{ kJ mol}^{-1}$ .

- (i) Construct a balanced equation for this reaction.



[1]

- (ii) Explain why the enthalpy changes of the two combustion reactions in (a) and (b) are different.

Due to complete combustion in (a), more energy is released due to the formation of  $\text{CO}_2$  (bond formation), compared with only C formed in the incomplete combustion in (b). (or reverse discussion)

[1]

- (iii) State the quantitative information that can be obtained from this difference in enthalpy changes.

(Standard) Enthalpy change of combustion of carbon /  $\Delta H_c(\text{C})$

[1]



- (c) The carbon-oxygen *bond energy* in carbon monoxide, CO, is 1077 kJ mol<sup>-1</sup>.

Carbon monoxide can be formed by the following reaction:



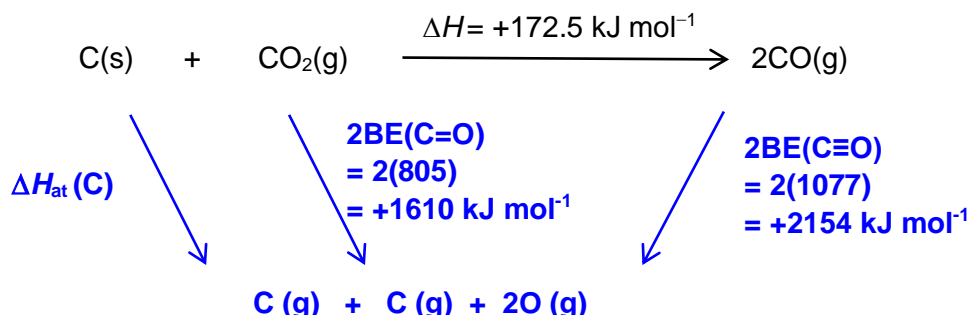
- (i) Explain, with the aid of a suitable equation, what is meant by the term *bond energy* of carbon monoxide.



*Bond energy* of CO is the energy required to break 1 mole of gaseous CO (triple) bond to form gaseous (C and O) atoms.

[2]

- (ii) Determine the enthalpy change of atomisation of carbon by using relevant bond energy data from the *Data Booklet* to complete the energy cycle below. Include relevant information in your cycle.



By Hess' Law,

$$\Delta H_{\text{at}}(\text{C}) + 2\text{BE}(\text{C}=\text{O}) = \Delta H + 2\text{BE}(\text{C}\equiv\text{O})$$

$$\Delta H_{\text{at}}(\text{C}) + 2(805) = 172.5 + 2(1077)$$

$$\begin{aligned}
 \Delta H_{\text{at}}(\text{C}) &= 172.5 + 2154 - 1610 \\
 &= \underline{+716.5 \text{ kJ mol}^{-1}}
 \end{aligned}$$

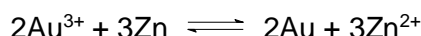
[3]

[Total: 12]



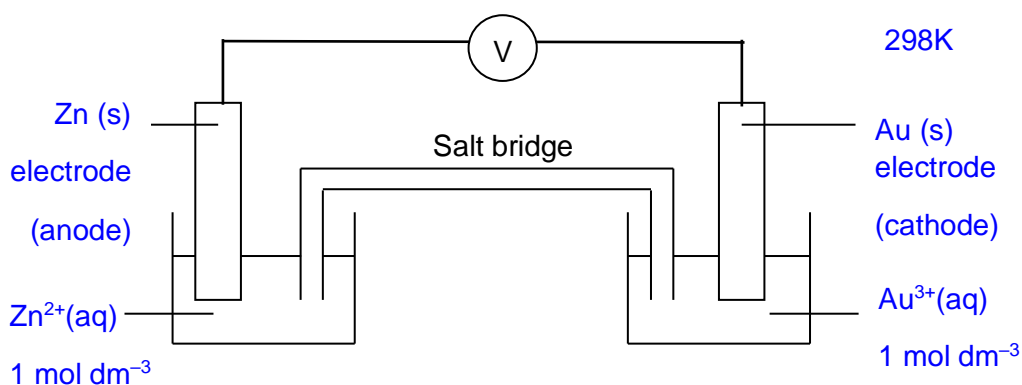
5 Use of the Data Booklet is relevant to this question.

A student wanted to study the following reaction.



He first sets up an electrochemical cell which comprises of  $\text{Au}^{3+}/\text{Au}$  and  $\text{Zn}^{2+}/\text{Zn}$  half-cells prepared under standard conditions.

- (a) (i) Draw a fully labelled diagram of the electrochemical cell under standard conditions.



[2]

- (ii) Given that  $E^{\ominus}_{\text{Au}^{3+}/\text{Au}}$  is +1.50 V, calculate the  $E^{\ominus}_{\text{cell}}$  of this cell.

$$E^{\ominus}_{\text{cell}} = +1.50 - (-0.76) = \underline{+2.26 \text{ V}}$$

[1]

- (iii) Suggest a replacement transition element ion-ion half-cell for the  $\text{Zn}^{2+}/\text{Zn}$  half-cell so that the direction of electron flow is reversed.



[1]

- (b) When the reaction in (a) begins,  $[\text{Au}^{3+}]$  starts to decrease while  $[\text{Zn}^{2+}]$  increases. In the study of electrochemical cells, the *Nernst equation*, given below, can be applied to determine the cell potential under non-standard conditions.

$$E_{\text{cell}} = E^{\ominus}_{\text{cell}} - \frac{0.0592}{n} \log_{10} Q$$

where  $n$  is the number of moles of electrons transferred and  $Q$  is the reaction quotient

given by  $\frac{[\text{Zn}^{2+}]}{[\text{Au}^{3+}]}$ .



- (i) Using your answer in (a)(ii), calculate the new  $E_{\text{cell}}$  using the Nernst equation, when  $[\text{Au}^{3+}]$  and  $[\text{Zn}^{2+}]$  are  $0.02 \text{ mol dm}^{-3}$  and  $2.47 \text{ mol dm}^{-3}$  respectively.

$$E_{\text{cell}} = +2.26 - \frac{0.0592}{6} \log_{10} \frac{[2.47]}{[0.02]} = \underline{+2.24 \text{ V}}$$

[1]

- (ii) Suggest the value of  $E_{\text{cell}}$  when the reaction goes to completion.

0 V

[1]

- (c) The redox reaction in (a) is an example of a spontaneous reaction which proceeds as predicted by the cell potential. However, not every chemical reaction agrees with the theoretical prediction. One example is the reaction between acidified  $\text{K}_2\text{Cr}_2\text{O}_7$  and water.

- (i) Using information from the *Data Booklet*, calculate  $\Delta G^\circ$  for the reaction between acidified  $\text{K}_2\text{Cr}_2\text{O}_7$  and water. Based on your value for  $\Delta G^\circ$ , comment on the spontaneity of the reaction.

$$\begin{aligned} \Delta G^\circ &= -nFE^\circ \\ &= -12 \times 96500 \times (1.33 - 1.23) \\ &= \underline{-1.16 \times 10^5 \text{ kJ mol}^{-1}} \end{aligned}$$

$\Delta G^\circ < 0$ , the reaction is spontaneous.

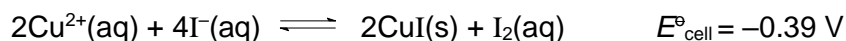
[3]

- (ii) The reaction between water and acidified  $\text{K}_2\text{Cr}_2\text{O}_7$  has an  $E^\circ_{\text{cell}}$  greater than 0 V under standard conditions, yet the reaction does not proceed. Suggest a reason for this observation.

The reaction has high activation energy so it cannot take place under standard condition.

[1]

- (iii) Another example of a reaction that does not agree with the theoretical prediction is the reaction between  $\text{Cu}^{2+}$  and  $\text{I}^-$  according to the equation below.



White precipitate of CuI is formed during the reaction. Suggest a reason why the reaction proceeds despite the  $E^\circ_{\text{cell}}$  being less than 0 V.

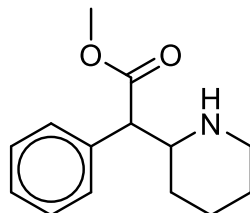
The continuous precipitation of CuI from the solution will shift the equilibrium position to the right and drive the reaction forward.

[1]

[Total: 11]

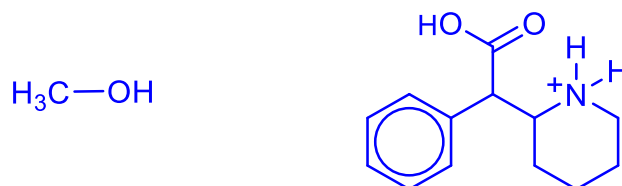


- 6 Adrenaline is a naturally occurring hormone and stimulant released in the body during times of danger or stress. Stimulant drugs that can mimic the effect of adrenaline have been developed for treatment of various conditions.
- (a) Methylphenidate is a stimulant drug commonly used in the treatment of Attention Deficit Hyperactive Disorder (ADHD).



methylphenidate

- (i) Draw the structures of the organic products formed when methylphenidate is heated with dilute hydrochloric acid.

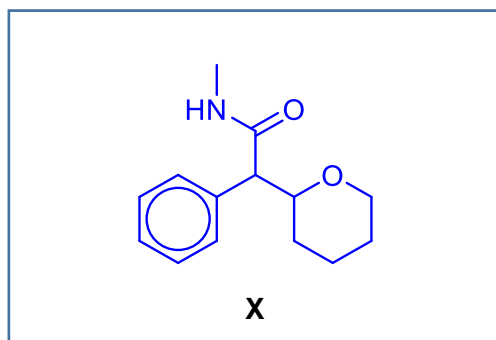


[2]

- (ii) An isomer of methylphenidate, compound **X**, is neutral and has the following structural properties:

- contains one aromatic six-membered ring
- contains

Suggest a structure for compound **X** and state its isomeric relationship to methylphenidate.



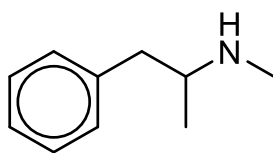
isomeric relationship to methylphenidate:

**constitutional isomer** (OR structural isomer)

[2]



- (c) Methamphetamine is a stimulant which has a structure similar to amphetamine.



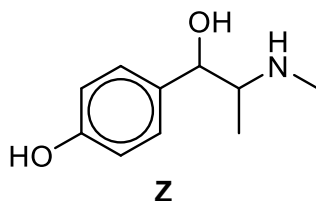
methamphetamine

- (i) The hydrochloride salt of methamphetamine exists as colourless crystals. Methamphetamine is immiscible with water whereas the salt is soluble in water. With reference to the interactions formed between each of the compounds and water, explain the difference in the solubility of methamphetamine and its salt in water.

Methamphetamine forms instantaneous dipole-induced dipole interactions with water whereas the salt is able to form ion-dipole interactions with water.

The strong interactions formed between the salt and water release sufficient energy to overcome hydrogen bonding between water molecules OR to cause detachment of ions from the crystal lattice. (OR weak i.d.-i.d. attraction of methamphetamine are not compatible with strong hydrogen bonding between water)

- (ii) In the human body, methamphetamine can be converted to compound **Z**. [2]



**Z**

Describe a simple chemical test which could be used to distinguish between methamphetamine and compound **Z**.

You should state the reagents and conditions required, together with the expected observations for each compound.

Add aqueous Br<sub>2</sub> to each compound

Compound Z will decolourise Br<sub>2</sub> with the formation of a white ppt whereas methamphetamine will give no visible observation.

Other possible test reagents: neutral FeCl<sub>3</sub> / Na / PCl<sub>5</sub> / hot acidified K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> (not KMnO<sub>4</sub>)

[2]

[Total: 16]

**End of Paper 2**



# TAMPINES MERIDIAN JUNIOR COLLEGE

## JC2 PRELIMINARY EXAMINATION

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### H2 CHEMISTRY

Paper 3 Free Response

**9729/03**

**23 September 2019**

**2 hours**

Candidates answer on Answer Booklet.

Additional Materials:                      Answer Booklet  
    Data Booklet

---

### READ THESE INSTRUCTIONS FIRST

Write your name and civics group on all your work you hand in.

Write in dark blue or black pen on both pages in the answer booklet.  
You may use an HB pencil for any diagrams, graphs or rough working.  
Do not use paper clips, glue or correction fluid.

#### Section A

Answer **all** questions.

#### Section B

Answer **one** question.

A *Data Booklet* is provided.

The use of an approved scientific calculator is expected, where appropriate.

The number of marks is given in brackets [    ] at the end of each question or part question.

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This document consists of **14** printed pages.

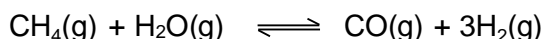


## Section A

Answer **all** the questions from this section.

- 1 Hydrocarbons,  $C_xH_y$ , are used extensively as sources of fuel in our modern day civilisation.
- (a)  $10\text{ cm}^3$  of a gaseous hydrocarbon  $C_5H_y$  was allowed to burn in an excess of oxygen at  $300\text{ }^\circ\text{C}$  and  $1\text{ atm}$ . In the reaction, there was an expansion of volume by  $20\text{ cm}^3$ .
- (i) Write a balanced equation, with state symbols, for the reaction at  $300\text{ }^\circ\text{C}$  and  $1\text{ atm}$ . [2]
- (ii) Determine the value of  $y$ . [2]

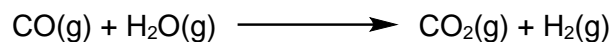
Methane,  $CH_4$ , is sometimes used in the production of hydrogen via a process known as steam reforming.



- (b) The steam reforming process is an endothermic reaction.
- (i) Using data from the *Data Booklet*, calculate a value for the enthalpy change of the forward reaction. [2]
- (ii) The actual value of the enthalpy change of reaction is found to be  $+206\text{ kJ mol}^{-1}$ . Suggest a reason why your calculated answer in (i) differs from this value. [1]
- (c) At  $600\text{ K}$ , the value of the equilibrium constant,  $K_p$ , for the steam reforming reaction is  $7.20 \times 10^{-4}$ .
- (i) Write the  $K_p$  expression for this reaction, giving its units. [2]
- (ii) Gaseous  $CH_4$ ,  $H_2O$  and  $CO$  are introduced into a closed container at  $600\text{ K}$  and their initial partial pressures are  $1.20\text{ atm}$ ,  $2.10\text{ atm}$  and  $1.80\text{ atm}$  respectively.
- Determine the partial pressure of  $H_2$  when equilibrium is reached.
- (You may assume that the extent of the forward reaction is small.) [3]
- (iii) Using information from (b), suggest how the temperature of the reaction can be changed so as to increase the yield of  $H_2$ . Explain your answer. [2]



- (d) Additional hydrogen can be recovered using the carbon monoxide produced in another reaction known as the water-gas shift reaction.



- (i) Name the type of hybridisation in the carbon atom in CO. Draw the hybrid orbitals around the carbon atom. [2]
- (ii) Given that the above reaction was conducted at 300 °C and 1 atm, calculate the volume of H<sub>2</sub> that can be recovered from 5 kg of CO. [3]
- (iii) The volume of CO<sub>2</sub> collected in the water-shift reaction should be the same as that of H<sub>2</sub>. However, the actual volume of CO<sub>2</sub> collected was smaller. Suggest a reason why this is so. [1]

[Total: 20]





- 2 Propanoic acid,  $\text{CH}_3\text{CH}_2\text{COOH}$  was initially known as propionic acid based on the Greek words, *protos*, meaning 'first' and *pion*, meaning 'fat'.

The  $\text{p}K_{\text{a}}$  values of  $\text{CH}_3\text{CH}_2\text{COOH}$  and  $\text{CH}_3\text{CH}(\text{Cl})\text{COOH}$  are listed below.

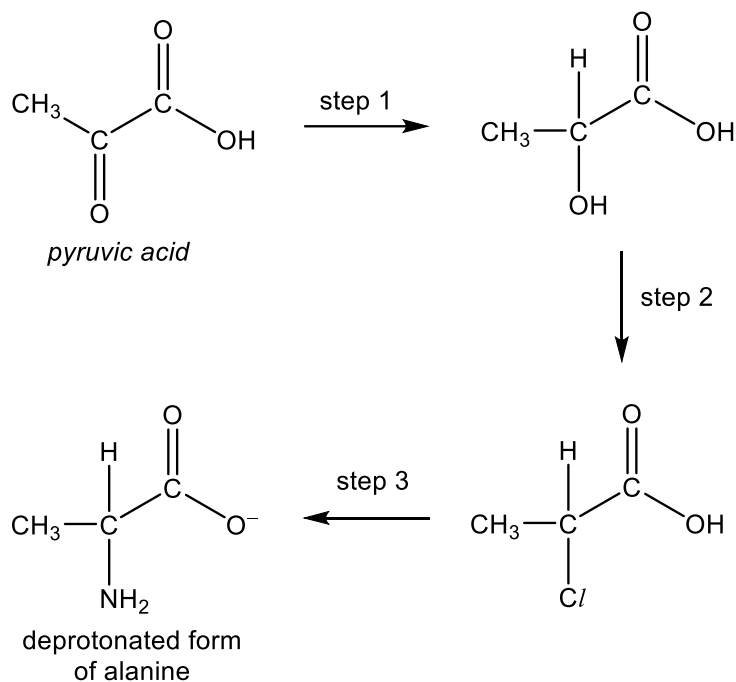
acid	structural formula	$\text{p}K_{\text{a}}$
1	$\text{CH}_3\text{CH}_2\text{COOH}$	4.9
2	$\text{CH}_3\text{CH}(\text{Cl})\text{COOH}$	2.8
3	$\text{CH}_2(\text{Cl})\text{CH}_2\text{COOH}$	

- (a) (i) Explain why acid 2 has a lower  $\text{p}K_{\text{a}}$  than acid 1. [2]
- (ii) Suggest a  $\text{p}K_{\text{a}}$  value for acid 3. [1]
- (b) A  $25.0 \text{ cm}^3$  solution of  $0.10 \text{ mol dm}^{-3}$   $\text{CH}_3\text{CH}_2\text{COOH}$  was titrated against  $0.20 \text{ mol dm}^{-3}$  sodium hydroxide,  $\text{NaOH}$ .
- (i) Calculate the pH of the  $0.10 \text{ mol dm}^{-3}$   $\text{CH}_3\text{CH}_2\text{COOH}$ . [1]
- (ii) Calculate the volume of  $\text{NaOH}$  required for complete neutralisation. [1]
- (iii) Write a suitable equation to explain why the pH at equivalence point is greater than 7. [1]
- (iv) Sketch the expected titration curve for this titration given that a total volume of  $25.0 \text{ cm}^3$  of  $\text{NaOH}$  was added. On the titration curve, indicate the initial pH value and the equivalence volume. [2]
- (v) A buffer involving  $\text{CH}_3\text{CH}_2\text{COOH}$  and its salt was formed during the progress of the titration. Circle the buffer region on the sketched curve in (iv) and indicate the corresponding pH value and volume at the maximum buffering capacity. [2]

There are many organic compounds such as amino acids and drug molecules that are derivatives of propanoic acid.

(c) The starting material to synthesise 2-aminopropanoic acid, also known as alanine can be either *pyruvic acid* or ethanal.

(i) The proposed synthesis for the deprotonated form of alanine from *pyruvic acid* is shown below.

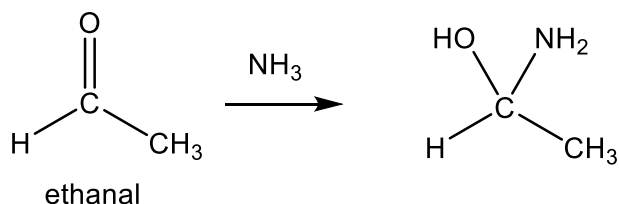


Suggest the reagents and conditions for steps 1, 2 and 3. [3]

(ii) State the **two** types of reaction that had occurred in step 3 of the above proposed synthesis. [2]

(iii) Write an equation to show how the zwitterion form of *alanine* can act as a buffer when a small amount of base is added. [1]

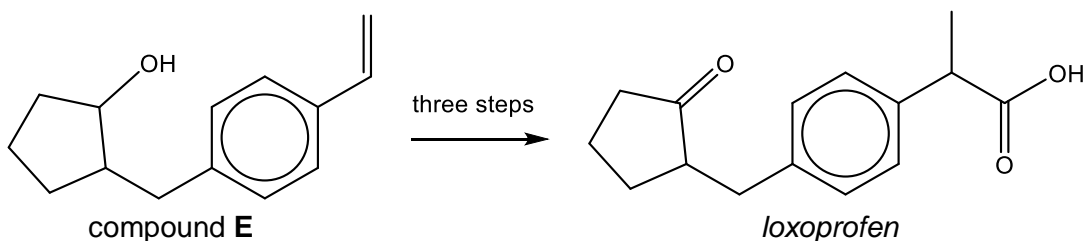
(iv) The first step to synthesise alanine from ethanal is shown below.



Explain whether ammonia can be considered as a Lewis base in the context of this synthesis. [1]

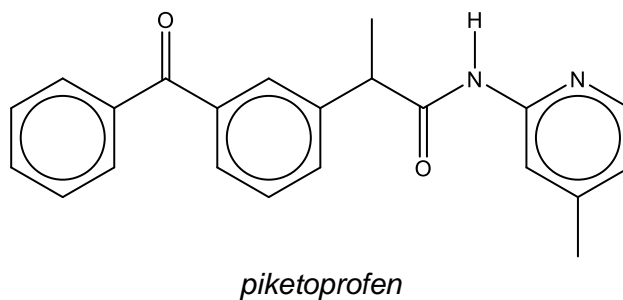
- (d) Non-steroidal anti-inflammatory drugs are used for the relief of pain. One example is *loxoprofen* that is considered as a propanoic acid derivative based on its chemical structure.

- (i) Suggest a three-step synthesis of *loxoprofen* starting from compound **E**.



[4]

- (ii) *Piketoprofen* is produced by the reaction between an acyl chloride and a suitable organic compound. Suggest the structures of the acyl chloride and the organic compound.



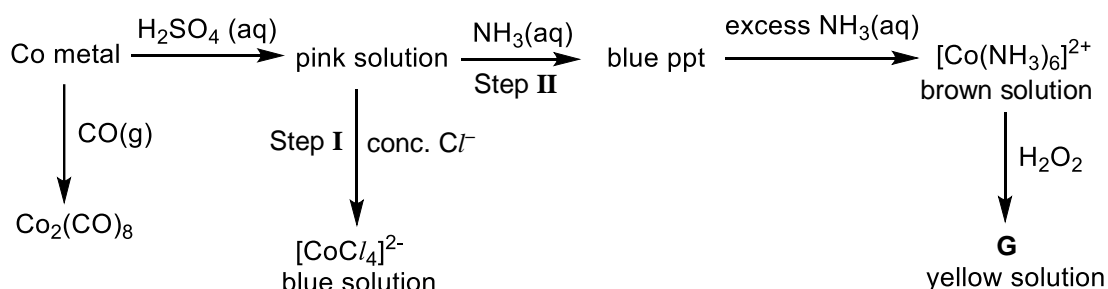
[1]

- (iii) The use of acyl chloride requires anhydrous conditions. Explain why acyl chloride undergoes hydrolysis more readily than chloroalkane. [2]

[Total: 24]

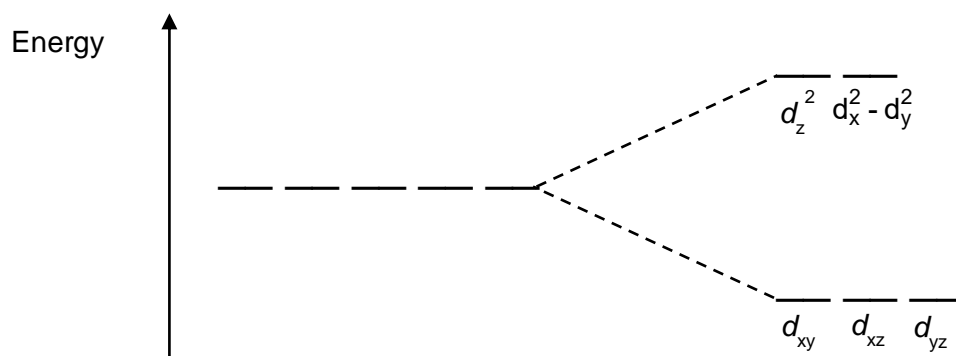
- 3 Cobalt is a transition element that plays an important role in hybrid electric vehicles and is also an essential part of vitamin B12. The common oxidation states of cobalt are +2 and +3.

- (a) Define *transition element*. [1]
- (b) Write the electronic configuration of cobalt(II) ion. [1]
- (c) State one **physical** characteristic property of transition elements that is different from the main group metals. Briefly explain why transition elements exhibit this property. [2]
- (d) The following sequence of reactions involving cobalt illustrates many of the characteristic properties of transition elements.



- (i) State the types of reaction occurring in steps I and II. [2]
- (ii) Suggest the formula of the cobalt-containing species **G**. [1]
- (iii) Cobalt is said to be a d-block element.

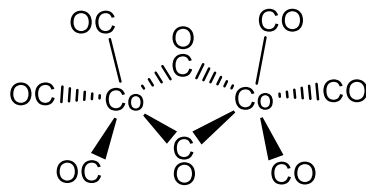
The five degenerate orbitals in the 3d subshell are split into two energy levels in the presence of ligands in an octahedral environment as shown.



Explain why the splitting occurs. [2]

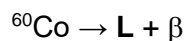
- (iv) Given the fact in (iii) that d orbitals split into 2 energy levels in the presence of ligands, explain why  $[\text{CoCl}_4]^{2-}$  solution is blue. [2]

- (v) Cobalt can react with carbon monoxide to form  $\text{Co}_2(\text{CO})_8$ , a commonly used reagent and catalyst in organic synthesis.



Suggest the co-ordination number and the oxidation state of cobalt in the complex,  $\text{Co}_2(\text{CO})_8$ . [1]

- (vi) With the aid of *Data Booklet* and given that  $E^\ominus_{[\text{Co}(\text{NH}_3)_6]^{3+}/[\text{Co}(\text{NH}_3)_6]^{2+}}$  is +0.10 V, predict the stability of an alkaline solution of  $[\text{Co}(\text{NH}_3)_6]^{2+}$  when left exposed to air. [2]
- (e) A radioactive form of cobalt,  $^{60}\text{Co}$ , is used in the inspection of materials to reveal internal structure, flaws, or foreign objects.
- (i) State the number of protons, neutrons and electrons present in the isotopic species,  $^{60}\text{Co}$ . [1]
- (ii) The radioactive decay of  $^{60}\text{Co}$  produces beta ( $\beta$ ) particles. A simplified balanced decay equation is provided below.



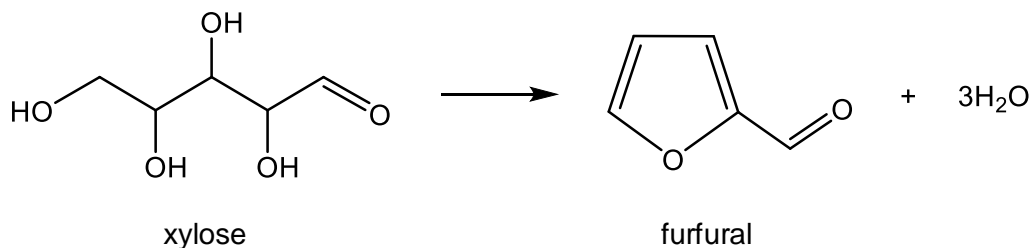
Given that  $\beta$  is  ${}_{-1}^0\text{e}$ , deduce the identity of the element L. [1]

[Total: 16]

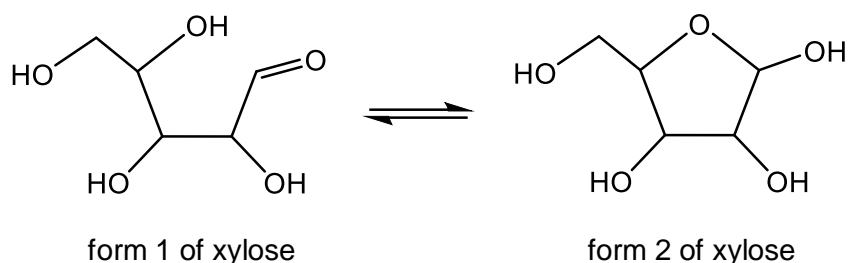
## Section B

Answer **one** question from this section.

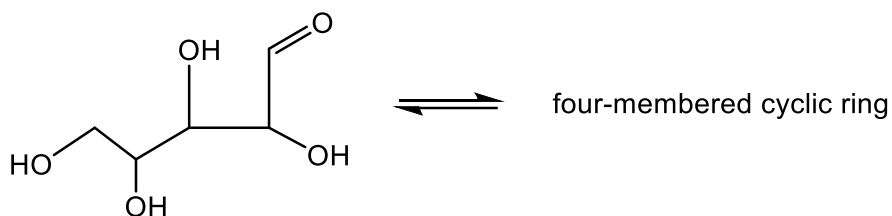
- 4** Furfural is an aromatic compound with all its carbon atoms lying on the same plane. Today, one of the ways to manufacture furfural is by the acid catalysed dehydration of xylose.



- (a)** Xylose exists in more than one form, one of which is the non-cyclic form shown below (i.e. form 1). Form 2 is a five-membered cyclic ring produced as follows.

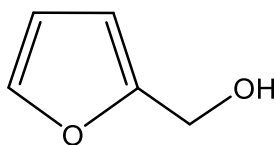


It is theoretically possible to produce a four-membered cyclic ring by following a similar pattern of reaction.

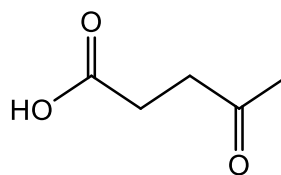


- (i) Draw the structure of the theoretical four-membered cyclic ring. [1]
- (ii) The four-membered cyclic ring is **not** actually produced because it is unstable. Suggest why it is unstable. [1]

- (b) Furfural can be reduced into furfuryl alcohol. Furfuryl alcohol can then be used to synthesise levulinic acid.



furfuryl alcohol



levulinic acid

- (i) Using the **molecular** formulae of furfuryl alcohol and levulinic acid, write a balanced equation for the synthesis of furfuryl alcohol into levulinic acid. [2]
- (ii) Using your answer in (i), state the type of reaction that has taken place. [1]
- (c) The standard reduction potential involving furfural,  $C_5H_4O_2$  measured against the standard hydrogen electrode (S.H.E.) is shown below.

electrode reaction		$E^\ominus / V$
 furfural	$+ 2H^+ + 2e^- \rightleftharpoons$ furfuryl alcohol	-0.80

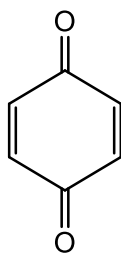
A neutral aqueous solution of furfural is prepared. Electrolysis of this solution is performed using copper at both electrodes to increase the percentage yield of the reaction.

When 0.030 A was passed through the cell for 2.0 hours, the *actual* mass of the product formed at the cathode was found to be 0.060 g. Copper is reacted at the anode but not the cathode.

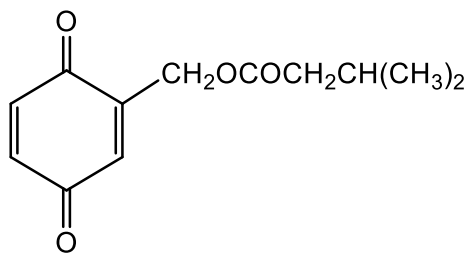
- (i) Using the  $E^\ominus$  values given above as well as that from the *Data Booklet*, deduce the products formed at the anode and the cathode.  
(In your deduction, you may use name or molecular formula to represent the structures of the respective organic compounds.) [3]
- (ii) Write the overall balanced equation for the reaction. [1]
- (iii) Calculate the *expected* mass of the product formed at the cathode. [2]
- (iv) Calculate the percentage yield of the product formed at the cathode. [1]
- (v) Besides the S.H.E., another standard electrode that can be used is the standard calomel electrode (S.C.E.). When the S.C.E. is compared against the S.H.E., the  $E^\ominus$  of the S.C.E. is +0.24 V.

Calculate the  $E^\ominus$  of the furfural / furfuryl alcohol half-cell when measured against the S.C.E. [1]

Another compound with all its carbon atoms lying on the same plane is paraquinone, with a characteristic irritating odour of hot plastic. One derivative of paraquinone is blattellaquinone which is a pheromone in cockroaches.

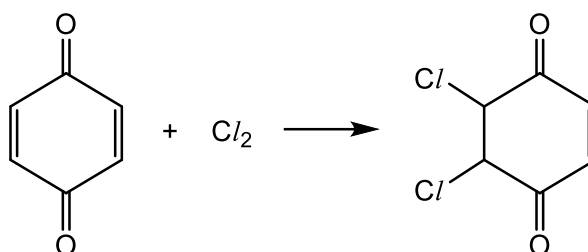


paraquinone



blattellaquinone

- (d) Paraquinone and limited chlorine react as follows.



Name and draw the mechanism of this reaction.

[3]

- (e) Draw the major products formed when **blattellaquinone** is separately reacted under suitable conditions with each of the following:

- (i) hydrogen gas [1]
- (ii) gaseous hydrogen bromide [1]
- (iii) hot acidified potassium manganate(VII) [2]

[Total: 20]



5 This question concerns the compounds of Period 3 elements.

(a) Properties of the oxides of some Period 3 elements, **P**, **Q** and **R**, are given below.

oxide	physical state at room conditions	electrical conductivity when molten
<b>P</b>	gas	nil
<b>Q</b>	solid	high
<b>R</b>	solid	low

These three oxides, in no particular order, are  $Al_2O_3$ ,  $SiO_2$  and  $SO_3$ .

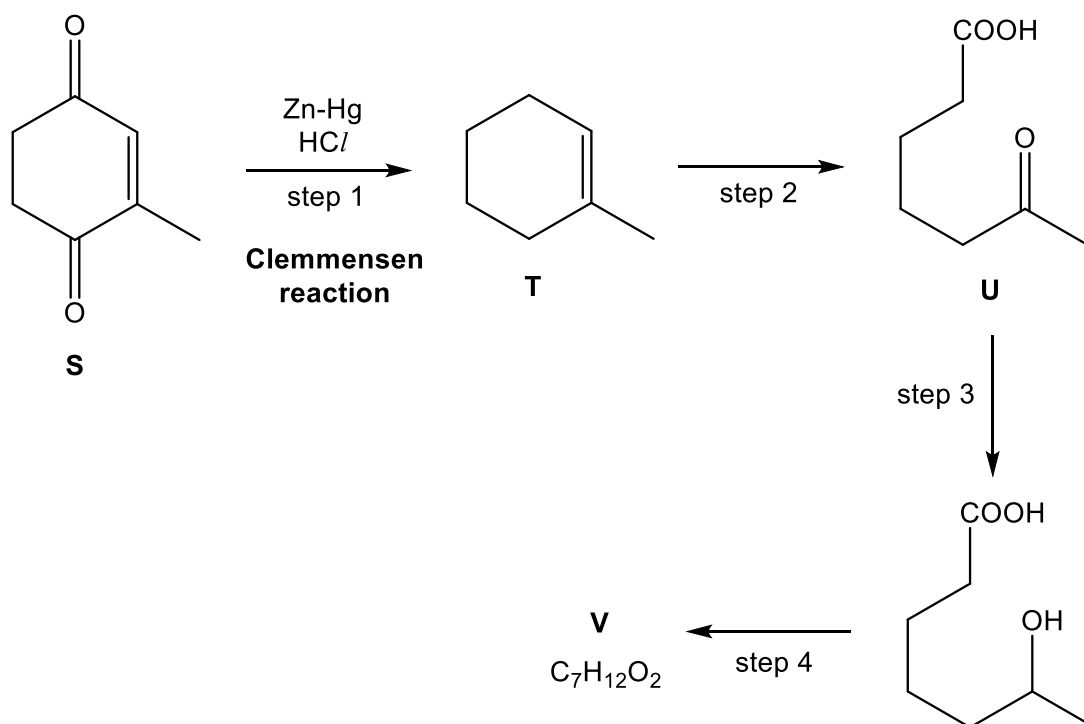
- (i) Identify **P**, **Q** and **R**. [1]
- (ii) Account for your answer, in terms of their structure and bonding. [4]
- (iii)  $Al_2O_3$  is described as an amphoteric oxide.  
Write two equations to show the amphoteric nature of  $Al_2O_3$ . [2]



- (b) Hydrogen chloride is a colourless gas commonly used in organic synthesis.

In the Clemmensen reaction, carbonyl compounds are reduced to alkanes using zinc-mercury and hydrogen chloride dissolved in an organic solvent.

A reaction scheme involving the Clemmensen reaction is shown below.



- (i) Write the balanced equation for the reduction of compound **S** to **T**. Use  $[\text{H}]$  to represent the formula of the reducing agent. [1]
- (ii) Suggest a reagent which can determine if the reaction in step 3 is complete. [1]
- (iii) Given that compound **V** is neutral, state the type of reaction occurring in step 4 and suggest the structure of compound **V**. [2]
- (iv) Compound **U** is more soluble in water than compound **S**.
  1. Suggest a reason why this is so. [1]
  2. Draw a labelled diagram to show how compound **U** dissolves in water. [1]

- (c)  $\text{HCl}$  is stable to heat while  $\text{HBr}$  and  $\text{HI}$ , can undergo thermal decomposition. At 700 K,  $\text{HBr}$  is approximately 10% decomposed but  $\text{HI}$ , is approximately 20% decomposed.

Explain these differences with reference to relevant data in the *Data Booklet* and the factors that affect them. [3]

- (d) Compound **W**,  $\text{C}_6\text{H}_{10}\text{O}_2$  is an ester which decolourises  $\text{Br}_2$  in  $\text{CCl}_4$  to form  $\text{C}_6\text{H}_{10}\text{Br}_2\text{O}_2$ .

Upon prolonged heating with excess acidified  $\text{KMnO}_4$ , 1 mol of **W** produces 1 mol of **X**,  $\text{C}_4\text{H}_6\text{O}_3$  and 2 mol of  $\text{CO}_2$ .

**X** gives a yellow precipitate **Y** when warmed with aqueous alkaline iodine. **X** also undergoes the Clemmensen reaction to give **Z**,  $\text{C}_4\text{H}_8\text{O}_2$ . Both **X** and **Z** produce effervescence when reacted with aqueous sodium carbonate.

Suggest structures for the identity of **W**, **X**, **Y** and **Z**. [4]

[Total: 20]

**End of Paper 3**





# TAMPINES MERIDIAN JUNIOR COLLEGE

## 2019 JC2 H2 Chemistry Prelim Exam Paper 3

### (Suggested Answers)

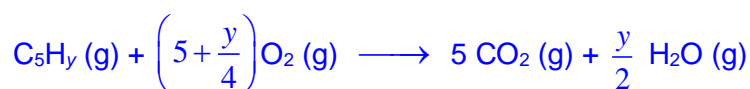
#### Section A

Answer **all** the questions from this section.

1 Hydrocarbons,  $C_xH_y$ , are used extensively as sources of fuel in our modern day civilisation.

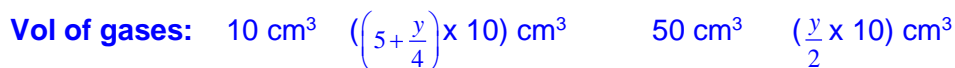
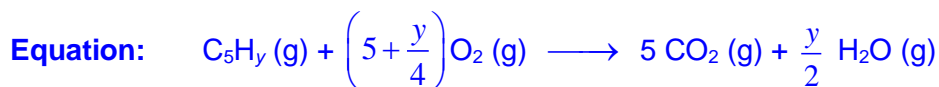
(a)  $10\text{ cm}^3$  of a gaseous hydrocarbon  $C_5H_y$  was allowed to burn in an excess of oxygen at  $300\text{ }^\circ\text{C}$  and  $1\text{ atm}$ . In the reaction, there was an expansion of volume by  $20\text{ cm}^3$ .

(i) Write a balanced equation, with state symbols, for the reaction at  $300\text{ }^\circ\text{C}$  and  $1\text{ atm}$ . [2]



(ii) Determine the value of  $y$ . [2]

Using Avogadro's Law, mole ratio  $\equiv$  volume ratio



$$\text{Volume of gases used up in the reaction} = 10 + \left(50 + \frac{10y}{4}\right) = \left(60 + \frac{10y}{4}\right)\text{ cm}^3$$

$$\text{Volume of gases produced in the reaction} = 50 + \left(\frac{y}{2}\right) \times 10 = (50 + 5y)\text{ cm}^3$$

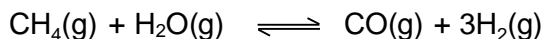
$$\text{Volume of gas produced} - \text{Volume of gas used up} = 10\text{ cm}^3$$

$$(50 + 5y) - \left(60 + \frac{10y}{4}\right) = 20$$

$$y = \underline{12}$$



Methane, CH<sub>4</sub>, is sometimes used in the production of hydrogen via a process known as steam reforming.



(b) The steam reforming process is an endothermic reaction.

- (i) Using data from the *Data Booklet*, calculate a value for the enthalpy change of the forward reaction. [2]

$$\begin{aligned}\Delta H_r &= \Sigma \text{BE (reactants)} - \Sigma \text{BE (products)} \\ &= 410 \times 4 + 460 \times 2 - (1077 + 436 \times 3) \\ &= \underline{+175 \text{ kJ mol}^{-1}}\end{aligned}$$

- (ii) The actual value of the enthalpy change of reaction is found to be +206 kJ mol<sup>-1</sup>. Suggest a reason why your calculated answer in (i) differs from this value. [1]

The bond energy calculation is an approximation method as the **bond energy values given in the *Data Booklet* are average values**.

(c) At 600 K, the value of the equilibrium constant,  $K_p$ , for the steam reforming reaction is  $7.20 \times 10^{-4}$ .

- (i) Write the  $K_p$  expression for this reaction, giving its units. [2]

$$K_p = \frac{(P_{\text{CO}})(P_{\text{H}_2})^3}{(P_{\text{CH}_4})(P_{\text{H}_2\text{O}})} \quad \text{atm}^2 \text{ (accept Pa}^2\text{)}$$

- (ii) Gaseous CH<sub>4</sub>, H<sub>2</sub>O and CO are introduced into a closed container at 600 K and their initial partial pressures are 1.20 atm, 2.10 atm and 1.80 atm respectively.

Determine the partial pressure of H<sub>2</sub> when equilibrium is reached.

(You may assume that the extent of the forward reaction is small.) [3]

	CH <sub>4</sub> (g)	+ H <sub>2</sub> O(g)	$\rightleftharpoons$	CO(g)	+ 3H <sub>2</sub> (g)
Initial pp/atm	1.20	2.10		1.80	0
Change pp/atm	-x	-x		+x	+3x
Eqm pp/atm	1.20 - x	2.10 - x		1.80 + x	3x

$$\begin{aligned}K_p &= \frac{(P_{\text{CO}})(P_{\text{H}_2})^3}{(P_{\text{CH}_4})(P_{\text{H}_2\text{O}})} \\ 7.20 \times 10^{-4} &= \frac{(1.80 + x)(3x)^3}{(1.20 - x)(2.10 - x)}\end{aligned}$$

Assuming x is small,

$$7.20 \times 10^{-4} = \frac{(1.80)(3x)^3}{(1.20)(2.10)}$$



Solving for x,  
 $x = 0.0334$

Partial pressure of  $H_2$  at equilibrium =  $3 \times 0.0334$   
 =  $0.100 \text{ atm}$

- (iii) Using information from (b), suggest how the temperature of the reaction can be changed so as to increase the yield of  $H_2$ . Explain your answer. [2]

The temperature should be raised to increase the yield of  $H_2$ .

When the temperature is raised, by Le Chatelier's Principle, the equilibrium position shifts to the right towards the endothermic reaction to absorb heat, increasing the yield of  $H_2$ .

- (d) Additional hydrogen can be recovered using the carbon monoxide produced in another reaction known as the water–gas shift reaction.



- (i) Name the type of hybridisation in the carbon atom in CO. Draw the hybrid orbitals around the carbon atom. [2]



sp hybridisation

- (ii) Given that the above reaction was conducted at  $300^\circ\text{C}$  and  $1 \text{ atm}$ , calculate the volume of  $H_2$  that can be recovered from  $5 \text{ kg}$  of CO. [3]

Amount of  $H_2$  that can be recovered =  $5000/28 = 178.6 \text{ mol}$

$$pV = nRT$$

$$V = \frac{nRT}{p}$$

$$V = \frac{178.6 \times 8.31 \times (300 + 273)}{101325}$$

$$= \underline{8.39 \text{ m}^3}$$

- (iii) The volume of  $CO_2$  collected in the water-shift reaction should be the same as that of  $H_2$ . However, the actual volume of  $CO_2$  collected was smaller. Suggest a reason why this is so. [1]

$CO_2$  deviates more from ideal gas behaviour as it has more significant intermolecular instantaneous dipole–induced dipole interaction. Hence it will occupy a smaller volume than  $H_2$ .

[Total: 20]



- 2 Propanoic acid,  $\text{CH}_3\text{CH}_2\text{COOH}$  was initially known as propionic acid based on the Greek words, *protos*, meaning 'first' and *pion*, meaning 'fat'.

The  $\text{p}K_{\text{a}}$  values of  $\text{CH}_3\text{CH}_2\text{COOH}$  and  $\text{CH}_3\text{CH}(\text{Cl})\text{COOH}$  are listed below.

acid	structural formula	$\text{p}K_{\text{a}}$
1	$\text{CH}_3\text{CH}_2\text{COOH}$	4.9
2	$\text{CH}_3\text{CH}(\text{Cl})\text{COOH}$	2.8
3	$\text{CH}_2(\text{Cl})\text{CH}_2\text{COOH}$	

- (a) (i) Explain why acid 2 has a lower  $\text{p}K_{\text{a}}$  than acid 1. [2]

The electron-withdrawing Cl group in acid 2 (OR  $\text{CH}_3\text{CH}(\text{Cl})\text{COOH}$ ) further reduces the intensity of the negative charge on  $\text{CH}_3\text{CH}(\text{Cl})\text{COO}^-$  to a greater extent.

$\text{CH}_3\text{CH}(\text{Cl})\text{COO}^-$  is more stable and  $\text{CH}_3\text{CH}(\text{Cl})\text{COOH}$  has a greater tendency to dissociate and therefore a stronger acid.

- (ii) Suggest a  $\text{p}K_{\text{a}}$  value for acid 3. [1]

Accept value between 2.8 to 4.9

- (b) A  $25.0 \text{ cm}^3$  solution of  $0.10 \text{ mol dm}^{-3}$   $\text{CH}_3\text{CH}_2\text{COOH}$  was titrated against  $0.20 \text{ mol dm}^{-3}$  sodium hydroxide, NaOH.

- (i) Calculate the pH of the  $0.10 \text{ mol dm}^{-3}$   $\text{CH}_3\text{CH}_2\text{COOH}$ . [1]

$$[\text{H}^+] = \sqrt{0.10 \times 10^{-4.9}} = 0.00112 \text{ mol dm}^{-3}$$

$$\text{pH} = -\log_{10}(0.00112) = 2.95$$

- (ii) Calculate the volume of NaOH required for complete neutralisation. [1]

$$\text{Amount of } \text{CH}_3\text{CH}_2\text{COOH} = (25 \div 1000) \times 0.1 = 2.50 \times 10^{-3} \text{ mol}$$

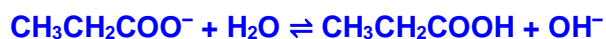


$$\text{Amount of NaOH required} = 2.50 \times 10^{-3} \text{ mol}$$

$$\text{Volume of NaOH required} = 2.50 \times 10^{-3} \div 0.20 = 0.0125 \text{ dm}^3 \text{ OR } 12.5 \text{ cm}^3$$



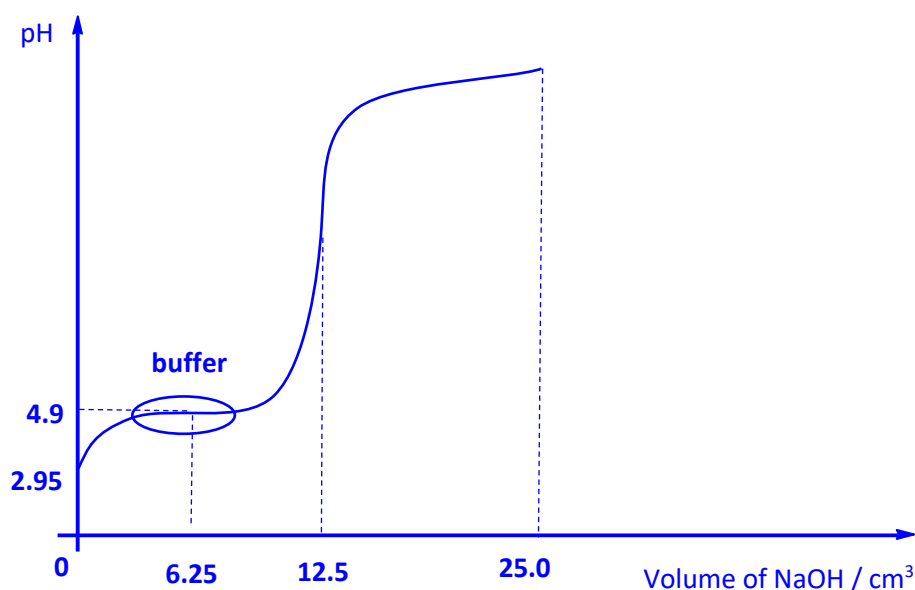
- (iii) Write a suitable equation to explain why the pH at equivalence point is greater than 7. [1]



Concept:

$\text{CH}_3\text{CH}_2\text{COO}^-$  undergoes hydrolysis to form  $\text{OH}^-$ . At equilibrium,  $[\text{OH}^-] > [\text{H}^+]$   
pH at equivalence point is basic ( $> 7$ ).

- (iv) Sketch the expected titration curve for this titration given that a total volume of  $25.0 \text{ cm}^3$  of NaOH was added. On the titration curve, indicate the initial pH value and the equivalence volume. [2]



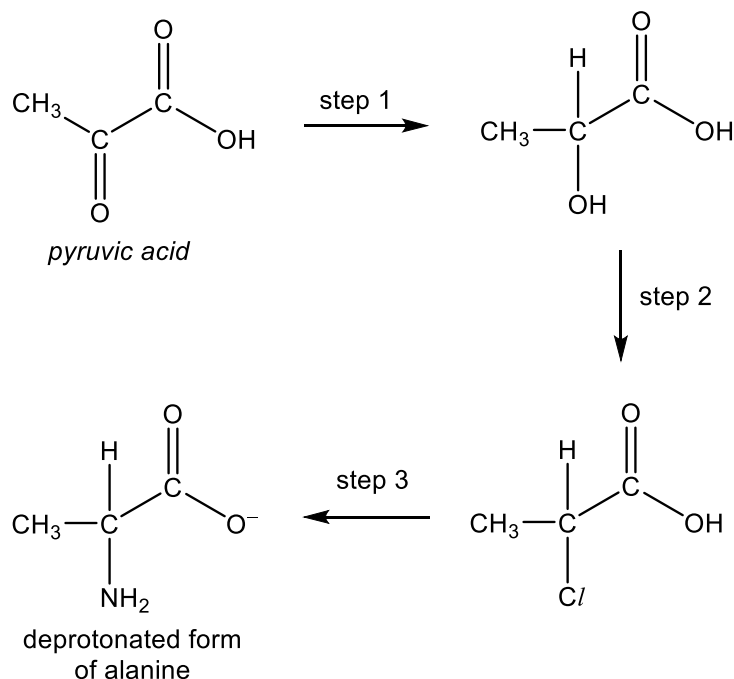
- (v) A buffer involving  $\text{CH}_3\text{CH}_2\text{COOH}$  and its salt was formed during the progress of the titration. Circle the buffer region on the sketched curve in (iv) and indicate the corresponding pH value and volume at the maximum buffering capacity. [2]



There are many organic compounds such as amino acids and drug molecules that are derivatives of propanoic acid.

(c) The starting material to synthesise 2-aminopropanoic acid, also known as alanine can be either *pyruvic acid* or ethanal.

(i) The proposed synthesis for the deprotonated form of alanine from *pyruvic acid* is shown below.



Suggest the reagents and conditions for steps 1, 2 and 3. [3]

Step 1: NaBH<sub>4</sub> in ethanol

Step 2: HCl (g), heat

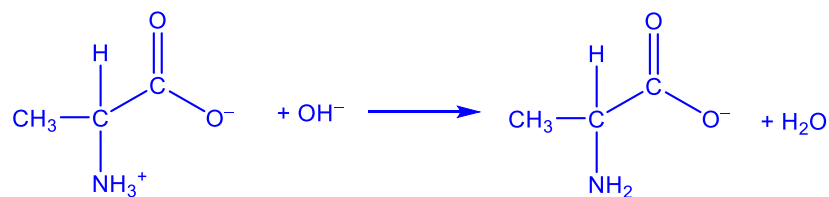
Step 3: excess conc. NH<sub>3</sub> in ethanol, heat in sealed tube

(ii) State the **two** types of reaction that had occurred in step 3 of the above proposed synthesis. [2]

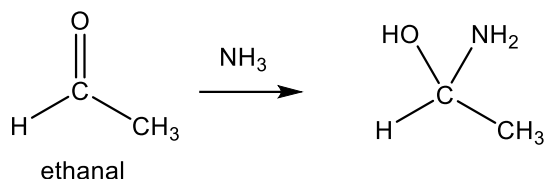
Nucleophilic substitution

Acid-base reaction (OR neutralisation)

- (iii) Write an equation to show how the zwitterion form of *alanine* can act as a buffer when a small amount of base is added. [1]



- (iv) The first step to synthesise alanine from ethanal is shown below.

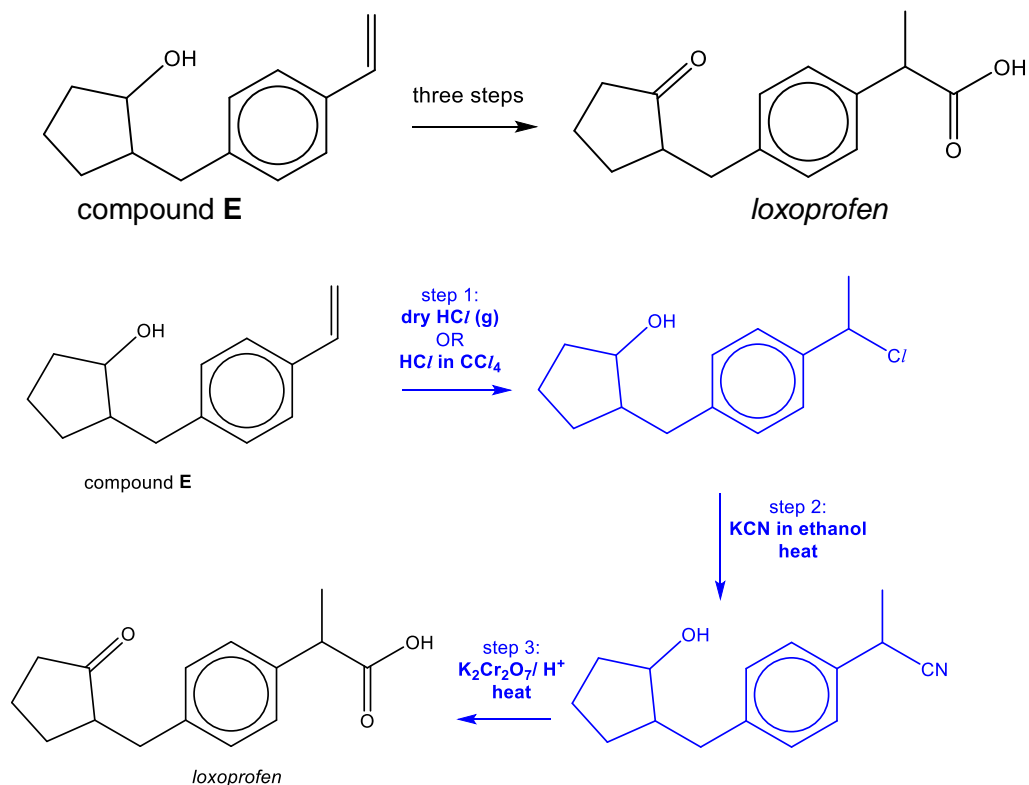


Explain whether ammonia can be considered as a Lewis base in the context of this synthesis. [1]

NH<sub>3</sub> uses its lone pair to form a dative bond with the carbonyl carbon therefore it is considered as a Lewis base.

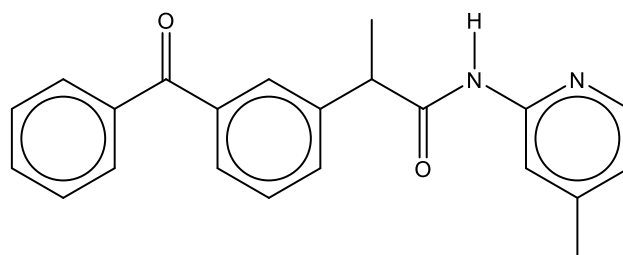
- (d) Non-steroidal anti-inflammatory drugs are used for the relief of pain. One example is *loxoprofen* that is considered as a propanoic acid derivative based on its chemical structure.

- (i) Suggest a three-step synthesis of *loxoprofen* starting from compound **E**.



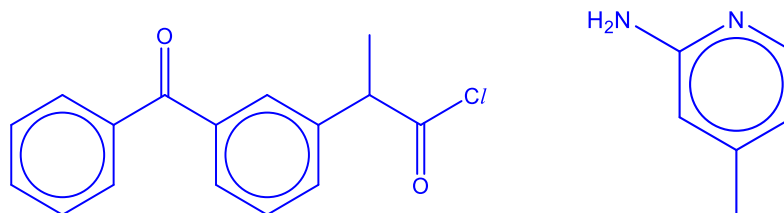
[4]

- (ii) *Piketoprofen* is produced by the reaction between an acyl chloride and a suitable organic compound. Suggest the structures of the acyl chloride and the organic compound.



*piketoprofen*

[1]



- (iii) The use of acyl chloride requires anhydrous conditions. Explain why acyl chloride undergoes hydrolysis more readily than chloroalkane. [2]

The carboxyl C (OR carbonyl C) is bonded to two (OR more) electronegative atoms, O and Cl compared to chloroalkane where the alkyl C is only bonded to one Cl resulting in a highly electron-deficient the carboxyl C atom and making the C atom highly susceptible to hydrolysis.

Hence, it undergoes hydrolysis more readily than chloroalkane.

[Total: 24]

- 3 Cobalt is a transition element that plays an important role in hybrid electric vehicles and is also an essential part of vitamin B12. The common oxidation states of cobalt are +2 and +3.

- (a) Define *transition element*. [1]

A transition element is a *d* block element that forms at least one stable ion with partially-filled *d* subshell

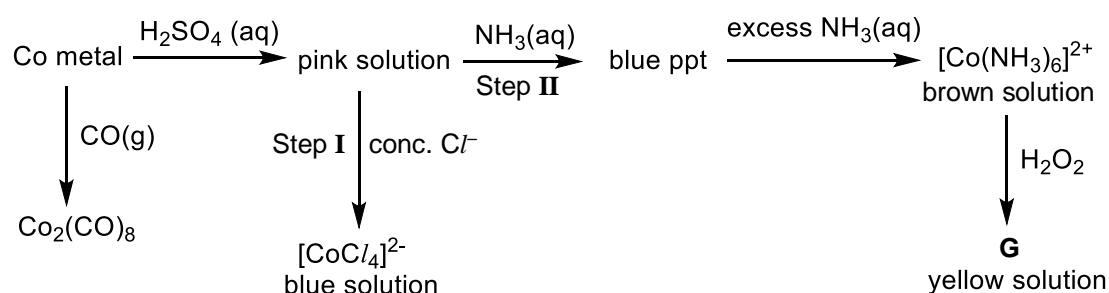
- (b) Write the electronic configuration of cobalt(II) ion. [1]

$1s^2 2s^2 2p^6 3s^2 3p^6 3d^7$  Or  $[Ar]3d^7$

- (c) State one **physical** characteristic property of transition elements that is different from the main group metals. Briefly explain why transition elements exhibit this property. [2]

- 1 Transition metals are harder/denser. It has relatively smaller atomic radius and higher relative atomic mass. Thus it has have higher mass per unit volume.
- 2 Transition metals have higher melting points. In transition metals, both the 3d and 4s electrons are involved in delocalization. For *s-block metals*, only the s electrons are involved in the delocalization. Thus there is stronger electrostatic forces of attraction is present between the transition metals cations and the sea of delocalised electrons.

- (d) The following sequence of reactions involving cobalt illustrates many of the characteristic properties of transition elements.



- (i) State the types of reaction occurring in steps **I** and **II**. [2]

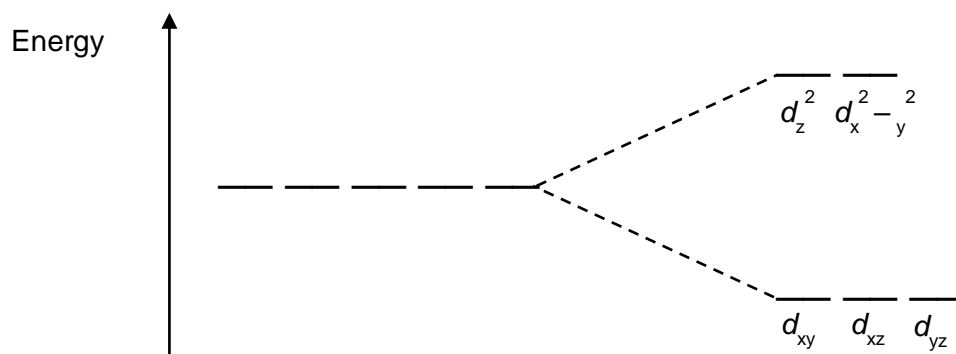
Step **I**: ligand exchange  
 Step **II**: precipitation

- (ii) Suggest the formula of the cobalt-containing species **G**. [1]

Formula for **G**:  $[\text{Co}(\text{NH}_3)_6]^{3+}$

- (iii) Cobalt is said to be a d-block element.

The five degenerate orbitals in the 3d subshell are split into two energy levels in the presence of ligands in an octahedral environment as shown.



Explain why the splitting occurs.

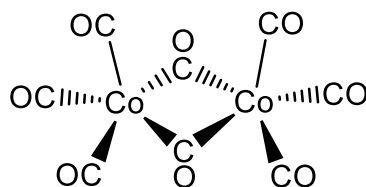
[2]

The upper energy level d orbitals ( $d_{x^2-y^2}$  and  $d_{z^2}$  orbitals) have their lobes pointing at the ligands along the coordinate axes. Hence, the electron pairs in these orbitals will be repelled by the ligands to a greater extent than those in lower energy d orbitals.

- (iv) Given the fact in (iii) that d orbitals split into 2 energy levels in the presence of ligands, explain why  $[\text{CoCl}_4]^{2-}$  solution is blue. [2]

The Co d electrons in lower energy d orbital is promoted to the higher d orbital by d-d transition. During the transition, the d electron absorbs orange wavelength from the visible region of the electromagnetic spectrum and the remaining wavelengths not absorbed appear as blue.

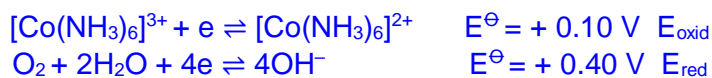
- (v) Cobalt can react with carbon monoxide to form  $\text{Co}_2(\text{CO})_8$ , a commonly used reagent and catalyst in organic synthesis.



Suggest the co-ordination number and the oxidation state of cobalt in the complex,  $\text{Co}_2(\text{CO})_8$ . [1]

Co-ordination number: 5  
Oxidation state of cobalt: 0

- (vi) With the aid of *Data Booklet* and given that  $E^\ominus_{[\text{Co}(\text{NH}_3)_6]^{3+}/[\text{Co}(\text{NH}_3)_6]^{2+}}$  is +0.10 V, predict the stability of an alkaline solution of  $[\text{Co}(\text{NH}_3)_6]^{2+}$  when left exposed to air. [2]



$$E_{\text{cell}} = 0.40 - 0.10 = +0.30 \text{ V} > 0$$

$[\text{Co}(\text{NH}_3)_6]^{2+}$  is oxidised to form  $[\text{Co}(\text{NH}_3)_6]^{3+}$  in open air.

- (e) A radioactive form of cobalt,  $^{60}\text{Co}$ , is used in the inspection of materials to reveal internal structure, flaws, or foreign objects.

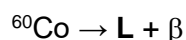
- (i) State the number of protons, neutrons and electrons present in the isotopic species,  $^{60}\text{Co}$ . [1]

**Protons = 27**

**Electrons = 27**

**Neutrons = 33**

- (ii) The radioactive decay of  $^{60}\text{Co}$  produces beta ( $\beta$ ) particles. A simplified balanced decay equation is provided below.



Given that  $\beta$  is  ${}^0_{-1}e$ , deduce the identity of the element L. [1]

Final proton number =  $27 + 1 = \underline{28}$

Identity = Ni or nickel

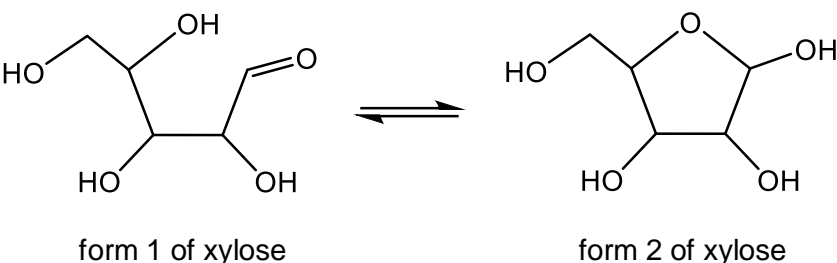
[Total: 16]



Answer **one** question from this section.

Answer **one** question from this section.

- (ii) The four-membered cyclic ring is **not** actually produced because it is unstable. Suggest why it is unstable. [1]



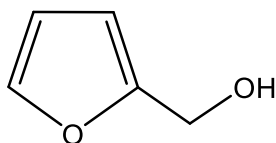
A chemical reaction diagram showing the cyclization of a linear sugar. On the left is the linear structure of 2,3,4,5-tetrahydroxyhexanal, drawn in a zig-zag conformation. The aldehyde group at C1 is at the top right, and the hydroxyl group at C4 is positioned to react with it. An equilibrium arrow points to the right, where the text "four-membered cyclic ring" is written.

- 
- Chemical reaction showing the equilibrium between the open-chain form and the cyclic hemiacetal form of D-glucose.

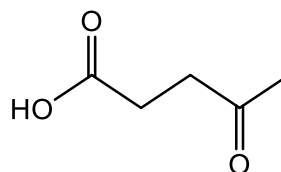
- (ii) The four-membered cyclic ring is **not** actually produced because it is unstable. Suggest why it is unstable. [1]

- (greater) **ring / angle strain** in the four-membered-ring
- smaller bond angle than ideal
- compression of bond pair in ring

- (b) Furfural can be reduced into furfuryl alcohol. Furfuryl alcohol can then be used to synthesise levulinic acid.



furfuryl alcohol



levulinic acid

- (i) Using the **molecular** formulae of furfuryl alcohol and levulinic acid, write a balanced equation for the synthesis of furfuryl alcohol into levulinic acid. [2]



- (ii) Using your answer in (i), state the type of reaction that has taken place. [1]

hydrolysis

- (c) The standard reduction potential involving furfural,  $\text{C}_5\text{H}_4\text{O}_2$  measured against the standard hydrogen electrode (S.H.E.) is shown below.

electrode reaction		$E^\circ / \text{V}$
 furfural	$+ 2\text{H}^+ + 2\text{e}^- \rightleftharpoons$ furfuryl alcohol	-0.80

A neutral aqueous solution of furfural is prepared. Electrolysis of this solution is performed using copper at both electrodes to increase the percentage yield of the reaction.

When 0.030 A was passed through the cell for 2.0 hours, the *actual* mass of the product formed at the cathode was found to be 0.060 g. Copper is reacted at the anode but not the cathode.

- (i) Using the  $E^\circ$  values given above as well as that from the *Data Booklet*, deduce the products formed at the anode and the cathode.  
(In your deduction, you may use name or molecular formula to represent the structures of the respective organic compounds.) [3]

At the anode:

$E^\circ_{\text{Cu}^{2+}/\text{Cu}}$  (+0.34 V) is less positive / smaller than  $E^\circ_{\text{O}_2/\text{H}_2\text{O}}$  (+1.23 V).  
Hence, Cu is preferentially oxidised to produce  $\text{Cu}^{2+}$ .

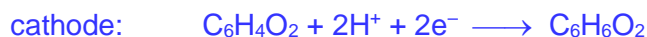
At the cathode:

$E^\circ_{\text{furfural} / \text{furfuryl alcohol}}$  (-0.80 V) is more positive / less negative / larger than and  $E^\circ_{\text{H}_2\text{O}/\text{H}_2}$  (-0.83 V).

Hence, furfural is preferentially reduce to produce furfuryl alcohol.



- (ii) Write the overall balanced equation for the reaction. [1]



- (iii) Calculate the *expected* mass of the product formed at the cathode. [2]

$$n_{\text{furfuryl alcohol}} = \frac{m_{\text{furfuryl alcohol}}}{M_{\text{r, furfuryl alcohol}}} = \frac{It}{zF}$$

$$\frac{m_{\text{furfuryl alcohol}}}{5(12) + 6(1) + 2(16)} = \frac{0.030 \times (2 \times 60 \times 60)}{2 \times 96500}$$

$$m_{\text{furfuryl alcohol}} = \underline{\underline{0.110 \text{ g}}}$$

If  $\text{H}_2$  gas produced:

$$\frac{m_{\text{H}_2}}{2} = \frac{0.030 \times (2 \times 60 \times 60)}{2 \times 96500}$$

$$m_{\text{H}_2} = 2.24 \times 10^{-3} \text{ g}$$

- (iv) Calculate the percentage yield of the product formed at the cathode. [1]

$$\text{percentage yield} = \frac{0.060}{0.110} \times 100\%$$

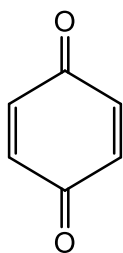
$$= \underline{\underline{54.5 \%}}$$

- (v) Besides the S.H.E., another standard electrode that can be used is the standard calomel electrode (S.C.E.). When the S.C.E. is compared against the S.H.E., the  $E^\circ$  of the S.C.E. is +0.24 V.

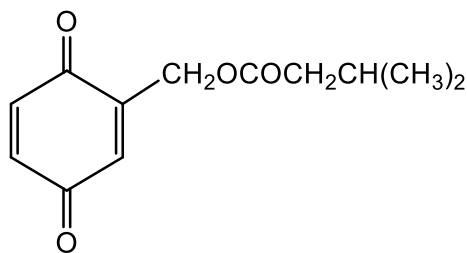
Calculate the  $E^\circ$  of the furfural / furfuryl alcohol half-cell when measured against the S.C.E.

$$E^\circ_{\text{furfural / furfuryl alcohol against SCE}} = -0.80 - (+0.24) = \underline{\underline{-1.04 \text{ V}}}$$

Another compound with all its carbon atoms lying on the same plane is paraquinone, with a characteristic irritating odour of hot plastic. One derivative of paraquinone is blattellaquinone which is a pheromone in cockroaches.

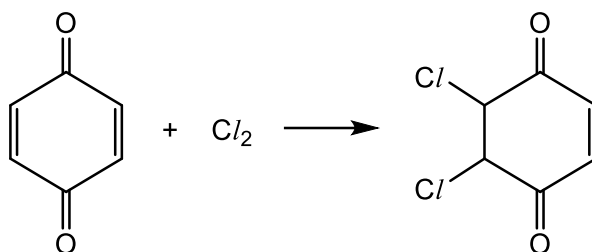


paraquinone



blattellaquinone

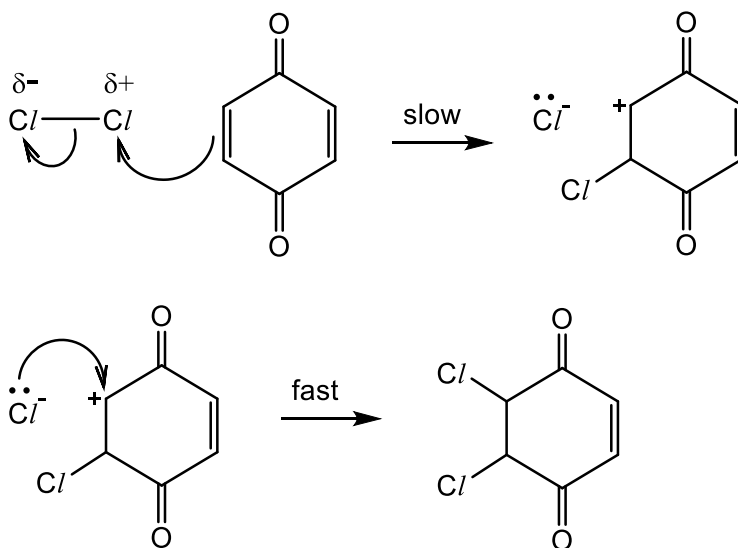
(d) Paraquinone and limited chlorine react as follows.



Name and draw the mechanism of this reaction.

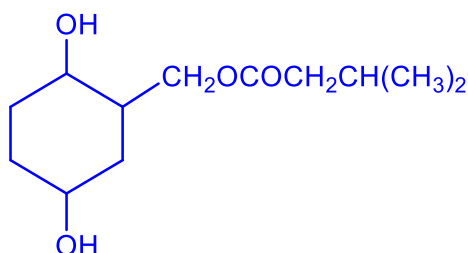
[3]

electrophilic addition

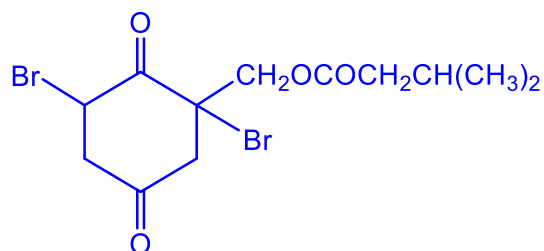
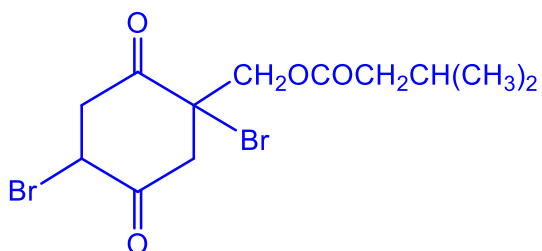


- (e) Draw the major products formed when **blattellaquinone** is separately reacted under suitable conditions with each of the following:

(i) hydrogen gas [1]

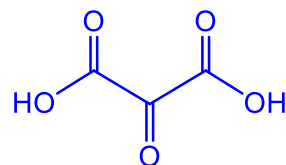
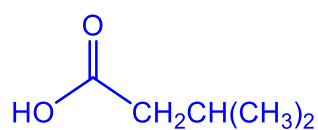
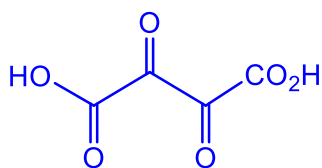


(ii) gaseous hydrogen bromide [1]



OR

(iii) hot acidified potassium manganate(VII) [2]



[Total: 20]

5 This question concerns the compounds of Period 3 elements.

(a) Properties of the oxides of some Period 3 elements, **P**, **Q** and **R**, are given below.

oxide	physical state at room conditions	electrical conductivity when molten
<b>P</b>	gas	nil
<b>Q</b>	solid	high
<b>R</b>	solid	low

These three oxides, in no particular order, are  $Al_2O_3$ ,  $SiO_2$  and  $SO_3$ .

(i) Identify **P**, **Q** and **R**. [1]

**P** is  $SO_3$ , **Q** is  $Al_2O_3$  and **R** is  $SiO_2$ .

(ii) Account for your answer, in terms of their structure and bonding. [4]

**P** ( $SO_3$ ) has a simple molecular structure with weak instantaneous dipole – induced dipole interactions resulting in its low melting point. It does not conduct electricity as there are no charged particles in the molten state.

**Q** ( $Al_2O_3$ ) has a giant ionic lattice structure with strong ionic bonds between its cations and anions resulting in its high melting point. It conducts electricity in the molten state as its ions become mobile.

**R** ( $SiO_2$ ) has a giant molecular structure with strong and extensive covalent bonds between Si and O atoms resulting in its high melting point. It conducts electricity poorly as there are no charged particles in the molten state.

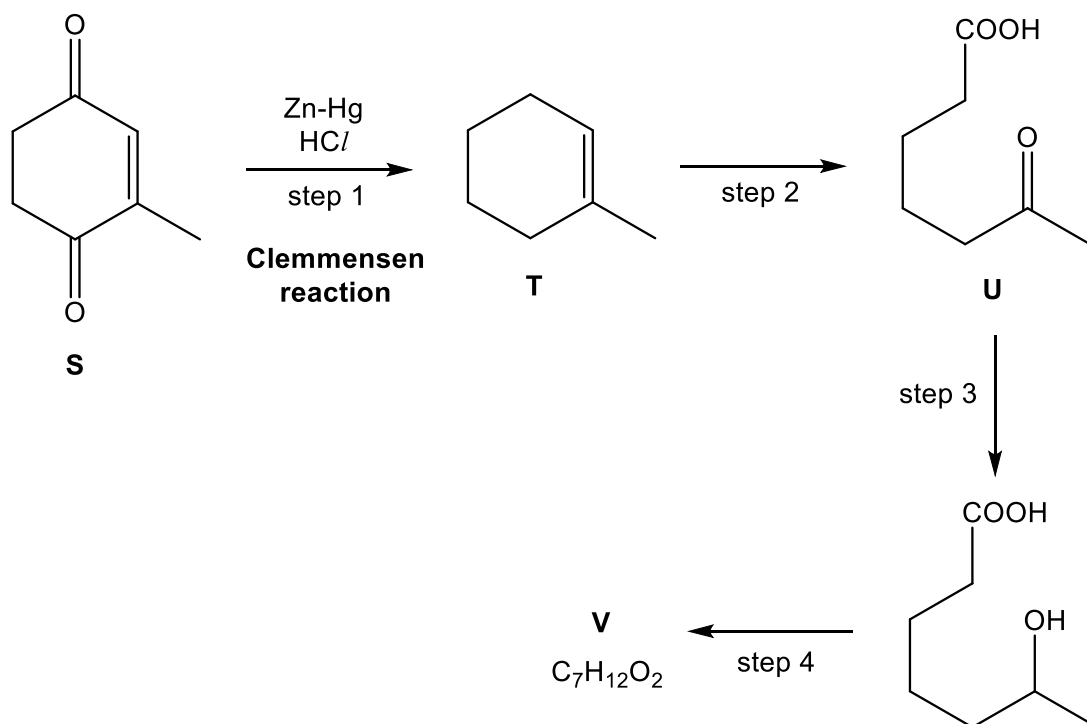
(iii)  $Al_2O_3$  is described as an amphoteric oxide.  
Write two equations to show the amphoteric nature of  $Al_2O_3$ . [2]



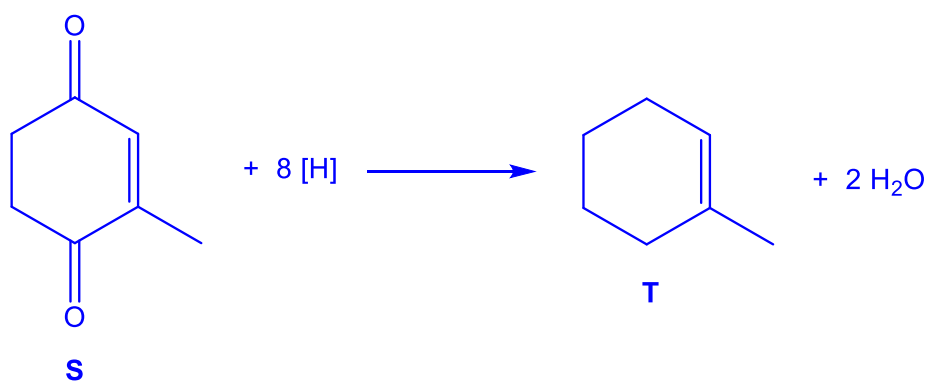
- (b) Hydrogen chloride is a colourless gas commonly used in organic synthesis.

In the Clemmensen reaction, carbonyl compounds are reduced to alkanes using zinc-mercury and hydrogen chloride dissolved in an organic solvent.

A reaction scheme involving the Clemmensen reaction is shown below.



- (i) Write the balanced equation for the reduction of compound **S** to **T**. Use  $[\text{H}]$  to represent the formula of the reducing agent. [1]

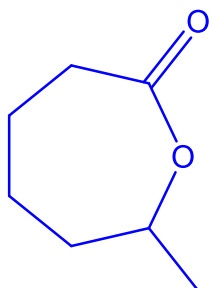


- (ii) Suggest a reagent which can determine if the reaction in step 3 is complete. [1]

**Brady's reagent/ 2,4-DNPH**

- (iii) Given that compound **V** is neutral, state the type of reaction occurring in step 4, and suggest the structure of compound **V**. [2]

step 4: **condensation**

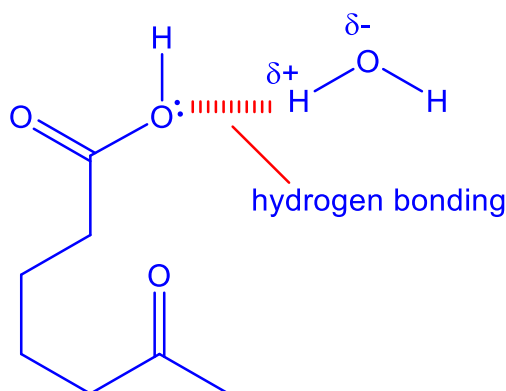


- (iv) Compound **U** is more soluble in water than compound **S**.

1. Suggest a reason why this is so. [1]

Compound **U** has more functional groups which form hydrogen bonding with water to a greater extent, hence it is more soluble in water than compound **S**.

2. Draw a labelled diagram to show how compound **U** dissolves in water. [1]



- (c)  $\text{HCl}$  is stable to heat while  $\text{HBr}$  and  $\text{HI}$ , can undergo thermal decomposition. At 700 K,  $\text{HBr}$  is approximately 10% decomposed but  $\text{HI}$ , is approximately 20% decomposed.

Explain these differences with reference to relevant data in the *Data Booklet* and the factors that affect them. [3]

**Bond energies ( $\text{kJ mol}^{-1}$ ):**  $\text{H-Cl}$  (431),  $\text{H-Br}$  (366),  $\text{H-I}$  (299)

Down Group 17, extent of thermal decomposition of  $\text{HX}$  increases/ thermal stability of  $\text{HX}$  decreases as less energy is needed to break  $\text{H-X}$  bond/  $\text{H-X}$  bond strength decreases.

This is due to an increase in size of halogen atom down group 17, resulting in less effective orbital overlap between H and halogen atom.



- (d) Compound **W**,  $C_6H_{10}O_2$  is an ester which decolourises  $Br_2$  in  $CCl_4$  to form  $C_6H_{10}Br_2O_2$ .

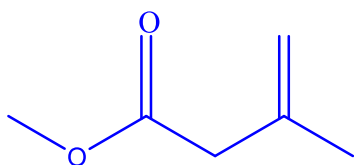
Upon prolonged heating with excess acidified  $KMnO_4$ , 1 mol of **W** produces 1 mol of **X**,  $C_4H_6O_3$  and 2 mol of  $CO_2$ .

**X** gives a yellow precipitate **Y** when warmed with aqueous alkaline iodine. **X** also undergoes the Clemmensen reaction to give **Z**,  $C_4H_8O_2$ . Both **X** and **Z** produce effervescence when reacted with aqueous sodium carbonate.

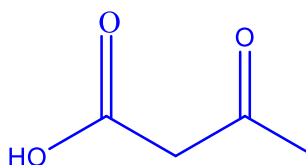
Suggest structures for the identity of **W**, **X**, **Y** and **Z**.

[4]

W:



X:



Y:



Z:



[Total: 20]

**End of Paper 3**



# TAMPINES MERIDIAN JUNIOR COLLEGE

## JC2 PRELIMINARY EXAMINATION

CANDIDATE  
NAME

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CIVICS GROUP

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### H2 CHEMISTRY

9729/04

Paper 4 Practical

4 September 2019

2 hours 30 minutes

Candidates answer on the Question Paper.

Additional materials: As listed in the Confidential Instructions

### READ THESE INSTRUCTIONS FIRST

Write your name and Civics Group in the spaces at the top of the page.

Give details of the practical shift and laboratory where appropriate, in the boxes provided.

Write in dark blue or black pen.

You may use an HB pencil for any diagrams or graphs.

Do not use staples, paper clips, glue or correction fluid.

Answer **all** questions in the spaces provided on the Question Paper.

The use of an approved scientific calculator is expected, where appropriate.  
You may lose marks if you do not show your working or if you do not use appropriate units.

Qualitative Analysis Notes are printed on pages 17 and 18.

At the end of the examination, fasten all your work securely together.

The number of marks is given in brackets [ ] at the end of each question or part question.

Shift
Laboratory

For Examiner's Use	
1	
2	
3	
Total	

This document consists of **18** printed pages.





Answer **all** the questions in the spaces provided.

**1 Determination of the concentration of a base and the enthalpy change of the neutralisation reaction**

**FA 1** is  $2.0 \text{ mol dm}^{-3}$  sulfuric acid,  $\text{H}_2\text{SO}_4$ .

**FA 2** is aqueous sodium hydroxide,  $\text{NaOH}$ .

The reaction of sulfuric acid and sodium hydroxide is exothermic.

In separate experiments, you will add increasing volumes of **FA 2** to a fixed volume of **FA 1**. In each experiment you will measure the maximum temperature rise,  $\Delta T$ . As the volume of **FA 2** is increased, this maximum temperature rise,  $\Delta T$ , will increase and then decrease.

By measuring the maximum temperature rise for different mixtures of the two reagents, you are to determine the following:

- the concentration of sodium hydroxide,  $\text{NaOH}$ , in **FA 2**
- the enthalpy change when 1 mol of  $\text{H}_2\text{SO}_4$  is neutralised by  $\text{NaOH}$

**(a) Method**

- Fill the labelled burette with **FA 1**.
- Support a styrofoam cup in the  $250 \text{ cm}^3$  beaker.
- Run  $10.00 \text{ cm}^3$  of **FA 1** from the burette into the styrofoam cup.
- Measure  $20.0 \text{ cm}^3$  of **FA 2** using a measuring cylinder.
- Place the thermometer in the **FA 2** in the measuring cylinder and record the steady temperature of the solution.
- Pour the **FA 2** into the styrofoam cup, stir and record the maximum temperature obtained in the reaction.
- Empty and rinse the styrofoam cup; shake dry the styrofoam cup. Rinse the thermometer.
- Carry out the experiment three more times. Each time use  $10.00 \text{ cm}^3$  of **FA 1**.
- Use  $30.0 \text{ cm}^3$ ,  $40.0 \text{ cm}^3$  and  $50.0 \text{ cm}^3$  of **FA 2** in these different experiments.

Carry out **two further experiments**.

Choose volumes of **FA 2** which will allow you to investigate more precisely the volume of **FA 2** that produces the highest temperature rise when added to  $10.00 \text{ cm}^3$  of **FA 1**.

**Results**

Record your results below in an appropriate form showing, for each experiment, the volumes of solutions used, temperature measurements and the temperature rise,  $\Delta T$ .

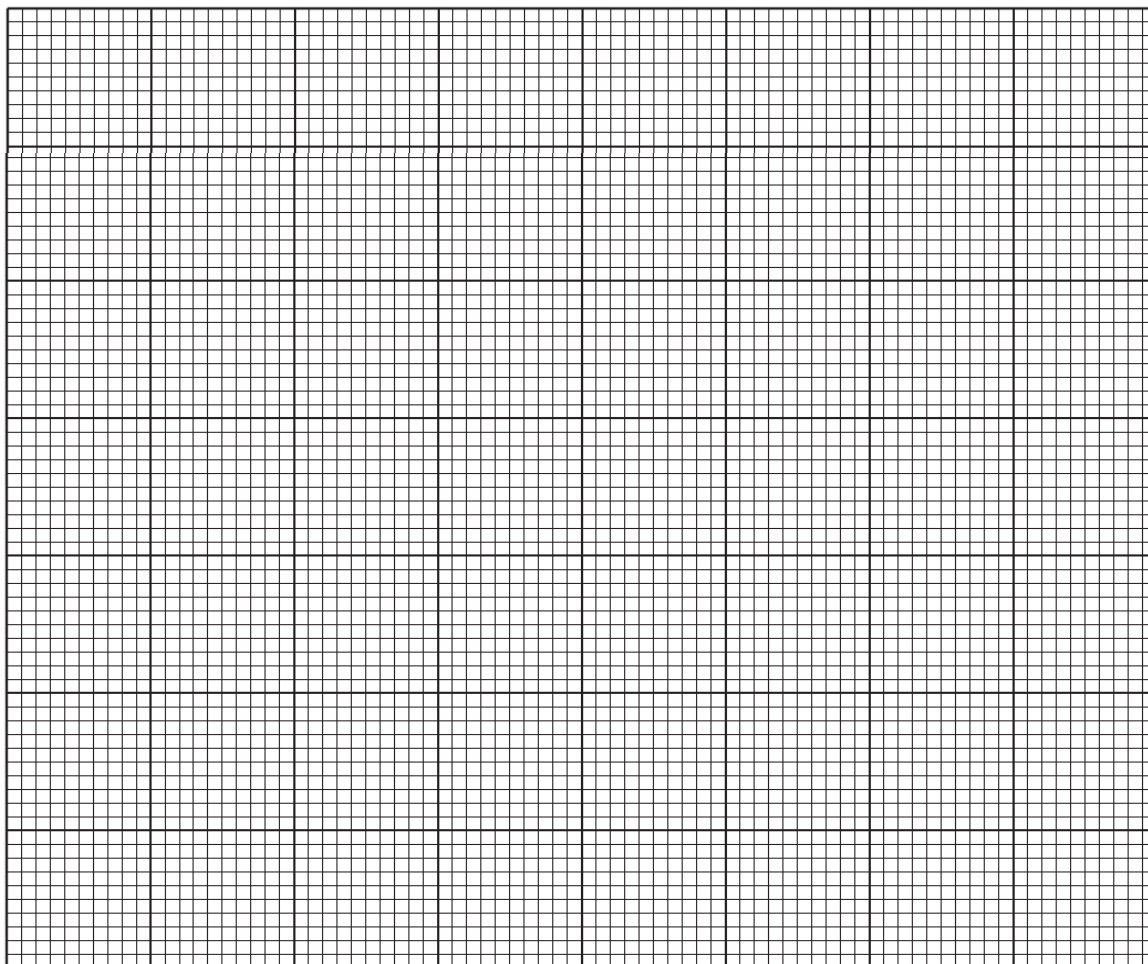
[4]



- (b) Plot a graph of temperature rise,  $\Delta T$ , on the y-axis against the volume of **FA 2** added on the x-axis.

Draw a line of best fit through the points where the temperature rise is increasing and another line through the points where the temperature rise is decreasing.

The intersection of these lines represents the temperature rise for the volume of **FA 2** that exactly neutralises the sulfuric acid present in 10.00 cm<sup>3</sup> of **FA 1**.



[3]

- (c) Read from the graph the volume of **FA 2** that gives the maximum temperature rise.

Volume of **FA 2** giving the maximum temperature rise = ..... cm<sup>3</sup> [1]

- (d) (i) Calculate the amount of NaOH required to neutralise the amount of  $\text{H}_2\text{SO}_4$  at the maximum temperature rise.

Amount of NaOH required = ..... mol  
[1]

- (ii) Hence, calculate the concentration of NaOH in **FA 2**.

Concentration of NaOH in **FA 2** = .....  $\text{mol dm}^{-3}$   
[1]

- (e) Read the maximum temperature rise from the graph and use this to calculate the enthalpy change when 1 mol of  $\text{H}_2\text{SO}_4$  is neutralised by NaOH. Give your answer in  $\text{kJ mol}^{-1}$ .

[4.18 J are absorbed or released when the temperature of 1  $\text{cm}^3$  of solution changes by 1  $^\circ\text{C}$ .]

Enthalpy change = .....  $\text{kJ mol}^{-1}$   
[2]



- (f) The enthalpy change of neutralisation,  $\Delta H_{\text{neut}}$ , between a strong acid and a strong base is  $-57 \text{ kJ mol}^{-1}$ .

Explain why the enthalpy change calculated in (e) is significantly more exothermic than  $\Delta H_{\text{neut}}$ .

.....  
.....  
.....[1]

- (g) A student suggested that the experiments carried out in (a) would be more accurate if volumes of  $20.00 \text{ cm}^3$  of  $1.0 \text{ mol dm}^{-3} \text{ H}_2\text{SO}_4$  were used instead.

State and explain whether you agree or disagree with the student's suggestion.

evaluation of student's suggestion .....

explanation .....

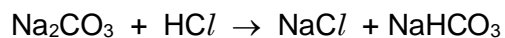
.....  
[1]

[Total: 14]



## 2 Determination of the percentage by mass of sodium carbonate in a mixture of sodium hydroxide and sodium carbonate

Sodium carbonate is neutralised by hydrochloric acid in two steps:



This step-wise neutralisation can be observed when the acid is added slowly to the sodium carbonate.

The percentage by mass of sodium carbonate in a mixture of sodium hydroxide and sodium carbonate can be determined by carrying out titrations using two different indicators. Since both sodium hydroxide and sodium carbonate react with acids, through careful selection of the indicators used for the titration, the volume of acid required to react with only the sodium carbonate can be found.

**FA 3** is  $0.125 \text{ mol dm}^{-3}$  hydrochloric acid,  $\text{HCl}$ .

**FA 4** is an aqueous solution containing sodium hydroxide,  $\text{NaOH}$ , and sodium carbonate,  $\text{Na}_2\text{CO}_3$ .

You are also provided with bromophenol blue indicator.

In this question, you will carry out titrations to determine the percentage by mass of sodium carbonate in the mixture of sodium hydroxide and sodium carbonate in solution **FA 4**.

(a) (i) **Titration of FA 4 against FA 3 using bromophenol blue**

1. Fill a burette with **FA 3**.
2. Pipette 25.0 cm<sup>3</sup> of **FA 4** into a conical flask.
3. Add four to five drops of bromophenol blue indicator.
4. Titrate the mixture in the flask with **FA 3** until the blue-violet colour of the solution changes to yellow.
5. Record your titration results, to an appropriate level of precision, in the space provided.

Repeat steps 2 to 5 to obtain consistent results.

**Titration results**

[6]

- (ii) From your titration results, obtain a suitable volume of **FA 3**,  $V_{\text{FA 3}}$ , to be used in your calculations. Show clearly how you obtained this volume.

$V_{\text{FA 3}} =$  ..... [1]



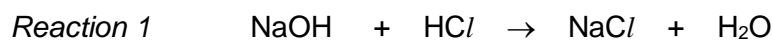
- (b) When the titrations in (a) were repeated using **phenolphthalein** as the indicator, 25.0 cm<sup>3</sup> of **FA 4** required 15.00 cm<sup>3</sup> of **FA 3**.

The following explains why different results are obtained using two different indicators.

- When phenolphthalein is used as the indicator, the following reactions have taken place at the end-point of the titration.



- When bromophenol blue is used as the indicator in (a), the following reactions have taken place at the end-point of the titration.



For the titration using **bromophenol blue**, the amount of Na<sub>2</sub>CO<sub>3</sub> reacted in *Reaction 2* is equal to the amount of sodium bicarbonate, NaHCO<sub>3</sub>, reacted in *Reaction 3*. Both the amounts of Na<sub>2</sub>CO<sub>3</sub> reacted in *Reaction 2* using **phenolphthalein or bromophenol blue** are the **same**.

Show your working and use appropriate significant figures in the final answers to all steps of your calculations.

- (i) Calculate the amount of HCl in the volume of **FA 3**,  $V_{\text{FA 3}}$ , determined in (a)(ii).

Amount of HCl in  $V_{\text{FA 3}}$  = .....

- (ii) Calculate the amount of HCl, in 15.00 cm<sup>3</sup> of **FA 3**.

Amount of HCl in 15.00 cm<sup>3</sup> of **FA 3** = .....

[1]



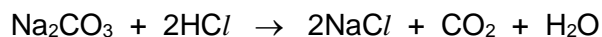
- (iii) With reference to the information given in **(b)** and your answers to **(b)(i)** and **(b)(ii)**, calculate the amount of  $\text{HCl}$  that reacted with  $\text{Na}_2\text{CO}_3$  in *Reaction 2* using **phenolphthalein** indicator.

Amount of  $\text{HCl}$  reacted with  $\text{Na}_2\text{CO}_3$  in *Reaction 2*  
using phenolphthalein = ..... [1]

- (iv) Use your answer to **(b)(iii)** to calculate the mass of  $\text{Na}_2\text{CO}_3$  present in  $25.0 \text{ cm}^3$  of **FA 4**.  
[ $A_r$ : C, 12.0; O, 16.0; Na, 23.0]

Mass of  $\text{Na}_2\text{CO}_3$  in  $25.0 \text{ cm}^3$  of **FA 4** = ..... [1]

- (v) The **overall** equation for the reaction of  $\text{Na}_2\text{CO}_3$  with  $\text{HCl}$  when **bromophenol blue** is used as indicator is given below.



Calculate the amount of  $\text{HCl}$  that reacted with  $\text{Na}_2\text{CO}_3$  in the above equation in  $25.0 \text{ cm}^3$  of **FA 4**.

Amount of  $\text{HCl}$  reacted with  $\text{Na}_2\text{CO}_3$  using bromophenol blue = ..... [1]





- (vi) Use your answers to (b)(i) and (b)(v) to calculate the mass of NaOH in 25.0 cm<sup>3</sup> of **FA 4**.  
[A<sub>r</sub> : H, 1.0; O, 16.0; Na, 23.0]

Mass of NaOH in 25.0 cm<sup>3</sup> of **FA 4** = ..... [1]

- (vii) Calculate the percentage by mass of Na<sub>2</sub>CO<sub>3</sub> in the mixture of NaOH and Na<sub>2</sub>CO<sub>3</sub> in **FA 4**.

**FA 4** contains ..... % by mass of Na<sub>2</sub>CO<sub>3</sub> [2]

- (c) The error (uncertainty) associated with **each reading** is given as follows:

50.00 cm<sup>3</sup> burette:                    ±0.05 cm<sup>3</sup>  
25.0 cm<sup>3</sup> pipette:                    ±0.06 cm<sup>3</sup>

Calculate the percentage error (uncertainty) when a

- 50.00 cm<sup>3</sup> burette
- 25.0 cm<sup>3</sup> pipette

is used to measure 25 cm<sup>3</sup> of **FA 4** into the conical flask.

Hence explain whether the 50.00 cm<sup>3</sup> burette or the 25.0 cm<sup>3</sup> pipette will be a more precise apparatus to measure 25 cm<sup>3</sup> of **FA 4**.

percentage error (uncertainty) of burette = ..... %  
of pipette = ..... %

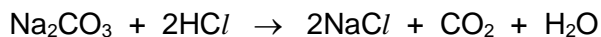
explanation .....

..... [2]



**(d) Planning**

You are to plan an experiment to determine the percentage by mass of sodium carbonate in an unknown solid sample by measuring the volume of carbon dioxide gas evolved on reaction with excess acid at room temperature and pressure.



You may assume that you are provided with:

- 0.5 mol dm<sup>-3</sup> hydrochloric acid, HCl;
- 0.5 g impure solid sample containing sodium carbonate, Na<sub>2</sub>CO<sub>3</sub>. Other impurities present are assumed to have no reaction with acid;
- 100 cm<sup>3</sup> gas syringe for gas collection;
- apparatus normally found in a school laboratory.

Your plan should include:

- calculations of suitable mass of impure sample and volume of excess hydrochloric acid to be used, based on a 100 cm<sup>3</sup> gas syringe;
- a fully-labelled diagram of the experimental set-up;
- practical details of how you would
  - ensure a known mass of solid sample and volume of acid are measured;
  - determine the volume of carbon dioxide evolved, including the measurements to be made;
  - ensure that an **accurate** and **reliable** volume of gas is obtained.

[*M<sub>r</sub>* : Na<sub>2</sub>CO<sub>3</sub>, 106.0]

**Diagram**

.....

.....

.....

.....

.....

.....

.....





### 3 Qualitative Analysis

Where reagents are selected for use in a test, the **name** or **correct formula** of the element or compound must be given.

Unless otherwise stated, the volumes given below are approximate and should be estimated rather than measured.

You should indicate clearly at what stage in a test a change occurs.  
If there is no observable change, write **no observable change**.

Rinse and reuse test-tubes and boiling tubes where possible.

(a) **FA 5** contains **two** cations and **two** anions from the lists on pages 17 and 18.

- To approximately half a boiling tube of distilled water, add all the **FA 5**.
- Stopper and shake the boiling tube thoroughly for one minute to make sure that no more of the solid will dissolve.
- Filter the mixture into a clean boiling tube.
- Place the filter funnel in a conical flask and wash the residue well with distilled water.
- **Keep both filtrate and residue for (a)(i) and (a)(ii) respectively.**

**While you are waiting for the mixture to filter, continue with (b) or (c).**

#### (i) Tests on the filtrate

Carry out the following tests and record your observations in Table 3.1 below.

**Table 3.1**

	test	observations
1.	To a 1 cm depth of the filtrate in a test-tube, add aqueous ammonia, slowly with shaking until no further change is seen;	[1]
	then add aqueous hydrogen peroxide.	[1]



**(ii) Tests on the residue**

Carry out the following tests and record your observations in Table 3.2 below.

**Table 3.2**

	test	observations
2.	Place the funnel containing the residue into a clean test-tube.  Pour approximately 5 cm <sup>3</sup> of dilute nitric acid onto the residue.  Collect the resultant filtrate.  Discard the first 1 cm depth of this resultant filtrate and collect the remaining filtrate in another clean test-tube for test 3.	[1]
3.	To 1 cm depth of the solution in a test-tube, add aqueous sodium hydroxide, slowly with shaking until no further change is seen.	[1]

**(iii) Identify the **two** cations present in FA 5. Use evidence from your observations in (a)(i) and (a)(ii) to support your deduction.**

cations present ..... and .....

evidence .....

.....

.....

.....

[2]

**(iv) The tests you have carried out in (i) and (ii) would have enabled you to identify only one of the two anions present in FA 5. Identify this anion.**

anion present .....

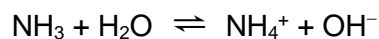
[1]



- (v) Suggest what type of reaction is happening when hydrogen peroxide is added in test (a)(i).

..... [1]

- (vi) In test 1 of (a)(i), aqueous ammonia behaved as an Arrhenius base:



In a separate experiment, an equal volume of aqueous ammonium chloride,  $\text{NH}_4\text{Cl}$  was added to a second portion of the filtrate that was used in (a)(i). When aqueous ammonia was then added to this resultant solution, no precipitate formed.

Suggest an explanation for the results of this experiment.

.....  
 .....  
 .....  
 ..... [2]

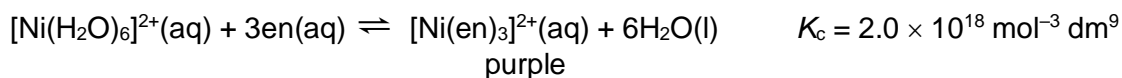
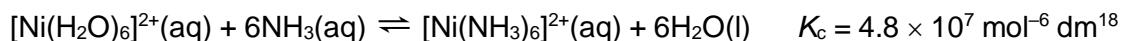
- (b) **FA 6** is an aqueous solution containing nickel(II) ion.

Carry out the following tests on **FA 6** and record your observations in Table 3.3 below.

**Table 3.3**

	<i>test</i>	<i>observations</i>
(i)	To a 1 cm depth of <b>FA 6</b> in a test-tube, add aqueous ammonia, slowly with shaking, until no further change is seen.	[1]
(ii)	To a 1 cm depth of <b>FA 6</b> in a test-tube, add aqueous sodium hydroxide, slowly with shaking, until no further change is seen.	[1]

- (iii) Nickel(II) ions form complexes with ligands such as ammonia and ethylenediamine as shown:



[en  $\equiv$  ethylenediamine]

The observation in **(b)(i)** is due to the formation of the nickel-ammonia complex.

Suggest, with reason, what might be observed if aqueous ammonia were added to a solution containing  $[\text{Ni}(\text{en})_3]^{2+}$  ions instead of  $\text{Ni}^{2+}(\text{aq})$ .

.....  
 .....  
 .....  
 .....[2]

- (c) **FA 7**, **FA 8** and **FA 9** are  $1.0 \text{ mol dm}^{-3}$  sulfuric acid,  $0.1 \text{ mol dm}^{-3}$  sulfuric acid and  $1.0 \text{ mol dm}^{-3}$  hydrochloric acid, but not necessarily in that order.

You are to plan and carry out **two** simple tests, using only the bench reagents provided, which will enable you to determine the identities of **FA 7**, **FA 8** and **FA 9**.

You should record, in a suitable form in the space below, your tests and observations. You should show clearly the observations for each of **FA 7**, **FA 8** and **FA 9** with all test reagents.

**FA 7** is .....

**FA 8** is .....

**FA 9** is .....

[4]

[Total: 18]



# Qualitative Analysis Notes

[ppt. = precipitate]

## (a) Reactions of aqueous cations

cation	reaction with	
	NaOH(aq)	NH <sub>3</sub> (aq)
aluminium, Al <sup>3+</sup> (aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH <sub>4</sub> <sup>+</sup> (aq)	ammonia produced on heating	–
barium, Ba <sup>2+</sup> (aq)	no ppt. (if reagents are pure)	no ppt.
calcium, Ca <sup>2+</sup> (aq)	white ppt. with high [Ca <sup>2+</sup> (aq)]	no ppt.
chromium(III), Cr <sup>3+</sup> (aq)	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II) Cu <sup>2+</sup> (aq)	pale blue ppt. insoluble in excess	blue ppt. soluble in excess giving dark blue solution
iron(II) Fe <sup>2+</sup> (aq)	green ppt. turning brown on contact with air insoluble in excess	green ppt. turning brown on contact with air insoluble in excess
iron(III), Fe <sup>3+</sup> (aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, Mg <sup>2+</sup> (aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn <sup>2+</sup> (aq)	off-white ppt., rapidly turning brown on contact with air insoluble in excess	off-white ppt., rapidly turning brown on contact with air insoluble in excess
zinc, Zn <sup>2+</sup> (aq)	white ppt. soluble in excess	white ppt. soluble in excess





**(b) Reactions of anions**

<b><i>anion</i></b>	<b><i>reaction</i></b>
carbonate, $\text{CO}_3^{2-}$	$\text{CO}_2$ liberated by dilute acids
chloride, $\text{Cl}^-(\text{aq})$	gives white ppt. with $\text{Ag}^+(\text{aq})$ (soluble in $\text{NH}_3(\text{aq})$ )
bromide, $\text{Br}^-(\text{aq})$	gives pale cream ppt. with $\text{Ag}^+(\text{aq})$ (partially soluble in $\text{NH}_3(\text{aq})$ )
iodide, $\text{I}^-(\text{aq})$	gives yellow ppt. with $\text{Ag}^+(\text{aq})$ (insoluble in $\text{NH}_3(\text{aq})$ )
nitrate, $\text{NO}_3^-(\text{aq})$	$\text{NH}_3$ liberated on heating with $\text{OH}^-(\text{aq})$ and Al foil
nitrite, $\text{NO}_2^-(\text{aq})$	$\text{NH}_3$ liberated on heating with $\text{OH}^-(\text{aq})$ and Al foil; $\text{NO}$ liberated by dilute acids (colourless $\text{NO} \rightarrow$ (pale) brown $\text{NO}_2$ in air)
sulfate, $\text{SO}_4^{2-}(\text{aq})$	gives white ppt. with $\text{Ba}^{2+}(\text{aq})$ (insoluble in excess dilute strong acids)
sulfite, $\text{SO}_3^{2-}(\text{aq})$	$\text{SO}_2$ liberated with dilute acids; gives white ppt. with $\text{Ba}^{2+}(\text{aq})$ (soluble in dilute strong acids)

**(c) Test for gases**

<b><i>gas</i></b>	<b><i>test and test result</i></b>
ammonia, $\text{NH}_3$	turns damp red litmus paper blue
carbon dioxide, $\text{CO}_2$	gives a white ppt. with limewater (ppt. dissolves with excess $\text{CO}_2$ )
chlorine, $\text{Cl}_2$	bleaches damp litmus paper
hydrogen, $\text{H}_2$	“pops” with a lighted splint
oxygen, $\text{O}_2$	relights a glowing splint
sulfur dioxide, $\text{SO}_2$	turns aqueous acidified potassium manganate(VII) from purple to colourless

**(d) Colour of halogens**

<b><i>halogen</i></b>	<b><i>colour of element</i></b>	<b><i>colour in aqueous solution</i></b>	<b><i>colour in hexane</i></b>
chlorine, $\text{Cl}_2$	greenish yellow gas	pale yellow	pale yellow
bromine, $\text{Br}_2$	reddish brown gas / liquid	orange	orange-red
iodine, $\text{I}_2$	black solid / purple gas	brown	purple





# TAMPINES MERIDIAN JUNIOR COLLEGE

## 2019 JC2 H2 Chemistry Prelim Exam Paper 4

### (Suggested Answers)

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#### 1 Determination of the concentration of a base and the enthalpy change of the neutralisation reaction

**FA 1** is  $2.0 \text{ mol dm}^{-3}$  sulfuric acid,  $\text{H}_2\text{SO}_4$ .

**FA 2** is aqueous sodium hydroxide,  $\text{NaOH}$ .

The reaction of sulfuric acid and sodium hydroxide is exothermic.

In separate experiments, you will add increasing volumes of **FA 2** to a fixed volume of **FA 1**. In each experiment you will measure the maximum temperature rise,  $\Delta T$ . As the volume of **FA 2** is increased, this maximum temperature rise,  $\Delta T$ , will increase and then decrease.

By measuring the maximum temperature rise for different mixtures of the two reagents, you are to determine the following:

- the concentration of sodium hydroxide,  $\text{NaOH}$ , in **FA 2**
- the enthalpy change when 1 mol of  $\text{H}_2\text{SO}_4$  is neutralised by  $\text{NaOH}$

#### (a) Method

- Fill the labelled burette with **FA 1**.
- Support a styrofoam cup in the  $250 \text{ cm}^3$  beaker.
- Run  $10.00 \text{ cm}^3$  of **FA 1** from the burette into the styrofoam cup.
- Measure  $20.0 \text{ cm}^3$  of **FA 2** using a measuring cylinder.
- Place the thermometer in the **FA 2** in the measuring cylinder and record the steady temperature of the solution.
- Pour the **FA 2** into the styrofoam cup, stir and record the maximum temperature obtained in the reaction.
- Empty and rinse the styrofoam cup; shake dry the styrofoam cup. Rinse the thermometer.
- Carry out the experiment three more times. Each time use  $10.00 \text{ cm}^3$  of **FA 1**.
- Use  $30.0 \text{ cm}^3$ ,  $40.0 \text{ cm}^3$  and  $50.0 \text{ cm}^3$  of **FA 2** in these different experiments.

Carry out **two further experiments**.

Choose volumes of **FA 2** which will allow you to investigate more precisely the volume of **FA 2** that produces the highest temperature rise when added to  $10.00 \text{ cm}^3$  of **FA 1**.

## Results

Record your results below in an appropriate form showing, for each experiment, the volumes of solutions used, temperature measurements and the temperature rise,  $\Delta T$ .

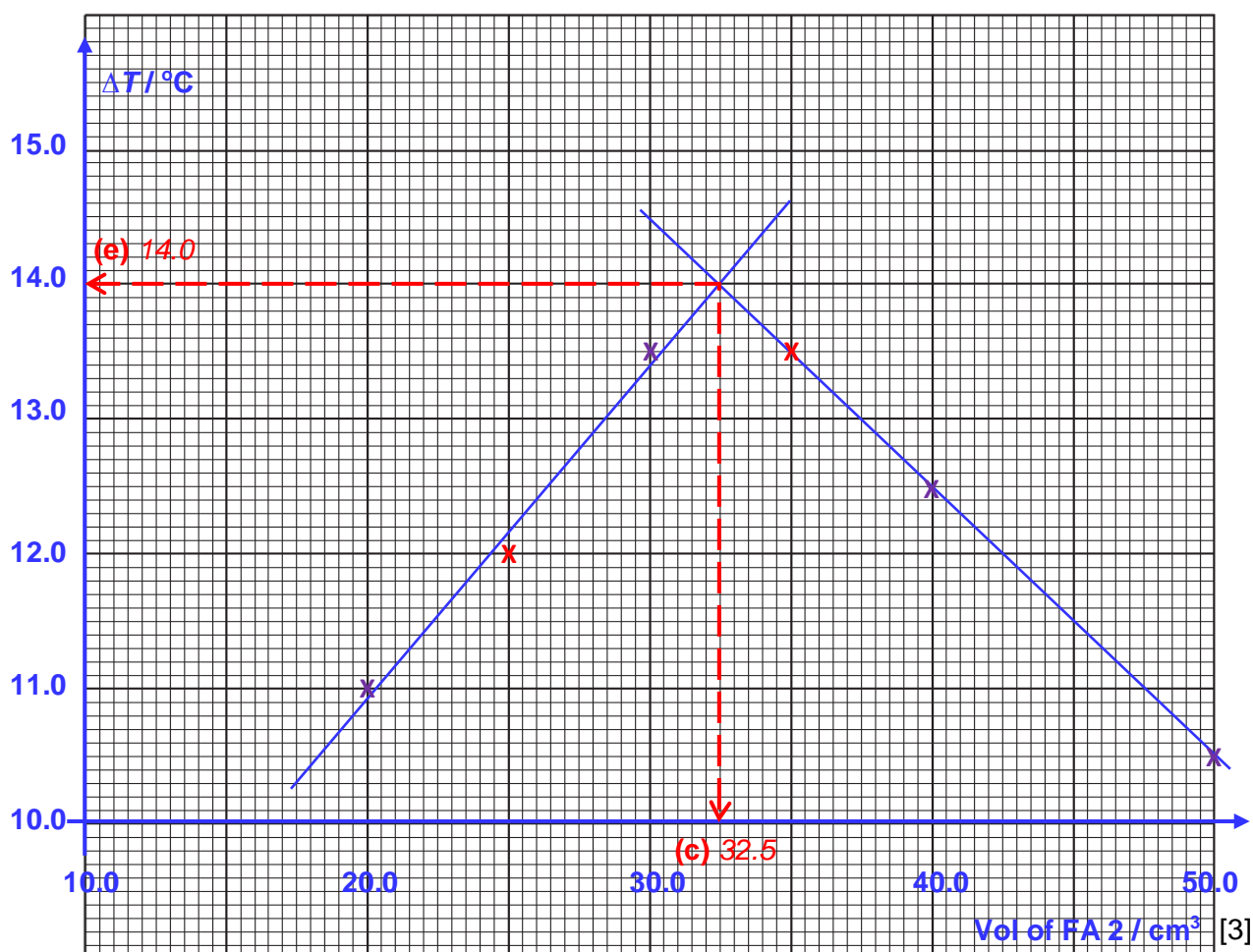
Expt	Volume of FA 1 / cm <sup>3</sup>	Volume of FA 2 / cm <sup>3</sup>	$T_i / ^\circ\text{C}$	$T_f / ^\circ\text{C}$	$\Delta T / ^\circ\text{C}$
1	10.00	20.0	31.5	42.5	11.0
2	10.00	30.0	31.5	45.0	13.5
3	10.00	40.0	31.5	44.0	12.5
4	10.00	50.0	31.5	42.0	10.5
5	10.00	25.0	31.5	43.5	12.0
6	10.00	35.0	31.5	45.0	13.5

[4]

- (b) Plot a graph of temperature rise,  $\Delta T$ , on the y-axis against the volume of **FA 2** added on the x-axis.

Draw a line of best fit through the points where the temperature rise is increasing and another line through the points where the temperature rise is decreasing.

The intersection of these lines represents the temperature rise for the volume of **FA 2** that exactly neutralises the sulfuric acid present in 10.00 cm<sup>3</sup> of **FA 1**.



[3]

- (c) Read from the graph the volume of **FA 2** that gives the maximum temperature rise.

Volume of **FA 2** giving the maximum temperature rise = ..... **32.5** ..... cm<sup>3</sup> [1]

- (d) (i) Calculate the amount of NaOH required to neutralise the amount of H<sub>2</sub>SO<sub>4</sub> at the maximum temperature rise.

$$\begin{aligned}\text{Amount of H}_2\text{SO}_4 &= 2.0 \times 0.010 \\ &= 0.0200 \text{ mol}\end{aligned}$$



$$\begin{aligned}\text{Amount of NaOH} &= 2 \times 0.020 \\ &= \underline{\underline{0.0400}} \text{ mol}\end{aligned}$$

Amount of NaOH required = ..... **0.0400** ..... mol [1]

- (ii) Hence, calculate the concentration of NaOH in **FA 2**.

$$\begin{aligned}\text{Concentration of NaOH in FA 2} &= 0.0400 \div \frac{32.5}{1000} \\ &= \underline{\underline{1.23}} \text{ mol dm}^{-3}\end{aligned}$$

Concentration of NaOH in **FA 2** = ..... **1.23** ..... mol dm<sup>-3</sup> [1]

- (e) Read the maximum temperature rise from the graph and use this to calculate the enthalpy change when 1 mol of H<sub>2</sub>SO<sub>4</sub> is neutralised by NaOH. Give your answer in kJ mol<sup>-1</sup>.

[4.18 J are absorbed or released when the temperature of 1 cm<sup>3</sup> of solution changes by 1 °C.]

$$\begin{aligned}\text{Quantity of heat absorbed by solution} &= (32.5 + 10.0) \times 4.18 \times 14.0 \\ &= \underline{\underline{2487 \text{ J OR } 2.487 \text{ kJ}}}\end{aligned}$$

$$\begin{aligned}\text{Enthalpy change} &= - \frac{2.487}{0.0200} \\ &= \underline{\underline{-124 \text{ kJ mol}^{-1}}}\end{aligned}$$

Enthalpy change = ..... **-124** ..... kJ mol<sup>-1</sup> [2]

- (f) The enthalpy change of neutralisation,  $\Delta H_{\text{neut}}$ , between a strong acid and a strong base is -57 kJ mol<sup>-1</sup>.

Explain why the enthalpy change calculated in (e) is significantly more exothermic than  $\Delta H_{\text{neut}}$ .

Enthalpy change in (e) is based on **1 mol of H<sub>2</sub>SO<sub>4</sub>** (or **2 mol of water** formed) while the enthalpy change of neutralisation,  $\Delta H_{\text{neut}}$  (-57 kJ mol<sup>-1</sup>), is based on **1 mol of water** formed.

[1]

- (g) A student suggested that the experiments carried out in (a) would be more accurate if volumes of 20.00 cm<sup>3</sup> of 1.0 mol dm<sup>-3</sup> H<sub>2</sub>SO<sub>4</sub> were used instead.

State and explain whether you agree or disagree with the student's suggestion.

*Accept any of the following:*

- Agree –

Lower (percentage) error as: acid spray is reduced (since reaction will be slower) *OR* smaller temperature rise so less heat loss *OR* larger volume used (*accept other reasons*)

- Disagree –

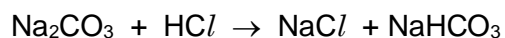
Higher (percentage) error as: smaller temperature change, so higher (percentage) error of reading *OR* reaction slower so more heat loss (*accept other reasons*)

[1]

[Total: 14]

## 2 Determination of the percentage by mass of sodium carbonate in a mixture of sodium hydroxide and sodium carbonate

Sodium carbonate is neutralised by hydrochloric acid in two steps:



This step-wise neutralisation can be observed when the acid is added slowly to the sodium carbonate.

The percentage by mass of sodium carbonate in a mixture of sodium hydroxide and sodium carbonate can be determined by carrying out titrations using two different indicators. Since both sodium hydroxide and sodium carbonate react with acids, through careful selection of the indicators used for the titration, the volume of acid required to react with only the sodium carbonate can be found.

**FA 3** is  $0.125 \text{ mol dm}^{-3}$  hydrochloric acid,  $\text{HCl}$ .

**FA 4** is an aqueous solution containing sodium hydroxide,  $\text{NaOH}$ , and sodium carbonate,  $\text{Na}_2\text{CO}_3$ .

You are also provided with bromophenol blue indicator.

In this question, you will carry out titrations to determine the percentage by mass of sodium carbonate in the mixture of sodium hydroxide and sodium carbonate in solution **FA 4**.

### (a) (i) Titration of FA 4 against FA 3 using bromophenol blue

1. Fill a burette with **FA 3**.
2. Pipette  $25.0 \text{ cm}^3$  of **FA 4** into a conical flask.
3. Add four to five drops of bromophenol blue indicator.
4. Titrate the mixture in the flask with **FA 3** until the blue-violet colour of the solution changes to yellow.
5. Record your titration results, to an appropriate level of precision, in the space provided.

Repeat steps 2 to 5 to obtain consistent results.

#### Titration results

	1	2	3
Final burette reading / $\text{cm}^3$	20.70	30.55	20.45
Initial burette reading / $\text{cm}^3$	0.00	10.00	0.00
Volume of <b>FA 3</b> / $\text{cm}^3$	20.70	20.55	20.45

✓

✓

[6]

- (ii) From your titration results, obtain a suitable volume of **FA 3**,  $V_{\text{FA 3}}$ , to be used in your calculations. Show clearly how you obtained this volume.

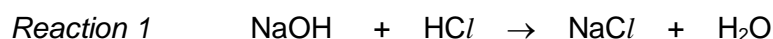
$$\begin{aligned}\text{Volume of FA 3, } V_{\text{FA 3}} &= \frac{20.55 + 20.45}{2} \\ &= \underline{20.50 \text{ cm}^3} \text{ (2 d.p.)}\end{aligned}$$

$$V_{\text{FA 3}} = \underline{\hspace{2cm} 20.50 \text{ cm}^3 \hspace{2cm}} \quad [1]$$

- (b) When the titrations in (a) were repeated using **phenolphthalein** as the indicator, 25.0 cm<sup>3</sup> of **FA 4** required 15.00 cm<sup>3</sup> of **FA 3**.

The following explains why different results are obtained using two different indicators.

- When phenolphthalein is used as the indicator, the following reactions have taken place at the end-point of the titration.



- When bromophenol blue is used as the indicator in (a), the following reactions have taken place at the end-point of the titration.



For the titration using **bromophenol blue**, the amount of Na<sub>2</sub>CO<sub>3</sub> reacted in *Reaction 2* is equal to the amount of sodium bicarbonate, NaHCO<sub>3</sub>, reacted in *Reaction 3*. Both the amounts of Na<sub>2</sub>CO<sub>3</sub> reacted in *Reaction 2* using **phenolphthalein** or **bromophenol blue** are the same.

Show your working and use appropriate significant figures in the final answers to all steps of your calculations.

- (i) Calculate the amount of HCl in the volume of **FA 3**,  $V_{\text{FA 3}}$ , determined in (a)(ii).

$$\begin{aligned}\text{Amount of HCl} &= 0.125 \times (V_{\text{FA 3}} \text{ in dm}^3) \text{ mol} \\ &= 0.125 \times \frac{20.50}{1000} \text{ mol} = \underline{2.56 \times 10^{-3} \text{ mol}} \\ \text{Amount of HCl in } V_{\text{FA 3}} &= \underline{\hspace{2cm} 2.56 \times 10^{-3} \text{ mol} \hspace{2cm}}\end{aligned}$$

- (ii) Calculate the amount of HCl in 15.00 cm<sup>3</sup> of **FA 3**.

$$\begin{aligned}\text{Amount of HCl} &= 0.125 \times \frac{15.00}{1000} = \underline{1.88 \times 10^{-3} \text{ mol}} \\ \text{Amount of HCl in 15.00 cm}^3 \text{ of FA 3} &= \underline{\hspace{2cm} 1.88 \times 10^{-3} \text{ mol} \hspace{2cm}}\end{aligned}$$

[1]

- (iii) With reference to the information given in (b) and your answers to (b)(i) and (b)(ii), calculate the amount of HCl that reacted with Na<sub>2</sub>CO<sub>3</sub> in *Reaction 2* using **phenolphthalein** indicator.

$$\begin{aligned}\text{Amount of HCl reacted with Na}_2\text{CO}_3 &= \text{ans (b)(i)} - (1.88 \times 10^{-3}) \text{ mol} \\ &= 2.56 \times 10^{-3} - 1.88 \times 10^{-3} = \underline{6.83 \times 10^{-4} \text{ mol}}\end{aligned}$$

$$\begin{aligned}\text{Amount of HCl reacted with Na}_2\text{CO}_3 \text{ in Reaction 2} \\ \text{using phenolphthalein} &= \underline{6.83 \times 10^{-4} \text{ mol}}\end{aligned}$$

[1]

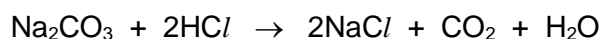
- (iv) Use your answer to (b)(iii) to calculate the mass of Na<sub>2</sub>CO<sub>3</sub> present in 25.0 cm<sup>3</sup> of **FA 4**.  
[A<sub>r</sub> : C, 12.0; O, 16.0; Na, 23.0]

$$\begin{aligned}\text{Mass of Na}_2\text{CO}_3 &= \text{ans (b)(iii)} \times 106.0 \text{ g} \\ &= 6.83 \times 10^{-4} \times 106.0 = \underline{0.0723 \text{ g}}\end{aligned}$$

$$\text{Mass of Na}_2\text{CO}_3 \text{ in 25.0 cm}^3 \text{ of FA 4} = \underline{0.0723 \text{ g}}$$

[1]

- (v) The **overall** equation for the reaction of Na<sub>2</sub>CO<sub>3</sub> with HCl when **bromophenol blue** is used as indicator is given below.



Calculate the amount of HCl that reacted with Na<sub>2</sub>CO<sub>3</sub> in the above equation in 25.0 cm<sup>3</sup> of **FA 4**.

$$\begin{aligned}\text{Amount of HCl} &= \text{ans (b)(iii)} \times 2 \text{ mol} \\ &= 6.83 \times 10^{-4} \times 2 = \underline{1.37 \times 10^{-3} \text{ mol}}\end{aligned}$$

$$\text{Amount of HCl reacted with Na}_2\text{CO}_3 \text{ using bromophenol blue} = \underline{1.37 \times 10^{-3} \text{ mol}}$$

[1]

- (vi) Use your answers to (b)(i) and (b)(v) to calculate the mass of NaOH in 25.0 cm<sup>3</sup> of **FA 4**.  
[A<sub>r</sub> : H, 1.0; O, 16.0; Na, 23.0]

$$\text{Amount of HCl reacted with NaOH} = (\text{ans (b)(i)}) - (\text{ans (b)(v)}) \text{ mol}$$

$$\begin{aligned}\text{Mass of NaOH} &= [(\text{ans (b)(i)}) - (\text{ans (b)(v)})] \times 40.0 \text{ g} \\ &= (2.56 \times 10^{-3} - 1.37 \times 10^{-3}) \times 40.0 = 1.20 \times 10^{-3} \times 40.0 = \underline{0.0478 \text{ g}}\end{aligned}$$

$$\text{Mass of NaOH in 25.0 cm}^3 \text{ of FA 4} = \underline{0.0478 \text{ g}}$$

[1]



- (vii) Calculate the percentage by mass of  $\text{Na}_2\text{CO}_3$  in the mixture of  $\text{NaOH}$  and  $\text{Na}_2\text{CO}_3$  in **FA 4**.

$$\begin{aligned}\% \text{ by mass of } \text{Na}_2\text{CO}_3 &= (\text{ans (b)(iv)}) \div [(\text{ans (b)(iv)}) + (\text{ans (b)(vi)})] \times 100 \% \\ &= \frac{0.0723}{0.0723 + 0.0478} \times 100 = \frac{0.0723}{0.1201} \times 100 = \underline{\underline{60.2\%}}\end{aligned}$$

**FA 4** contains ..... **60.2** ..... % by mass of  $\text{Na}_2\text{CO}_3$

[2]

- (c) The error (uncertainty) associated with **each reading** is given as follows:

50.00 cm <sup>3</sup> burette:	±0.05 cm <sup>3</sup>
25.0 cm <sup>3</sup> pipette:	±0.06 cm <sup>3</sup>

Calculate the percentage error (uncertainty) when a

- 50.00 cm<sup>3</sup> burette
- 25.0 cm<sup>3</sup> pipette

is used to measure 25 cm<sup>3</sup> of **FA 4** into the conical flask.

Hence explain whether the 50.00 cm<sup>3</sup> burette or the 25.0 cm<sup>3</sup> pipette will be a more accurate apparatus to measure 25 cm<sup>3</sup> of **FA 4**.

$$\% \text{ error (uncertainty) of burette} = (2 \times 0.05)/25 \times 100\% = \underline{\underline{0.40\%}}$$

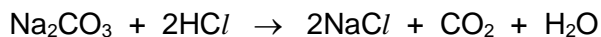
$$\% \text{ error (uncertainty) of pipette} = 0.06/25 \times 100\% = \underline{\underline{0.24\%}}$$

A **25.0 cm<sup>3</sup> pipette** has a **lower % error/uncertainty** and hence is **more accurate** to measure 25 cm<sup>3</sup> of **FA 4**.

[2]

**(d) Planning**

You are to plan an experiment to determine the percentage by mass of sodium carbonate in an unknown solid sample by measuring the volume of carbon dioxide gas evolved on reaction with excess acid at room temperature and pressure.



You may assume that you are provided with:

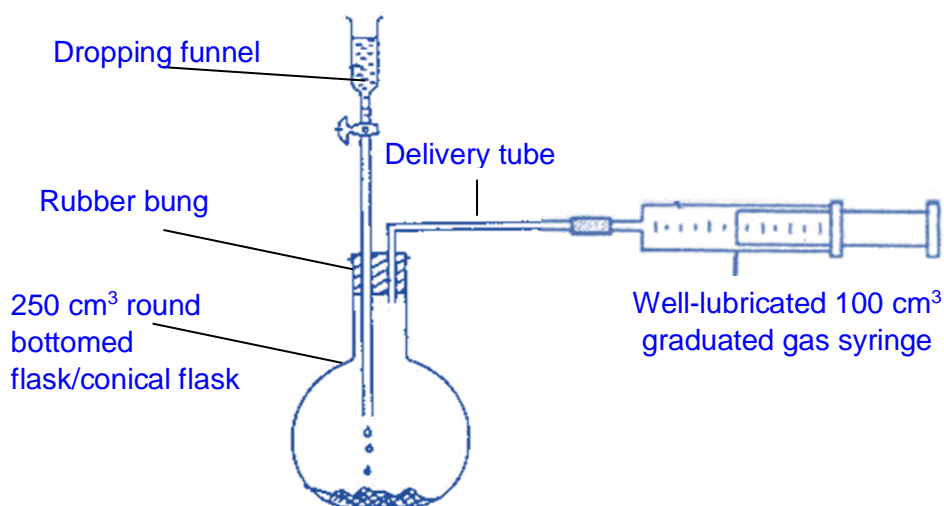
- 0.5 mol dm<sup>-3</sup> hydrochloric acid, HCl;
- 0.5 g impure solid sample containing sodium carbonate, Na<sub>2</sub>CO<sub>3</sub>. Other impurities present are assumed to have no reaction with acid;
- 100 cm<sup>3</sup> gas syringe for gas collection;
- apparatus normally found in a school laboratory.

Your plan should include:

- calculations of suitable mass of impure sample and volume of excess hydrochloric acid to be used, based on a 100 cm<sup>3</sup> gas syringe;
- a fully-labelled diagram of the experimental set-up;
- practical details of how you would
  - ensure a known mass of solid sample and volume of acid are measured;
  - determine the volume of carbon dioxide evolved, including the measurements to be made;
  - ensure that an **accurate** and **reliable** volume of gas is obtained.

[*M<sub>r</sub>* : Na<sub>2</sub>CO<sub>3</sub>, 106.0]

[7]

**Diagram**

**Pre-calculations**

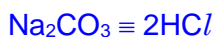
Assuming conditions of r.t.p. and 50 to 100 cm<sup>3</sup> of gas collected, eg. 80 cm<sup>3</sup> of CO<sub>2</sub> gas to be collected:

$$\text{No of mole of CO}_2 = \frac{80}{24000} = 3.33 \times 10^{-3} \text{ mol}$$



$$\text{Mass of Na}_2\text{CO}_3 = 3.33 \times 10^{-3} \times 106 = 0.353 \text{ g}$$

Assuming that impure sample is 100% pure, mass of sample required = **0.353 g** (about 0.35g)



$$\text{Minimum volume of HCl} = \frac{3.33 \times 10^{-3} \times 2}{0.5} = \mathbf{13.32 \text{ cm}^3} \text{ (excess acid; any vol > 13.32 cm}^3\text{)}$$

**Procedure*****Weighing by difference***

1. Weigh about **0.35 g** of impure solid sample in a weighing bottle using a mass balance.
2. Transfer the impure sample to a 250 cm<sup>3</sup> round bottom flask/conical flask.
3. Re-weigh the weighing bottle to obtain mass of residual solid.

***Alternative***

1. Weigh about **0.35 g** of impure solid sample and transfer into a 250 cm<sup>3</sup> round bottom flask/conical flask.

***Gas collection***

2. Using a **25 cm<sup>3</sup>** measuring cylinder, transfer **20 cm<sup>3</sup>** of solution into a dry dropping funnel.
3. Read the initial reading of the 100 cm<sup>3</sup> **gas syringe** (or other appropriate apparatus).
4. Run the solution from the dropping funnel into the 250 cm<sup>3</sup> conical flask. Close the tap when all the solution has flowed into the conical flask.
5. Swirl the flask once and leave it to stand.
6. Read the final reading of the **gas syringe** after the reaction is completed, **when there is no further change to the reading of the gas syringe.**

[Total: 23]

### 3 Qualitative Analysis

Where reagents are selected for use in a test, the **name** or **correct formula** of the element or compound must be given.

Unless otherwise stated, the volumes given below are approximate and should be estimated rather than measured.

You should indicate clearly at what stage in a test a change occurs.

If there is no observable change, write **no observable change**.

Rinse and reuse test-tubes and boiling tubes where possible.

(a) **FA 5** contains **two** cations and **two** anion from the lists on pages 17 and 18.

- To approximately half a boiling tube of distilled water, add all the **FA 5**.
- Stopper and shake the boiling tube thoroughly for one minute to make sure that no more of the solid will dissolve.
- Filter the mixture into a clean boiling tube.
- Place the filter funnel in a conical flask and wash the residue well with distilled water.
- **Keep both filtrate and residue for (a)(i) and (a)(ii) respectively.**

**While you are waiting for the mixture to filter, continue with (b) or (c).**

#### (i) Tests on the filtrate

Carry out the following tests and record your observations in Table 3.1 below.

**Table 3.1**

	test	observations
1.	To a 1 cm depth of the filtrate in a test-tube, add aqueous ammonia, slowly with shaking until no further change is seen;	<ul style="list-style-type: none"> <li>• <u>Off-white / beige / pale or light brown (not cream) ppt</u></li> <li>• Ppt rapidly <u>turns brown on contact with air / darkens on standing</u> OR <u>Ppt insoluble in excess NH<sub>3</sub></u></li> </ul> <div>[1]</div>
	then add aqueous hydrogen peroxide.	<ul style="list-style-type: none"> <li>• Ppt / solid turns <u>brown / darker brown / brown-black</u></li> <li>• <u>Effervescence / bubbling</u> OR <u>Gas evolved relights glowing splint</u></li> </ul> <div>[1]</div>

**(ii) Tests on the residue**

Carry out the following tests and record your observations in Table 3.2 below.

**Table 3.2**

	test	observations
2.	Place the funnel containing the residue into a clean test-tube.  Pour approximately 5 cm <sup>3</sup> of dilute nitric acid onto the residue.  Collect the resultant filtrate.  Discard the first 1 cm depth of this resultant filtrate and collect the remaining filtrate in another clean test-tube for test 3.	<ul style="list-style-type: none"> <li>• <u>Effervescence</u> observed when acid is poured onto the residue</li> <li>• <u>Colourless filtrate</u> obtained</li> </ul> <p>[1]</p>
3.	To 1 cm depth of the solution in a test-tube, add aqueous sodium hydroxide, slowly with shaking until no further change is seen.	<ul style="list-style-type: none"> <li>• <u>White ppt</u></li> <li>• Ppt <u>insoluble in excess NaOH</u></li> </ul> <p>[1]</p>

- (iii)** Identify the **two** cations present in **FA 5**. Use evidence from your observations in **(a)(i)** and **(a)(ii)** to support your deduction.

cations present Mn<sup>2+</sup> and Mg<sup>2+</sup>

evidence

In test 1, addition of NH<sub>3</sub> formed off-white ppt which turned brown / insoluble in excess, indicating presence of Mn<sup>2+</sup>.

In test 3, addition of NaOH formed white ppt which was insoluble in excess, indicating presence of Mg<sup>2+</sup>.

[2]

- (iv)** The tests you have carried out in **(i)** and **(ii)** would have enabled you to identify only one of the two anions present in **FA 5**. Identify this anion.

anion present CO<sub>3</sub><sup>2-</sup>

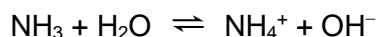
[1]

- (v)** Suggest what type of reaction is happening when hydrogen peroxide is added in test **(b)(i)**.

Redox / decomposition of H<sub>2</sub>O<sub>2</sub> / disproportionation of H<sub>2</sub>O<sub>2</sub>  
(allow oxidation of Mn<sup>2+</sup> / oxidation or reduction of H<sub>2</sub>O<sub>2</sub>)

[1]

- (vi) In test 1 of **(a)(i)**, aqueous ammonia behaved as an Arrhenius base:



In a separate experiment, an equal volume of aqueous ammonium chloride,  $\text{NH}_4\text{Cl}$  was added to a second portion of the filtrate that was used in **(a)(i)**. When aqueous ammonia was then added to this resultant solution, no precipitate formed.

Suggest an explanation for the results of this experiment.

Presence of ammonium chloride increased  $[\text{NH}_4^+]$  and shifted position of equilibrium to the left, decreasing  $[\text{OH}^-]$ .

$[\text{OH}^-]$  insufficient to cause precipitation of the metal hydroxide,  $(\text{MnOH})_2$ .

[2]

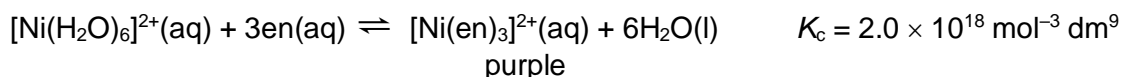
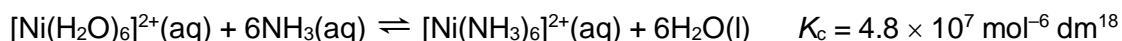
- (b) **FA 6** is an aqueous solution containing nickel(II) ion.

Carry out the following tests on **FA 6** and record your observations in Table 3.3 below.

**Table 3.3**

	<i>test</i>	<i>observations</i>
(i)	To a 1 cm depth of <b>FA 6</b> in a test-tube, add aqueous ammonia, slowly with shaking, until no further change is seen.	<ul style="list-style-type: none"> <li>Solution (<b>FA 6</b>) turns from green to <u>blue</u> (not dark blue) (Ignore any ppt)</li> </ul> <p>[1]</p>
(ii)	To a 1 cm depth of <b>FA 6</b> in a test-tube, add aqueous sodium hydroxide, slowly with shaking, until no further change is seen.	<ul style="list-style-type: none"> <li><u>Green ppt</u></li> <li><u>Ppt insoluble in excess</u></li> </ul> <p>[1]</p>

- (iii) Nickel(II) ions form complexes with ligands such as ammonia and ethylenediamine as shown:



[en  $\equiv$  ethylenediamine]

The observation in **(b)(i)** is due to the formation of the nickel-ammonia complex.

Suggest, with reason, what might be observed if aqueous ammonia were added to a solution containing  $[\text{Ni}(\text{en})_3]^{2+}$  ions instead of  $\text{Ni}^{2+}(\text{aq})$ .

No observable change / no colour change / purple solution remained.

Any one of the following:

- **$[\text{Ni}(\text{en})_3]^{2+}(\text{aq})$  complex is more stable**
- **$[\text{Ni}(\text{NH}_3)_6]^{2+}(\text{aq})$  complex is less stable**
- **en is a stronger ligand** (and so unable to be displaced by  $\text{NH}_3$ )
- **$\text{NH}_3$  is a weaker ligand** (and so unable to displace en)

[2]

- (c) **FA 7**, **FA 8** and **FA 9** are  $1.0 \text{ mol dm}^{-3}$  sulfuric acid,  $0.1 \text{ mol dm}^{-3}$  sulfuric acid and  $1.0 \text{ mol dm}^{-3}$  hydrochloric acid, but not necessarily in that order.

You are to plan and carry out **two** simple tests, using only the bench reagents provided, which will enable you to determine the identities of **FA 7**, **FA 8** and **FA 9**.

You should record, in a suitable form in the space below, your tests and observations. You should show clearly the observations for each of **FA 7**, **FA 8** and **FA 9** with all test reagents.

TWO tests only	Test	<b>FA 7</b>	<b>FA 8</b>	<b>FA 9</b>
<i>EITHER</i> (allow identification by elimination, sequence may be swapped)	Add aqueous $\text{BaNO}_3$	No ppt	White ppt	White ppt
	Add aqueous $\text{AgNO}_3$	White ppt	No ppt	No ppt
<i>AND</i> (accept other correct simple tests)	Add Mg strip	Strong / fast effervescence	Strong / fast effervescence	Weak / slow effervescence

**FA 7** is  **$1.0 \text{ mol dm}^{-3}$  hydrochloric acid** .....

**FA 8** is  **$1.0 \text{ mol dm}^{-3}$  sulfuric acid** .....

**FA 9** is  **$0.1 \text{ mol dm}^{-3}$  sulfuric acid** .....

[4]

[Total: 18]