Anglo-Chinese Junior College

JC2 Preliminary Examination
Higher 2

A Methodist Institution
(Founded 1886)

CHEMISTRY
Paper 1 Multiple Choice

9729/01
9 September 2024
1 hour

Additional Materials: Multiple Choice Answer Sheet
Data Booklet

READ THESE INSTRUCTIONS FIRST

Write in soft pencil.

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

Write your name, Centre number 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.

Read the instructions on the Answer Sheet very carefully.

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.

1 The incomplete combustion of a gaseous hydrocarbon produced 80 cm^3 of carbon dioxide, 40 cm^3 of carbon monoxide and 160 cm^3 of water vapour.

What volume of oxygen was used for combustion of the hydrocarbon?

A 40 cm^3

B 80 cm^3

C 160 cm^3

D 180 cm^3

2 0.01 mol of an unknown ion $\mathbf{G}^{2+}$ required 17.25 cm^3 of 0.23 mol dm^{-3} acidified $KMnO_4$ to reach the end-point.

What is the final oxidation state of element **G**?

A +3 **B** +4 **C** +5 **D** +6

3 Which ion will be deflected the most in an applied electric field?

A $^{79}Br^+$ **B** $^{81}Br^{2+}$ **C** $^{81}Br^+$ **D** $^{82}Br^{2+}$

4 An unstable ion has

- a nucleon number of 219,
- 51 more neutrons than electrons,
- an atomic number of 84, 85, 86, or 87,

What could this ion be?

A Po^{2+} **B** At^{3+} **C** Rn^{4+} **D** Fr^{5+}

5 Which species contains two π bonds?

1 BF_3NH_3
2 $CH_2CHCH_2CH_3$
3 CH_2CHCHO
4 $HCO_2CH_2COCH_3$

A 1 and 4 only
B 2 and 3 only
C 2 and 4 only
D 3 and 4 only

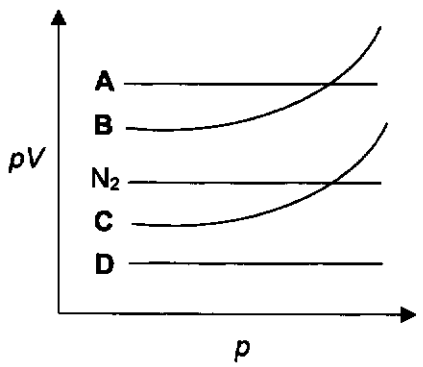
6 What is the strongest intermolecular force in ethanal, ethylamine and decan-1-ol?

	ethanal	ethylamine	decan-1-ol
A	hydrogen bonds	hydrogen bonds	induced dipoles
B	permanent dipoles	hydrogen bonds	induced dipoles
C	permanent dipoles	permanent dipoles	hydrogen bonds
D	hydrogen bonds	permanent dipoles	hydrogen bonds

7 The volumes and pressures of equal masses of two gases, N_2 and NH_3, are separately investigated at constant temperature.

The results are plotted on a graph of pV against p. Both gases behave as ideal gases under the conditions chosen. The result for N_2 is given.

Which plot shows the result for NH_3?



8 What can be added to a mixture of MgO and Al_2O_3 to separate them by filtration?

1 water
2 HCl(aq)
3 NaOH(aq)

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

9 The following table shows the results of two experiments involving Group 17 halides, X^- and Y^-.

experiment	deduction
halogen Z_2 added to X^-	X_2 formed
halogen Z_2 added to Y^-	Y_2 not formed

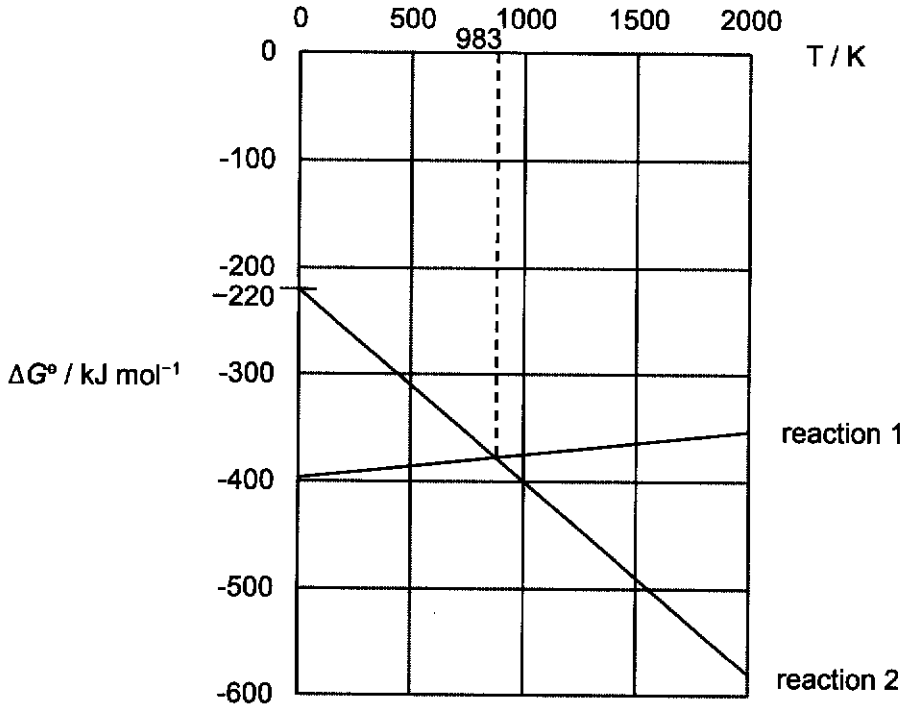
Which row shows the halogens in decreasing order of oxidising strengths?

A Y_2, Z_2, X_2
B Y_2, X_2, Z_2
C X_2, Z_2, Y_2
D X_2, Y_2, Z_2

10 An Ellingham diagram is a plot of ΔG versus temperature and it can be used to show the stability of compounds at various temperatures.

The following Ellingham diagram is for reactions 1 and 2.

reaction 1 $\quad W + X \rightarrow Y$
reaction 2 $\quad 2W + X \rightarrow 2Z$



Which statement is **incorrect**?

A Reaction 1 is favoured at lower temperatures.

B The entropy change of reaction 2 is negative.

C The enthalpy change of reaction 2 is -220 kJ mol^{-1}.

D At 983 K, ΔG of the reaction $2Z \rightarrow W + Y$ is zero.

11 When an instant cold pack is used, a vigorous reaction occurs, and the temperature falls from 25 °C to 5 °C.

What are the correct signs of ΔG and ΔS for this reaction?

	ΔG	ΔS
A	+	+
B	+	−
C	−	+
D	−	−

12 The Dushman reaction is represented by the following equation.

$$IO_3^-(aq) + 5I^-(aq) + 6H^+(aq) \rightarrow 3I_2(aq) + 3H_2O(l)$$

The rate equation for this reaction is as follows.

$$\text{rate} = k[IO_3^-][I^-]^2[H^+]^2$$

When the concentration of each reactant is a mol dm^{-3}, the initial rate was found to be y mol dm^{-3} s^{-1}.

What will be the initial rate of the reaction if $[IO_3^-]$ is $2a$, $[I^-]$ is $\frac{1}{2}a$, and $[H^+]$ is $4a$?

A $2y$ **B** $4y$ **C** $8y$ **D** $16y$

13 3.0 mol of Q, 1.5 mol of R and 0.2 mol of S are mixed in a 2.0 dm^3 flask and allowed to reach equilibrium.

$$4Q(g) + R(g) \rightleftharpoons S(g)$$

The equilibrium mixture contained 0.8 mol of S.

What is the equilibrium concentration of Q in the flask?

A 2.4 mol dm^{-3}

B 1.2 mol dm^{-3}

C 0.6 mol dm^{-3}

D 0.3 mol dm^{-3}

14 Water dissociates according to the equation:

$$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq)$$

The pH of water at different temperatures are shown below.

temperature / K	pH
298	7.0
333	6.5

Which statements are true?

1 The dissociation of water is endothermic.

2 The pK_a of water increases when the temperature increases.

3 Water becomes more acidic when the temperature increases.

A 1 only

B 1 and 2 only

C 2 and 3 only

D 1, 2 and 3

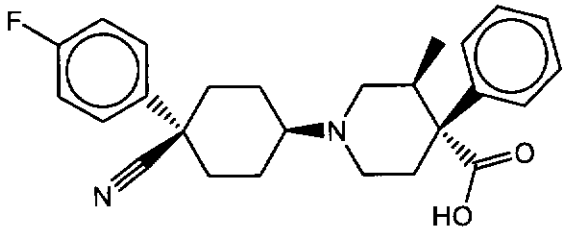
15 The table below describes some indicators.

indicator	colour in acid	colour in alkali	pK_a	range of pH for colour change
methyl orange	red	yellow	3.7	3.2 – 4.4
thymol blue	yellow	blue	8.9	8.0 – 9.6

For the titration of NaOH(aq) against HCOOH(aq), which row shows the most suitable indicator and the corresponding colour change?

	indicator	colour change
A	methyl orange	red to orange
B	methyl orange	yellow to orange
C	thymol blue	yellow to green
D	thymol blue	blue to green

16 Levocabastine is an antihistamine used in the treatment of sore eyes.



Levocabastine

Which functional group is **not** present in Levocabastine?

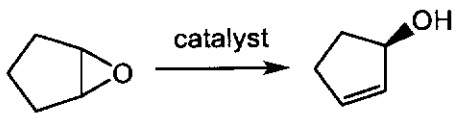
A alcohol

B amine

C aryl halide

D nitrile

17 1,2-epoxycyclopentane can be converted to cyclopent-2-en-1-ol in a single reaction.



1,2-epoxycyclopentane cyclopent-2-en-1-ol

Which statement about the reaction is correct?

A 1,2-epoxycyclopentane rotates plane-polarised light.

B A reducing agent is used for this reaction.

C Cyclopent-2-en-1-ol is more volatile than the 1,2-epoxycyclopentane.

D An isomerisation reaction has occurred.

18 Both benzene and propene react with bromine.

Which statement best explains the difference in the reactivity between these compounds?

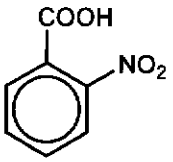
A Benzene is a planar molecule which allows ease of attack by bromine whereas propene is a non-planar molecule.

B The carbocation intermediate produced in the reaction of benzene with bromine is stabilised by resonance.

C The sideway overlap of p orbitals in benzene means the C–C bonds alternate between long, single bonds and short, double bonds.

D The delocalisation of electrons in benzene causes it to be more stable.

19 Benzene reacts in a three-stage process to produce 2-nitrobenzoic acid.



2-nitrobenzoic acid

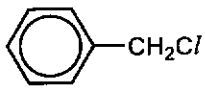
Which reagents could be used for the three-stage process?

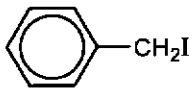
	first stage	second stage	third stage
A	CH_3Cl, $AlCl_3$	HNO_3(aq)	$KMnO_4$, dilute H_2SO_4, heat under reflux
B	conc HNO_3, conc H_2SO_4	CH_3Cl, $AlCl_3$	$KMnO_4$, dilute H_2SO_4, heat under reflux
C	CH_3Cl, $AlCl_3$	conc HNO_3, conc H_2SO_4	$KMnO_4$, dilute H_2SO_4, heat under reflux
D	CH_3Cl, $AlCl_3$	$KMnO_4$, dilute H_2SO_4, heat under reflux	conc HNO_3, conc H_2SO_4

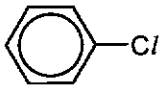
20 Compound **X** is boiled with aqueous sodium hydroxide, cooled and then acidified with dilute nitric acid. Aqueous silver nitrate was subsequently added to the mixture.

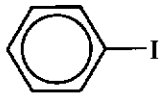
It was observed that a precipitate, which formed when aqueous silver nitrate was added, dissolved upon the addition of aqueous ammonia to the mixture.

What could be the structure of **X**?

A 

C 

B 

D 

21 The mechanism for the reaction between ethanal and hydrogen cyanide is given below.

step 1: $CH_3CHO + CN^- \rightarrow CH_3CHOCN^-$

step 2: $CH_3CHOCN^- + HCN \rightarrow CH_3CH(OH)(CN) + CN^-$

Which statement regarding the mechanism and the reaction is correct?

A The negative charge is on the nitrogen atom in the intermediate.

B There is one sp^2 hybridised carbon atom in the intermediate.

C The ethanal behaves as the nucleophile in step 1.

D The mixture does not rotate plane-polarised light after the reaction.

22 An unknown organic compound has the molecular formula $C_5H_{12}O$. It was subjected to the following chemical tests.

test	observations
alkaline aqueous iodine, warm	yellow precipitate is seen
hot acidified $KMnO_4$	purple solution decolourises

Two students saw the tests and each made a comment.

student E The compound is a secondary alcohol.

student F The compound is definitely pentan-2-ol.

Which students are correct?

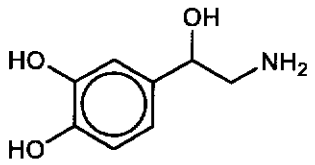
	student E	student F
A	✓	✓
B	✗	✓
C	✓	✗
D	✗	✗

key

✓ = correct

✗ = not correct

23 Noradrenaline functions in the brain as a neurotransmitter.



noradrenaline

How many moles of sodium hydroxide will react with one mole of noradrenaline?

A 1

B 2

C 3

D 4

24 Which statement regarding ethanoic acid is true?

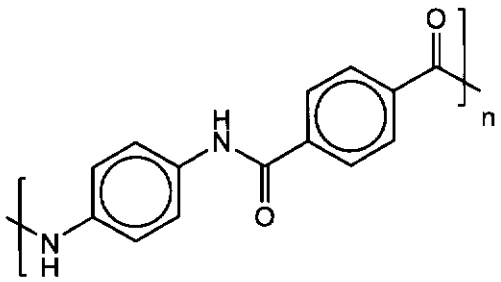
A It reacts with hydrogen chloride to form ethanoyl chloride.

B It can be reduced to ethanol with hydrogen gas in the presence of Pt.

C It does not form a yellow precipitate when warmed with alkaline aqueous iodine.

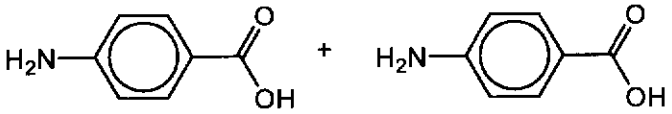
D It reacts with phenol in the presence of concentrated sulfuric acid to form phenyl ethanoate.

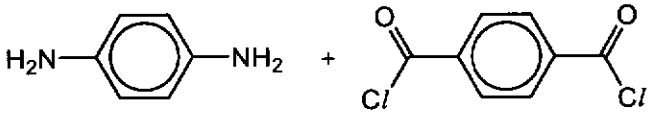
25 Kevlar is a lightweight and strong material, used to make tyres and bulletproof vests. Its structure is given below.

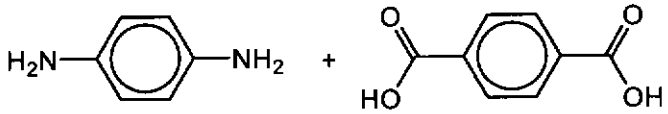


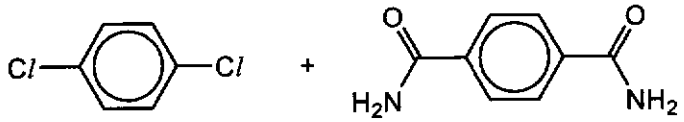
Kevlar

Which pair of monomers produces Kevlar in the greatest yield?

A 

B 

C 

D 

26 A peptide chain isolated from a protein in the medicinal mushroom *Lingzhi* is shown below.

ser-gly-arg-asn-leu-gly-val-lys-pro-ser

The enzyme trypsin will only hydrolyse a polypeptide chain at a peptide bond where the carboxyl group has been donated by either lysine (lys) or arginine (arg).

Which fragments could be made when trypsin acts on the peptide chain from *Lingzhi*?

1 ser-gly-arg

2 lys-pro-ser

3 asn-leu-gly-val-lys

4 arg-asn-leu-gly-val

A 1, 2, 3 and 4

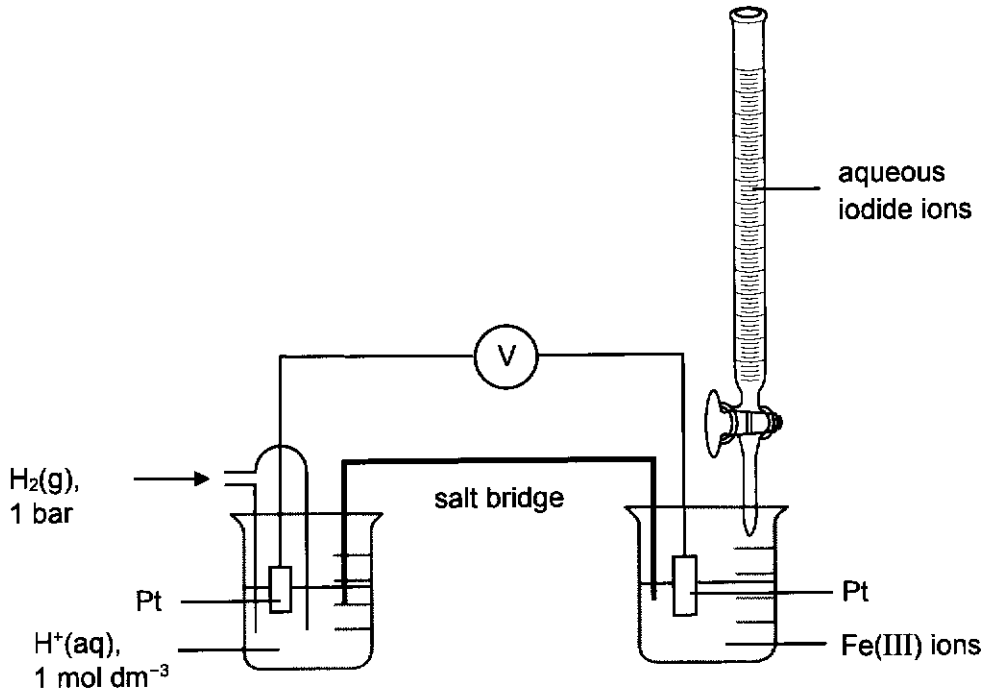
B 1 and 3 only

C 2 and 4 only

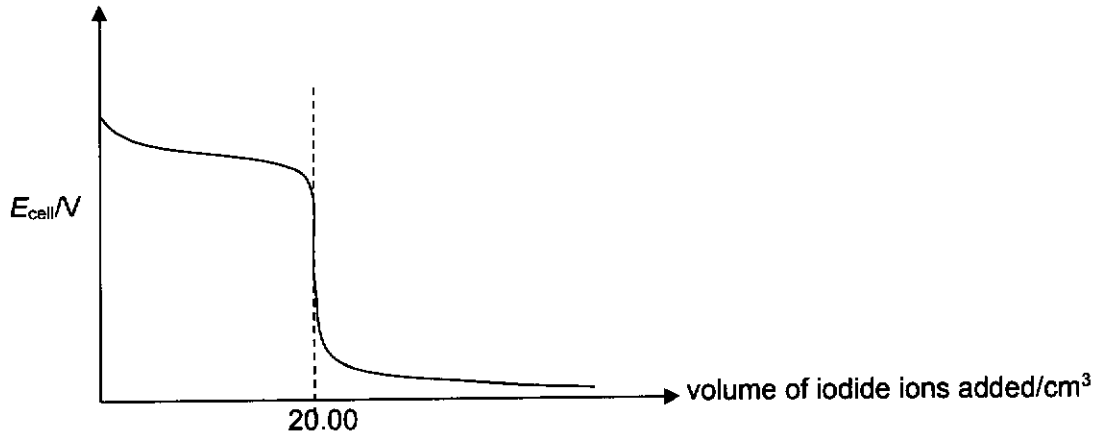
D 2 and 3 only

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

Aqueous iodide ions were added to an aqueous solution containing 50 cm^3 of iron(III) ions as shown below.



The titration curve obtained is shown below.



What is the volume of iodide ions added for the E_{cell} value to be +0.77 V?

A 0.00 cm^3 **B** 10.00 cm^3

C 20.00 cm^3 **D** 40.00 cm^3

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

By considering $E^{\ominus}$ values, which aqueous species will oxidise Sn^{2+} to Sn^{4+}?

1 H_2O_2, H^+

2 I_2

3 V^{3+}

A 1, 2 and 3 only

B 1 and 2 only

C 2 and 3 only

D 1 only

29 A complex of chromium with the general formula $CrCl_3 \cdot 6H_2O$ forms an aqueous solution.

When 0.01 mol of an aqueous solution of this compound was treated with an excess of aqueous silver nitrate, 2.87 g of precipitate was obtained.

What is the formula of the chromium complex?

A $[Cr(H_2O)_6]^{3+}$

B $[Cr(H_2O)_5Cl]^{2+}$

C $[Cr(H_2O)_4Cl_2]^{+}$

D $[Cr(H_2O)_3Cl_3]$

30 A student carried out two experiments on separate samples of aqueous $CuSO_4$.

Experiment 1

When aqueous potassium iodide was added to a sample of aqueous $CuSO_4$, a white precipitate in a brown solution was formed.

Experiment 2

When aqueous ammonia is added to another sample of aqueous $CuSO_4$, a pale blue precipitate is formed. The precipitate dissolves when an excess of aqueous ammonia is added, forming a deep blue solution.

Which statement about experiments 1 and 2 is **incorrect**?

A Ligand exchange occurred in experiment 2.

B The pale blue precipitate is $[Cu(OH)_2(H_2O)_4]$.

C Reduction of copper(II) ions occurred in experiment 1.

D The complex ion in the deep blue solution has a tetrahedral shape.

-End of paper-

Anglo-Chinese Junior College

JC2 Preliminary Examination
Higher 2

A Methodist Institution
(Founded 1886)

CANDIDATE NAME		FORM CLASS	
TUTORIAL CLASS		INDEX NUMBER	

CHEMISTRY
Paper 2 Structured Questions

9729/02
21 August 2024
2 hours

Candidates answer on the Question Paper.

Additional materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your form class, index number and name in the spaces provided at the top of this page.
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.

A Data Booklet is provided.

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

For Examiner's Use	
Question no.	**Marks**
1	**/ 12**
2	**/ 11**
3	**/ 10**
4	**/ 10**
5	**/ 10**
6	**/ 22**
Presentation of answers	
TOTAL	**/ 75**

Section B: Structured Questions (75 marks)

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

1 **Y** and **Z** are two elements found in Period 3. Their fifth to eighth ionisation energies are given in Table 1.1.

Table 1.1

successive ionisation energies / kJ mol^{-1}	5th	6th	7th	8th
Y	6530	9353	11019	33606
Z	7004	8496	27107	31719

(a) (i) State and explain the group number of **Y**.

.....

.....

.....

.....[1]

(ii) Complete the electronic configurations of Y^+ and Z^+.

Y^+ $1s^2$.....

Z^+ $1s^2$.....[1]

(iii) From your answer in **(a)(ii)**, explain why the second ionisation energy of **Y** is expected to be lower than **Z**.

.....

.....

.....[1]

(iv) However, it turns out that the second ionisation energies of **Y** and **Z** are 2300 kJ mol^{-1} and 2260 kJ mol^{-1} respectively.
Suggest why **Y** has a higher second ionisation energy than **Z**.

.....

.....[1]

(b) (i) The atomic radii of some Period 4 elements are shown in Fig. 1.1.

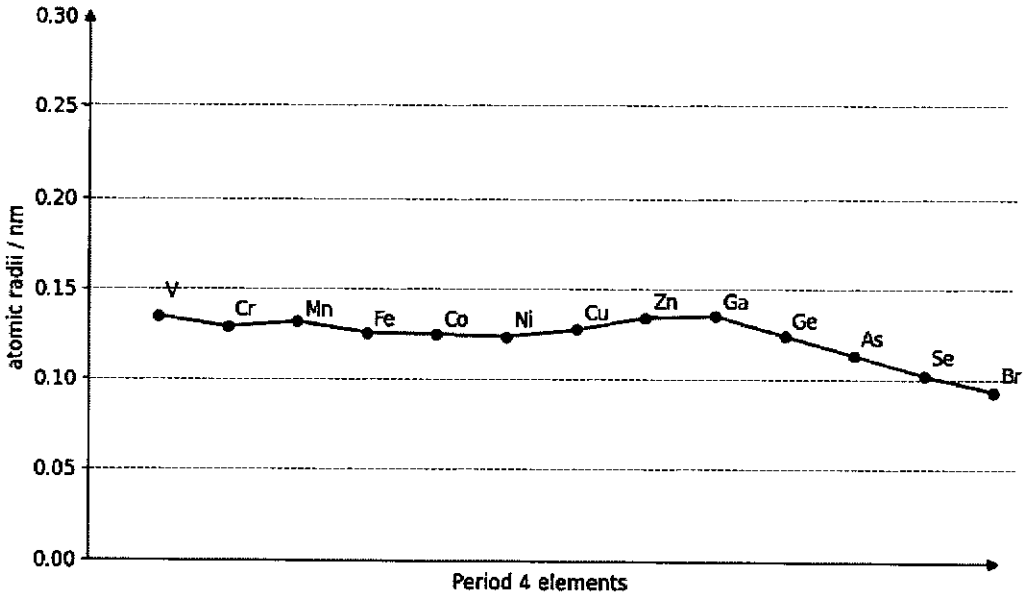


Fig. 1.1

With reference to Fig. 1.1, describe and explain the shape of the graph from

- V to Zn
- Ga to Br

.....

.....

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.....

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.....

.....

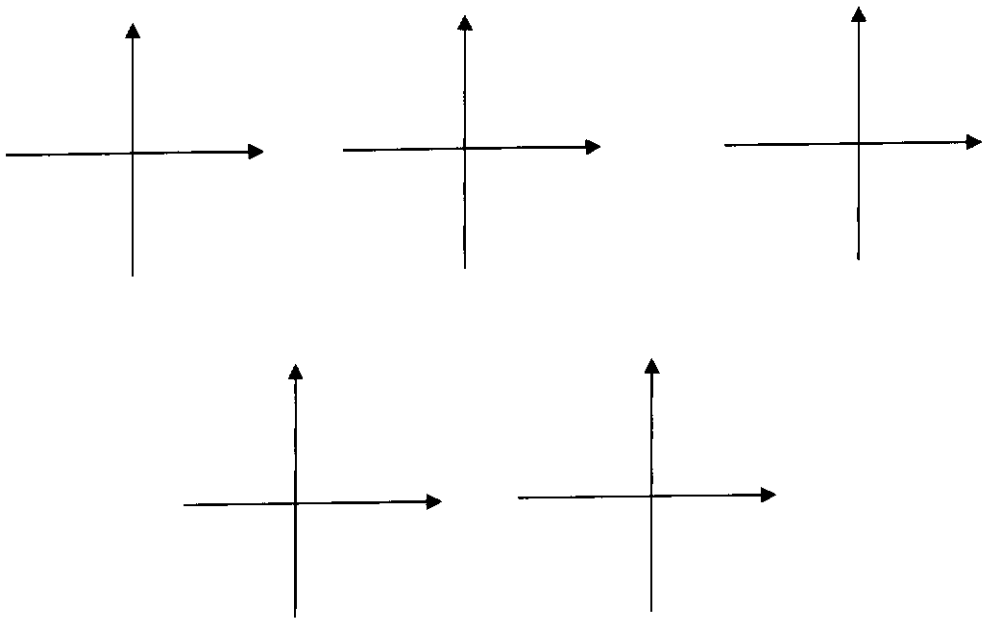
.....

.....[4]

(ii) With reference to the *Data Booklet* or otherwise, on Fig. 1.1, sketch the ionic radii of the Period 4 elements.

You may assume that V to Zn form doubly charged cations. [2]

(c) Draw and label the d orbitals in cobalt ion.



[2]

[Total: 12]

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2 The hydroboration-oxidation reaction of an alkene bond using borane, BH_3, provides a useful method for hydration. Using this reaction, 1-methylcyclohexene can be converted to trans-2-methylcyclohexanol as shown in Fig. 2.1.

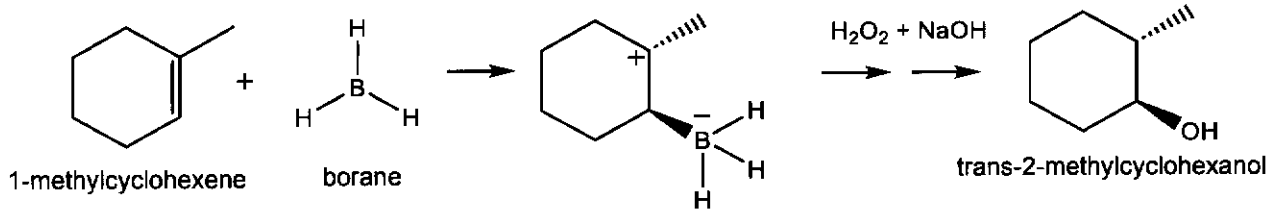

Fig. 2.1

(a) (i) Explain the role of borane in Fig. 2.1.

.....

.....

.....[1]

(ii) Suggest why the *trans* configuration is favoured in the product formed in Fig. 2.1.

.....

.....

.....[1]

(b) Suggest a chemical test that would allow you to distinguish between 2-methylcyclohexanol and ethanol. Include a relevant equation in your answer.

.....

.....

.....

.....[2]

(c) Borane dimerises to form the more stable diborane, B_2H_6, shown in Fig. 2.2.

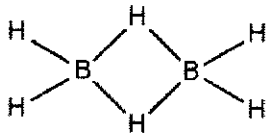

Fig. 2.2

(i) Suggest **two** unusual features about the bonding shown in Fig. 2.2.

.....

.....

.....

.....[2]

(ii) Fig. 2.3 depicts another equivalent representation of the bonding in diborane. The bridging B-H-B bonds are curved, giving them the name 'banana bonds'.

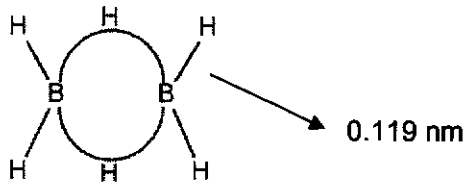

Fig. 2.3

The 'banana bonds' consist of three-centre-two-electron bonds, which are electron-deficient chemical bonds where three atoms share two electrons.

State the total number of bonding electrons in diborane.

.....[1]

(iii) The B–H bonds in diborane have different bond lengths. The terminal B–H bonds are 0.119 nm in length.

Explain how the bond length of the bridging B–H bonds compares with the terminal B–H bonds.

Note: Fig. 2.3 is not drawn to scale.

.....

.....

.....[1]

(d) 1-methylcyclohexene can react with iodine monochloride, IC*l*.

Name and describe the mechanism of this reaction, showing curly arrows, charges, dipoles and any relevant lone pairs.

[3]

[Total: 11]

3 Cyanogen chloride, C*l*CN, exists as a highly toxic gas and reacts rapidly with hydroxide ions.

equation 1 $ClCN + OH^- \rightarrow HOCN + Cl^-$

(a) (i) State the hybridisation of the carbon atom in cyanogen chloride.

.....[1]

(ii) Name the *type of reaction* occurring in equation 1.

.....[1]

(b) (i) 0.06 g of cyanogen chloride was fully dissolved in 100 cm^3 of 2 mol dm^{-3} aqueous sodium hydroxide.

The rate constant, k, for the reaction is 4.2 $mol^{-1}\,dm^3\,s^{-1}$.

Construct the rate equation for equation 1.

.....[1]

(ii) Calculate the concentration of cyanogen chloride in the solution.

[1]

(iii) Using your answer in **(b)(ii)** and the information in **(b)(i)**, deduce the half-life of the reaction.

[1]

(c) (i) In a separate experiment, 0.15 g of gaseous cyanogen chloride was found to occupy a volume of 72.3 cm^3 at 127 °C and a pressure of 102.7 kPa.

Calculate the relative molecular mass of cyanogen chloride using the experimental data.

[1]

(ii) Pure cyanogen chloride was used in the experiment.

Suggest why there is a difference between the theoretical value of its relative molecular mass and the value obtained in **(c)(i)**.

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.....[2]

(d) Cyanogen chloride can react with sulfinic acids to form sulfonyl cyanides.

An example of a sulfinic acid is shown in Fig. 3.1.

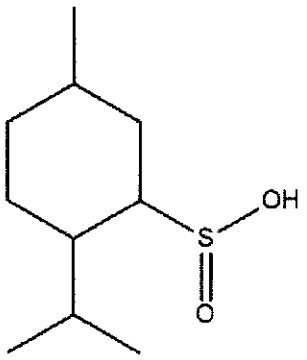

Fig. 3.1

Chiral centres have four different substituent groups bonded to it. The lone pair of electrons on atoms can also be considered a distinct group.

Identify the chiral carbons of sulfinic acid shown on Fig. 3.1 by marking them with an asterisk (*). [1]

(e) Cyanogen chloride can trimerise to form a 6-membered cyclic molecule with molecular formula, $(ClCN)_3$. This molecule has no overall dipole moment.

Suggest a possible structure of the trimer.

[1]

[Total: 10]

4 Pyrite, FeS_2, is often referred to as "Fool's Gold" because it resembles gold to the untrained eye. It is one of the most abundant sulfide mineral available.

Table 4.1 shows some physical properties of pyrite and gold against other substances.

Table 4.1

compound	gold	FeS_2 (pyrite)	steel
melting point / °C	1064	1177	1425
Mohs hardness	2.5	6.3	6.5
density / g cm^{-3}	19.0	5.0	7.9

(a) (i) Explain the high melting points of gold and pyrite.

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.....[2]

(ii) Mohs Hardness Scale is a measure of a substance's resistance to scratching. The substance's hardness is measured against another substance of known hardness on the Mohs Hardness Scale. A substance can only scratch a substance of equal or lower Mohs hardness value.

Suggest a simple way to distinguish between gold and pyrite.

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.....[1]

(iii) Pyrite and steel have similar values on the Mohs Hardness Scale that are relatively higher than that of metals. Explain this phenomenon, making reference to their lattice structure.

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.....[2]

(b) Due to its shiny and gold-like appearance, pyrite is widely used in decorative items. However, over time, items with pyrite were found to be cracked and discoloured. When exposed to air and moisture, the iron-containing mineral can form rust, Fe_2O_3, along with a toxic gas, SO_2, and corrosive acid.

(i) Construct a balanced equation of the formation of rust from pyrite.

.....[1]

(ii) Draw the 'dot-and-cross' diagram of the disulfide ion, S_2^{2-}.

[1]

(c) Iron(II) compounds are generally only stable in neutral, non-oxidising conditions. It is difficult to determine the lattice energy of FeS_2 experimentally.

Table 4.2

	value / kJ mol^{-1}
standard enthalpy change of formation of $FeS_2(s)$	–178
standard enthalpy change of atomisation of Fe(s)	+347
standard enthalpy change of atomisation of S(s)	+279
$2S(g) + 2e^- \rightarrow S_2^{2-}(g)$	–512

Use the data given in Table 4.2, together with data from the *Data Booklet* to calculate the lattice energy of FeS_2.

Show your working.

[3]

[Total: 10]

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5 2–(2–chloroethyl)phenol can be used in a synthesis pathway shown in Fig. 5.1.

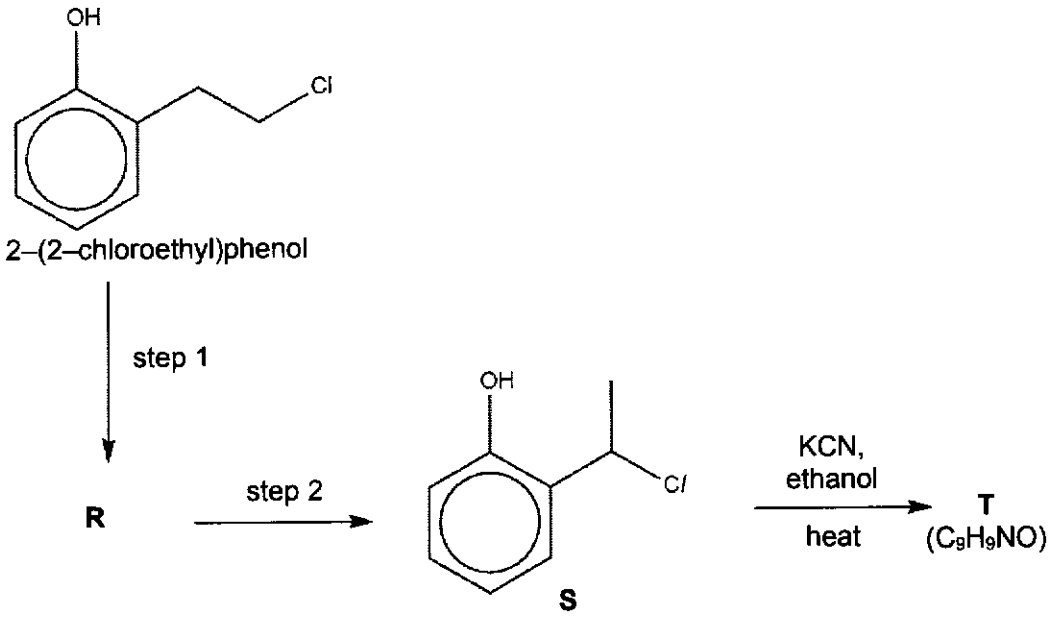


Fig. 5.1

1 mol of compound **R** reacts with 3 mol of aqueous Br_2 to give a white precipitate.

(a) **(i)** Suggest what this observation indicate about the functional groups in **R**.

.....

.....[1]

(ii) Describe the reagents and conditions needed for steps 1 and 2.

Step 1: .....

Step 2: .....[2]

(iii) Suggest the structures of **R** and **T**.

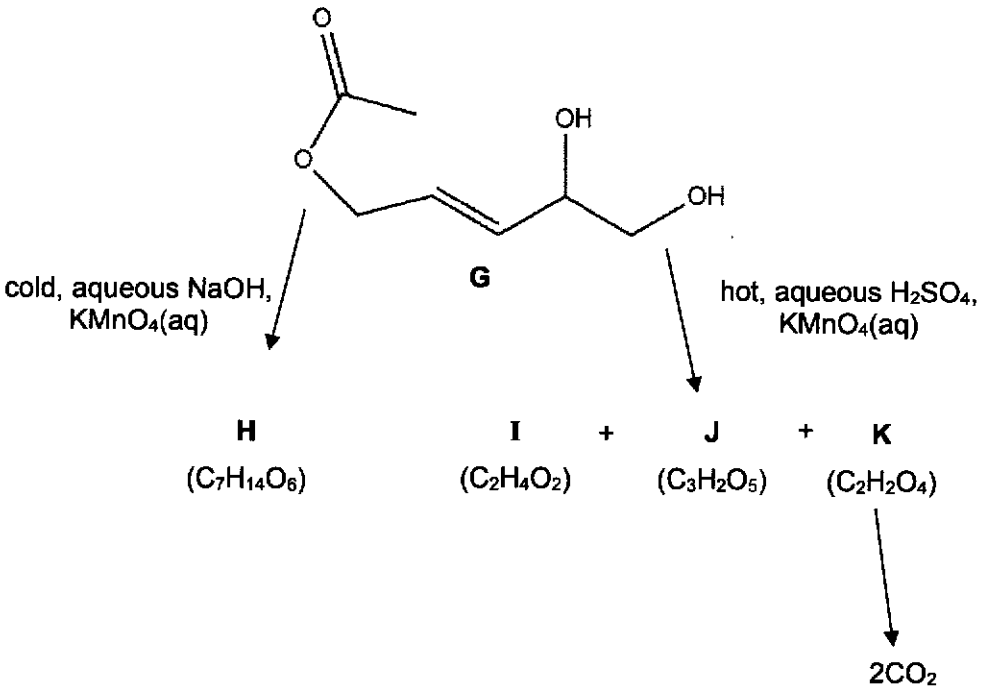
[2]

(iv) Describe the relationship between 2-(2-chloroethyl)phenol and compound **S**.

.....[1]

(b) Hot, concentrated potassium manganate(VII) oxidises several classes of organic compounds to ketones, carboxylic acids or carbon dioxide. By this means, the structures of compounds can be determined. Some compounds are easily oxidised, while others require longer heating.

Compound **G** can be oxidised by $KMnO_4$ under different conditions to give various products.



Suggest the structures of the compounds **H**, **I**, **J** and **K**.

[4]

[Total: 10]

6 The salinity of seawater is due to the many dissolved molecules and ions present in it. Table 6.1 shows some significant species present in seawater, some of which play a role in maintaining the pH of seawater.

Table 6.1

species	concentration in parts per million (ppm)
Cl^-	19300
Na^+	10800
Ca^{2+}	420
HCO_3^-	116
CO_3^{2-}	9.54
$Si(OH)_4$	9.32
CO_2	0.660
$SiO(OH)_3^-$	0.285

The concentration of dissolved species is measured in parts per million. This refers to the mass in grams of the species dissolved in a million grams of water.

Oceans serve as a natural sink for carbon, by absorbing about 30% of carbon dioxide emissions from the atmosphere. The processes, and their associated equations, involved in the absorption of carbon dioxide by seawater are numbered 1 to 4 in Table 6.2.

Table 6.2

process	equation	K_a at 25 °C
1	$CO_2(g) \rightleftharpoons CO_2(aq)$	-
2	$CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$	-
3	$H_2CO_3(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + H_3O^+(aq)$	4.5×10^{-7}
4	$HCO_3^-(aq) + H_2O(l) \rightleftharpoons CO_3^{2-}(aq) + H_3O^+(aq)$	4.7×10^{-11}

Process 3 and 4 represent the first and second acid dissociation constant of carbonic acid respectively.

(a) Some species in Table 6.1 form Brønsted-Lowry conjugate acid-base pairs which are responsible for buffering the pH of seawater.

(i) Identify two Brønsted-Lowry conjugate acid-base pairs in Table 6.1.

conjugate acid-base pair 1: .....

conjugate acid-base pair 2: ..... [1]

(ii) Using one of the conjugate acid-base pairs in **(a)(i)**, write equation(s) to show how the buffer system helps to maintain the pH of seawater.

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..... [1]

(b) The carbon–oxygen bond length in some compounds is given in Table 6.3.

Table 6.3

species containing carbon–oxygen bond	bond length / nm
CH_3OH	0.143
HCHO	0.123
H_2CO_3	0.134

(i) Draw the displayed formula for H_2CO_3.

[1]

(ii) Considering the overlap of atomic orbitals, suggest why all the carbon–oxygen bonds in H_2CO_3 have a bond length that is in between that of CH_3OH and HCHO.

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..... [2]

Process 2 is thought to proceed via the two steps described below.

step 1: Water behaves as nucleophile and attacks a carbon dioxide molecule.

step 2: An intramolecular proton transfer occurs within the intermediate to form carbonic acid.

(iii) Draw a mechanism for process 2. Show relevant curly arrows, dipoles, charges and lone pairs of electrons in your answer.

[2]

(iv) Hence, suggest and explain which step is likely to be the rate determining step in the mechanism of **(b)(iii)**.

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..... [1]

(c) **(i)** Write the K_a expression for process 3.

[1]

(ii) The concentration of CO_2 is assumed as the concentration of H_2CO_3 while the density of water is 1 g cm^{-3}. The pH of seawater is 8.0.

Use this information and that from Table 6.1 to calculate another value for the first acid dissociation of H_2CO_3.

[2]

(iii) Suggest a reason why the K_a value calculated in **(c)(ii)** differs from that in Table 6.2.

.....

..... [1]

Corals are soft bodied organisms that build their skeletons by precipitating calcium carbonate from seawater, allowing for the storage of large amounts of carbon in the corals' skeleton. This is done by bringing seawater into a calcifying space between the existing coral skeleton and the coral body, where protons are pumped out to increase the concentration of carbonate ions. The carbonate ions are then precipitated together with calcium ions as calcium carbonate on the surface of the existing coral skeleton.

With rising carbon dioxide emissions into the atmosphere due to human activities, the pH levels of seawater are decreasing. This has led to an acidification of the oceans and corals find it increasing challenging to build their calcium carbonate skeletons.

(d) State one human activity that is increasing the emission of carbon dioxide into the atmosphere.

..... [1]

(e) The K_{sp} values and relative solubilities of $CaCO_3$, $Ca(OH)_2$ and $Ca(HCO_3)_2$ at 25 °C are given in Table 6.4.

Table 6.4

species	K_{sp} value	solubility
$CaCO_3$	6.0×10^{-9}	sparingly soluble
$Ca(OH)_2$	5.02×10^{-6}	sparingly soluble
$Ca(HCO_3)_2$	–	soluble

When carbon dioxide is bubbled into a saturated solution of calcium hydroxide, a white precipitate is observed.

(i) Write the K_{sp} expression for calcium hydroxide and state its units.

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..... [1]

(ii) Calculate the concentration, in mol dm^{-3}, of $Ca^{2+}(aq)$ in a saturated solution of calcium hydroxide.

[1]

(iii) Calculate the concentration of $CO_3^{2-}(aq)$ present in solution when calcium carbonate begins to precipitate.

[1]

(iv) The following reaction occurs when carbon dioxide is continuously bubbled through a saturated solution of calcium hydroxide.

$$H_2CO_3 + CO_3^{2-} \rightleftharpoons 2HCO_3^-$$

Use information from Table 6.2 to calculate a value for K_c and state what the K_c value indicates about the position of equilibrium.

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..... [1]

(v) Using the equation provided in **(e)(iv)** and information from Table 6.4, predict and explain the likely observations made when carbon dioxide is continuously bubbled through a saturated solution of calcium hydroxide.

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..... [2]

(vi) Using the equation provided in **(e)(iv)** and your answer in **(e)(v)**, describe how the increasing carbon dioxide emissions in the atmosphere makes it challenging for corals to build their calcium carbonate skeleton.

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..... [1]

(f) Aragonite and calcite are two different solid forms of calcium carbonate that can be precipitated by corals.

Some information about these two forms of calcium carbonate is provided below.

Table 6.5

form of calcium carbonate	$\Delta H_f^{\ominus}$ / kJ mol^{-1}	$\Delta S_f^{\ominus}$ / J mol^{-1} K^{-1}
aragonite	−1207.8	+88.0
calcite	−1207.6	+91.7

The entropy change, $\Delta S_{rxn}^{\ominus}$, of a reaction, can be determined using the following formula:

$$\Delta S_{rxn}^{\ominus} = \sum m\Delta S_f^{\ominus}(\text{products}) - \sum n\Delta S_f^{\ominus}(\text{reactants})$$

where m and n are the coefficients of the products and reactants in the balanced equation.

Use information from Table 6.5 to show that the conversion of aragonite to calcite is a spontaneous process under standard conditions.

$$CaCO_3\ (\text{aragonite}) \rightarrow CaCO_3\ (\text{calcite})$$

[2]

[Total: 22]

End of Paper

Anglo-Chinese Junior College

JC2 Preliminary Examination
Higher 2

A Methodist Institution
(Founded 1886)

CANDIDATE NAME			FORM CLASS	2		
TUTORIAL CLASS	2CH		INDEX NUMBER			

CHEMISTRY

Paper 3 Free Response

9729/03
27 August 2024
2 hours

Candidates answer on the Question Paper.
Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your index number and name on all the work you hand in.
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. If additional space is required, you should use the pages at the end of this booklet. The question number must be clearly shown.

Section A
Answer **all** questions.

Section B
Answer **one** question.
Circle the number of the question you have attempted.

A Data Booklet is provided.
The use of an approved scientific calculator is expected, where appropriate.

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.

For Examiners' use only	
Section A	
1	**/ 20**
2	**/ 20**
3	**/ 20**
Section B	
4 / 5	**/ 20**
Presentation	
Total	**/ 80**

Section A

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

1 **(a)** Describe the variation in the behaviour of Period 3 chlorides NaCl, $AlCl_3$ and PCl_5 separately with water.

Write equations for any reactions described and state the pH of the resultant solutions. [3]

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(b) When soil becomes acidic, aluminium leeches out of minerals into the soil. High aluminium content in soil affects root growth and causes the roots to be brittle. These problems are minimised if the topsoil pH is maintained above 5.5.

In a study of a soil condition, a sample of soil water was titrated with $EDTA^{4-}$, a hexadentate ligand, to determine its aluminium ion concentration.

equation 1 $\quad [Al(H_2O)_6]^{3+}(aq) + EDTA^{4-}(aq) \rightleftharpoons [Al(EDTA)]^{-}(aq) + 6H_2O(l)$

(i) State the type of reaction in equation 1. [1]

(ii) The concentration of aluminium ions in the soil water sample was found to be 2.90×10^{-5} mol dm^{-3}. Calculate the pH of the water sample, given that the aqueous complex of Al^{3+} has a K_a value of 7.9×10^{-6}.

You may assume that the complex of Al^{3+} behaves as a weak monobasic acid, HA. [1]

(iii) Another 25 cm^3 sample of soil water was found to contain 0.250 mol dm^{-3} of NaH_2PO_4. 20 cm^3 of solution **A** which contains aqueous Na_2HPO_4 was added to the water sample to obtain a solution buffered at pH 6.8.

Calculate the concentration of HPO_4^{2-} in solution **A**, given that the pK_a value of $H_2PO_4^-$ is 7.2. [3]

(c) The reactions of ethylbenzene to form **H**, **J** and **K** are shown in Fig.1.1.

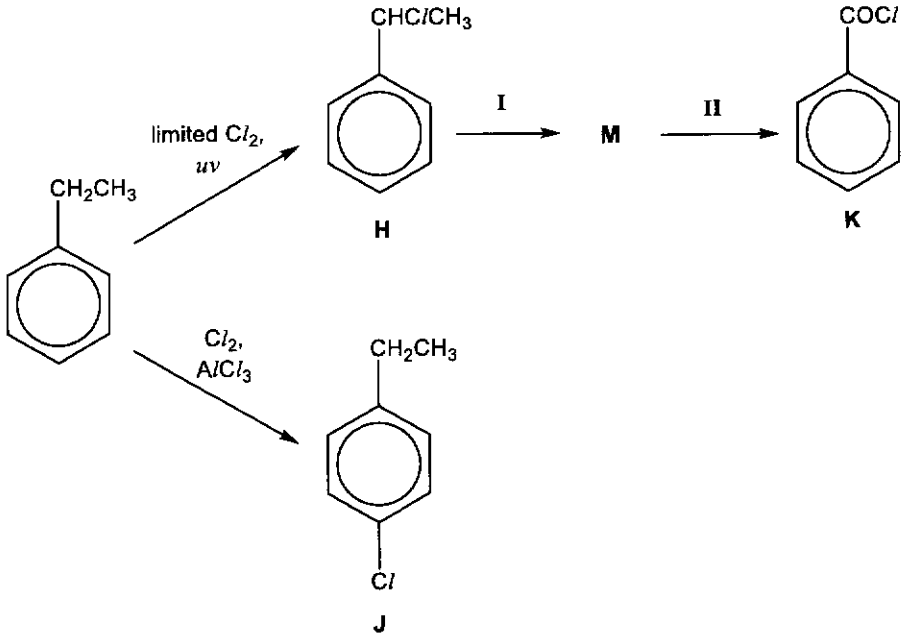

Fig. 1.1

(i) Suggest the reagents and conditions needed for reactions **I** and **II** and suggest the structure of **M** in Fig. 1.1. [3]

(ii) Describe and explain the relative ease of hydrolysis of **H**, **J** and **K**. [3]

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(d) Graphene is a nanomaterial comprising of a single layer of graphite. Compared with copper, it has higher tensile strength and similar electrical conductivity while having lower mass. An experiment was conducted to electroplate copper onto graphene.

In the experiment, a copper anode and graphene cathode was immersed in aqueous copper(II) sulfate as the electrolyte.

(i) Describe the observations at the cathode and the electrolyte after some time. [1]

(ii) The graphene at the cathode is a square with a length of 0.1 m.

Assume that each copper occupies a cube length of 3.0×10^{-12} m, the graphene has no thickness and there is uniform plating of copper.

Calculate

1. the amount of Cu atoms to cover **both** sides of the graphene with a depth of 500 atoms
2. the time required to achieve this using a current of 5.0 A. [3]

(iii) The student replicated this experiment to electroplate graphene with Al. He replaced aqueous $CuSO_4$ with aqueous $Al(NO_3)_3$ and the copper plate with an aluminium plate.

Using $E^\ominus$ values from the *Data Booklet*, suggest if this experiment will be successful. [2]

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[Total: 20]

2 The oxime functional group R–C=N–OH undergoes a rearrangement reaction to form amide in the presence of aluminium oxide. During the reaction, the alkyl group that is trans to the OH group migrates to the N atom. Fig. 2.1 shows an example of this rearrangement.

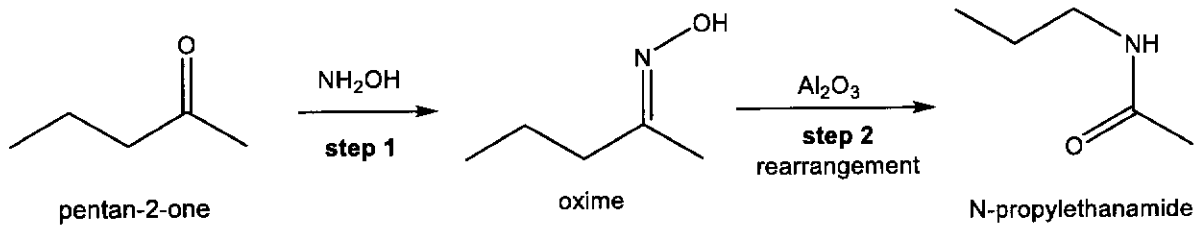

Fig. 2.1

(a) **(i)** Write a balanced equation for step 1 and suggest the type of reaction that occurred. [2]

(ii) A molecule of oxime contains both σ and π bonds.

Draw labelled diagrams to show how orbitals of the C atom and N atom overlap to form

- a σ bond
- a π bond [2]

(iii) Oximes may exist as cis-trans isomers. State and explain the feature of the oxime molecule which allows them to show cis-trans isomerism. [1]

(iv) Suggest a simple chemical test to distinguish pentan-2-one and N-propylethanamide shown in Fig. 2.1. [2]

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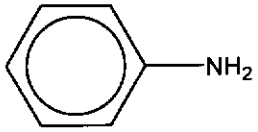
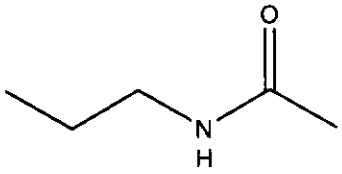
(b) The pK_b values of three nitrogen containing compounds are given in Table 2.1.

Table 2.1

name	structure	pK_b
phenylamine		9.4
ethylamine	$CH_3CH_2NH_2$	3.4
N-propylethanamide		14.4

Rank the compounds in order of increasing basicity and explain your reasoning. [3]

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(c) Zwitterion **A** $C_5H_9NO_2$ reacts with hot acidified potassium manganate(VII) to form compound **B** $C_3H_7NO_2$ and compound **C**, $C_2H_2O_4$. Compound **C** further oxidises to form a gas that forms white precipitate in limewater. **B** does not rotate plane polarised light.

Compound **A** also reacts with $SOCl_2$ to form **D** C_5H_8NOCl which further reacts to form a neutral compound **E** C_5H_7NO.

E is also formed when the oxime **F** C_5H_7NO reacts in the presence of aluminium oxide.

(i) Describe the formation of a *zwitterion*. [1]

(ii) Suggest possible structures for **A**, **B**, **C**, **D**, **E** and **F**. For each reaction, state the type of reaction described and explain what the information tells you about the functional groups present in each compound. [9]

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[Total: 20]

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3 (a) (i) Using relevant $E^{\ominus}$ values from the *Data Booklet*, describe the trend in reactivity of Group 2 metals as reducing agents. [2]

(ii) Using the *Data Booklet* or otherwise, explain another property of Group 2 metals that supports this trend. [2]

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(b) Thermogravimetric analysis, TGA, is an analytical technique primarily used to characterise materials by measuring the change in mass that occurs as a sample is heated at a constant rate.

A thermogram from the TGA of calcium carbonate and magnesium carbonate is shown in Fig. 3.1.

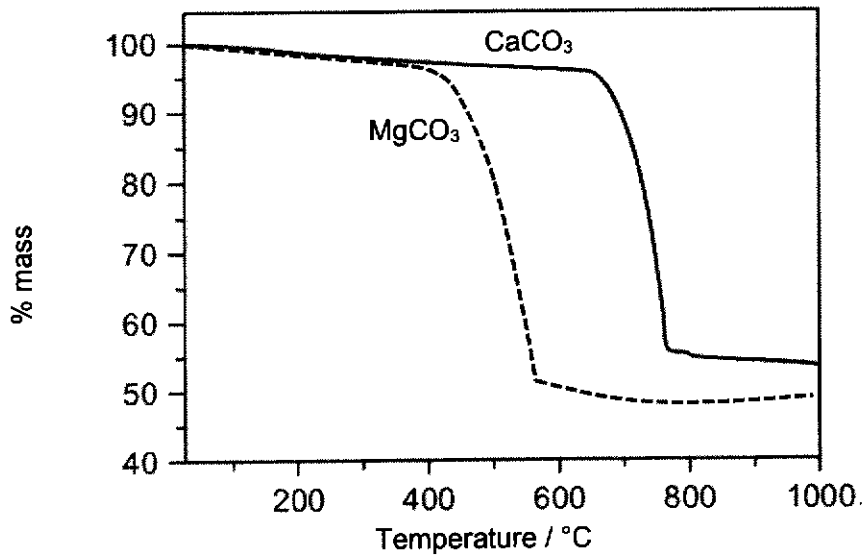

Fig. 3.1

(i) For both samples, the thermogram shows significant loss in mass when the temperature is high enough.

Write an equation for the heating of calcium carbonate at about 800 °C. [1]

(ii) With reference to your equation in **(b)(i)**, explain the differences between the thermogram of calcium carbonate and magnesium carbonate in terms of

- the temperature when the carbonate starts to have significant decrease in mass,
- the final mass of product obtained, given that the same initial mass is used for both carbonates. [4]

(iii) Explain the difference in melting points of calcium carbonate and magnesium carbonate in terms of structure and bonding. [2]

(c) (i) Explain what is meant by the term *standard enthalpy change of combustion.* [1]

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A bomb calorimeter consists of a thermally-insulated sealed metal container immersed in water. A sample of calcium is placed into the metal container, after which the container is filled with high pressure of excess oxygen. The sample is then ignited and the temperature change in the surrounding water is recorded.

Some data is recorded in Table 3.1.

Table 3.1

mass of calcium / g	1.41
mass of water / g	150
temperature of water before ignition / °C	28.6
temperature of water after ignition / °C	56.0
heat capacity of calorimeter, C_p / J K^{-1}	191
specific heat capacity of water, c / J g^{-1} K^{-1}	4.18

(ii) The heat released, q, can be found using the following relationship.

$$q = (C_p + mc)\,\Delta T$$

Together with the information in Table 3.1, calculate the enthalpy change of combustion of calcium. [2]

(iii) The experiment was repeated with 1 bar of oxygen gas. The value of the enthalpy change of combustion obtained was smaller than that in **(c)(ii)**.

Suggest a reason for the discrepancy. [1]

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(d) The decarboxylation of carboxylic acids to obtain alkenes can be achieved in a series of steps.

The overall balanced equation of the reaction process is shown.

$$R\text{–}COOH + Pb(CH_3CO_2)_4 \xrightarrow{Cu(CH_3CO_2)_2} \text{alkene} + CO_2 + 2CH_3COOH + Pb(CH_3CO_2)_2$$

The process of decarboxylation of butanoic acid, $CH_3CH_2CH_2COOH$, with lead tetraethanoate, $Pb(CH_3CO_2)_4$ in the presence of catalytic amounts of $Cu(CH_3CO_2)_2$ is shown in Fig. 3.2.

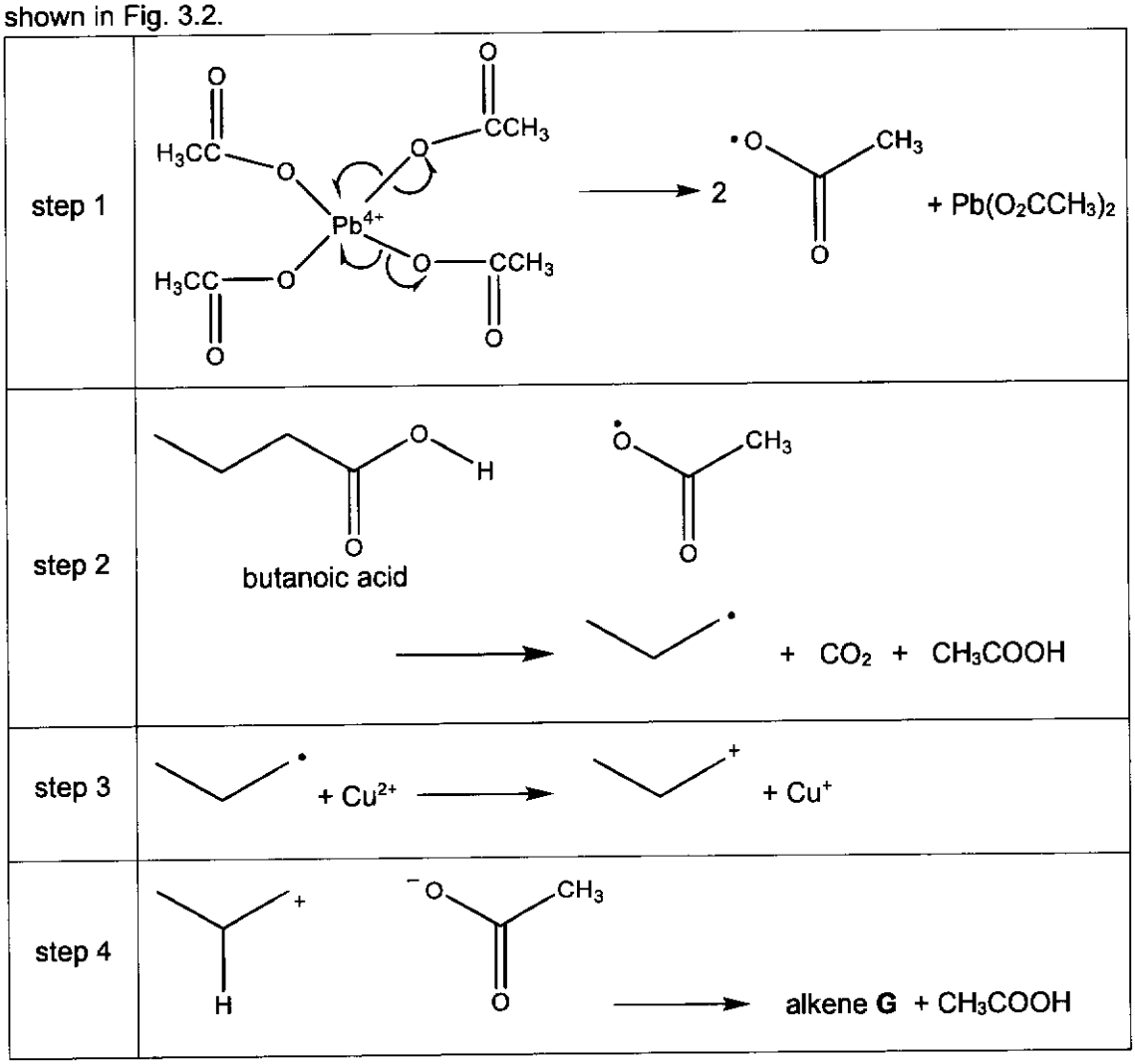

Fig. 3.2

(i) Steps 1 and 2 of the decarboxylation process involve the generation of free radicals. The mechanism of step 1 has been drawn in Fig. 3.2. Complete the mechanism on step 2 on Fig. 3.2 by adding **five** half arrows. [1]

(ii) Complete the mechanism of step 4 on Fig. 3.2 by adding **two** full arrows, hence deduce the structure of **G**. [2]

(iii) Name the types of reaction for steps 3 and 4. [2]

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[Total: 20]

Section B

Answer **one** question from this section.

4 (a) The zinc-air battery involves a porous zinc electrode that reacts to form zincate, $Zn(OH)_4^{2-}$.

$$Zn(OH)_4^{2-}(aq) + 2e^- \rightleftharpoons Zn(s) + 4OH^-(aq) \qquad E^\ominus = -1.25\ V$$

The other electrode in the battery is the oxygen electrode in an alkaline medium.

(i) Draw a fully labelled diagram of the experimental set-up used to measure this $E^\ominus_{cell}$ and indicate the direction of electron flow. [3]

(ii) Calculate the standard Gibbs free energy change, $\Delta G^\ominus$, for the oxidation of one mole of zinc in the zinc-air battery. [2]

(iii) Predict how the E_{cell} will change when water is added into the $Zn(OH)_4^{2-}/Zn$ half-cell. [2]

(iv) The zinc-air battery can be recharged and is relatively cheaper to produce.

Suggest one **other** advantage of using the zinc-air battery. [1]

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(b) (i) In the Contact Process, vanadium oxide catalyses the formation of sulfur trioxide, which is eventually converted to sulfuric acid through further reactions.

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

State the type of catalyst in this reaction and describe how vanadium oxide speeds up this gaseous reaction. [3]

(ii) In aqueous solution, vanadium ions form complexes of which the colours are lilac $[V(H_2O)_6]^{2+}$, green $[V(H_2O)_6]^{3+}$ and blue $[VO(H_2O)_5]^{2+}$.

Explain why vanadium ions are often coloured in aqueous solutions. [3]

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(c) In the nitration of benzene, sulfuric acid and nitric acid are used to generate the highly reactive nitronium ion.

Fig. 4.1 shows the incomplete mechanism for the formation of the nitronium ion.

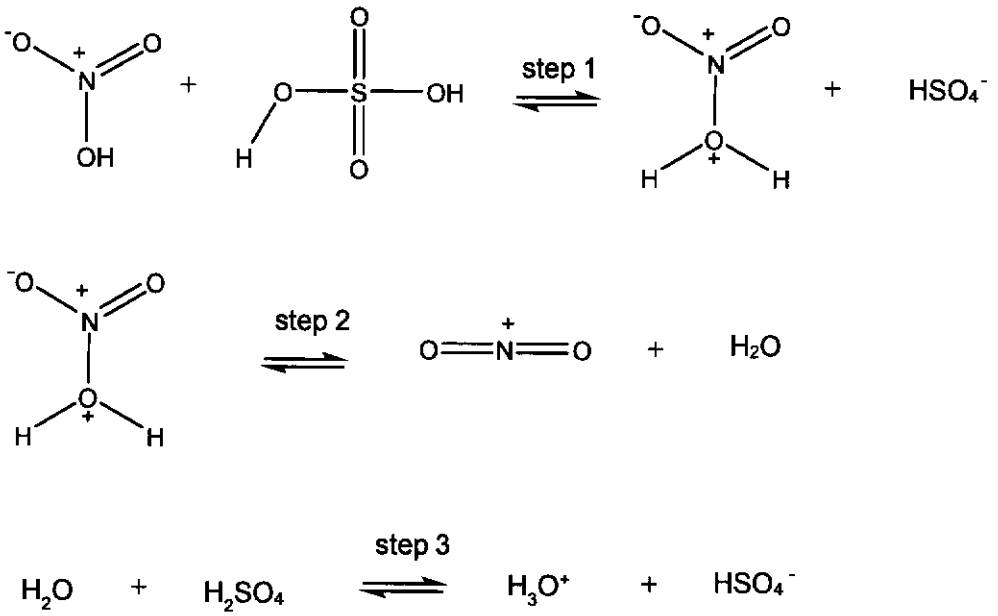

Fig. 4.1

(i) On Fig. 4.1, draw curly arrows, partial charges and insert relevant lone pairs in steps 1 and 2 to complete the mechanism for the formation of the nitronium ion. [2]

(ii) State the role of sulfuric acid in step 1. [1]

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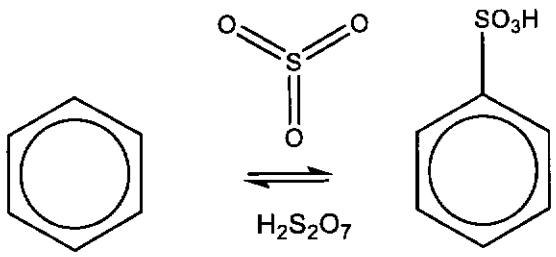
(d) (i) Benzene can also undergo electrophilic substitution with sulfur trioxide in the presence of fuming sulfuric acid.



Explain why sulfur trioxide can act as an electrophile. [1]

(ii) Suggest a mechanism for the reaction between benzene and sulfur trioxide. Show the displayed structure of the electrophile, the structure of the intermediate and the movement of electron pairs by using curly arrows. [2]

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5 The "OXO" reaction is industrially important in making aldehydes and ketones from alkenes. For example, propanal can be synthesised from ethene, C_2H_4, as shown in the following equation.

$$CH_2{=}CH_2(g) + CO(g) + H_2(g) \rightleftharpoons CH_3CH_2CHO(g) \qquad \Delta H < 0$$

(a) In an experiment, an equimolar mixture of C_2H_4, CO and H_2 is added to a sealed vessel and heated to 500 K in the presence of rhodium catalyst. At equilibrium, 99% of C_2H_4 has reacted. The total pressure in the vessel is 40.8 atm at equilibrium.

(i) Write the expression for the equilibrium constant, K_p, for this reaction. Use your expression to calculate the value of K_p for this reaction. Include its units. [4]

(ii) The actual conditions used for the manufacturing of propanal in the OXO process is 480 K and 100 atm in the presence of a rhodium based catalyst.

Explain the conditions used for the manufacture of propanal. [2]

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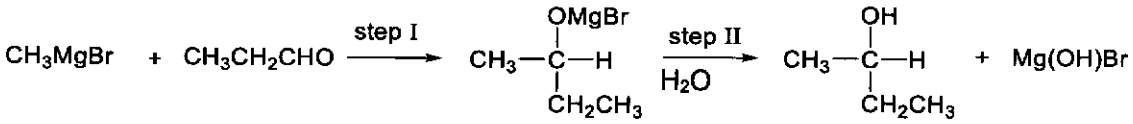
(b) The Grignard reagent is a class of covalent compounds involving magnesium. One example of a Grignard reagent is CH_3MgBr which is prepared by treating magnesium metal with bromomethane in an ether solvent.

A typical example of the use of a Grignard reagent is the two-step reaction of CH_3MgBr with propanal, CH_3CH_2CHO, to form butan-2-ol.



(i) State the types of reaction for steps I and II. [2]

(ii) State the reagents and conditions to convert butan-2-ol to 2-bromobutane. [1]

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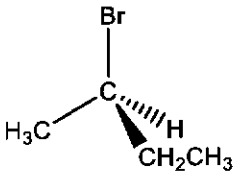
"R" and "S" are used to denote enantiomers. R and S isomers rotate plane polarised light in opposite directions.

The R isomer of $CH_3CH_2CHBrCH_3$ is shown below.

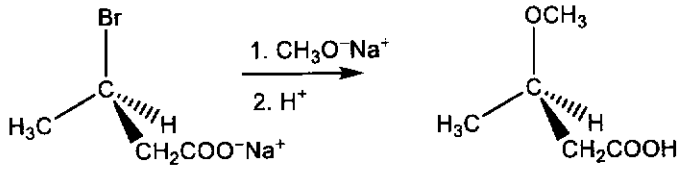


When a sample of the R isomer of $CH_3CH_2CHBrCH_3$ is heated with $CH_3O^-Na^+$ in methanol, the S isomer of $CH_3CH_2CH(OCH_3)CH_3$ is obtained.

(iii) Name and draw the reaction mechanism for this reaction using the given structure of the R isomer of $CH_3CH_2CHBrCH_3$. Show relevant lone pairs of electrons, dipoles and curly arrows. [3]

(iv) In the presence of $CH_3O^-Na^+$, the R isomer of 3-bromobutanoic acid, $CH_3CH(Br)CH_2COOH$ is converted to $CH_3CH(Br)CH_2COO^-Na^+$.

When the R isomer of $CH_3CH(Br)CH_2COO^-Na^+$ is reacted with $CH_3O^-Na^+$ followed by acidification, the R isomer of $CH_3CH(OCH_3)CH_2COOH$ was obtained.



Explain why this is so. [1]

(v) Explain why 3-bromobutanoic acid is a stronger acid than butanoic acid. [2]

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(c) Butanoic acid can be converted to calcium butanoate, $(CH_3CH_2CH_2COO)_2Ca$ when reacted with calcium hydroxide. Calcium butanoate supplements are sometimes used to support digestive health as it is known to have anti-inflammatory properties and supports the health of the colon.

(i) Write an equation for the reaction between butanoic acid and calcium hydroxide. [1]

(ii) Given that the solubility of calcium butanoate is 0.0161 mol dm^{-3}, calculate the K_{sp} of calcium butanoate stating its units. [2]

(iii) Calculate the solubility of calcium butanoate in a solution containing 0.1 mol dm^{-3} of calcium chloride. [1]

(iv) The ΔG^{e}_{sol} of an ionic compound in J mol^{-1}, is given by the following expression.

$$\Delta G^{e}_{sol} = -RT \ln K_{sp}$$

Calculate the ΔG^{e}_{sol} in kJ mol^{-1}, for calcium butanoate. [1]

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Additional answer space

If you use the following pages to complete the answer to any question, the question number must be clearly shown.

Anglo-Chinese Junior College

JC2 Preliminary Examination
Higher 2

A Methodist Institution
(Founded 1886)

CHEMISTRY
Paper 1 Multiple Choice

9729/01
9 September 2024
1 hour

Additional Materials: Multiple Choice Answer Sheet
Data Booklet

READ THESE INSTRUCTIONS FIRST

Write in soft pencil.

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

Write your name, Centre number 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.

Read the instructions on the Answer Sheet very carefully.

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.

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

Solutions

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

1 The incomplete combustion of a gaseous hydrocarbon produced 80 cm^3 of carbon dioxide, 40 cm^3 of carbon monoxide and 160 cm^3 of water vapour.

What volume of oxygen was used for combustion of the hydrocarbon?

	A	40 cm^3
	B	80 cm^3
	C	160 cm^3
	D	180 cm^3

$C_xH_y + \frac{9}{2}O_2 \rightarrow 2CO_2 + CO + 4H_2O$

40 80 40 160

Comparing volume ratio of gases,

$40 \times \frac{9}{2} = 180\ cm^3$

2 0.01 mol of an unknown ion G^{2+} required 17.25 cm^3 of 0.23 mol dm^{-3} acidified $KMnO_4$ to reach the end-point.

What is the final oxidation state of element **G**?

A	+3	**B**	+4	**C**	+5	**D**	+6

$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$

Amt of MnO_4^- = 0.01725 x 0.23
= 3.968×10^{-3} mol

Amt of e^- = $3.968 \times 10^{-3} \times 5$
= 1.984×10^{-2} mol

$1.984 \times 10^{-2} / 0.01 = 1.98 \approx 2$

1 mol of X^{2+} loses 2 mol of e^-, so final O.S of X is +4.

3 Which ion will be deflected the most in an applied electric field?

	A	$^{79}Br^{+}$	**B**	$^{81}Br^{2+}$	**C**	$^{81}Br^{+}$	**D**	$^{82}Br^{2+}$

Angle of deflection is directly proportional to charge/mass ratio.

$^{81}Br^{2+}$ has the largest charge/mass ratio, so it will be deflected the most in an electric field.

4 An unstable ion has

- a nucleon number of 219,
- 51 more neutrons than electrons
- an atomic number of 84, 85, 86, or 87.

What could this ion be?

	A	Po^{2+}	**B**	At^{3+}	**C**	Rn^{4+}	**D**	Fr^{5+}

	Po^{2+}	At^{3+}	Rn^{4+}	Fr^{5+}
number of protons	84	85	86	87
number of electrons	82	82	82	82
number of neutrons	133	133	133	133
nucleon number	217	218	219	220

5 Which species contains two π bonds?

1	BF_3NH_3
2	$CH_2CHCH_2CH_3$
3	CH_2CHCHO
4	$HCO_2CH_2COCH_3$

A	1 and 4 only
B	2 and 3 only
C	2 and 4 only
D	3 and 4 only

1 contains a dative bond between the boron atom and nitrogen atom.

2 contains only one π bond in the alkene.

3 contains two π bonds, one in the alkene and one in the aldehyde.

4 contains two π bonds, one in ester and one in ketone.

6 What is the strongest intermolecular force in ethanal, ethylamine and decan-1-ol?

	ethanal	ethylamine	decan-1-ol
A	hydrogen bonds	hydrogen bonds	induced dipoles
B	permanent dipoles	hydrogen bonds	induced dipoles
C	permanent dipoles	permanent dipoles	hydrogen bonds
D	hydrogen bonds	permanent dipoles	hydrogen bonds

Ethanal has permanent dipoles between its molecules as it is a polar molecule.

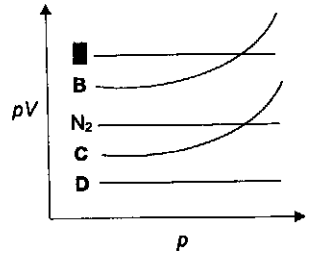
Ethylamine has hydrogen bonding between its molecules due to the lone pair of electrons on oxygen and the hydrogen bonded to oxygen in its molecules.

While there is hydrogen bonding between molecules of decan-1-ol, strongest intermolecular force in decan-1-ol is instantaneous dipole-induced dipoles due to the large electron cloud of the molecule.

7 The volumes and pressures of equal masses of two gases, N_2 and NH_3, are separately investigated, at constant temperature.

The results are plotted on a graph of pV against p. Both gases behave as ideal gases under the conditions chosen. The result for N_2 is given.

Which plot shows the result for NH_3?



Since both gases behave ideally, the pV against p plot for NH_3 is also a constant.

NH_3 has a lower molar mass than N_2. Since equal mass of gas is used, there are more NH_3 and given $pV = nRT$, its pV value will be higher.

8 What can be added to a mixture of MgO and Al_2O_3 to separate them by filtration?

	1	water
	2	HCl(aq)
	3	NaOH(aq)

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

MgO and Al_2O_3 are both insoluble in water, thus cannot be separated with water and then filtration.

Both Al_2O_3 and MgO are soluble in aqueous HCl as they react with HCl to give soluble products. Hence, they cannot be separated by HCl(aq) and then filtration.

Al_2O_3 is soluble in aqueous NaOH to form $NaAl(OH)_4$ while MgO is insoluble. Hence, NaOH(aq) and then filtration can separate the two oxides.

9 The following table shows the results of two experiments involving Group 17 halides, X^- and Y^-.

experiment	deduction
halogen Z_2 added to X^-	X_2 formed
halogen Z_2 added to Y^-	Y_2 not formed

Which row shows the halogens in decreasing order of oxidising strengths?

A	Y_2, Z_2, X_2
B	Y_2, X_2, Z_2
C	X_2, Z_2, Y_2
D	X_2, Y_2, Z_2

Z_2 can oxidise X^-. Thus, Z_2 is a stronger oxidising agent than X_2.

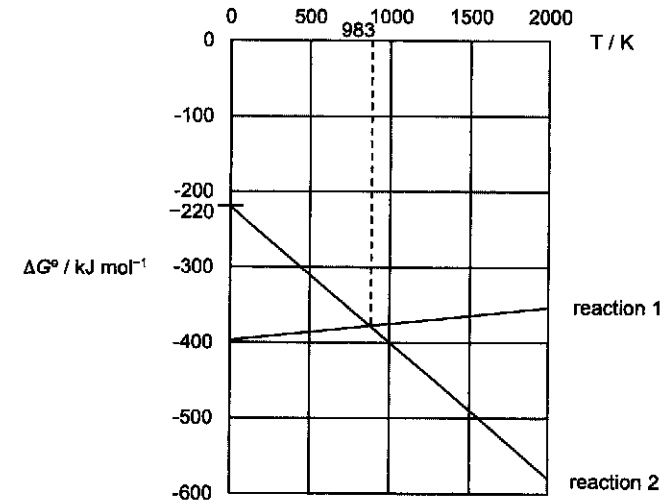
There is no visible reaction between Z_2 and Y^-, Z_2 cannot oxidise Y^-.
Hence Y_2 is a stronger oxidising agent than Z_2

Thus, the strongest oxidising agent is Y_2, followed by Z_2, then X_2.

10 An Ellingham diagram is a plot of ΔG versus temperature and it can be used to show the stability of compounds at various temperatures.

The following Ellingham diagram is for reactions 1 and 2.

Reaction 1: W + X → Y
Reaction 2: 2W + X → 2Z



Which statement is **incorrect**?

A	Reaction 1 is favoured at lower temperatures.
B	The entropy change of reaction 2 is negative.
C	The enthalpy change of reaction 2 is –220 kJ mol^{-1}
D	At 983 K, ΔG of the reaction 2Z → W + Y is zero.

A is correct. As temperature decreases, ΔG becomes more negative.

B is incorrect. $\Delta G = \Delta H - T\Delta S$. The gradient of the graph is $-\Delta S$. Since gradient of reaction 2 is negative, ΔS (entropy change) of reaction 2 is positive.

C: Since $\Delta G = \Delta H - T\Delta S$, the y-intercept is ΔH, hence is –220 kJ mol^{-1}.

D: The lines for reaction 1 and 2 intersect at 983 K, the ΔG for both reactions have the same value, approximately –370 kJ mol^{-1}.

Reaction 1: W + X → Y –370 kJ mol^{-1}

Reaction 2: $2W + X \rightarrow 2Z$ $\quad -370$ kJ mol^{-1}

The reaction: $2Z \rightarrow W + Y$ is Reaction 1 – Reaction 2

Hence, ΔG of the reaction is $-370 - (-370) = 0$

11 When an instant cold pack is used, a vigorous reaction occurs, and the temperature falls from 25 °C to 5 °C.

What are the correct signs of ΔG and ΔS for this reaction?

	ΔG	ΔS
A	+	+
B	+	–
C	–	+
D	–	–

A spontaneous reaction occurred (indicated by the drop in temperature) so ΔG is negative.

The reaction is endothermic as the temperature fell. ΔS must be positive for negative $-T\Delta S$ term to outweigh the positive ΔH term so that overall ΔG is negative.

12 The Dushman reaction is represented by the following equation.

$$IO_3^-(aq) + 5I^-(aq) + 6H^+(aq) \rightarrow 3I_2(aq) + 3H_2O(l)$$

The rate equation for this reaction is as follows.

$$\text{rate} = k[IO_3^-][I^-]^2[H^+]^2$$

When the concentration of each reactant is a mol dm^{-3}, the initial rate was found to be y mol dm^{-3} s^{-1}.

What will be the initial rate of the reaction if $[IO_3^-]$ is $2a$, $[I^-]$ is $\frac{1}{2}a$, and $[H^+]$ is $4a$?

A $2y$ **B** $4y$ **C** $8y$ **D** $16y$

Initial rate = $k[a][a]^2[a]^2$

$y = ka^5$

new initial rate = $k[2a][\frac{1}{2}a]^2[4a]^2 = 8ka^5 = 8y$

13 3.0 mol of Q, 1.5 mol of R and 0.2 mol of S were mixed in a 2.0 dm^3 flask and allowed to reach equilibrium.

$$4Q(g) + R(g) \rightleftharpoons S(g)$$

The equilibrium mixture contained 0.8 mol of S.

What is the equilibrium concentration of Q in the flask?

A 2.4 mol dm^{-3}

B 1.2 mol dm^{-3}

C 0.6 mol dm^{-3}

D 0.3 mol dm^{-3}

	4Q(g)	+ R(g)	⇌ S(g)
I / mol	3.0	1.5	0.2
C / mol	-2.4	-0.6	+0.6
E / mol	0.6	0.9	0.8

eqm concentration of Q = 0.6/2 = 0.3 mol dm^{-3}

14 Water dissociates according to the equation

$$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq)$$

The pH of water at different temperatures are shown below.

temperature / K	pH
298	7.0
333	6.5

Which statements are true?

1 The dissociation of water is endothermic.

2 The pK_a of water increases when temperature increases.

3 Water becomes more acidic when temperature increases.

A 1 only

B 1 and 2 only

C 2 and 3 only

D 1, 2 and 3

Option 1: When temperature increases, pH deceases, thus $[H^+]$ increases. The POE shifts right when temperature increases to absorb the additional heat present favouring an endothermic process, thus the dissociation of water is endothermic.

Option 2: Since POE shifts right, K_a value ($K_a = \frac{[H^+][OH^-]}{[H_2O]}$)increases. Thus, pK_a decreases.

Option 3: Water is always neutral as $[H^+] = [OH^-]$.

15 The table below describes some indicators.

indicator	colour in acid	colour in alkali	pK_a	range of pH for colour change
methyl orange	red	yellow	3.7	3.2 – 4.4
thymol blue	yellow	blue	8.9	8.0 – 9.6

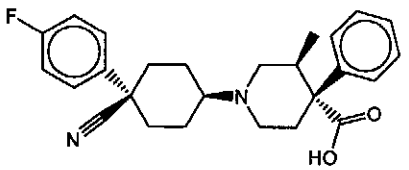
For the titration of NaOH(aq) against HCOOH(aq), which row shows the most suitable indicator and the corresponding colour change?

	indicator	colour change
A	methyl orange	red to orange
B	methyl orange	yellow to orange
C	thymol blue	yellow to green
D	thymol blue	blue to green

The titration is between a strong base and weak acid. Hence the equivalence point pH > 7 as a basic salt is produced. Thymol blue will be a suitable indicator.

Since NaOH is in the conical flask, thymol blue will turn from blue to green.

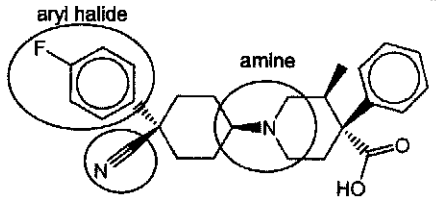
16 Levocabastine is an antihistamine used in the treatment of sore eyes.



Levocabastine

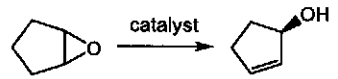
Which functional group is **not** present in Levocabastine?

D	alcohol
B	amine
C	aryl halide
D	nitrile



nitrile Levocabastine

17 1,2-epoxycyclopentane can be converted to cyclopent-2-en-1-ol in a single reaction.



1,2-epoxycyclopentane cyclopent-2-en-1-ol

Which statement about the reaction is correct?

A	1,2-epoxycyclopentane rotates plane-polarised light.
B	A reducing agent is used for this reaction.
C	Cyclopent-2-en-1-ol is more volatile than the 1,2-epoxycyclopentane.
D	An isomerisation reaction has occurred.

A: 1,2-epoxycyclopentane contains an internal plane of symmetry and does not rotate plane-polarised light.

B: The average oxidation number of carbon in both compounds remains the same so it is not reduction.

C: Cyclopent-2-en-1-ol contains hydrogen bonding between its molecules which are stronger than the permanent dipole – permanent dipole interactions between 1,2-epoxycyclopentane. Cyclopent-2-en-1-ol has a higher boiling point and is less volatile than 1,2-epoxycyclopentane.

D: The number of atoms in 1,2-epoxycyclopentane and cyclopent-2-en-1-ol are the same.

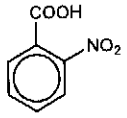
18 Both benzene and propene react with bromine.

Which statement best explains the difference in the reactivity between these compounds?

A	Benzene is a planar molecule which allows ease of attack by bromine whereas propene is a non-planar molecule.
B	The carbocation intermediate produced in the reaction of benzene with bromine is stabilised by resonance.
C	The sideway overlap of p orbitals in benzene means the C–C bonds alternate between long, single bonds and short, double bonds.
D	The delocalisation of electrons in benzene causes it to be more stable.

The difference in reactivity towards electrophiles stems from the stability of benzene, requiring a strong electrophile with a full positive charge for reaction. This stability comes from the delocalisation of electrons in benzene.

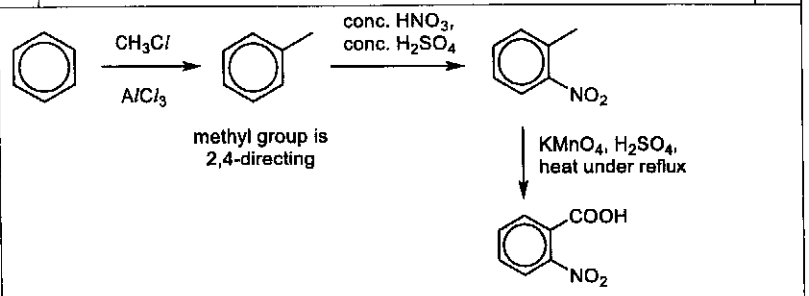
19 Benzene reacts in a three-stage process to produce 2-nitrobenzoic acid?



2-nitrobenzoic acid

Which reagents could be used for the three-stage process?

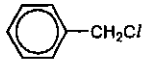
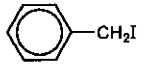
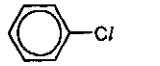
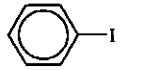
	first stage	second stage	third stage
A	CH_3Cl, $AlCl_3$	HNO_3(aq)	$KMnO_4$, dilute H_2SO_4, heat under reflux
B	conc HNO_3, conc H_2SO_4	CH_3Cl, $AlCl_3$	$KMnO_4$, dilute H_2SO_4, heat under reflux
C	CH_3Cl, $AlCl_3$	conc HNO_3, conc H_2SO_4	$KMnO_4$, dilute H_2SO_4, heat under reflux
D	CH_3Cl, $AlCl_3$	$KMnO_4$, dilute H_2SO_4, heat under reflux	conc HNO_3, conc H_2SO_4



20 Compound **X** is boiled with aqueous sodium hydroxide, cooled and then acidified with dilute nitric acid. Aqueous silver nitrate was subsequently added to the mixture.

It was observed that a precipitate, which formed when aqueous silver nitrate was added, dissolved upon the addition of aqueous ammonia to the mixture.

What could be the structure of **X**?

A		**C**	
B		**D**	

Only alkyl halides will undergo nucleophilic substitution with NaOH(aq) to liberate the halide ion, giving a positive test with $AgNO_3$(aq).

Only AgCl will dissolve with the addition of NH_3(aq), so the compound contains an alkyl chloride.

21 The mechanism for the reaction between ethanal and hydrogen cyanide is given below.

step 1: $CH_3CHO + CN^- \rightarrow CH_3CHOCN^-$

step 2: $CH_3CHOCN^- + HCN \rightarrow CH_3CH(OH)(CN) + CN^-$

Which statement regarding the mechanism and the reaction is correct?

A	The negative charge is on the nitrogen atom in the intermediate.
B	There is one sp^2 hybridised carbon atom in the intermediate.
C	The ethanal behaves as the nucleophile in step 1.
D	The mixture does not rotate plane-polarised light after the reaction.

A: The negative charge is on the oxygen atom in the intermediate.

B: There is no sp^2 hybridised carbon atom in the intermediate.

C: Ethanal behaves as the electrophile in step 1.

D: As CN^- attacks both sides of the plane of the sp^2 carbon in ethanal, the resulting mixture will contain equal amounts of both enantiomers.

22 An unknown organic compound has the molecular formula $C_5H_{12}O$. It was subjected to the following chemical test.

test	observations
alkaline aqueous iodine, warm	yellow precipitate is seen
hot acidified $KMnO_4$	purple solution decolourises

Two students saw the tests and each made a comment.

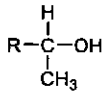
student E The compound is a secondary alcohol.

student F The compound is definitely pentan-2-ol.

Which students are correct?

	student E	student F	
A	✓	✓	key
B	✗	✓	✓ = correct
C	✓	✗	✗ = not correct
D	✗	✗	

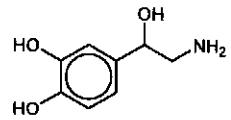
There is no degree of unsaturation in the molecular formula $C_5H_{12}O$. This means the compound does not contain a ketone nor alkene.

The positive test with alkaline aqueous iodine means the compound has the structural formula  .

The positive test with hot acidified $KMnO_4$ indicates the compound can be oxidised and contains a primary or secondary alcohol. Student E is correct.

Student F is not correct as the alcohol may be 3-methylbutan-2-ol.

23 Noradrenaline functions in the brain as a neurotransmitter.



noradrenaline

How many moles of sodium hydroxide will react with one mole of noradrenaline?

A	1	
B	2	
C	3	
D	4	

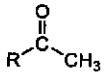
Only phenol is sufficiently acidic to react with NaOH. Alcohols do not react with NaOH.

24 Which statement regarding ethanoic acid is true?

A	It reacts with hydrogen chloride to form ethanoyl chloride.
B	It can be reduced to ethanol with hydrogen gas in the presence of Pt.
C	It does not form a yellow precipitate when warmed with alkaline aqueous iodine.
D	it reacts with phenol in the presence of concentrated sulfuric acid to form phenyl ethanoate.

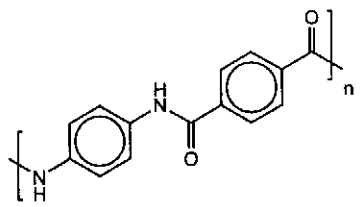
A: To form CH_3COCl, either $SOCl_2$ or PCl_5 must be used. HCl only reacts with alcohols.

B: The unsaturated π bonds in the carboxylic acid can be reduced to give primary alcohol.

C: Only alcohols with the structure  or carbonyl compounds with the structure  will give a positive test with alkaline aqueous iodine.

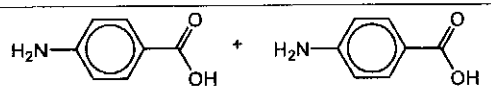
D To form phenyl ethanoate, phenol needs to react with ethanoyl chloride, not ethanoic acid. Carboxylic acids only forms esters with alcohols, not phenols.

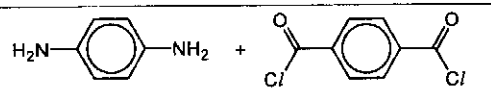
25 Kevlar is a light weight and strong material, used to make tyres and bulletproof vests. Its structure is given below.

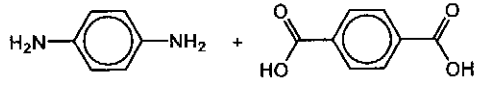


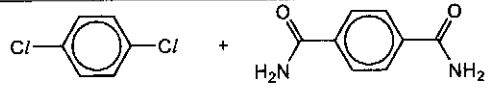
Kevlar

Which option produces Kevlar in the greatest yield?

A 

B 

C 

D 

A: The structure of the reactant is incorrect as each benzene ring is bonded to one N atom and C atom. In Kevlar, one benzene ring is bonded to 2 N atoms, while another is bonded to 2 C atoms, in a repetitive fashion.

B: The amine reacts with the acyl chloride in a condensation reaction.

C: The amine reacts with the carboxylic acid in an acid-base reaction.

D: Amides do not react with aryl halides.

26 A peptide chain isolated from a protein in the medicinal mushroom *Lingzhi* is shown below.

ser-gly-arg-asn-leu-gly-val-lys-pro-ser

The enzyme trypsin will only hydrolyse a polypeptide chain at a peptide bond where the carboxyl group has been donated by either lysine (lys) or arginine (arg).

Which fragments could be made when trypsin acts on the peptide chain from *Lingzhi*?

1	ser-gly-arg
2	lys-pro-ser
3	asn-leu-gly-val-lys
4	arg-asn-leu-gly-val

A	1, 2, 3 and 4
B	1 and 3 only
C	2 and 4 only
D	1 and 4 only

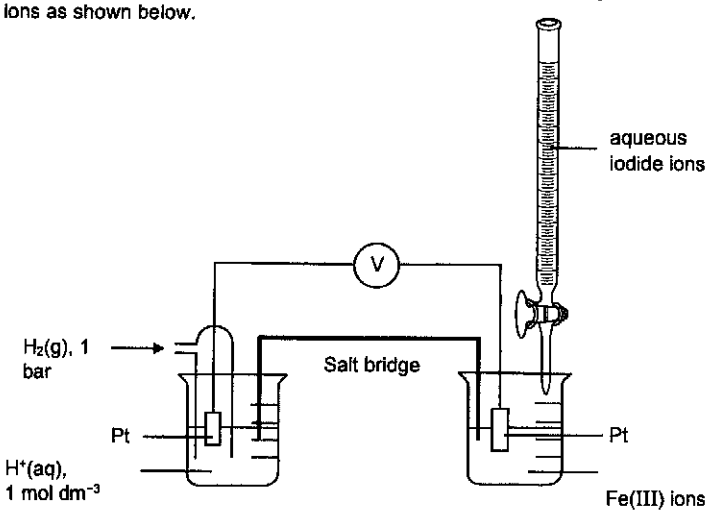
By convention, the carboxyl group is on the right hand side of the amino acid. Hence, we need to cut on the right hand side of arg and lys.

ser-gly-arg|asn-leu-gly-val-lys|pro-ser

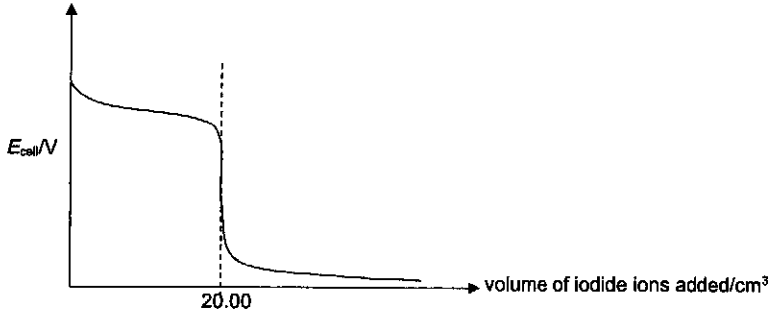
Hence, only 1 and 3 can be obtained.

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

Aqueous iodide ions were added to an aqueous solution containing 50 cm^3 of iron(III) ions as shown below.



The titration curve obtained is shown below.



What is the volume of iodide ions added for the E_{cell} value to be +0.77 V?

	A	0.00 cm^3	**C**	20.00 cm^3
	■	10.00 cm^3	**D**	40.00 cm^3

At 0.0 cm^3, the solution only contains Fe^{3+} ions.

When I^- ions are added, it reduces the Fe^{3+} to Fe^{2+}. $2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$
This creates a half cell of Fe^{3+}/Fe^{2+} measured against H^+/H_2 between 0 to 20 cm^3, as there will be a mixture containing Fe^{3+} and Fe^{2+} in solution.

At 10.0 cm^3, the $[Fe^{3+}] = [Fe^{2+}]$, hence, $E^\ominus(Fe^{3+} / Fe^{2+})$ value for the half-cell is 0.77V.
$E_{cell} = 0.77 - 0.00 = +0.77V$.

At 20.0cm^3, the mixture only contains I_2 and Fe^{2+}. After 20.0 cm^3, the mixture contains I_2, I^- and Fe^{2+} and the half-cell measured against H^+/H_2 will become I_2/I^-.

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

By considering $E^\ominus$ values, which aqueous species will oxidise Sn^{2+} to Sn^{4+}?

	■	H_2O_2, H^+
	■	I_2
	3	V^{3+}
A		1, 2 and 3 only
■		1 and 2 only
C		2 and 3 only
D		1 only

$Sn^{4+} + 2e^- \rightleftharpoons Sn^{2+}$ $E^\ominus = +0.15V$

Since Sn^{2+} is oxidised, it is at the oxidation half-cell. The species to be reduced is at the reduction half-cell.

Hence, the $E^\ominus$ of the aqueous species > +0.15V for the reaction to be feasible.

$E^\ominus(H_2O_2,H^+/H_2O) = +1.77V$ and $E^\ominus(I_2/I^-) = +0.54V$ hence can oxidise Sn^{2+}.

$E^\ominus(V^{3+}/V^{2+}) = -0.26V$, hence cannot oxidise Sn^{2+}.

29 A complex of chromium with the general formula $CrCl_3 \cdot 6H_2O$ forms an aqueous solution.

When 0.01 mol of an aqueous solution of this compound was treated with an excess of aqueous silver nitrate, 2.87 g of precipitate was obtained.

What is the formula of the chromium complex?

	A	$[Cr(H_2O)_6]^{3+}$	**C**	$[Cr(H_2O)_4Cl_2]^+$

	[redacted]	$[Cr(H_2O)_5Cl]^{2+}$	**D**	$[Cr(H_2O)_3Cl_3]$

Amt of AgCl ppt = 2.87 ÷ 143.4
= 0.0200 mol

Ratio of Cl^-: $CrCl_3 \cdot 6H_2O$ = 0.02 ÷ 0.01
= 2

There are 2 anions Cl^- that are not in the complex ion. Hence the complex only contains 1 Cl^-.

30 A student carried out 2 experiments on separate samples of aqueous $CuSO_4$.

Experiment 1

When aqueous potassium iodide was added to a sample of aqueous $CuSO_4$, a white precipitate in a brown solution was formed.

Experiment 2

When aqueous ammonia is added to another sample aqueous of $CuSO_4$, a pale blue precipitate is formed. The precipitate dissolves when an excess of aqueous ammonia is added, forming a deep blue solution.

Which statement about experiments 1 and 2 is **incorrect**?

	A	Ligand exchange occurred in Experiment 2.
	B	The pale blue precipitate is $[Cu(OH)_2(H_2O)_4]$.
	C	Reduction of copper(II) ions occurred in Experiment 1.
	[redacted]	The complex ion in the deep blue solution has a tetrahedral shape.

Experiment 1:

$2Cu^{2+} + 4I^- \rightarrow 2CuI + I_2$

Reduction of Cu^{2+} to Cu^+ occurred in experiment 1.

The white ppt is CuI

Ligand exchange occurred in experiment 2

$[Cu(H_2O)_6]^{2+} + 2OH^- \rightleftharpoons [Cu(OH)_2(H_2O)_4] + 2H_2O$

The blue ppt is $[Cu(OH)_2(H_2O)_4]$

$[Cu(H_2O)_6]^{2+} + 4NH_3 \rightleftharpoons [Cu(NH_3)_4(H_2O)_2]^{2+} + 4H_2O$

The deep blue solution is due to $[Cu(NH_3)_4(H_2O)_2]^{2+}$. The ion has an octahedral shape as there are 6 ligands about the metal centre.