RIVER VALLEY HIGH SCHOOL
JC 2 PRELIMINARY EXAMINATION

CANDIDATE NAME					
CLASS	2	4	J		
CENTRE NUMBER	S				

INDEX NUMBER				

H2 CHEMISTRY 9729/02

Paper 2 Structured Questions

16 September 2025

2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your Centre number, index number, class and name on all the work that 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.
DO **NOT** WRITE IN ANY BARCODES.

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.

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 Number	**1**	**2**	**3**	**4**	**5**	**6**		
Marks	13	15	9	16	10	12		
significant figures			**units**				**Total**	75

This document consists of **28** printed pages.

1 **(a)** Fig. 1.1 shows the successive ionisation energies of an element **A** in Period 3.

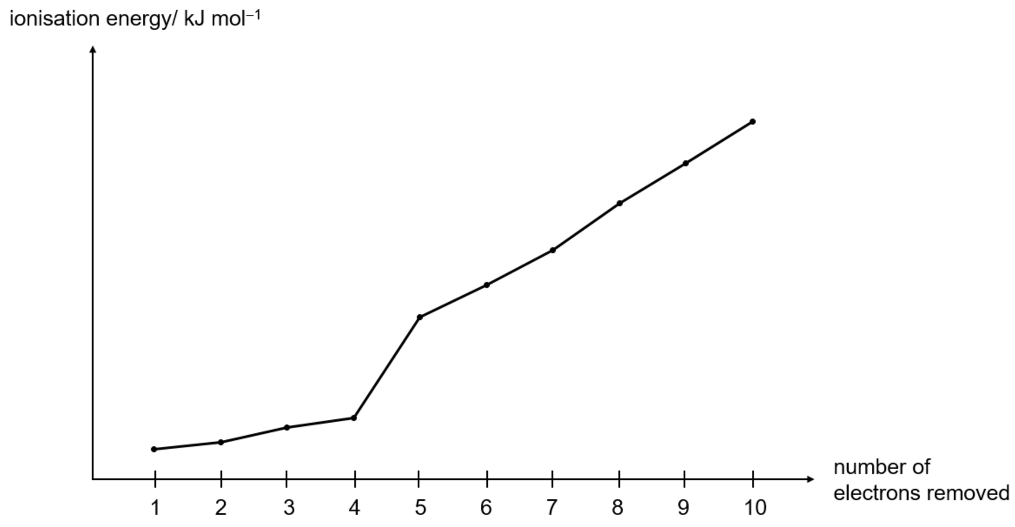

Fig. 1.1

(i) Explain why the successive ionisation energies of element **A** increase as shown in the graph.

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(ii) Identify which group element **A** belongs to. Explain your reasoning.

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(b) Calcium and scandium are both found in Period 4 of the Periodic Table.

Explain why the atomic radius of scandium is smaller than that of calcium.

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(c) Like Group 2 carbonates, the hydroxides of Group 2 elements can undergo thermal decomposition. In the process, water vapour is produced.

(i) Write an equation for the decomposition of calcium hydroxide.

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

(ii) Nickel(II) hydroxide can undergo thermal decomposition similar to calcium hydroxide.

Given that the atomic radius of scandium and nickel are approximately similar, deduce whether nickel(II) hydroxide would decompose at a higher or lower temperature than calcium hydroxide. Explain your reasoning.

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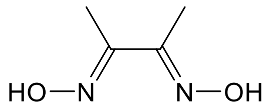
(d) Nickel(II) compounds can be analysed using dimethylglyoxime ($C_4H_8N_2O_2$).



dimethylglyoxime
$C_4H_8N_2O_2$

An excess of a solution of dimethylglyoxime is first added to an acidic solution of a nickel(II) compound. When aqueous ammonia is next added, a nickel(II) complex, $Ni(C_4H_7N_2O_2)_2$, is produced.

The following equation shows the reaction:

$$[Ni(H_2O)_6]^{2+} + 2C_4H_8N_2O_2 + 2NH_3 \longrightarrow Ni(C_4H_7N_2O_2)_2 + 2NH_4^+ + 6H_2O$$

(i) State the role of ammonia in the above reaction.

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(ii) Draw the structure of $C_4H_7N_2O_2^-$.

[1]

(iii) The $Ni(C_4H_7N_2O_2)_2$ complex is square planar in shape with respect to the nickel(II) ion. Each ligand in the complex is bidentate with the nitrogen atoms datively bonded to the nickel(II) ion. The –OH group in each ligand forms a hydrogen bond with another ligand.

Complete Fig. 1.2 to show the structure of the $Ni(C_4H_7N_2O_2)_2$ complex and label one of the two hydrogen bonds clearly.

Ni^{2+}

Fig. 1.2

[2]

(iv) In the formation of a square planar complex, the ligands approach the central metal ion along the *x* and *y* axes.

Fig. 1.3 shows how the 3d orbitals of the nickel(II) ion in a square planar complex are split based on the crystal field theory.

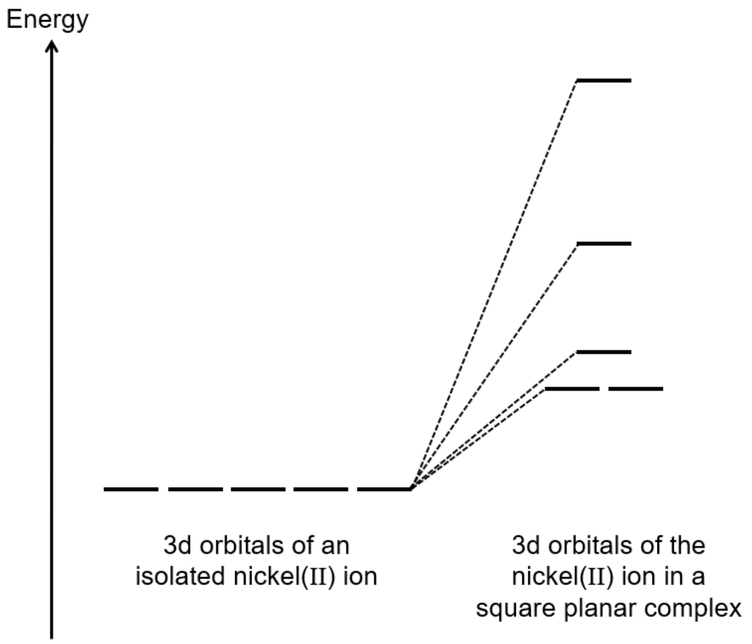


Fig. 1.3

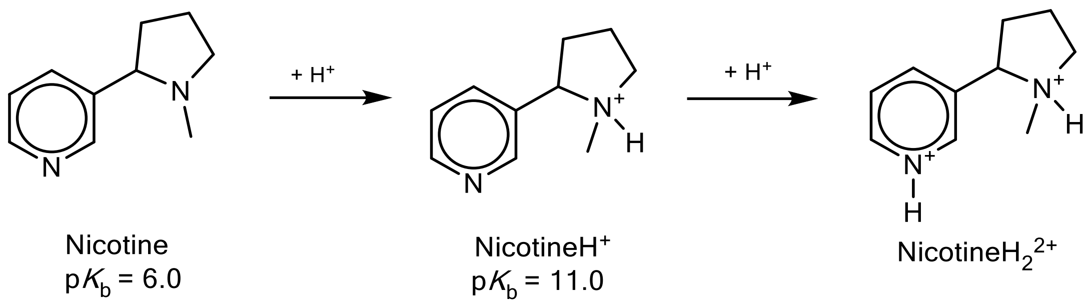
State the identity of the 3d orbital with the highest energy in the nickel(II) ion in a square planar complex.

…………………………………………………………………………………… [1]

[Total: 13]

2 Nicotine is a weak diprotic base consisting of an aromatic pyridine ring joined to a saturated pyrrolidine ring. It is highly addictive and is found in tobacco and vapes.

Values for the base dissociation constants, pK_b, for nicotine is shown below.



(a) State what is meant by the term *Lewis base*.

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(b) 25.00 cm^3 of an aqueous solution of nicotine was titrated against 0.100 mol dm^{-3} hydrochloric acid, HC*l*. At the 2nd equivalence point, it was found that 49.0 cm^3 of HC*l* was added.

(i) Calculate the concentration of $NicotineH_2^{2+}$, in mol dm^{-3}, at the 2nd equivalence point.

[1]

(ii) Calculate the pH of the solution at the 2nd equivalence point.

[2]

(iii) Prove that the initial pH of nicotine is 10.5.

[3]

(iv) Sketch the shape of the pH curve of nicotine against the volume of HC*l* added on Fig. 2.1 using all relevant information given or calculated. Mark clearly where the equivalence points occur.

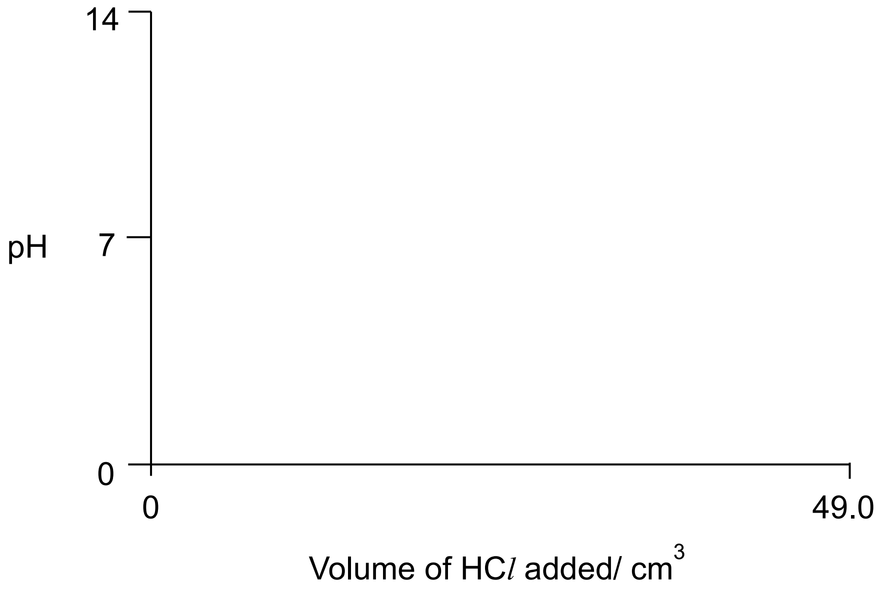
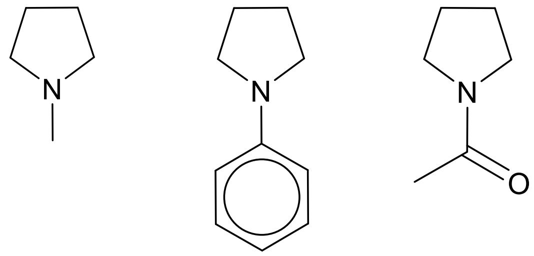


Fig. 2.1

[1]

(c) Aqueous solutions of **X**, **Y** and **Z** are basic. Fig. 2.2 shows them listed in decreasing order of basicity.

most basic



least basic

X **Y** **Z**

Fig. 2.2

Explain the relative basicities of aqueous solutions of **X**, **Y** and **Z** in terms of their structures.

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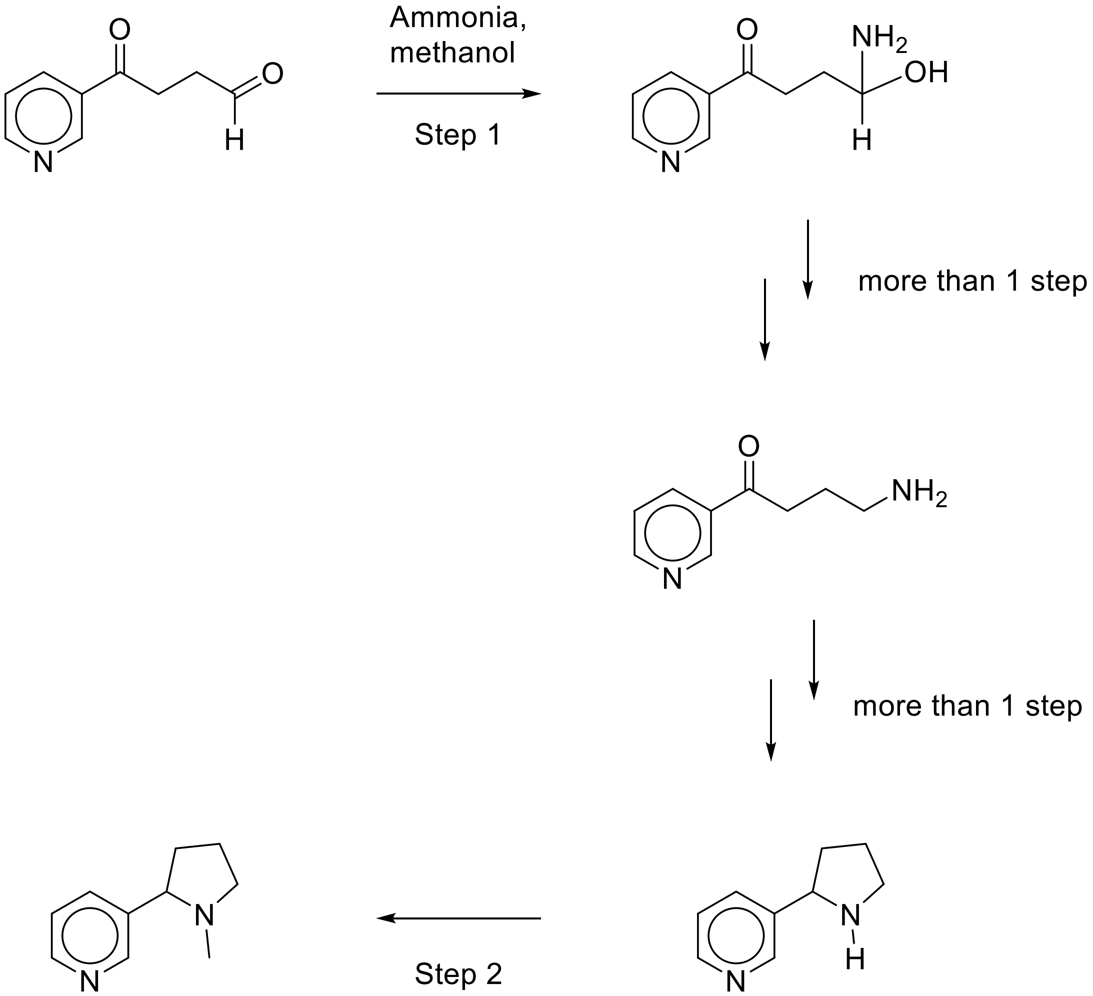
(d) The following diagram shows the partial synthesis route of nicotine formation:



(i) Suggest the type of reaction in Step 1.

.... [1]

(ii) Complete Fig. 2.3 to suggest a mechanism for this reaction. Show the structure of the intermediate and the movement of the lone pairs, dipoles, curly arrows and charges.

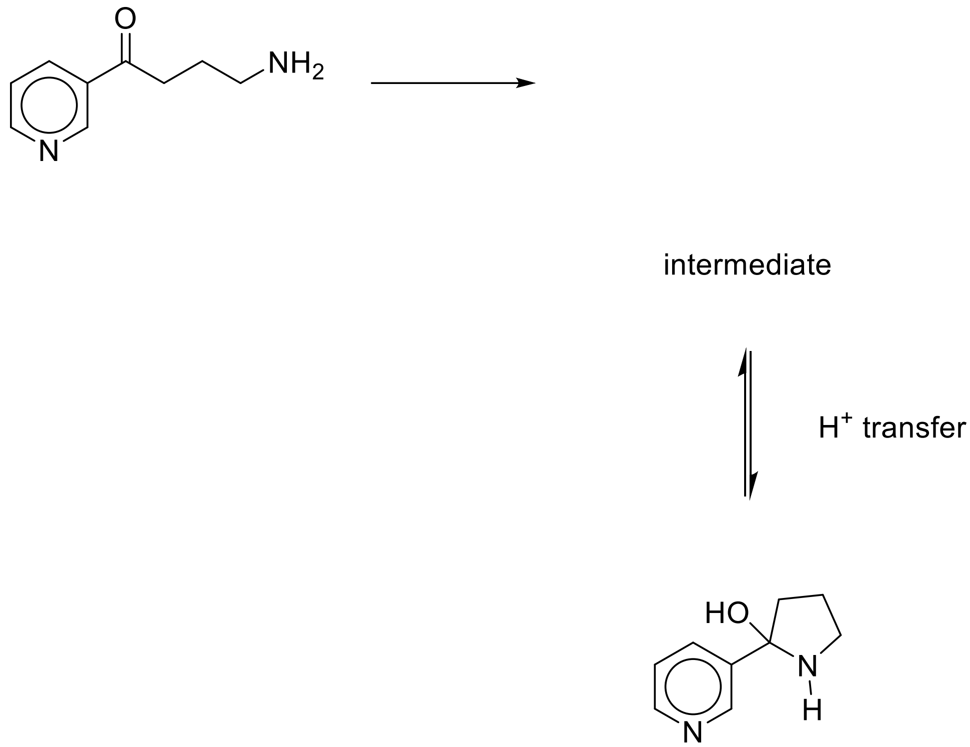


Fig. 2.3

[2]

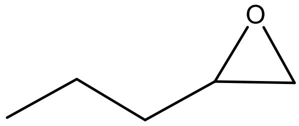
(iii) Suggest the reagent and conditions for Step 2.

.... [1]

[Total: 15]

3 Epoxides are a class of organic compounds with a three-membered ring structure. The three-membered ring in epoxides makes them highly reactive and susceptible to ring-opening reactions.

One such epoxide is 1,2-epoxypentane, $C_5H_{10}O$, with the structure as shown below.



(a) Suggest why epoxides are susceptible to ring-opening reactions.

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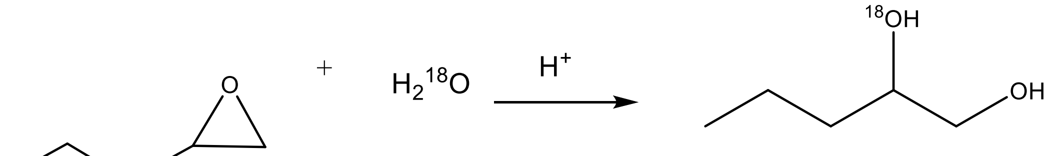
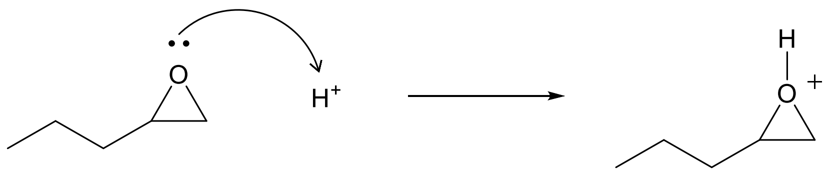
.... [2]

(b) An example of an epoxide ring-opening reaction is the hydrolysis of 1,2-epoxypentane in the presence of a strong acid catalyst to form 1,2-pentanediol. The hydrolysis is carried out using "heavy-oxygen water", $H_2{}^{18}O$.



1,2-pentanediol

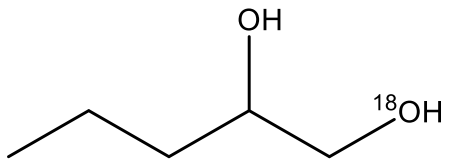
It is found that the reaction follows a S_N1 mechanism. Some details of the mechanism are given below.

Step 1	
Step 2	Heterolytic fission of the C–O bond to generate a carbocation intermediate.
Step 3	Attack of the carbocation by one molecule of $H_2{}^{18}O$ to form a new C–O bond.
Step 4	Loss of a proton to form 1,2−pentanediol and regenerate the acid catalyst.

(i) Describe Steps 2 to 4 of the S_N1 mechanism. Show all relevant lone pairs and charges and indicate the movement of electron pairs with curly arrows.

[3]

(ii) Presence of trace amounts of an isotopic isomer **A** is formed in the reaction too.



Isomer **A**

Suggest how isotopic isomer **A** could have been formed during the reaction and why it was formed only in trace amounts in the S_N1 mechanism.

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(c) **X** and **Y** are a pair of stereoisomers with the same molecular formula as 1,2-epoxypentane that share the following properties:

- two sp^2 hybridised carbon atoms
- different melting points
- reacts with PCl_5 to give white fumes
- does not have a chiral carbon

Draw the structures of **X** and **Y** and indicate the type of isomerism.

[2]

[Total: 9]

4 This question is about carbon–containing species.

Compounds **P**, **Q**, **R** and **S** are structural isomers with molecular formula of $C_9H_{10}O_2$. The results of six tests carried out on these isomers are shown in Table 4.1.

Table 4.1

Test	**P**	**Q**	**R**	**S**
Rotate plane–polarised light	Yes	Yes	No	Yes
Add $FeCl_3$(aq)	No purple complex	Purple complex	Purple complex	Purple complex
Heat with acidified $K_2Cr_2O_7$	Orange solution turns green	Orange solution turns green	Orange solution remains	Orange solution turns green
Warm with Fehling's reagent	No brick red ppt	Brick red ppt	No brick red ppt	No brick red ppt
Warm with Tollen's reagent	Grey ppt	Grey ppt	No grey ppt	No grey ppt
Add cold alkaline $KMnO_4$	Purple $KMnO_4$ remains	Purple $KMnO_4$ remains	Purple $KMnO_4$ remains	Purple $KMnO_4$ turns colourless

(a) Using the information in Table 4.1, state the structure for each of these four isomers.

[4]

(b) Isomer **Q** is found to be soluble in NaOH(aq). Explain.

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A fuel cell is a galvanic cell that converts chemical potential energy to electrical energy.

An example is the molten–carbonate fuel cell (MCFC). It is developed to directly utilise fuels like hydrogen gas, natural gas, biogas, and coal gas. The diagram of a MCFC is shown in Fig. 4.1.

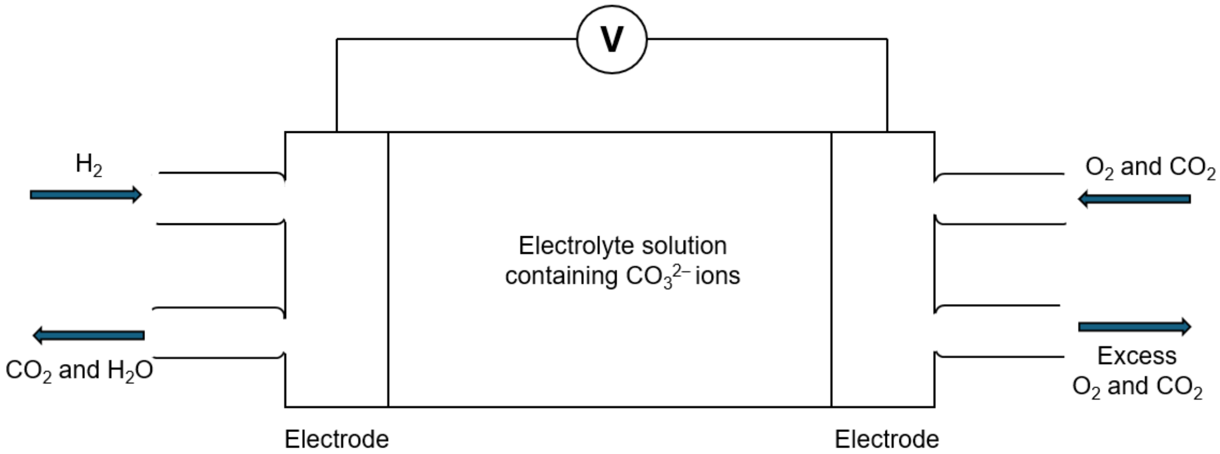

Fig. 4.1

(c) **(i)** Given that CO_3^{2-} ions are produced and used up at the cathode and anode respectively as part of acid-base reactions, deduce the half-equations at the cathode and anode of MCFC.

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.... [2]

(ii) Indicate the direction of electron flow in Fig. 4.1. [1]

Another example of fuel cell is the direct–formic acid fuel cell (DFAFC). It uses formic acid, HCOOH.

Equation 1 $CO_2 + 2H^+ + 2e^- \rightleftharpoons HCOOH$ $E^\ominus = -0.61V$

The other electrode in the DFAFC is the oxygen electrode.

The electrolyte used in the DFAFC is an aqueous acid.

(d) **(i)** Use the *Data Booklet* to calculate the $E^\ominus_{cell}$ of DFAFC.

[1]

(ii) State and explain how the value of the cell emf changes when pressure of CO_2 is increased.

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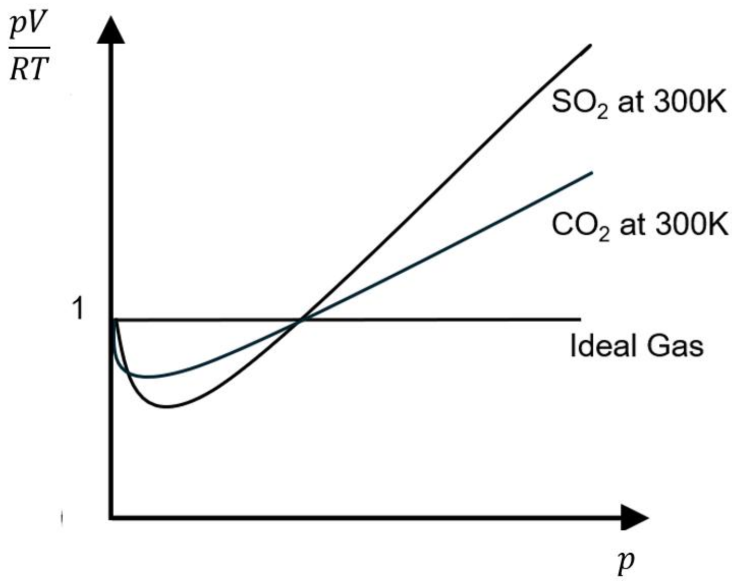
.... [2]

(e) CO_2 is a real gas.

The diagram below shows the plots of *pV/RT* against *p* for one mole of an ideal gas, one mole of CO_2 and one mole of SO_2 at 300K.



(i) State three basic assumptions of the kinetic theory applied to an ideal gas.

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(ii) Explain the difference in behaviour between CO_2 and SO_2 at 300K.

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[Total: 16]

5 On 4 August 2020, a large explosion occurred at a port warehouse in Beirut, Lebanon, due to the detonation of approximately 2750 tonnes of ammonium nitrate (NH_4NO_3) stored improperly. This explosion released energy comparable to 1.1 kilotons of trinitrotoluene (TNT) and generated a seismic event measuring 3.3 in magnitude on the Richter scale.

When heated or subjected to shock, ammonium nitrate can undergo the following decomposition reaction:

$$2NH_4NO_3(s) \rightarrow 2N_2(g) + O_2(g) + 4H_2O(g)$$

Data on the standard enthalpy changes of formation (at 298 K) and entropies are provided in the table below:

Substance	$\Delta H_f^{\ominus}$/kJ mol^{-1}	$S^{\ominus}$/J mol^{-1} K^{-1}
$NH_4NO_3(s)$	−365	151
$N_2(g)$	0	192
$O_2(g)$	0	206
$H_2O(g)$	−242	189

The standard enthalpy change of reaction, $\Delta H^{\ominus}$, can be calculated from relevant standard enthalpy changes of formation, $\Delta H_f^{\ominus}$. In the same way, the standard entropy change of reaction, $\Delta S^{\ominus}$, can be calculated from relevant entropies of the substances involved.

(a) Show that the standard enthalpy change for the decomposition of one mole of ammonium nitrate is −119 kJ mol^{-1}.

[1]

(b) Calculate the standard entropy change for the decomposition of one mole of ammonium nitrate.

[1]

(c) Calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, for the decomposition of one mole of ammonium nitrate at 298 K.

[1]

(d) Suggest why heating or an external shock might still be required to initiate the reaction.

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(e) **(i)** Use of the *Data Booklet* is relevant to this question.

Calculate the total energy released, in MJ, when 2750 tonnes of ammonium nitrate were completely decomposed in the Beirut explosion.

[1 MJ = 10^6 J; 1 ton = 10^6 g]

[2]

(ii) Assuming all the gaseous products are collected at 298 K and 1.00 atm, use the ideal gas equation to calculate the total volume of gas produced in m^3.

[2]

(iii) Considering the real-world conditions in the Beirut explosion, state how the actual total volume of gas produced might differ from your answer in **(e)(ii)** and suggest one possible reason to explain why.

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[Total: 10]

6 The troposphere is a layer of the atmosphere that begins at the Earth's surface and extends approximately to 15 km above the Earth's surface. Most types of clouds are found in the troposphere. Clouds hold water, either in the form of tiny water droplets or ice crystals.

The atmospheric pressure, measured in MPa, changes with altitude, x km, as follows.

$$\ln\frac{P_0}{P_x} = 0.119\,x$$

P_0 is the atmospheric pressure at the Earth's surface = 0.101325 MPa

P_x is the atmospheric pressure at altitude x km

The melting temperature of ice, T, measured in kelvin, changes with atmospheric pressure, in MPa, as shown.

$$P_x - P_0 = 3595 \times \ln\left(\frac{T_x}{T_0}\right)$$

T_x is melting temperature at altitude x km

T_0 is the melting temperature of ice at the Earth's surface

Cloud seeding is an engineering technique used to induce and enhance rainfall. The idea of cloud seeding is to introduce ice nucleating particles (INP), which induce ice formation in clouds. These ice crystals grow and become too heavy and eventually fall out of cloud. If the temperature is above the freezing point, rain is observed.

The most common INP is silver iodide, AgI. The crystalline structure of AgI is similar to that of ice, allowing it to induce freezing. Fig. 6.1 shows the structure of ice. In ice, all four hydrogen bonds are formed, resulting in a tetrahedral coordination around each water molecule.

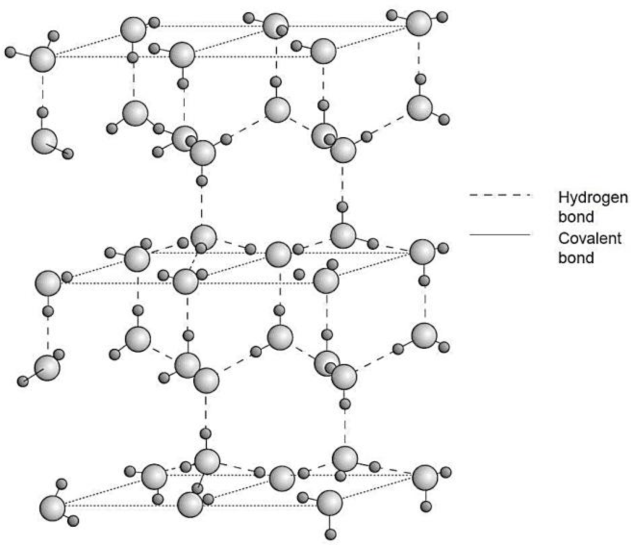


Fig. 6.1

(a) (i) By calculating the melting temperature at 15 km above the Earth's surface, show that the melting temperature of ice remains relatively constant in the troposphere range.

[2]

(ii) The air temperature decreases by 6.5 °C for every 1 km increase in elevation.

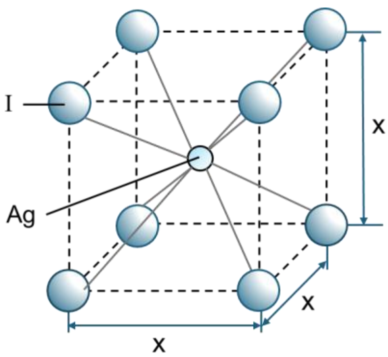
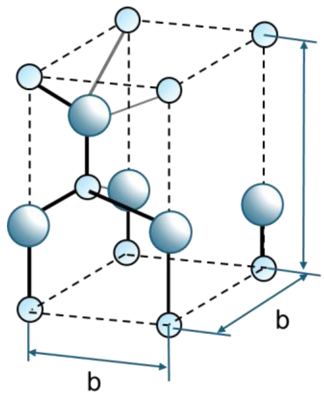
Determine the height at which ice crystals begin to form in the atmosphere, considering the average temperature in Singapore during September is 31°C.

[1]

(b) **(i)** Table 6.1 shows the structure of the simplest repeat unit in two possible crystalline structures of silver iodide.

In structure **A**, each Ag^+ is surrounded by 8 I^-. In structure **B**, each Ag^+ is surrounded by 4 I^-.

Table 6.1

	Structure **A**	Structure **B**
		
Number of Ag^+ in a unit cell	1	2
Number of I^- in a unit cell	1	2
Cell parameters/ nm	x = 0.656	a = 0.755, b = 0.466

Using the information from Fig. 6.1 and Table 6.1, deduce which is the crystal structure of AgI that allows it to nucleate ice.

.... [1]

(ii) Hence, determine the density of AgI in g cm^{-3}.

[1 nm= 10^{-7} cm]

[2]

Table 6.2 shows data relevant to this question.

Table 6.2

	Energy/ kJ mol^{-1}
enthalpy change of atomisation of Ag(s)	+285
enthalpy change of sublimation of $I_2(s)$ $I_2(s) \rightarrow I_2(g)$	+62.4
electron affinity of I(g)	−295.4
enthalpy change of formation of AgI	−62

(c) Use the data in Table 6.2, together with data from the *Data Booklet*, to calculate a value for the lattice energy of silver iodide, AgI.

Show your working.

[3]

(d) (i)

Table 6.3

Compound	Experimental lattice energies/ kJ mol^{-1}	Theoretical lattice energies/ kJ mol^{-1}
Sodium chloride	−781	−766
Silver fluoride	−967	−953
Silver iodide	−889	−808

Silver fluoride has the same crystalline structure as sodium chloride, unlike silver iodide. Like sodium chloride, there is close agreement between the experimental and theoretical values of lattice energy for AgF but not AgI.

Suggest a reason for this.

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(ii) Silver(I) ions are known to be highly toxic to aquatic life. However, scientific findings show that at the concentrations used during typical cloud seeding operations, AgI poses negligible environmental risk. This is postulated to be due to its endothermic enthalpy change of solution.

Use your knowledge of the enthalpy factors that are involved in the process of dissolving an ionic salt in water, suggest a reason for this.

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[Total: 12]

Additional answer space

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