

NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE
NAME

CLASS

TUTOR'S
NAME

CHEMISTRY

Paper 3 Free Response

9729/03

September 2025

2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name and class 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.

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 Examiner's Use	
1	/ 22
2	/ 20
3	/ 18
4	/ 20
5	/ 20
Total	/ 80

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

[Turn Over

1 (a) The pH values of the solutions of four chlorides are given in Table 1.1.

compound	pH of 1.0 mol dm ⁻³ solution
BeCl ₂	x
NaCl	7.0
AlCl ₃	3.0
PCl ₅	1.0

- (i) Explain the difference in pH values of solutions of NaCl , AlCl_3 and PCl_5 , in terms of the structures of the chlorides. Include appropriate equation(s) in your answer. [4]
- (ii) Using the *Data Booklet*, suggest how the pH value of 1.0 mol dm^{-3} solution of BeCl_2 compares to 1.0 mol dm^{-3} solution of AlCl_3 . Explain your answer. [2]
- (iii) At certain temperatures, aluminum chloride exists as Al_2Cl_6 molecules. Draw the structure of Al_2Cl_6 . Label the co-ordinate bonds on your structure. [1]

[illegible]

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- (b) Beryllium, in Period 2, is the only element in Group 2 that shares very similar chemical properties with aluminium which is in Period 3.

Describe the similarities in their acid-base behaviour and explain why beryllium oxide reacts similarly like aluminium oxide. Illustrate the reactions of beryllium oxide with equations. [2]

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(c) BrC/ reacts with benzene in the presence of AlCl_3 in an electrophilic substitution reaction to produce bromobenzene.

(i) Explain why bromobenzene is made in preference to chlorobenzene during the reaction. [1]

(ii) Hence, draw the electrophilic substitution mechanism of the reaction. [2]

(iii) The position of substitution in the electrophilic substitution of mono-substituted arene depends on the nature of the group, **Z**, already attached to the ring. This selectivity can be explained based on the stability of the intermediate formed in the first step. Fig. 1.1 shows three possible first steps in the mono-bromination of a mono-substituted arene and the products obtained.

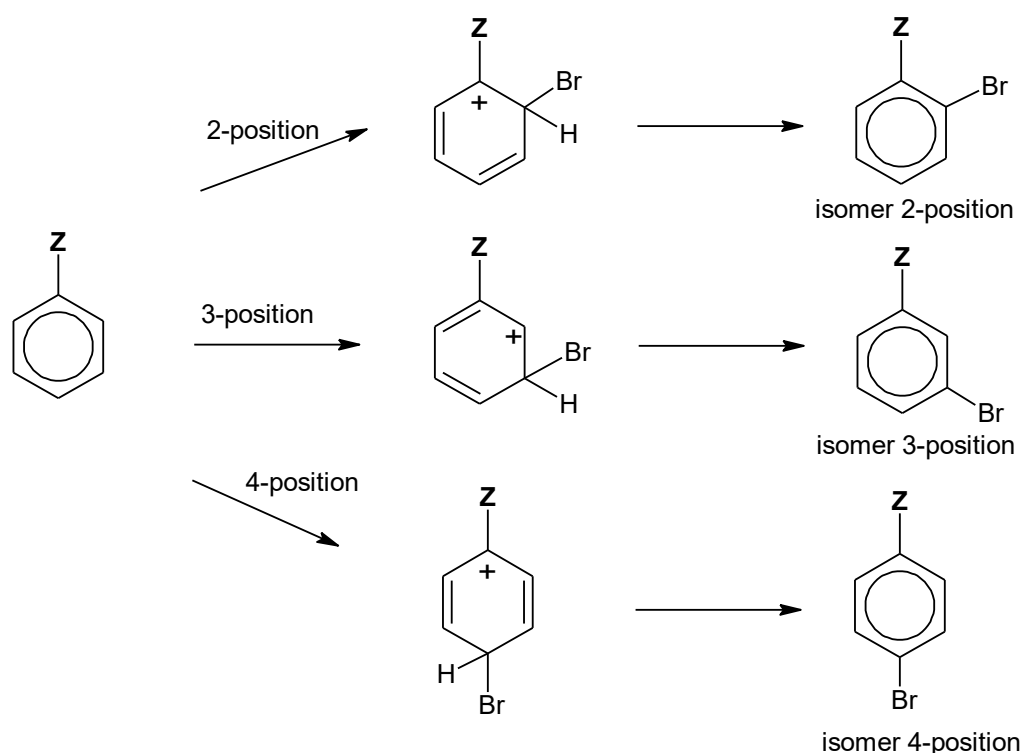
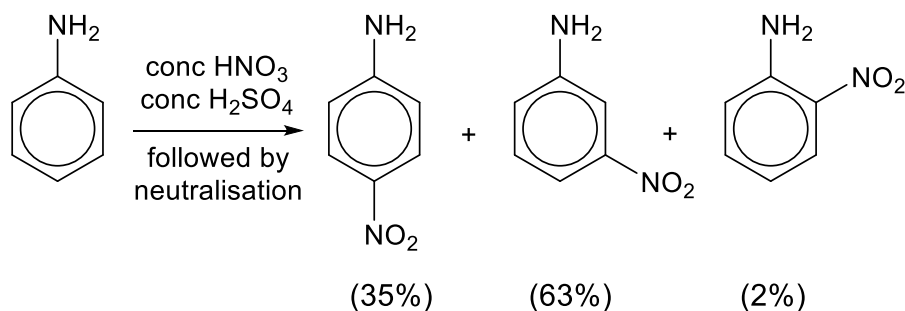


Fig. 1.1

Use this information to predict which substituted isomers in Fig. 1.1 will be formed the least and the most when **Z** is a $-\text{C}(\text{CH}_3)_3$ group. Explain your reasoning. [2]

(iv) When **Z** is a $-\text{NH}_2$ group and was reacted with concentrated HNO_3 and concentrated H_2SO_4 , the proportion of 3-nitrophenylamine was found to be unexpectedly high.



Explain why 3-nitrophenylamine was the major product. [1]

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(d) Three organohalogeno compounds are shown.

$\text{C}_6\text{H}_5\text{CH}_2\text{Cl}$	$\text{C}_6\text{H}_5\text{Cl}$	$\text{C}_6\text{H}_5\text{COCl}$
A	B	C

Arrange **A**, **B** and **C** in order of increasing relative rate of hydrolysis. Explain your answer. [3]

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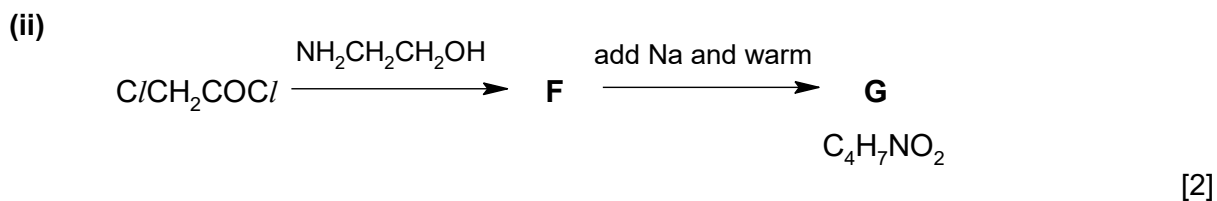
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E and **G** are cyclic compounds.



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[Turn Over

- 2 (a) A calorimeter containing 300 cm^3 of water at $25\text{ }^\circ\text{C}$ was calibrated. 10 kJ of heat energy from a heating coil was used to increase the temperature of water by $7.5\text{ }^\circ\text{C}$. Calculate the heat capacity of the empty calorimeter. [2]

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- (b) Ag_2CO_3 is a sparingly soluble salt. A 100 cm^3 saturated solution of Ag_2CO_3 in water was found to contain $2.57 \times 10^{-4}\text{ mol dm}^{-3}$ of Ag^+ ions.

- (i) Calculate the K_{sp} of Ag_2CO_3 and state its units. [2]
- (ii) Hence, calculate the solubility of Ag_2CO_3 when 2.50 g of Na_2CO_3 solid was added to the solution above. [2]

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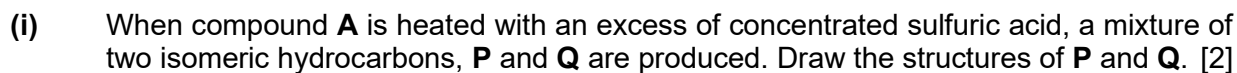
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$$Al_2I_6(g) \rightleftharpoons 2AlI_3(g) \quad \Delta H > 0$$

- (i) A 10.0 g sample of Al_2I_6 was allowed to vapourise in a 2 dm^3 vessel at 400°C . Calculate the initial pressure of Al_2I_6 . [1]
- (ii) Given that the degree of dissociation of Al_2I_6 was 0.35, calculate the value of K_p for the equilibrium at 400°C . State its units. [3]
- (iii) Explain the effect on the degree of dissociation of Al_2I_6 if the reaction was carried out at 300°C . [2]

[illegible]



(ii) Suggest the type of reaction in step 1. [1]

(iii) State the reagents and conditions required for steps 2 to 4 and draw the structures of **B** and **C**. [5]

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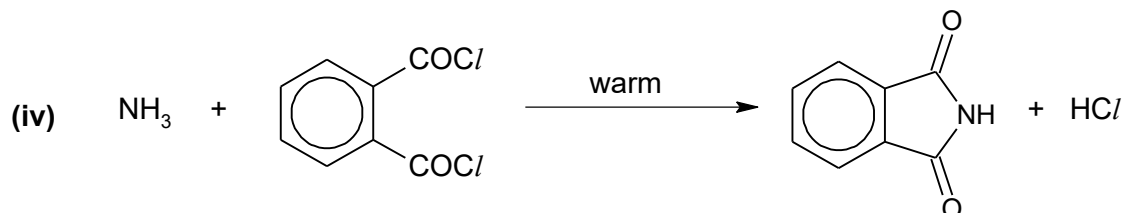
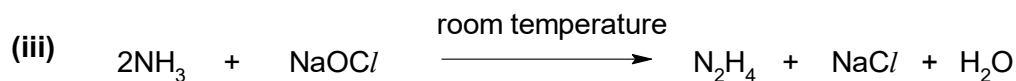
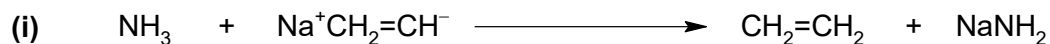
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Compound	Molecular formula
Ammonia	NH_3
Tetrazene	N_4H_4
Hydrogen azide	HN_3

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- [illegible]

- (c)** Ammonia can react in various ways: as an acid, as a base, as a nucleophile, as an oxidising agent and as a reducing agent. Study the following reactions and decide how ammonia is reacting in each case. Explain your answers fully. [4]

This image shows a full page of white paper designed for handwriting practice. It features 15 evenly spaced, horizontal dashed lines that run across the entire width of the page. These lines are intended to guide the placement of letters and help children learn proper letter height and alignment. There are no margins, text, or other markings on the page.

- (d) State the type of reaction in **(c)(iv)**. Fig. 3.1 shows the mechanism for the reaction in **(c)(iv)**. Complete the mechanism for steps 1 to 3 on Fig. 3.1. Show all charges and relevant lone pairs and show the movement of electron pairs by using curly arrows. [3]

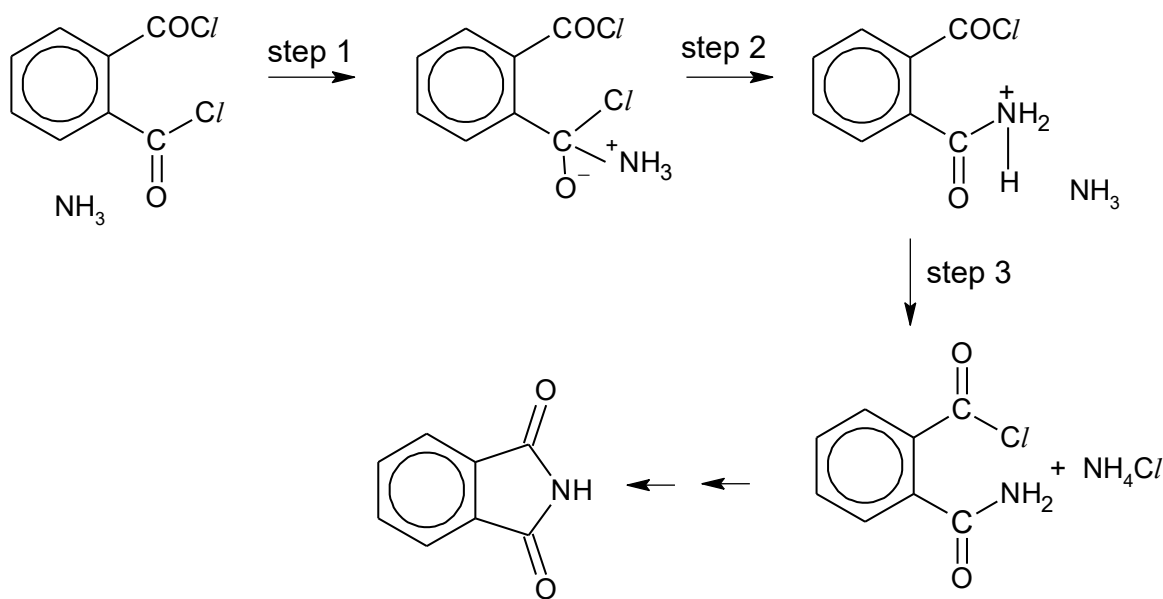
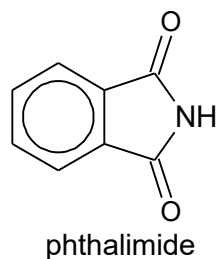


Fig. 3.1

- (e) Phthalimide is a white solid that is slightly soluble in water. The stability of this compound is attributed to the presence of the benzene ring and $\text{C}=\text{O}$ groups, which allows for resonance to take place. The nitrogen atom in phthalimide is sp^2 hybridised.



- (i) By reference to the hybridisation of the N atom and orbital overlap, suggest how the electrons are arranged in the second shell of the sp^2 nitrogen atom in phthalimide. [2]
- (ii) Suggest and explain how the basicity of 4-methylphenylamine might compare to that of phthalimide. [2]

- (f) Amino acids are critical to life, and they serve as building blocks of proteins.

Lysine is an alpha amino acid which shows both acidic and basic properties. The R group of lysine is $-(CH_2)_4NH_2$. In acidic solution, lysine is completely protonated.

10.0 cm^3 of completely protonated lysine is titrated with 1.00 mol dm^{-3} sodium hydroxide solution. Its titration curve is shown in Fig. 3.2.

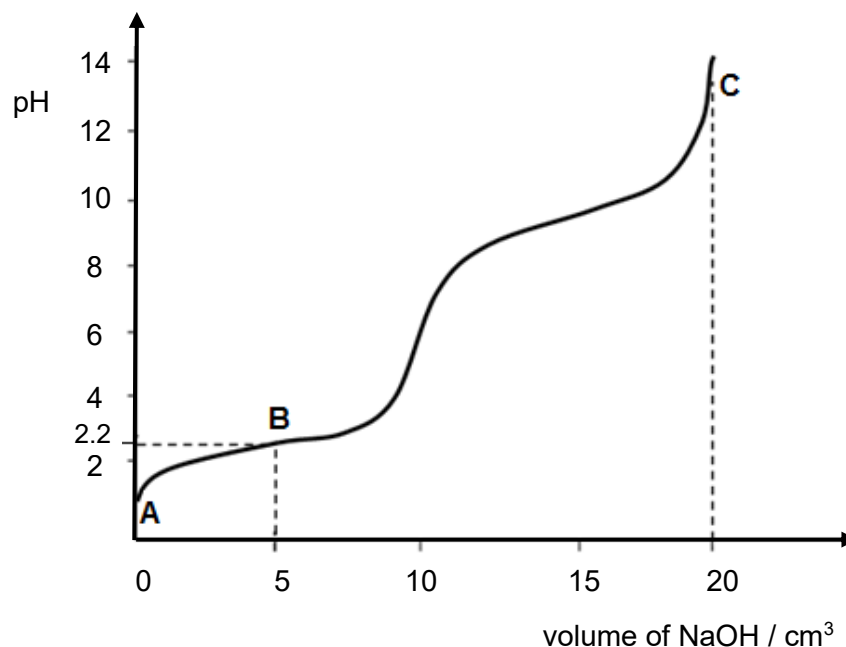


Fig. 3.2

- (i) Calculate the first dissociation constant K_{a1} of fully protonated lysine. [1]
- (ii) With the aid of an equation, explain how the species present at point **B** can resist changes in pH when a small amount of base is added. [2]
- (iii) Calculate the pH when 10.0 cm^3 of $0.0200\text{ mol dm}^{-3}$ sodium hydroxide is added to the solution at point **B**. (You may represent the fully protonated lysine as HA.) [2]

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Section B

Answer **one** question from this section.

- 4 (a) Lead(II) carbonate decomposes on heating in the same way as magnesium carbonate. By using relevant data from the *Data Booklet*, predict and explain which of the two carbonates, lead(II) carbonate or magnesium carbonate, would have a higher decomposition temperature. [2]

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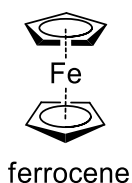
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- (b) Ferrocene, $\text{Fe}(\text{C}_5\text{H}_5)_2$, is an orange solid. In this complex, C_5H_5^- is the ligand and it donates π electrons from the ring to the vacant 3d orbital of Fe.



Ferrocene can undergo a series of different reactions and some are analogues of organic reactions. Two reactions of ferrocene are shown in Fig. 4.1.

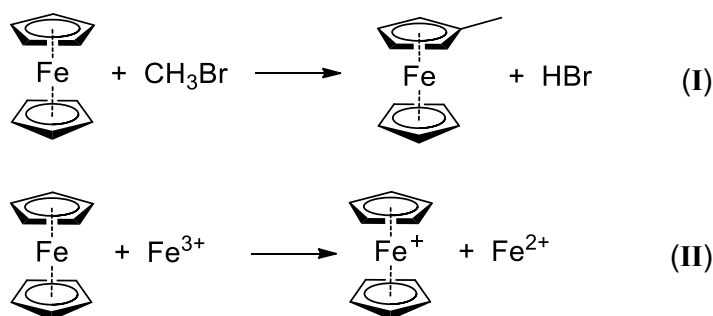
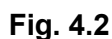


Fig. 4.1

- (i) State the type of reaction for reaction (I). [1]
- (ii) State the oxidation number of Fe in ferrocene and write its electronic configuration. [1]
- (iii) Explain why ferrocene is a coloured complex. [2]

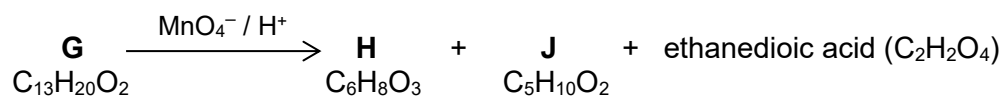


(v) By considering reaction (II), suggest if $E^{\circ}(\text{Fe}(\text{C}_5\text{H}_5)_2^+|\text{Fe}(\text{C}_5\text{H}_5)_2)$ is more or less positive than $E^{\circ}(\text{Fe}^{3+}|\text{Fe}^{2+})$. Explain your answer. [1]

Explain with the aid of equations how it works. You may use $\text{Fe}(\text{C}_5\text{H}_5)_2$ to represent ferrocene. [3]

(vii) By considering your answers for (v) and (vi), suggest a value for $E^\circ(\text{Fe}(\text{C}_5\text{H}_5)_2^+|\text{Fe}(\text{C}_5\text{H}_5)_2)$. [1]

[illegible]



Compound **J** evolves CO_2 with NaHCO_3 . **J** also reacts with LiAlH_4 to give a compound which does not undergo elimination reaction with concentrated sulfuric acid.

Compound **H** gives an orange precipitate with 2,4-dinitrophenylhydrazine reagent. **H** has no reaction with Tollens' reagent. When one mole of **H** reacts with an excess of alkaline aqueous iodine, two moles of yellow precipitate are produced.

Use the information above to deduce the structures for compounds **G**, **H** and **J**. [7]

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$$\text{H}_2\text{C}=\text{CH}_2(\text{g}) + \text{O}(\text{g}) \longrightarrow \text{H}_2\text{C}-\text{CH}_2(\text{g}) \quad \Delta H^\circ = -354 \text{ kJ mol}^{-1}$$

epoxyethane

- (i) Use the *Data Booklet* to calculate a theoretical value for the sum of the C–C and $2 \times$ C–O bond energies in epoxyethane. [1]
- (ii) Use the ΔH° value for the reaction between ethene molecules and oxygen atoms given above to calculate the actual value for the sum of the C–C and $2 \times$ C–O bond energies in epoxyethane. Suggest an explanation for the difference between the theoretical and actual values. [2]
- (iii) Predict, with a reason, the entropy change for the above reaction. [2]
- (iv) Hence, explain if the reaction is feasible at high, low or all temperatures. [1]

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- (b) Dinitrogen pentoxide, N_2O_5 , exist as colourless crystals that sublime slightly above room temperature. It exists as covalent molecules $\text{O}_2\text{N}-\text{O}-\text{NO}_2$ in the gas phase, but as ionic $[\text{NO}_2^+ \text{NO}_3^-]$ in the solid or in solution.

When heated in CCl_4 solvent, N_2O_5 decomposes on heating to give NO_2 and O_2 . The mechanism for the thermal decomposition of N_2O_5 is thought to involve three steps.

- There is an initial homolytic breaking of an N–O bond to give $\text{NO}_2\cdot$ and $\text{NO}_3\cdot$ radicals.
- This is followed by the dimerisation of the $\text{NO}_3\cdot$ radical to give N_2O_6 , which contains a –O–O– peroxide bond.
- The third step involves the dissociation of this dimer via further N–O bond cleavage to form the products.

Use the information to draw out the mechanism for the thermal decomposition of N_2O_5 . You are advised to use structural formulae for all species so that it is clear which bonds are broken and which are formed. Indicate any unpaired electrons by a dot (\cdot). [3]

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You may assume the three N–O bonds in NO_3 have the same strength.

[4]

	$\Delta H / \text{kJ mol}^{-1}$
1 st electron affinity of $\text{NO}_3(\text{g})$	–317
bond energy of N–O bonds in $\text{NO}_3(\text{g})$	+400
standard enthalpy change of atomisation of $\text{Mg}(\text{s})$	+148
standard enthalpy change of formation of $\text{Mg}(\text{NO}_3)_2(\text{s})$	–791

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OC(=O)CC(=O)CC(=O)O

- (i) Give the systematic name for compound **L**. [1]
- (ii) Suggest structures for **J** and **K** and explain the reactions described. [6]

[illegible]

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[illegible]