



CANDIDATE
NAME

Suggested Solutions

CG

INDEX NO

CHEMISTRY

9729/02

Paper 2 Structured Questions

1 September 2025

2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name, class and index number in the spaces 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.

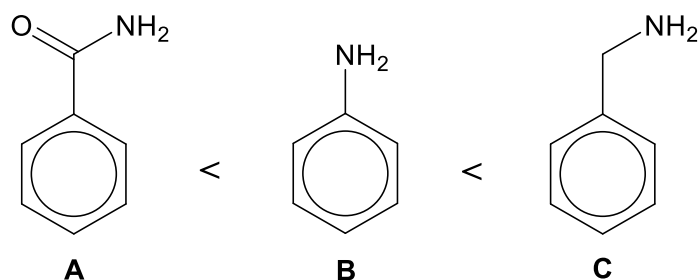
A Data Booklet is provided.

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

For Examiner's Use		
1	/ 18	
2	/ 24	
3	/ 17	
4	/ 16	
Penalty	units	significant figures
Overall	/ 75	

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

- 1 (a) Compounds **A**, **B** and **C** are shown in order of increasing basicity. Explain this order.



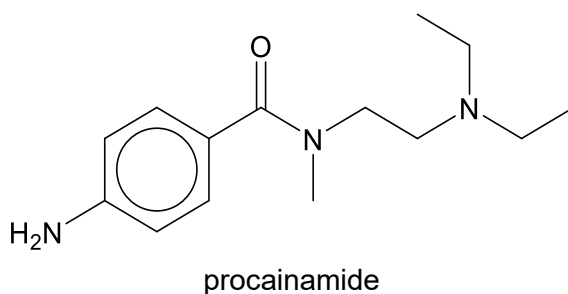
C is most basic as the N is attached to an **electron donating alkyl group** which **increases the electron density on the N atom** and hence **increasing the availability of lone pair** of electrons to accept H^+ .

In compound **B**, there is **delocalisation of lone pair of electrons on N atom into the benzene ring**. Hence this **decreases the availability of lone pair** of electrons on the N atom to accept H^+ , making compound **B** less basic than **C**.

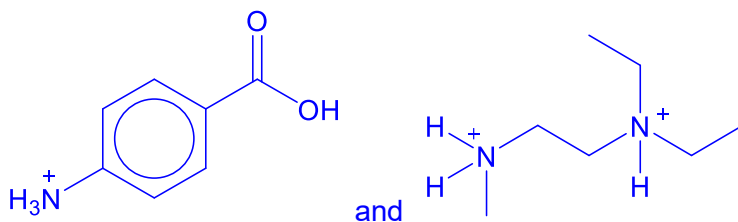
A is an amide and is neutral because the **lone pair of electrons on the N atom is delocalised into the electron-withdrawing C=O group**, hence **unavailable** to accept a H^+ ion. Hence compound **A** is the least basic amongst the three compounds.

[3]

- (b) Amides can be found in many drugs such as paracetamol and procainamide. Procainamide can be used for the treatment of cardiac arrhythmias.



Predict the products obtained when procainamide undergoes reaction with hot, dilute H_2SO_4 .



[2]

- (c) Compound **J** can be synthesised by the following route in Fig. 1.1, with all the carbon atoms coming from compound **E**.

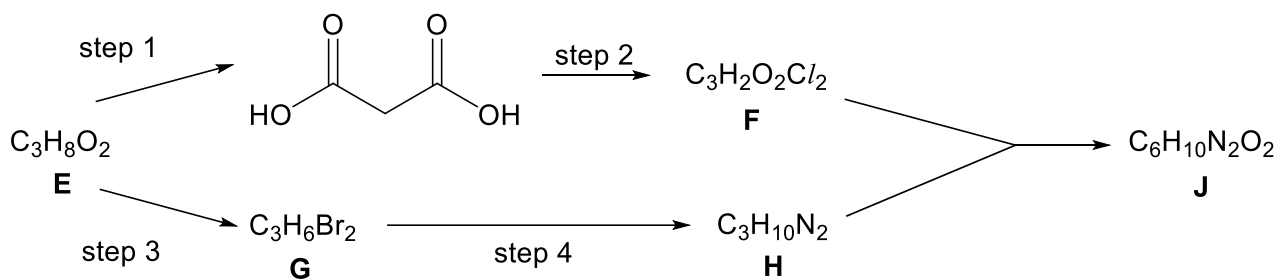
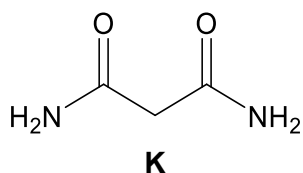


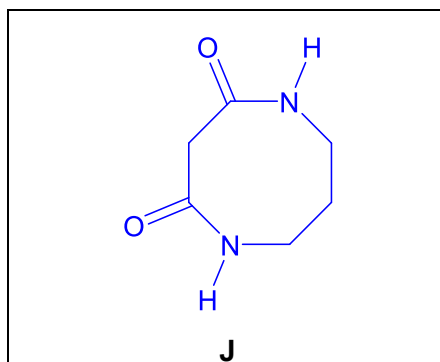
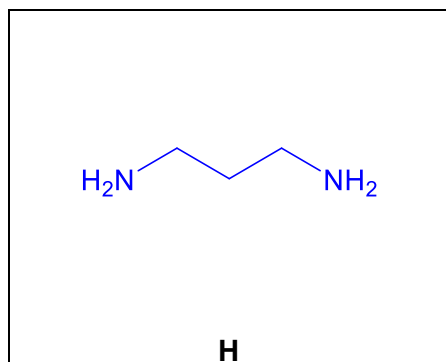
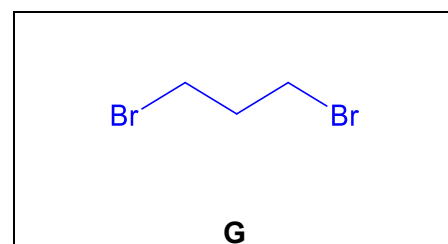
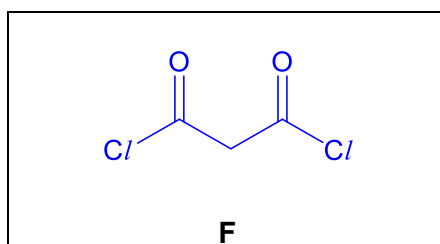
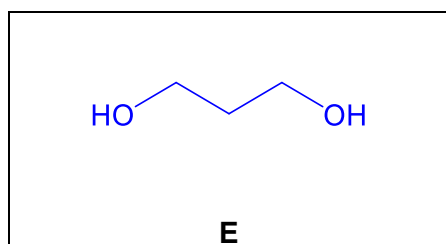
Fig. 1.1

- Compound **E** does not react with $NaOH(aq)$ but reacts with Na to give a gas that extinguishes a lighted splint with a 'pop' sound.
- Compound **H** is soluble in dilute HCl and can also be obtained from the reaction of compound **K** with $LiAlH_4$.



- Compound **J** is neutral and is a cyclic molecule.

(i) Draw the structure of compounds **E** to **H**, and **J**.



(ii) State the reagents and conditions for steps 2 and 4.

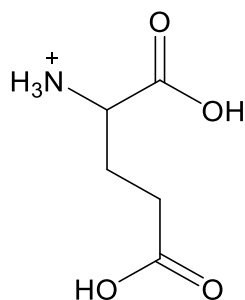
step 2 (anhydrous) PCl_5 / PCl_3 / $SOCl_2$

step 4 excess NH_3 in ethanol, heat in sealed tube

[5]

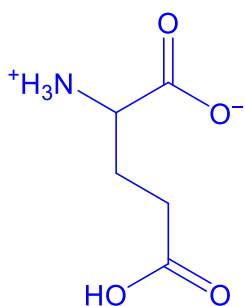
[2]

- (d) The compounds responsible for the umami flavour of soy sauce are salts of glutamic acid.



glutamic acid

Glutamic acid has pK_a values of 2.1, 4.1 and 9.5. Draw the structure of the zwitterion. Suggest a pH at which the predominant species of glutamic acid is a zwitterion.



pH between 2.1 and 4.1 is accepted (students are to give a pH, not a pH range) [2]

- (e) A polypeptide contains 9 amino acid residues. It was partially hydrolysed to give a mixture of tripeptides.

asp-gly-tyr
glu-tyr-lys
gly-glu-tyr
met-asp-gly
tyr-ala-gly

Determine the sequence of amino acids that make up the primary structure of the polypeptide.

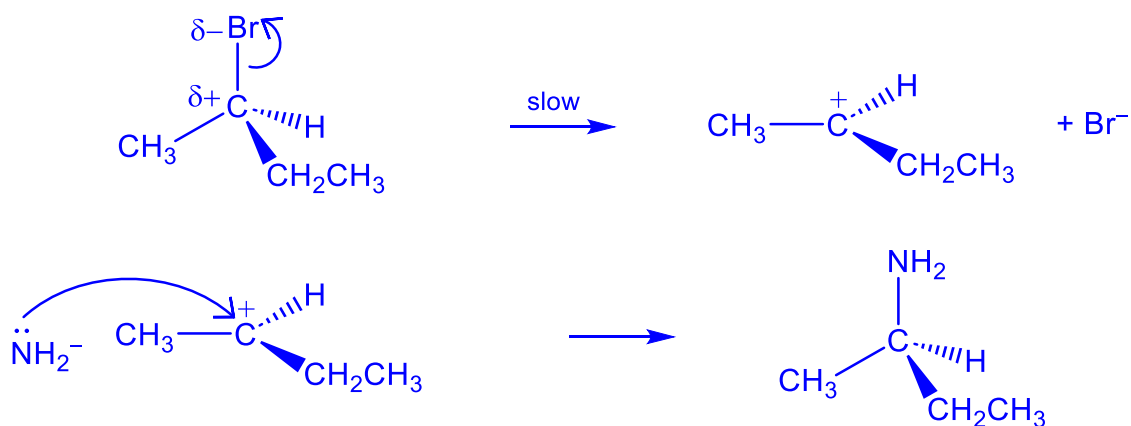
met-asp-gly-tyr-ala-gly-glu-tyr-lys [1]

- (f) Halogenoalkanes can react with NH_2^- to produce amines.

A sample that contains only one enantiomer of 2-bromobutane reacts completely with NH_2^- to produce a mixture that does not rotate plane-polarised light.

Draw a mechanism for the reaction between NH_2^- and 2-bromobutane. Include all relevant lone pairs, dipoles, curly arrows and charges.

Nucleophilic substitution, $\text{S}_\text{N}1$

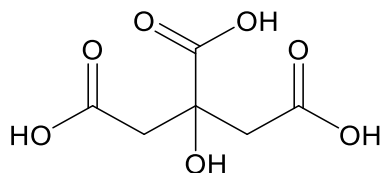


[3]

[Total: 18]

- 2 Citric acid, $C_6H_8O_7$, is a naturally occurring weak organic acid found in citrus fruits. It has a wide range of applications in the food, cleaning products and healthcare industries.

It is triprotic and has the following structure.



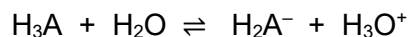
- (a) (i) Citric acid is a Brønsted-Lowry acid.

Explain what is meant by this statement.

Citric acid is a **proton/ H^+ donor**. [1]

- (ii) The dissociation of citric acid in water occurs in three steps.

Using H_3A as a simplified representation of citric acid, the first dissociation step is as shown:



Write the balanced equation for the second dissociation step of citric acid in water.

$H_2A^- + H_2O \rightleftharpoons HA^{2-} + H_3O^+$ [1]

- (iii) Identify the two conjugate acid-base pairs in the dissociation step you have written in (a)(ii).

acid	H_2A^-	conjugate base	HA^{2-}
base	H_2O	conjugate acid	H_3O^+

[1]

- (iv) Explain why the carboxylic acid group on citric acid is a stronger Brønsted-Lowry acid than the hydroxyl group.

The **carboxylate ion is more stable** than the alkoxide ion as the **negative charge** on the O atom of the carboxylate ion is **more effectively delocalised between the two electronegative oxygen atoms**. [1]

- (b) The pK_a values for citric acid are shown in Table 2.1.

Table 2.1

	pK_1	pK_2	pK_3
citric acid	3.1	4.8	6.4

- (i) Calculate the pH of 0.10 mol dm^{-3} citric acid at 298 K (ignore the effect of pK_2 and pK_3 on the pH). Show your working.

$$K_1 = 10^{-3.1}$$

$$= 0.00079433$$

$$[\text{H}_3\text{O}^+] = \sqrt{K_1 \times c}$$

$$= \sqrt{0.00079433 \times 0.1}$$

$$= 0.0089125 \text{ mol dm}^{-3}$$

$$\text{pH} = -\log 0.0089125$$

$$= 2.05$$

[2]

- (ii) A buffer solution with a pH of 3.40 is made by adding 50 cm^3 of solution L containing monosodium citrate to 100 cm^3 of $0.0200 \text{ mol dm}^{-3}$ citric acid.

Calculate the concentration of monosodium citrate in solution L.

You may use NaH_2A to represent monosodium citrate, and H_3A to represent citric acid.

Let the conc of monosodium citrate in solution L be $x \text{ mol dm}^{-3}$.

Amount of monosodium citrate used = $0.05x \text{ mol}$

Amount of citric acid used = $0.1 \times 0.0200 = 0.002 \text{ mol}$

$\text{pH} = \text{p}K_a + \lg [\text{salt}]/[\text{acid}]$

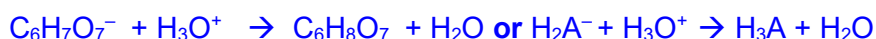
$$3.40 = 3.1 + \lg [(0.05x \div 0.150) / (0.002 \div 0.150)]$$

$$\lg (0.05x / 0.002) = 0.3$$

$$x = 0.0798 \text{ mol dm}^{-3}$$

[3]

- (iii) Using an equation, explain how the citric acid/monosodium citrate buffer solution in (b)(ii) resists pH changes when a small amount of acid is added to it.



When a small amount of H_3O^+ is added, most of the H_3O^+ ions are removed by $\text{C}_6\text{H}_7\text{O}_7^- / \text{H}_2\text{A}^-$. Hence, the $[\text{H}_3\text{O}^+]$ in the solution does not increase much / does not change significantly and the pH of the solution is kept relatively constant.

[2]

- (iv) 10 cm³ of 0.100 mol dm⁻³ citric acid was titrated against 0.100 mol dm⁻³ sodium hydroxide. The titration curve is shown in Fig. 2.1.

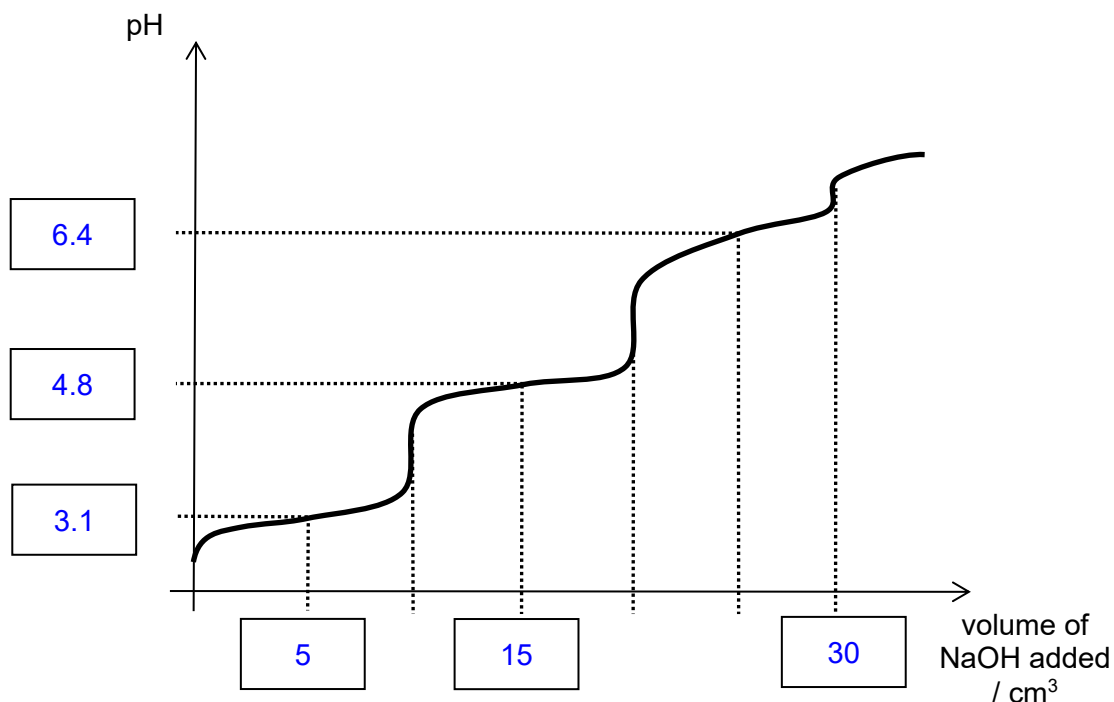
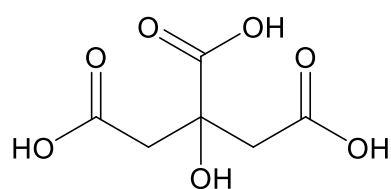


Fig. 2.1

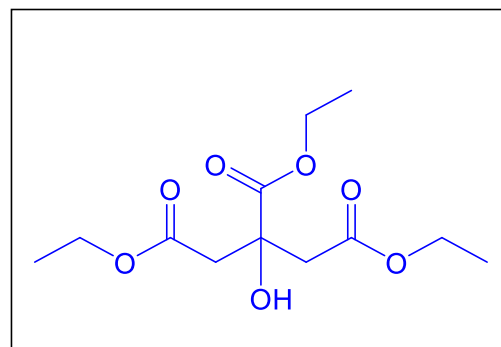
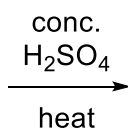
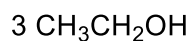
Fill in the boxes above with the correct pH values and NaOH volumes.

[2]

- (c) A sample of citric acid is heated with excess ethanol in the presence of a small amount of concentrated sulfuric acid.



+



- (i) In the box above, draw the skeletal structure of the organic product formed.

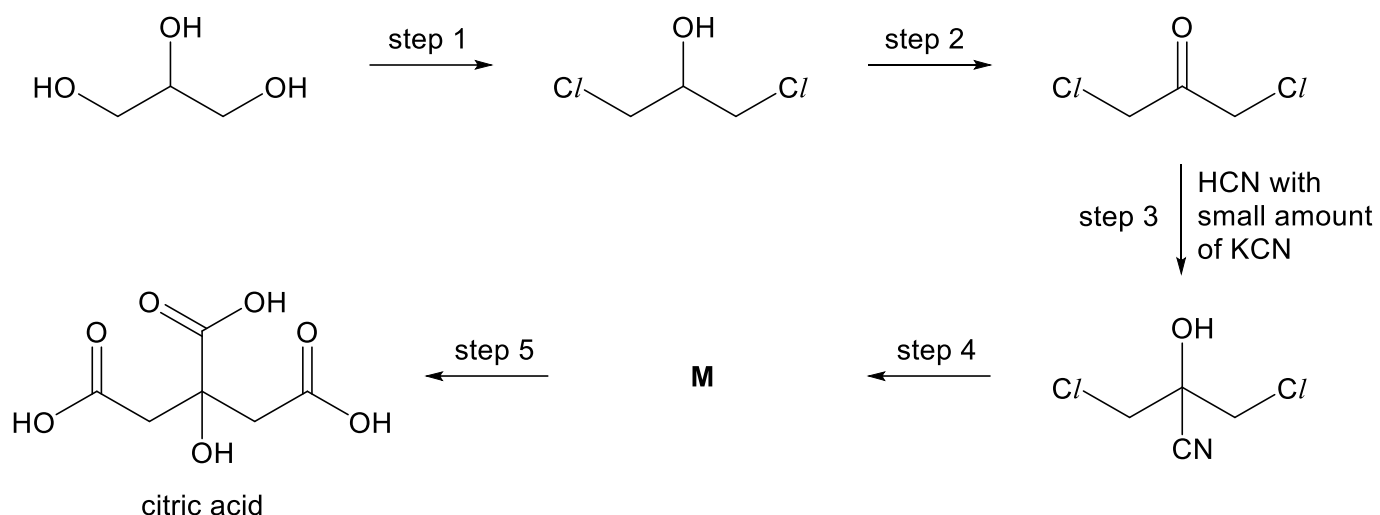
[1]

- (ii) State the type of reaction that has occurred.

Condensation

[1]

(d) Citric acid can be synthesised from glycerol in 5 steps according to the following reaction scheme.



- (i) Step 1 is a nucleophilic substitution reaction. Using specific reagents and conditions, only the primary alcohol groups of glycerol are substituted to produce a chloroalkane.

Suggest why substitution occurs only at the primary alcohol groups.

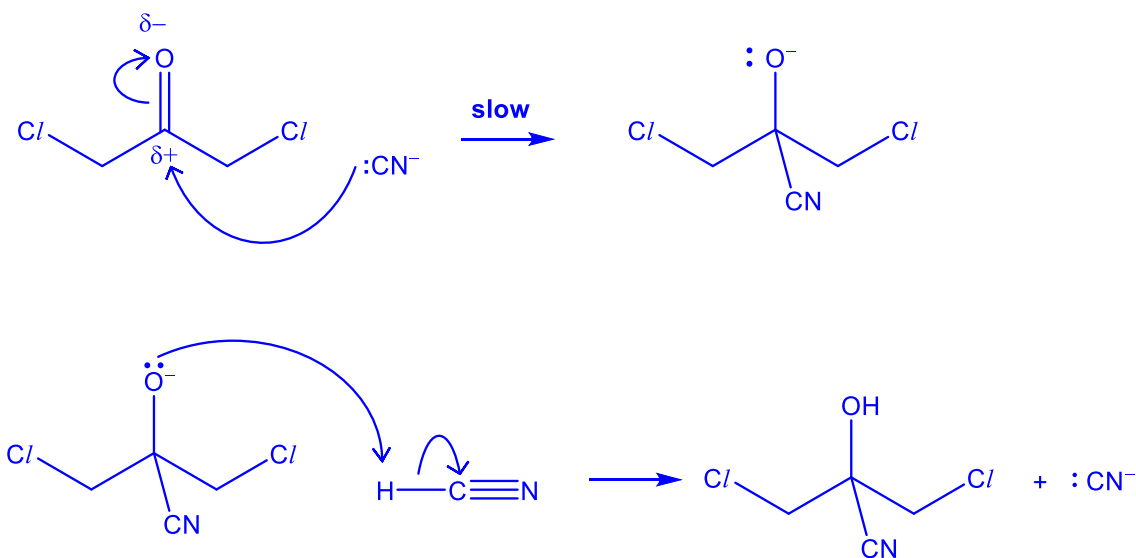
There is less steric hindrance at the primary alcohol groups which allows the nucleophile to approach more easily.

OR

The reactive carbon of a primary alcohol has fewer electron-donating alkyl groups and is thus more electron-deficient, so it is more susceptible to nucleophilic attack. [1]

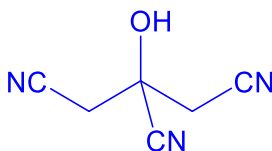
- (ii) Draw the mechanism for step 3 of the reaction scheme. Include all relevant lone pairs, dipoles, curly arrows and charges.

Nucleophilic addition



[3]

- (iii) Draw the structure of the intermediate compound, **M**, and state the reagents and conditions for steps 4 and 5.

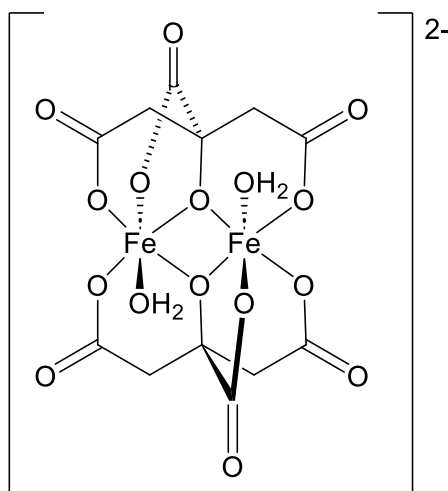
**M**

step 4 ethanolic NaCN, heat

step 5 dilute H₂SO₄, heat

[3]

- (e) Fully-deprotonated citric acid, C₆H₄O₇⁴⁻, can form soluble complexes with iron ions. The structure of one such complex which involves two C₆H₄O₇⁴⁻ as ligands is shown below.



- (i) Determine the oxidation state of iron in this complex. Show how you arrived at your answer.

Let oxidation state of iron in this complex be +x.

$$2x + (-8) = -2$$

$$2x = 6$$

$$x = 3, \text{ i.e., oxidation state is } +3$$

[1]

- (ii) A solution containing C₆H₄O₇⁴⁻ removes rust by forming a soluble complex with iron ions, while a solution containing citric acid removes rust via an acid-base reaction.

Suggest a reason why C₆H₄O₇⁴⁻ is preferred over citric acid in removing rust from steel.

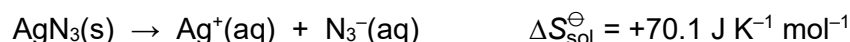
Citric acid could **further react with steel in an acid-metal reaction** whereas the solution containing C₆H₄O₇⁴⁻ will not further corrode the steel.

[1]

[Total: 24]

3 Silver azide, AgN_3 , is sparingly soluble in water at 25 °C.

(a) The equation for the entropy change of solution is shown.



The standard enthalpy change of formation for these species are shown in Table 3.1.

Table 3.1

species	$\text{AgN}_3(\text{s})$	$\text{Ag}^+(\text{aq})$	$\text{N}_3^-(\text{aq})$
$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	+315.0	+105.9	+272.7

(i) Explain the significance of the sign of the entropy change for the dissolution of silver azide.

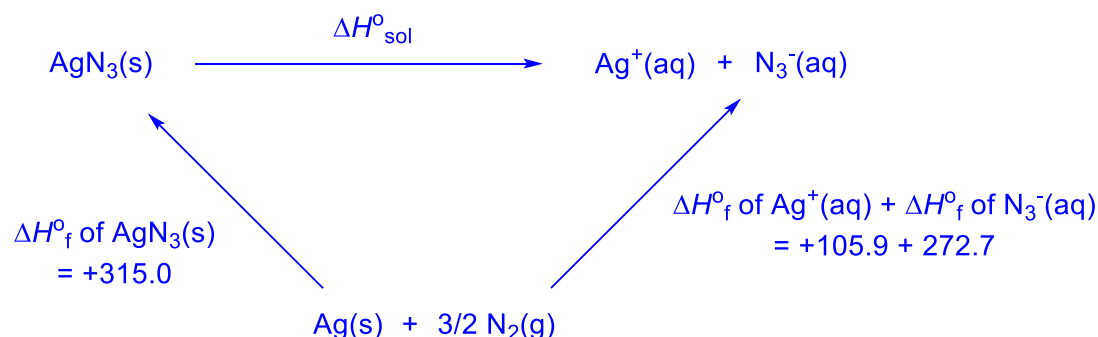
The **orderly arrangement of ions in the ionic lattice is disrupted / the ions are mobile/free to move about**, which leads to **more ways to arrange them / distribute energy**, leading to **more disorder** and an **increase in entropy**.

OR

The dissolution results in an **increase in the number of dissolved ions/particles**, which leads to **more ways to arrange them / distribute energy**, leading to **more disorder** and an **increase in entropy**. [1]

(ii) Calculate $\Delta H_{\text{sol}}^\ominus$ and $\Delta G_{\text{sol}}^\ominus$ for silver azide and use this information to explain why AgN_3 is only sparingly soluble in water at 25 °C.

Show your working.



$$\Delta H_{\text{sol}}^\ominus = -(315.0) + (105.9 + 272.7) = +63.6 \text{ kJ mol}^{-1}$$

$$\Delta G_{\text{sol}}^\ominus = \Delta H_{\text{sol}}^\ominus - T\Delta S_{\text{sol}}^\ominus = +63.6 - 298(70.1/1000) = +42.7 \text{ kJ mol}^{-1}$$

Since $\Delta G_{\text{sol}}^\ominus > 0$, the dissolution of AgN_3 is non-spontaneous and thus AgN_3 is sparingly soluble at 25 °C. [3]

- (b) In an experiment, solid sodium azide, $\text{NaN}_3(\text{s})$, was added slowly to a 1 dm^3 solution containing $2.00 \times 10^{-4} \text{ mol}$ of $\text{Ag}^+(\text{aq})$, and the amount of AgN_3 precipitated out was measured.

Fig. 3.1 shows the graph of amount of AgN_3 precipitated out against amount of NaN_3 added. The graph is not drawn to scale.

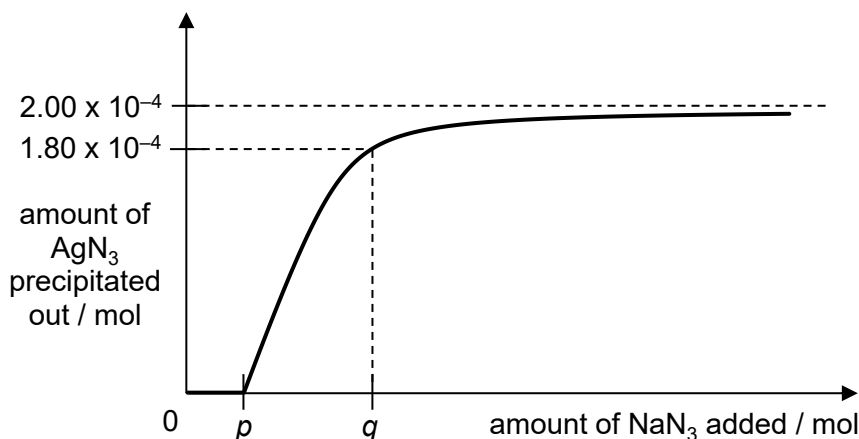


Fig. 3.1

The K_{sp} value of AgN_3 is 2.80×10^{-9} .

- (i) Explain why AgN_3 is just about to precipitate out when $p \text{ mol}$ of NaN_3 was added.

The solution is saturated when $p \text{ mol}$ of NaN_3 is added. At that instant, ionic product = K_{sp} and the precipitate is (just about to be) formed. [1]

- (ii) Hence, or otherwise, determine the value of p .

$$\begin{aligned} [\text{Ag}^+][\text{N}_3^-] &= 2.80 \times 10^{-9} \\ (2.00 \times 10^{-4}) \times p &= 2.80 \times 10^{-9} \\ p &= 1.40 \times 10^{-5} \end{aligned} \quad [1]$$

- (iii) Calculate the $[\text{Ag}^+]$ remaining in the solution when $1.80 \times 10^{-4} \text{ mol}$ of AgN_3 has precipitated out.

$$[\text{Ag}^+]_{\text{remaining in solution}} = 2.00 \times 10^{-4} - 1.80 \times 10^{-4} = 2.00 \times 10^{-5} \quad [1]$$

- (iv) By considering your answer in (b)(iii) and the $[\text{N}_3^-]$ remaining in solution, determine the value of q , which is amount of NaN_3 to be added for $1.80 \times 10^{-4} \text{ mol}$ of AgN_3 to precipitate out.

After $1.80 \times 10^{-4} \text{ mol}$ of AgN_3 has precipitated out, ionic product = K_{sp}
i.e. $[\text{Ag}^+]_{\text{remaining in solution}} \times [\text{N}_3^-]_{\text{remaining in solution}} = 2.80 \times 10^{-9}$

$$[\text{N}_3^-]_{\text{remaining in solution}} = q - 1.80 \times 10^{-4}$$

$$(2.00 \times 10^{-5})(q - 1.80 \times 10^{-4}) = 2.80 \times 10^{-9}$$

$$q = 3.20 \times 10^{-4} \quad [1]$$

- (v) Comment on the change in gradient of the graph as it approaches 2.00×10^{-4} on the y-axis.

The **gradient becomes less steep**. A much higher concentration of $[\text{N}_3^-]$ is required for ionic product to exceed K_{sp} and let a little AgN_3 precipitate out, because the **$[\text{Ag}^+]_{\text{remaining in solution}}$ becomes increasingly low**. [1]

- (c) Some information about N_3^- is provided in Table 3.2.

Table 3.2

shape of N_3^- ion	linear
N–N–N bond angle	180°

The bond length between nitrogen atoms in different molecules is shown in Table 3.3.

Table 3.3

molecule containing nitrogen-nitrogen bond	bond length / nm
N_2	0.110
N_3^-	0.116
$\text{H}_2\text{N}-\text{NH}_2$	0.145

Fig. 3.2 shows one possible arrangement of valence electrons and bonds in N_3^- .

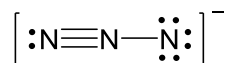


Fig. 3.2

- (i) Nitrogen atoms undergo the same type of hybridisation as carbon atoms.

Using Fig. 3.2 and/or information from Table 3.2, suggest the hybridisation of the central N atom in N_3^- .

Explain your answer.

sp hybridization. There are two π bonds / the shape is linear / there are 2 bond pairs and 0 lone pairs around N / there are only 2 regions of electron density / 2 electron pairs around N. [2]

- (ii) Use information from Table 3.3 to explain why Fig. 3.2 does **not** represent an accurate model for the bonding in N_3^- .

The figure shows **a triple N–N bond and a single N–N bond**, which should have **different bond lengths**. However, **Table 3.3 only gives one N–N bond length**, which suggests that the two N–N bonds have the same length. [1]

- (d) N_3^- is frequently used as a nucleophile in organic reactions because it allows nitrogen to be introduced into an organic compound.

Fig. 3.3 shows how an acid chloride can be converted into an amine with the use of N_3^- as one of the reagents.

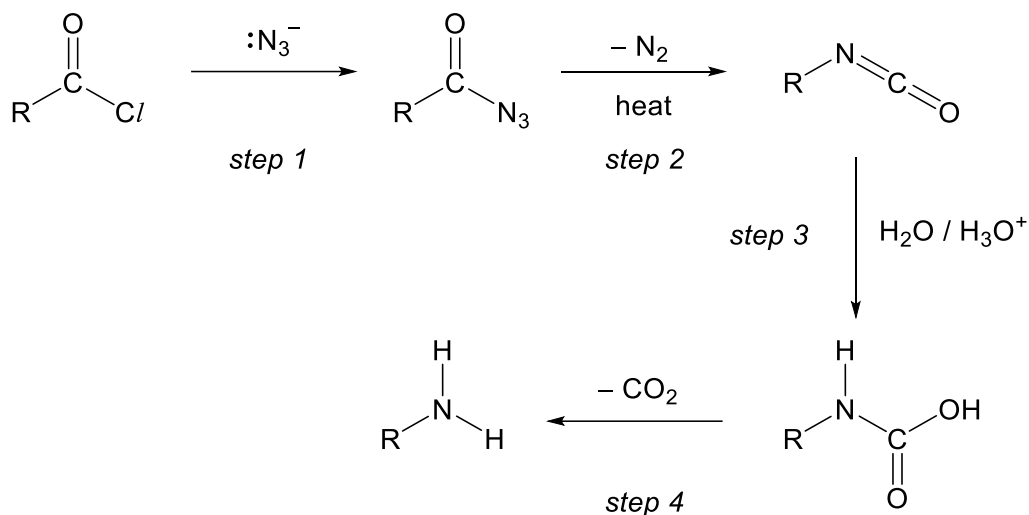


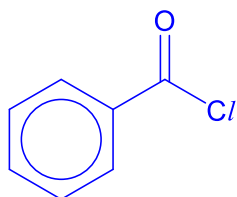
Fig. 3.3

- (i) Suggest the type of reaction in *step 3*.

Addition (of water)

[1]

- (ii) Draw the structure of the acid chloride that will be converted to phenylamine through the process shown in Fig. 3.3.



[1]

- (iii) On Fig. 3.4, draw curly arrows to complete the mechanism for *step 3*. Show all relevant dipoles and lone pairs in your answer. [2]

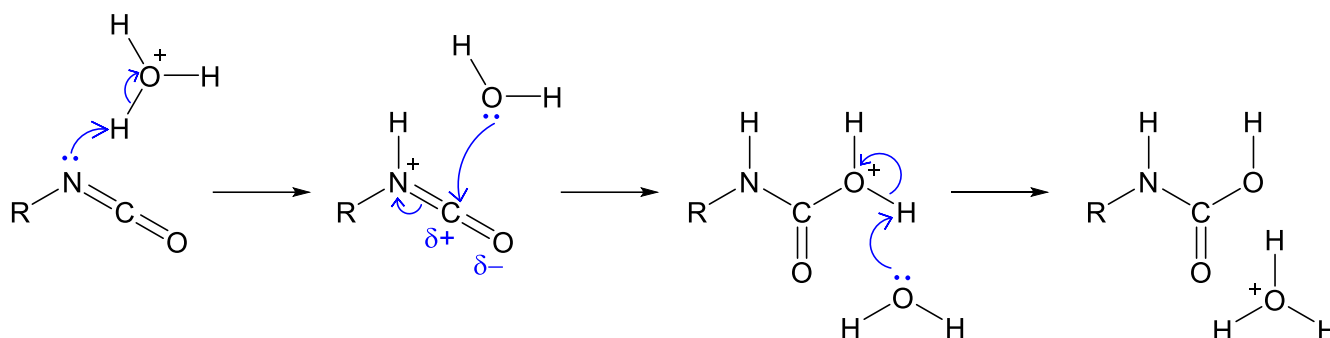


Fig. 3.4

- (iv) In Fig. 3.4, H_3O^+ serves two roles. One of the roles it serves is that of a Brønsted-Lowry acid.

Deduce the other role of H_3O^+ . Explain your answer.

H_3O^+ is a **catalyst** because it was **used / participated in the reaction** and then **regenerated**. [1]

[Total: 17]

4 This question is about the chemistry of noble gases in Group 18 of the Periodic Table.

(a) Noble gases are known for their behaviour that closely resembles an ideal gas, especially under certain conditions.

(i) State and explain the **two** conditions under which a real gas behaves most closely to an ideal gas.

High temperature – gas particles have **high kinetic energy / move fast to overcome intermolecular forces of attraction** OR gas particles have **high kinetic energy and move further apart so volume of gas particles is insignificant** compared to volume of container.

Low pressure – gas particles are **further apart** so the **intermolecular forces of attraction are insignificant** OR gas particles are **further apart so volume of gas particles is insignificant** compared to volume of container [2]

(ii) Explain why Ne behaves more closely to an ideal gas than HF.

The predominant intermolecular force of attraction between Ne particles is **weak instantaneous dipole-induced dipole interactions** while that between HF particles is **hydrogen bonding, which is stronger**. [2]

(b) A 3 dm³ vessel containing He at 4.0 kPa is connected to an empty 2 dm³ vessel at constant temperature.

(i) Show that the pressure of He after the two vessels are connected is 2.4 kPa.

Since temperature is constant and number of moles of He remains the same,

$$\begin{aligned} p_1 V_1 &= p_2 V_2 \\ 4.0 \times 3 &= p_2 \times (3+2) \\ p_2 &= 12/5 = 2.4 \text{ kPa (shown)} \end{aligned} \quad [1]$$

Xe is then pumped into the connected vessels until the total pressure inside the vessels is 6.0 kPa.

(ii) Calculate the partial pressure of Xe in the vessels.

$$\begin{aligned} p_{\text{total}} &= p_{\text{He}} + p_{\text{Xe}} \\ 6.0 &= 2.4 + p_{\text{Xe}} \\ p_{\text{Xe}} &= 3.6 \text{ kPa} \end{aligned} \quad [1]$$

(iii) Hence, or otherwise, calculate the mole fraction of Xe.

$$\text{mole fraction of Xe} = p_{\text{Xe}} / p_{\text{total}} = 3.6 / 6.0 = 0.6 \quad [1]$$

Table 4.1 provides information on some noble gases.

Table 4.1

	He	Ne	Ar	Kr	Xe
relative atomic mass	4.0	20.2	39.9	83.8	131.3
atomic radius / nm	0.140	0.160	0.190	0.202	0.216
density / g dm ⁻³	0.179	0.900	1.78	3.71	5.85
first ionisation energy / kJ mol ⁻¹	2370	2080	1520	1350	1170
boiling point / °C	-269	-246	-186	-152	-107

- (c) Noble gases were long believed to be totally unreactive but stable compounds of Kr and Xe are now known. Highly electronegative elements such as fluorine and oxygen form many compounds with Xe, for example, XeF₂, XeF₄ and XeO₄. All of these compounds are simple covalent molecules.

- (i) Ne is in period 2 and does not form any compound at all. Explain why.

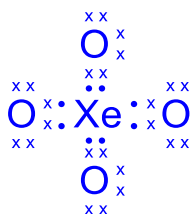
Ne does not have low-lying / energetically-accessible/available vacant orbitals to accept more electrons / expand octet. [1]

- (ii) Describe the covalent bond in a molecule of XeF₄.

Electrostatic forces of attraction between shared electrons and the positively-charged Xe and F nuclei. [1]

- (iii) Draw the 'dot-and-cross' diagram for XeO₄.

Use VSEPR theory to predict the shape of and bond angle in XeO₄. Explain your answer.



Shape is **tetrahedral**, bond angle is **109.5°**.

There are **4 bond pairs and 0 lone pairs**. Based on VSEPR theory, these bond pairs would **space out to minimise repulsion**. [3]

- (iv) Xe can form XeF₂ and XeF₄ but Kr can only form KrF₂.

Use information from Table 4.1 to suggest a reason why Kr does not form a compound with four fluorine atoms.

The atomic radius of Kr is smaller than that of Xe, so Kr is unable to accommodate 4 F atoms around it. [1]

- (d) The first noble gas compound was synthesised by reacting Xe with PtF_6 .

PtF_6 is a strong oxidant that is able to extract an electron from Xe, thus forming $\text{Xe}^+[\text{PtF}_6]^-$, which is an ionic compound.

- (i) Explain why the Xe^+ ion can be described as a radical.

Xe^+ has an unpaired electron. [1]

- (ii) Although PtF_6 is able to extract an electron from Xe, it is unable to do so from He and Ne. Use information from Table 4.1 to suggest why this is so.

The first ionisation energies of He and Ne are too large, so it is difficult to extract an electron from them. [1]

- (e) He has an unusually low abundance in earth's atmosphere despite being the most abundant Group 18 element in the solar system.

Use information from Table 4.1 to suggest a reason for the low abundance of He in earth's atmosphere.

Density of He is low and it escapes into space from earth's atmosphere easily. [1]

[Total: 16]