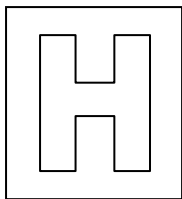


Candidate Name: _____

Class Adm No

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2025 Preliminary Examination Pre-University 3

H2 CHEMISTRY

Paper 2 Structured Questions

9729/02

3 September 2025

2 hours

Candidates answer on the Question paper.

Additional materials: Data Booklet

Suggested answers

- 1 The fire triangle (Fig 1.1), shows the three components necessary for combustion. Disrupting any one of these components can suppress or extinguish a fire.

For
Examiners'
Use

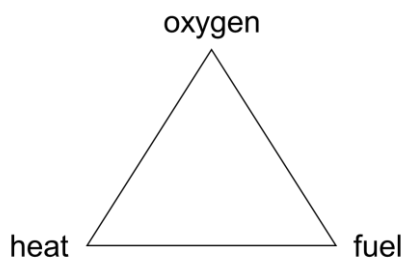
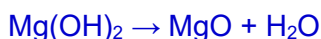


Fig 1.1

Fire retardants are substances added to materials to reduce flammability by disrupting the fire triangle.

- (a) Magnesium hydroxide, $\text{Mg}(\text{OH})_2$, is an example of an inorganic fire retardant. It undergoes thermal decomposition upon heating and releases water vapour in the process.

- (i) Write a balanced equation for the thermal decomposition of magnesium hydroxide. State symbols are **not** required. [1]



- (ii) With reference to the components in Fig 1.1, suggest two ways in which this decomposition reaction helps to suppress a fire. [1]

The decomposition process is endothermic, which removes the heat component from the fire triangle.

Water (vapour) released dilutes the oxygen that is available, reducing the amount of oxygen in the fire triangle.

Magnesium oxide forms a protective barrier over the fuel, keeping oxygen and the fuel separated.

Any 1 for [1]

Aluminium hydroxide, $\text{Al}(\text{OH})_3$ is also a good fire retardant. It undergoes thermal decomposition in the same way as magnesium hydroxide.

- (iii) Explain why the thermal decomposition temperature of $\text{Al}(\text{OH})_3$ is lower than that of $\text{Mg}(\text{OH})_2$. [2]

Al^{3+} has a higher charge density than Mg^{2+} and polarises the O–H bond and weakens it to a larger extent, hence it decomposes at a lower temperature.

[1] higher charge density

[1] polarises O–H bond and weakens to a larger extent

- (iv) Hence, explain whether $\text{Al}(\text{OH})_3$ would be a better fire retardant compared to $\text{Mg}(\text{OH})_2$. [1]

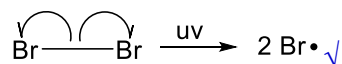
Better since the decomposition will occur at the lower temperature and release water vapour earlier in a fire.

- (b) Halogenated fire retardants often use bromine or chlorine derivatives and they release hydrogen halides or halogen radicals upon decomposition which disrupt free radical chain reactions that sustain combustions.

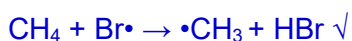
- (i) One method of preparing brominated organic compounds is free radical substitution.

Draw the mechanism for the formation of bromomethane from methane. [3]

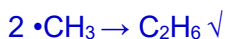
Initiation ✓



Propagation ✓



Termination ✓



8 ticks – [3]

5 – 7 ticks – [2]

3 – 4 ticks – [1]

Tetrabromobisphenol A (TBBPA) is a common brominated flame retardant. It can be made from bisphenol A (BPA) in a single step reaction, as shown in Fig. 1.2.

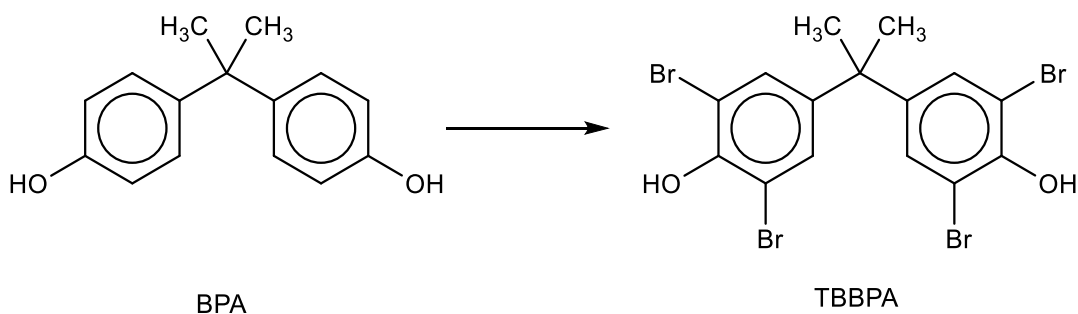
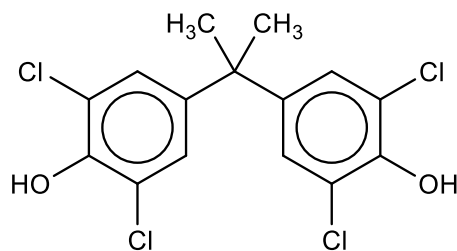


Fig 1.2

- (ii) State the reagent and conditions required to convert BPA to TBBPA. [1]

$\text{Br}_2(\text{aq})$



TCBPA

Tetrachlorobisphenol (TCBPA) is the chlorinated analogue of TBBPA, where the bromine atoms are replaced with chlorine.

- (iii) Using relevant data from the *Data Booklet*, explain the difference in strength between C–Cl and C–Br. [2]

C–Cl bond: 340 kJ mol⁻¹

C–Br bond: 280 kJ mol⁻¹

[1] for both values

The C–Br bond is weaker than the C–Cl bond because the Br atom is larger than the Cl atom, resulting in a longer bond and lower extent of orbital overlap. [1]

- (iv) Hence, explain whether TCBPA would be a better flame retardant than TBBPA. [1]

No it will be less effective because the C–Cl bond requires more energy to break and hence will not produce HCl or Cl radical as easily as TBBPA to suppress the fire.

Link bond energy to ease of formation of HX or X radical which suppresses fire.

- (c) Despite their effectiveness, halogenated fire retardants such as TBBPA are being phased out due to concerns over the release of toxic persistent organic pollutants during fires.

Suggest one reason why Mg(OH)₂ is considered a safer alternative to halogenated fire retardants. [1]

The products of Mg(OH)₂ decomposition (MgO and H₂O) are non-toxic.

[Total: 13]

- 2 (a) Lead(II) sulfate, PbSO_4 , is a sparingly soluble white solid that was historically used as a pigment in paints.

- (i) Write an expression for the solubility product, K_{sp} , of PbSO_4 , stating its units. [1]

$$K_{\text{sp}} = [\text{Pb}^{2+}][\text{SO}_4^{2-}], \text{ units: mol}^2 \text{ dm}^{-6}$$

- (ii) Calculate the solubility of PbSO_4 in pure water, given the value of K_{sp} is 1.60×10^{-8} . [1]

Let solubility of PbSO_4 be $x \text{ mol dm}^{-3}$

$$x^2 = 1.60 \times 10^{-8}$$

$$x = 1.26 \times 10^{-4} \text{ mol dm}^{-3} \text{ [1]}$$

- (iii) A common method used by early artists to prepare PbSO_4 was to mix solutions of Na_2SO_4 and $\text{Pb}(\text{NO}_3)_2$.

A solution of $0.0200 \text{ mol dm}^{-3}$ $\text{Pb}(\text{NO}_3)_2$ was mixed with an equal volume of Na_2SO_4 to prepare PbSO_4 .

Calculate the minimum concentration of Na_2SO_4 required for PbSO_4 to be formed. [2]

Upon mixing, $[\text{Pb}^{2+}] = 0.0200 / 2 = 0.0100 \text{ mol dm}^{-3}$

Hence $[\text{SO}_4^{2-}]$ at equilibrium $= 1.60 \times 10^{-8} / 0.0100 = 1.60 \times 10^{-6} \text{ mol dm}^{-3}$ [1]

However, before mixing, the concentration is double.

Hence $[\text{Na}_2\text{SO}_4]$ required $= 1.60 \times 10^{-6} \times 2 = 3.20 \times 10^{-6} \text{ mol dm}^{-3}$ [1]

- (b) Due to the increased awareness of the toxicity of lead compounds, titanium dioxide, TiO_2 , is now widely used as a non-toxic alternative to PbSO_4 in white pigments by modern artists.

- (i) Write the full electronic configuration of the titanium ion in TiO_2 . [1]



- (ii) Explain what is meant by the term *transition element*. [1]

A transition element is a **d-block element** which forms **one or more stable ions**, in compounds, with a **partially filled d-subshell**.

- (iii) Explain why TiO_2 appears white despite containing a transition element. [2]

TiO_2 has no electrons in the 3d subshell. [1]

Hence no wavelength of light is absorbed [1] and all are reflected hence it appears white.

- (c) Copper obtained from the extraction of copper ores is often impure and contains small amounts of other metals such as zinc, silver and lead.

To obtain high purity copper for electrical use, impure copper is placed at the anode and a pure copper rod is placed at the cathode in an electrolytic cell. The electrolyte used is aqueous copper(II) sulfate.

- (i) Write the half equation for the reaction occurring at the anode for copper. [1]



- (ii) Using relevant data from the *Data Booklet*, explain how zinc and silver impurities are removed during the purification process. [3]

$$E^{\ominus}(\text{Zn}^{2+}/\text{Zn}): -0.76 \text{ V}$$

$$E^{\ominus}(\text{Ag}^{+}/\text{Ag}): +0.80 \text{ V}$$

$$E^{\ominus}(\text{Cu}^{2+}/\text{Cu}): +0.34 \text{ V}$$

Since $E^{\ominus}(\text{Zn}^{2+}/\text{Zn})$ is more negative than $E^{\ominus}(\text{Cu}^{2+}/\text{Cu})$, Zn will be oxidised before Cu and forms Zn^{2+} in the electrolyte. [1]

$E^{\ominus}(\text{Ag}^{+}/\text{Ag})$ is less negative than $E^{\ominus}(\text{Cu}^{2+}/\text{Cu})$, hence it will not be oxidised and be found at the bottom of the anode as Ag metal. [1]

At the cathode, since $E^{\ominus}(\text{Zn}^{2+}/\text{Zn})$ is more negative than $E^{\ominus}(\text{Cu}^{2+}/\text{Cu})$, it will not be reduced and remain as Zn^{2+} in the electrolyte. [1]

While the lead impurity was expected to dissolve into the electrolyte as Pb^{2+} ions, it was instead found in the anodic sludge as a compound.

- (iii) State the identity of the compound and explain how it was formed. [2]



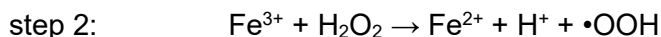
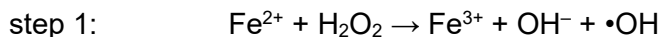
When Pb^{2+} is formed, it reacts with the SO_4^{2-} present in the electrolyte to form PbSO_4 and hence is deposited in the anodic sludge. [1]

[Total: 14]

- 3 Advanced Oxidation Processes (AOPs) are used to degrade organic pollutants in wastewater through the formation of highly reactive hydroxyl radicals ($\bullet\text{OH}$).

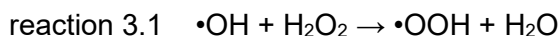
Two examples of AOPs are the Fenton reaction and the UV/ H_2O_2 process which generate hydroxyl radicals ($\bullet\text{OH}$) from H_2O_2 that is mixed in with the wastewater.

In the Fenton reaction, hydrogen peroxide reacts with iron(II) ions in acidic solution to generate hydroxyl radicals ($\bullet\text{OH}$) as well as hydroperoxyl radicals ($\bullet\text{OOH}$).

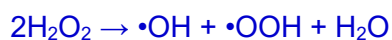


It is known that $\bullet\text{OH}$ is much more reactive than $\bullet\text{OOH}$ and is mainly responsible for the oxidation of organic pollutants.

In fact, $\bullet\text{OH}$ is so reactive that it reacts with hydrogen peroxide to form $\bullet\text{OOH}$ (reaction 3.1).



- (a) Write the overall equation for the Fenton reaction. [1]



- (b) It is said that Fe^{2+} acts as a catalyst in the Fenton reaction.

- (i) Explain how you can tell that Fe^{2+} is acting as a catalyst in this reaction. [1]

Fe^{2+} reacts in step 1 and is regenerated in step 2 of the reaction.

- (ii) State whether Fe^{2+} acts as a homogeneous or heterogeneous catalyst in the Fenton reaction. Explain your answer. [1]

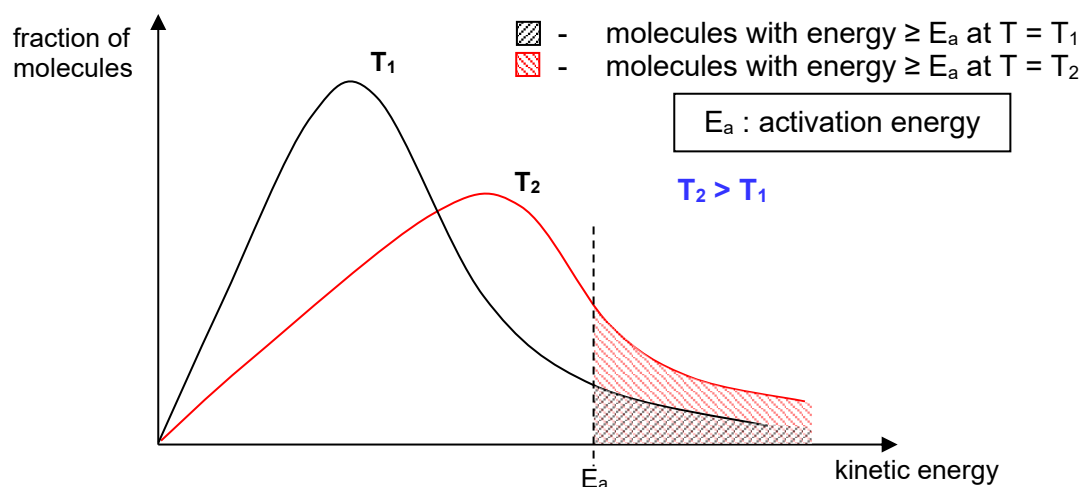
Homogeneous because the catalyst and the reactants are in the same phase.

- (c) Suggest a reason why the Fenton reaction is less effective at high pH values. [1]

At higher pH values, Fe^{2+} or Fe^{3+} precipitate out as $\text{Fe}(\text{OH})_2$ or $\text{Fe}(\text{OH})_3$, decreasing their availability for the Fenton reaction.

Idea that the ions precipitate out and hence the catalyst can no longer function

- (d) Explain, with the aid of a labelled Boltzmann distribution curve, how increasing the temperature increases the effectiveness of the Fenton reaction. [3]



[1] for graph (axes, start from origin, shape of graph T_2 flatter than T_1 , shading, single E_a)

When temperature increases from T_1 to T_2 , the average kinetic energy of H_2O_2 particles increase and the fraction of H_2O_2 particles having energy $\geq E_a$ increases. [1]

The frequency of effective collisions is higher hence more $\bullet OH$ radicals are generated and the reaction is more effective. [1]

- (e) It was observed that the effectiveness of the degradation decreased when the concentration of H_2O_2 exceeded its optimal level.

Suggest a reason for this observation.

[1]

When the concentration of H_2O_2 is too high, it reacts with the reactive $\bullet OH$ radical to form the $\bullet OOH$ radical, which is less effective at degrading the organic pollutants.

Idea that H_2O_2 reacts with the $\bullet OH$ radical instead of the pollutant, generating the weaker $\bullet OOH$ radical.

In the UV/ H_2O_2 process, short wavelength UV C radiation produced by UV lamps penetrates the solution and decomposes H_2O_2 to form hydroxyl radicals (reaction 3.2).



- (f) State the type of bond fission that occurs in reaction 3.2 when hydrogen peroxide is decomposed by UV light to form hydroxyl radicals. [1]

Homolytic fission

- (g) At times, the wastewater may be turbid due to the presence of suspended particles.

Explain why the UV/ H_2O_2 process may be less effective in turbid water.

[1]

The suspended particles block the UV from reaching the H_2O_2 and decreases the amount of hydroxyl radicals formed.

Idea that the particles absorb/reflect the UV, preventing it from reacting with the H_2O_2

Table 3.1 compares selected characteristics of the two processes.

Table 3.1

process	reagents required	pH range	byproduct
Fenton	Fe^{2+} and H_2O_2	~2.8	$Fe(OH)_3$ sludge
UV/ H_2O_2	H_2O_2	5–9	None

- (h) State one advantage and one disadvantage that the UV/ H_2O_2 process has over the Fenton reaction. [2]

advantage: can be used over a wider pH range, no byproducts

disadvantage: requires energy/electricity to power the UV lamps.

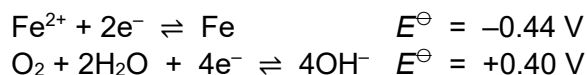
[Total: 12]

- 4 (a) The process of rusting begins with the formation of iron(II) hydroxide when iron is exposed to air and moisture. The iron(II) hydroxide is further oxidised to iron(III) hydroxide and eventually forms iron(III) oxide, Fe_2O_3 , commonly known as rust.

- (i) Explain why the Fe^{2+} ion is smaller than the Fe atom. [1]

Fe^{2+} ion has one less electron shell compared to the Fe atom, hence the attraction of the nucleus on the valence electrons is stronger, resulting in a smaller size.

- (ii) Using relevant data from the *Data Booklet*, explain why the oxidation of iron to iron(II) ions is spontaneous in the presence of air and moisture.



[2]

$$E^\ominus_{\text{cell}} = E^\ominus_{\text{cathode}} - E^\ominus_{\text{anode}}$$

$$= +0.40 - (-0.44)$$

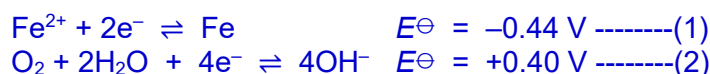
$$= +0.84\text{V} > 0$$

Since E^\ominus_{cell} is positive, the reaction is spontaneous

[1] for quoting 2 correct E^\ominus values

[1] for calculating E^\ominus_{cell}

- (iii) Explain how the formation of $\text{Fe}(\text{OH})_2$ causes the actual cell potential to be more positive than the value you calculated in (a)(ii). [2]



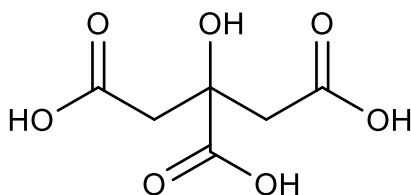
When $\text{Fe}(\text{OH})_2$ is formed, $[\text{Fe}^{2+}]$ decreases, causing the POE of (1) to shift to the left. As a result, E_{anode} becomes more negative than -0.44 V . [1]

At the same time, $[\text{OH}^-]$ decreases as well, causing the POE of (2) to shift to the right. As a result, E_{cathode} becomes more positive than $+0.40 \text{ V}$. [1]

These two cause the actual E_{cell} to be more positive.

- (b) A student investigates if lemon juice can be used to clean rusted iron surfaces.

Lemon juice contains citric acid, a weak acid.



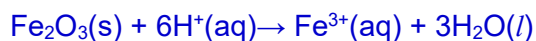
citric acid

- (i) Explain what is meant by a *weak acid*. [1]

A weak acid is an acid that partially dissociate or ionise in aqueous solution to give H^+ .

- (ii) Rust reacts with citric acid to form soluble iron(III) ions.

Write a balanced equation for the reaction of Fe_2O_3 with citric acid. Include state symbols in your equation. You may use H^+ to represent the acid from citric acid. [1]



Subsequently, citrate ions (Cit) act as tridentate ligands and bind to the iron(III) ions to form a soluble iron(III) citrate complex, $[Fe(Cit)_2]^{x-}$.

Fig 4.1 shows the structure of $[Fe(Cit)_2]^{x-}$.

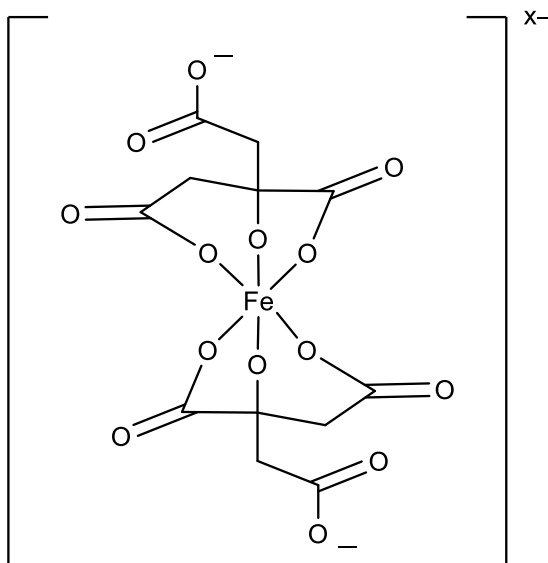


Fig. 4.1

- (iii) Give two reasons why Fe^{3+} is able to form complexes with ligands such as citrate ions. [2]

Fe^{3+} has a high charge density which draws lone pairs of electrons from the ligands [1]
and has energetically accessible vacant orbitals to accept lone pairs of electrons to form dative bonds. [1]

- (iv) State the coordination number of Fe^{3+} in $[\text{Fe}(\text{Cit})_2]^{x-}$. [1]

6

- (v) State the charge on the citrate ligand in $[\text{Fe}(\text{Cit})_2]^{x-}$. [1]

4-

accept -4

- (vi) Hence, determine the value of x in $[\text{Fe}(\text{Cit})_2]^{x-}$. [1]

Charge = $+3 + 2(-4) = -5$

x = 5

Each Cit ligand has a charge of 4-. There are two of them bound to Fe^{3+} hence the overall charge is -5

[Total: 12]

- 5 (a) Ring strain in cycloalkanes arises when the bond angles in the molecules deviate from their ideal tetrahedral angle of 109.5° .

Cyclohexane, C_6H_{12} , is considered largely strain free while smaller cycloalkanes like cyclopropane, C_3H_6 , experience significant ring strain.

The ring strain represents stored potential energy that contributes to the molecule's enthalpy change of combustion, a factor of significant interest in fuel research aimed at identifying high-energy-density compounds.

Table 5.1 shows the enthalpy change of combustion of gaseous cyclohexane and cyclopropane.

Table 5.1

compound	enthalpy change of combustion, $\Delta H_c / \text{kJ mol}^{-1}$
cyclohexane(g)	-3887
cyclopropane(g)	-2091

- (i) Write a balanced equation for the complete combustion of gaseous cyclohexane. [1]



- (ii) Using the information given in Table 5.1, calculate the average heat released per CH_2 group for gaseous cyclohexane in kJ mol^{-1} . [1]

In C_6H_{12} , there are 6 CH_2 groups

$$\text{average heat released per } \text{CH}_2 \text{ group} = 3887 \div 6 = 648 \text{ kJ mol}^{-1}$$

- (iii) Using your answer to (a)(ii), calculate the theoretical enthalpy change of combustion of cyclopropane, assuming it has no ring strain. [1]

In C_3H_6 , there are 3 CH_2 groups.

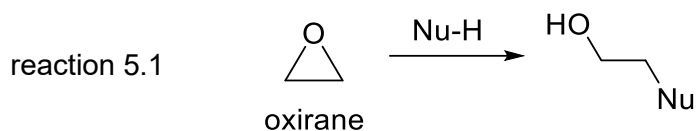
$$\text{Theoretical } \Delta H_c (\text{C}_3\text{H}_6) = 3 \times -647.833 = -1940 \text{ kJ mol}^{-1}$$

- (iv) Hence, calculate the ring strain energy present in one mole of cyclopropane. [1]

$$\text{Ring strain energy} = 2091 - 1943.5 = 148 \text{ kJ}$$

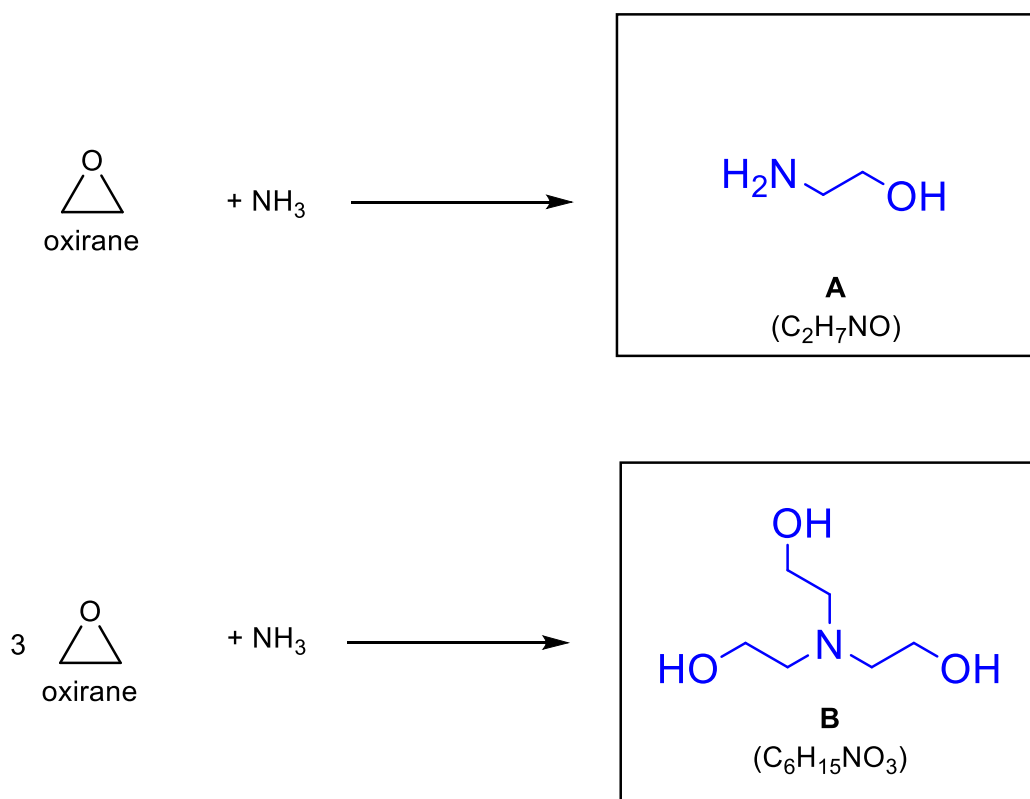
- (b) An epoxide contains a three-membered ring compound consisting of two carbon atoms and one oxygen atom. Since it experiences the same ring strain as cyclopropane, it is highly reactive towards nucleophiles. The simplest epoxide is oxirane, C_2H_4O .

When oxirane reacts with nucleophiles, the ring opens as shown in reaction 5.1.



- (i) When oxirane reacts with NH_3 in a 1:1 ratio, compound **A** (C_2H_7ON) is formed. However, when oxirane reacts with NH_3 in a 3:1 ratio, compound **B** ($C_6H_{15}NO_3$) is formed.

Draw the structures of **A** and **B**.



[2]

Epichlorohydrin is a useful epoxide used in the manufacture of epoxy resins. It can be prepared from 3-chloro-1-propene by a sequence of reactions as shown in Fig 5.1.

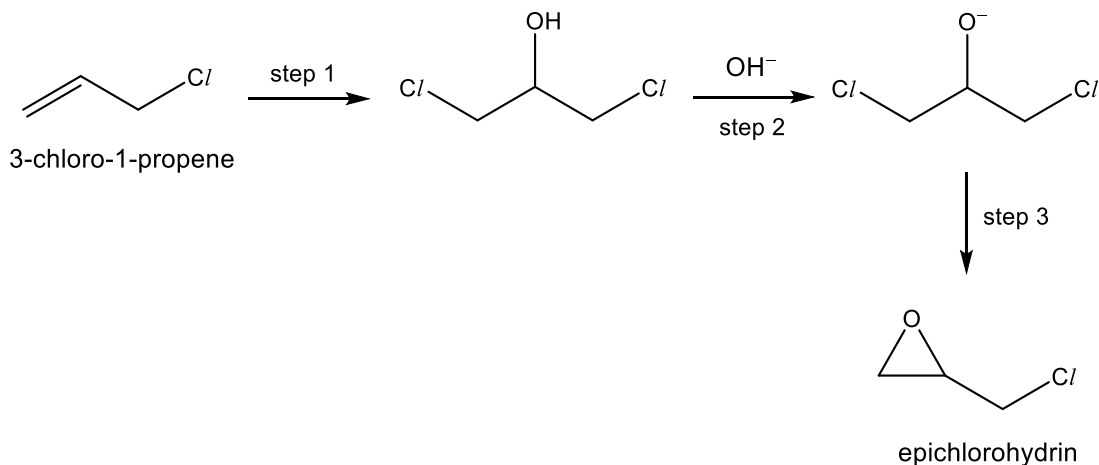


Fig 5.1

- (ii) State the reagent and conditions required for step 1. [1]

$\text{Cl}_2(\text{aq})$

- (iii) State the type of reaction for step 2 and step 3. [2]

step 2 : acid – base

step 3 : nucleophilic substitution

- (c) The acid-catalysed hydrolysis of styrene epoxide forms 1-phenyl-1,2-ethanediol as seen in Fig 5.2.

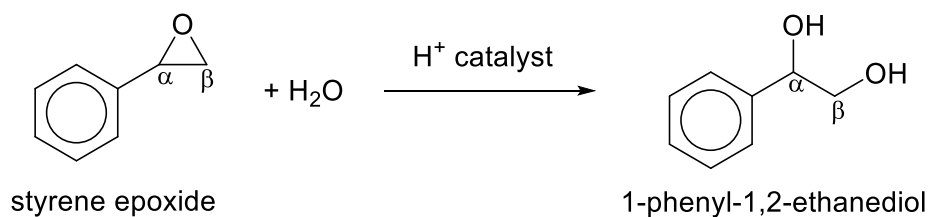


Fig 5.2

A student proposed that the reaction proceeds via the following mechanism:

- step 1: The protonation of the O atom in the epoxide by H^+ catalyst.
- step 2: A nucleophilic attack by H_2O on the carbon of the epoxide leading to the opening of the ring.
- step 3: The deprotonation of the H_2O^+ group forming the diol and regenerating the H^+ catalyst.

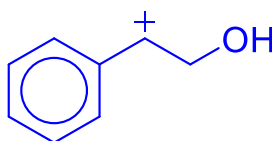
- (i) Based on your understanding of steric hindrance, circle the carbon, α or β , of the epoxide that would be attacked by the H_2O nucleophile in Fig 5.2. [1]

Circle β

Isotopic labelling is used in kinetic studies to learn about the mechanisms of a reaction. H_2^{18}O is a water molecule that contains ^{18}O instead of ^{16}O . The hydrolysis reaction was carried out with H_2^{18}O as the nucleophile.

A study of the hydrolysis products revealed that all ^{18}O were incorporated in the α -position. The conclusion drawn was that a stable carbocation intermediate must have formed before the nucleophilic attack by H_2^{18}O .

- (ii) Suggest the structure of the carbocation intermediate formed and explain why it is stable. [2]



As the α carbon is bonded to the benzene ring, the electrons from the benzene ring delocalise to the carbocation and stabilise the positive charge.

- (d) Nitrocellulose is produced by reacting cellulose with a nitrating mixture of concentrated nitric acid and concentrated sulfuric acid.

Sulfuric acid donates a proton to nitric acid from to form an intermediate, H_2NO_3^+ . This intermediate then decomposes to form the nitronium ion, NO_2^+ . The NO_2^+ generated then reacts with the alcohol groups of cellulose to form nitrocellulose.

- (i) Write the equation for the decomposition of the intermediate to form the nitronium ion. [1]



- (ii) Draw the dot-and-cross diagram of the nitronium ion and hence state its shape. [2]

shape:.....



Linear [1]

The empirical formula of nitrocellulose is $\text{C}_6\text{H}_7\text{O}_{11}\text{N}_3$. Complete combustion of nitrocellulose produces carbon dioxide, water vapour and nitrogen.

- (iii) Balance the combustion equation of nitrocellulose with the correct stoichiometric coefficients.



[1]



- (iv) During magic performances, magicians often use nitrocellulose as flash paper to produce dramatic flashes of flame without leaving a mess.

Suggest why nitrocellulose is suitable for this purpose.

[1]

The combustion products are all gaseous and there is no residue left.

- (v) State two main assumptions of the kinetic theory as applied to an ideal gas.

[2]

The gas particles have negligible volume when compared with the volume of the container. [1]

The gas particles have negligible intermolecular forces of attraction. [1]

- (vi) Complete Table 5.2 by identifying the most significant type of intermolecular force of attraction present between each of the gas molecules formed during the combustion of nitrocellulose.

Table 5.2

Gas	most significant intermolecular force of attraction
CO_2	instantaneous dipole – induced dipole
H_2O	hydrogen bonding
N_2	instantaneous dipole – induced dipole

[2]

[2] for all 3 [1] for any 2

- (vii) Arrange the three gases, CO_2 , H_2O and N_2 , in order of increasing deviation from ideal gas behaviour at 400 K. Explain your answer.

[3]

[1] for correct order N_2 , CO_2 , H_2O

[1] for H_2O having the most significant IMF (hydrogen bond) hence deviates the most.

[1] for CO_2 having more significant id–id than N_2 because it has a larger electron cloud size.

[Total: 24]