

Answers for JPJC 2025 H2 Chem Prelim Paper 2

- 1 Nitrogen is found in inorganic compounds such as the oxides of nitrogen, NO_2 and NO .

- (a) NO_2 can be produced from the thermal decomposition of gaseous N_2O_5 .

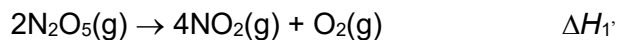


Table 1.1 gives some data relevant to this question.

Table 1.1

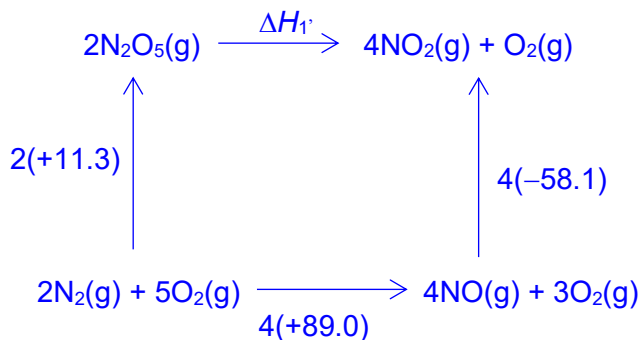
process	$\Delta H^\circ / \text{kJ mol}^{-1}$
standard enthalpy change of formation of $\text{N}_2\text{O}_5(\text{g})$	+11.3
standard enthalpy change of formation of $\text{NO}(\text{g})$	+89.0
$\text{NO}(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}) \rightarrow \text{NO}_2(\text{g})$	-58.1

- (i) Explain what is meant by standard enthalpy change of formation.

It is the heat change when 1 mole of substance is formed from its constituent elements in their standard states under the standard conditions of 298 K and 1 bar.

[1]

- (ii) Use data from Table 1.1 to calculate ΔH_1° . You may find it helpful to draw an energy cycle.

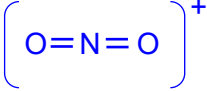
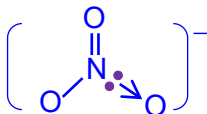


$$\begin{aligned} \Delta H_1^\circ &= -2(+11.3) + 4(+89.0) + 4(-58.1) \\ &= +101 \text{ kJ mol}^{-1} \end{aligned}$$

[2]

- (iii) In the solid state, N_2O_5 has an ionic structure and consists of the ions, NO_2^+ and NO_3^- .

Draw and name the shapes of NO_2^+ and NO_3^- .

ion	NO_2^+	NO_3^-
diagram of shape		
name of shape	linear	trigonal planar

[3]

- (b) Nitrogen dioxide, NO_2 , and dinitrogen tetraoxide, N_2O_4 , exist in dynamic equilibrium with each other.



At 50°C and a pressure of $1.68 \times 10^5 \text{ Pa}$, 4.60 g of the equilibrium gaseous mixture occupies 1.00 dm^3 .

- (i) Assuming the gaseous mixture behaves ideally, calculate the average relative molecular mass, M_r , of the gaseous mixture.

$$M_r = \frac{4.60 \times 8.31 \times (273 + 50)}{1.68 \times 10^5 \times 1.00 \times 10^{-3}}$$

$$= 73.5$$

[1]

- (ii) Using the following relationships, calculate the mole fraction of N_2O_4 , m , and the mole fraction of NO_2 , n , in the mixture.

$$m + n = 1$$

$$\text{Average } M_r = 92m + 46n$$

$$73.5 = 92m + 46n$$

$$73.5 = 92(1 - n) + 46n$$

$$73.5 = 92 - 92n + 46n$$

$$46n = 18.5$$

$$n = 0.402$$

$$m = 1 - 0.402 = 0.598$$

[1]

- (iii) Hence calculate the partial pressures of N_2O_4 and NO_2 in the mixture.

$$P_{\text{N}_2\text{O}_4} = 0.598 \times 1.68 \times 10^5 = 1.00 \times 10^5 \text{ Pa}$$

$$P_{\text{NO}_2} = 0.402 \times 1.68 \times 10^5 = 6.75 \times 10^4 \text{ Pa}$$

[1]

- (iv) Write an expression for equilibrium constant, K_p , for the reaction, and calculate its value. Include units in your answer.

$$K_p = \frac{(p_{\text{NO}_2})^2}{p_{\text{N}_2\text{O}_4}}$$

$$K_p = \frac{(6.75 \times 10^4)^2}{1.00 \times 10^5} = 4.54 \times 10^4 \text{ Pa (or 45.4 kPa)}$$

[3]

- (v) State and explain the effect of increasing the temperature on the average M_r of the equilibrium mixture.

Increasing the temperature will shift the position of equilibrium in $\text{N}_2\text{O}_4(\text{g}) = 2\text{NO}_2(\text{g})$ to the right to favour the endothermic reaction so as to absorb some heat.

Hence, there is a higher mole fraction of NO_2 , so the average M_r will decrease.

[2]

- (c) With the aid of suitable equations, describe and explain the role of NO_2 in the oxidation of atmospheric sulfur dioxide.

NO_2 acts as a homogeneous catalyst in the oxidation of atmospheric SO_2 since both NO_2 and SO_2 have the same gaseous phase.

Step 1 : $\text{NO}_2 + \text{SO}_2 \rightarrow \text{NO} + \text{SO}_3$

Step 2 : $\text{NO} + \frac{1}{2}\text{O}_2 \rightarrow \text{NO}_2$

[2]

[Total: 16]

- 2 Copper(I) salts in aqueous solution are unstable as shown by equation 1.



- (a) (i) Using relevant data from the *Data Booklet*, calculate ΔG° , in kJ mol^{-1} , for the above reaction.



$$E_{\text{cell}} = +0.52 - (+0.15) = +0.37 \text{ V}$$

$$\Delta G^\circ = -nFE_{\text{cell}} = -(1)(96500)(0.37) = -35705$$

$$= -35.7 \text{ kJ mol}^{-1}$$

[2]

- (ii) Deduce the sign of ΔS° for the reaction and explain your answer.

ΔS° is negative (or $\Delta S^\circ < 0$) as there is a decrease in disorderliness since the more disordered aqueous ions react to form a more ordered solid Cu.

OR number / amount of aqueous ions decreases from 2 to 1 as the reaction proceeds.

[1]

- (iii) Hence, determine if the reaction in equation 1 is exothermic or endothermic. Explain your answer.

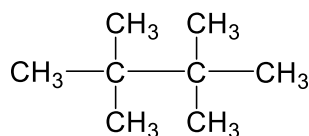
$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

$$\Delta S^\circ < 0, -T\Delta S^\circ > 0, \Delta G^\circ < 0,$$

so $\Delta H^\circ < 0$. Forward reaction is exothermic.

[1]

- (b) Some copper(I) compounds are used as reagents in organic reactions where new carbon-carbon bonds are formed. Larger alkanes can also be formed through the reaction of alkanes with some halogens. However, the yield of the larger alkanes obtained through such a reaction is low.
- (i) Trace amount of alkane **A** is obtained when 2-methylpropane reacts with bromine in the presence of ultraviolet light.

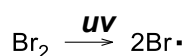


A

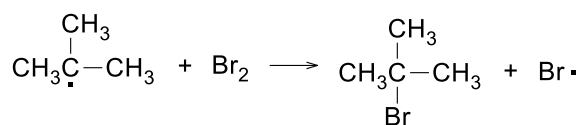
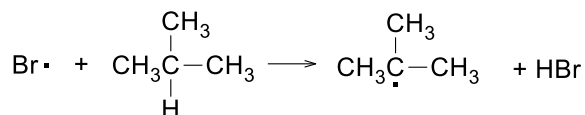
Outline the mechanism of this reaction, clearly showing how **A** is formed in the above reaction.

(Free radical substitution)

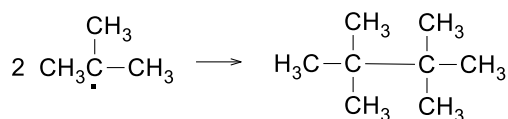
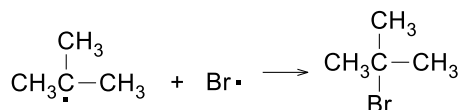
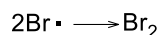
Initiation:



Propagation:



Termination:



[3]

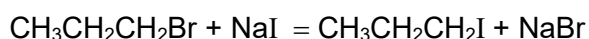
- (ii) Chloroalkanes can be formed by the above mechanism but not iodoalkanes. Use relevant data from the *Data Booklet* to explain why iodoalkanes cannot be formed.

Iodoalkanes cannot be made by free-radical substitution as the first propagation step is MORE endothermic
 $(\Delta H = 410 - 299 = +111 \text{ kJ mol}^{-1})$

OR LESS energy is evolved from the formation of the WEAK H-I bond
 $(299 \text{ kJ mol}^{-1})$ compared to that of H-Br $(366 \text{ kJ mol}^{-1})$.

[1]

- (iii) Iodoalkanes can be made by warming a bromoalkane with a solution of sodium iodide in dry propanone, in which sodium bromide is almost insoluble.

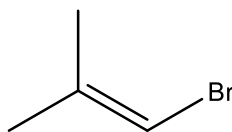


Suggest why the above reaction produces a high yield of $\text{CH}_3\text{CH}_2\text{CH}_2\text{I}$ despite the C-I bond being weaker than the C-Br bond.

Sodium bromide being insoluble in propanone can be precipitated, causing the $[\text{NaBr}]$ to be low. This will cause the position of equilibrium to shift to the right to form more NaBr, allowing the reaction to go to almost to completion.

[1]

- (iv) A student wanted to distinguish 2-bromo-2-methylpropane, $(\text{CH}_3)_3\text{CBr}$, from compound **B** shown below.



compound **B**

The student suggested the following method:

Step 1: To 2 cm^3 of each compound, add an equal volume of NaOH(aq) .

Step 2: Then add 1 cm^3 of $\text{AgNO}_3(\text{aq})$.

Step 3: Then add excess of dilute HCl(aq) .

Identify and explain two improvements to the student's proposed method.

Improvement 1: Heating is required in step 1.

Heating is necessary to break the C-X bond via nucleophilic substitution to give X^- for precipitation with silver nitrate.

Improvement 2: Mixture should be acidified before adding AgNO_3 .

Any excess NaOH will react with Ag^+ to form a brown Ag_2O precipitate, making it difficult to observe the white AgCl ppt.

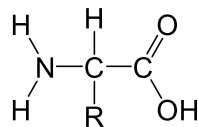
Improvement 3: HNO_3 should be used to acidify the mixture.

Cl^- in HCl gives white ppt with AgNO_3 , giving wrong conclusion.

[2]

[Total: 11]

- 3 Amino acids are the fundamental building blocks of proteins and play crucial roles in various biological processes. Amino acids are crystalline solids with high melting points, are water-soluble, and exist as zwitterions. The general structure of an α -amino acid is given below.



where R represents the side-chain on the α -carbon of amino acid.

- (a) Explain why amino acids exist as crystalline solids at room temperature.

A lot of energy is required to overcome the strong ionic bonds / electrostatic forces of attraction between $-\text{NH}_3^+$ and $-\text{COO}^-$ of the zwitterionic form. Hence, amino acids have high melting point and exist as solid at room temperature.

[1]

- (b) The Strecker synthesis is one method to prepare α -amino acids in the laboratory by reacting readily available aldehydes or ketones in the presence of NH_4Cl and KCN .

However, the Strecker synthesis lacks chirality control, producing racemic mixtures. This poses serious issues in pharmaceuticals, where specific enantiomers are crucial for safety and biological compatibility.

Alanine (2-aminopropanoic acid) can be prepared from the Strecker synthesis as shown in Fig. 3.1.

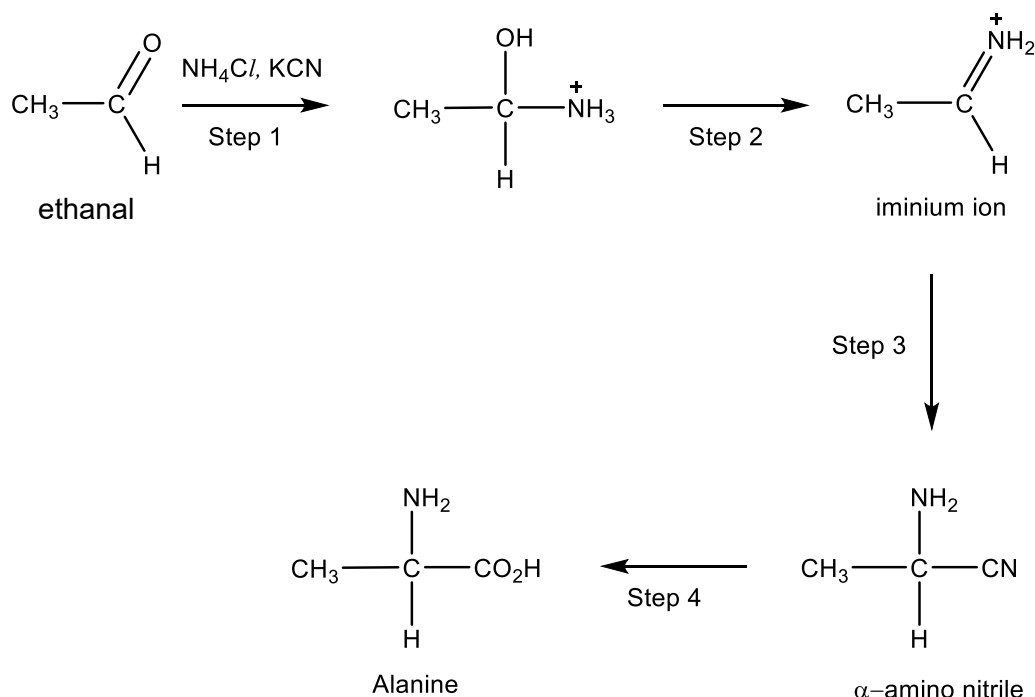


Fig. 3.1

- (i) State the type of reaction that occurred in steps 2 and 4.

step 2: elimination

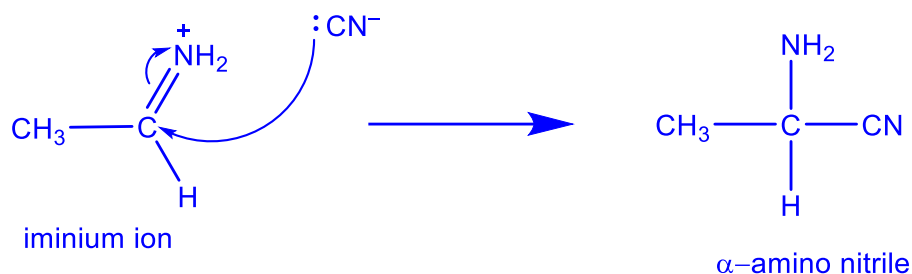
step 4: hydrolysis

[2]

- (ii) Step 3 in the Strecker synthesis involves the reaction of the iminium ion and CN^- to form the α -amino nitrile. This reaction is similar to the reaction between CN^- and carbonyl compounds.

State and describe the mechanism for step 3. In your answer, show relevant lone pairs of electrons and show the movement of electrons by curly arrows.

Type of mechanism: Nucleophilic Addition



[2]

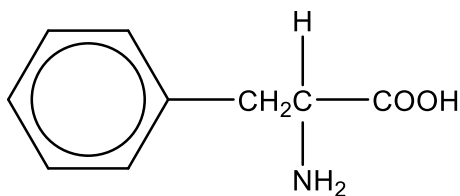
- (iii) Using your answer in (b)(ii), explain why alanine formed by the Strecker Synthesis method exists as a racemic mixture.

Alanine contains a chiral centre at the α -carbon.

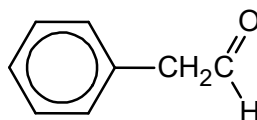
There is equal probability for the CN^- to attack either side of the trigonal planar C of C=NH_2^+ in the iminium ion, hence forming a 1:1 mixture of enantiomers (racemic)

[1]

- (iv) Phenylalanine can also be formed via the Strecker synthesis. Suggest the structure of the starting compound necessary for step 1 of the Strecker synthesis to obtain phenylalanine.

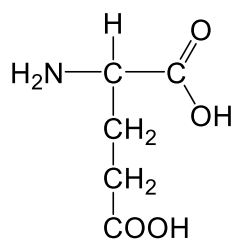


phenylalanine



[1]

- (c) Glutamic acid is a non-essential α -amino acid vital for protein synthesis and is the main excitatory neurotransmitter in vertebrates.



Glutamic acid

Glutamic acid has pK_a values of 2.1, 4.1 and 9.5.

- (i) Explain the difference in the pK_a values of the two carboxylic acid groups on glutamic acid.

Since the electron-withdrawing N of $-\text{NH}_2$ is closer to $\alpha\text{-COO}^- / \alpha\text{-COOH}$, the negative charge on $\alpha\text{-COO}^-$ is dispersed more and hence, $\alpha\text{-COO}^-$ is more stable than the side-chain $-\text{COO}^-$.

Hence, the $\alpha\text{-COOH}$ is a stronger acid and has a lower pK_a than side-chain COOH .

[2]

The following graph in Fig. 3.2 was obtained when protonated glutamic acid was titrated with aqueous potassium hydroxide.

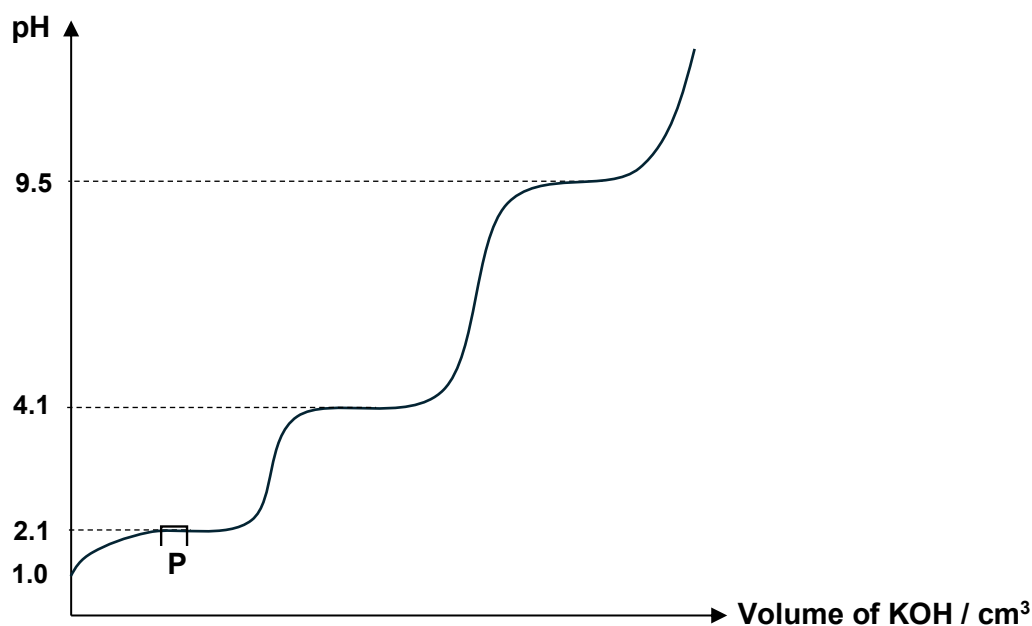
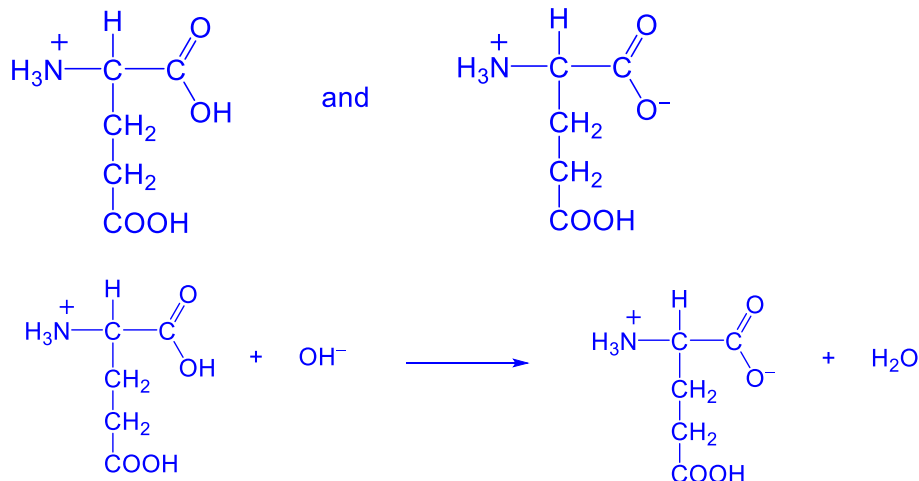


Fig 3.2

- (ii) The pH of the solution changes only gradually around point **P** as aqueous KOH is added to the glutamic acid solution.

Identify the 2 major species present at point **P** and write an equation to illustrate how glutamic acid can maintain the pH of a solution at 2.1 when a small amount of OH^- is added.

At pH 2.1, the major species present are



[2]

- (iii) State what is meant by the term *zwitterion*.

Zwitterion is a species which contains both positive and negative charge such that there is / but has no overall electrical charge.

[1]

- (iv) Indicate on Fig. 3.2 with a cross (x) to show the point at which the predominant species of glutamic acid in the solution is the zwitterion. Explain your answer.

Point indicated on the graph between 2.2 – 4.

the α -COOH is deprotonated / exists as α -COO $^-$ but the side-chain -COOH and α -NH $_2$ remain protonated.

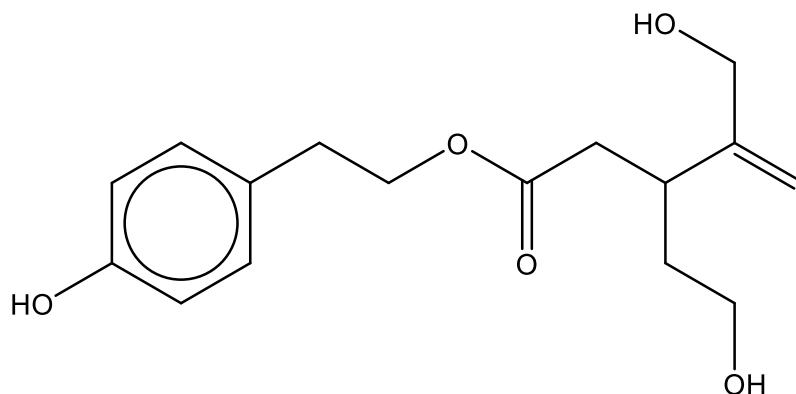
Hence, glutamic acid exists as a zwitterion.

[2]

[Total: 14]

- 4 Oleocanthal, $C_{17}H_{20}O_5$, is a naturally occurring compound found in olive oil, known for its anti-inflammatory and antioxidant properties. When oleocanthal is reacted with $NaBH_4$, compound **C** is formed.

Fig. 4.1 shows the structural formula of a molecule of compound **C**.



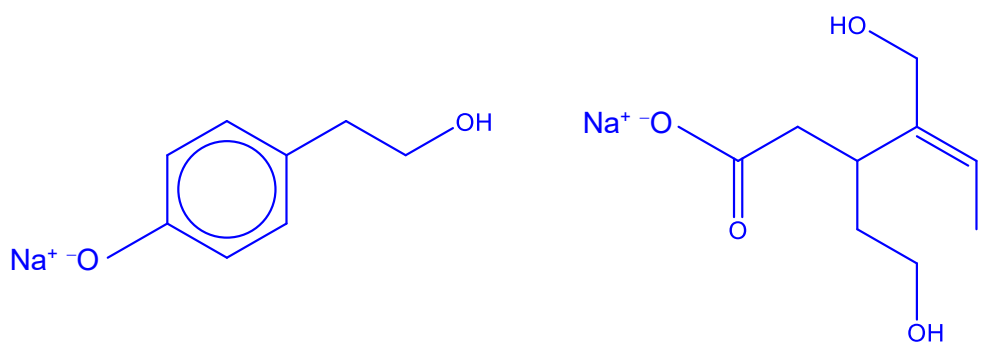
Compound **C**

Fig. 4.1

- (a) (i) The molecule of compound **C** contains sp^2 hybridised carbon atoms. Describe how sp^2 hybridised orbitals are formed.
They are formed by mixing one s orbital and two p orbitals to form three identical sp^2 hybrid orbitals of the same energy and arranged in a trigonal planar arrangement. [1]
- (ii) State the number of sp^2 hybridised carbon atoms in a molecule of compound **C**.
9 [1]
- (iii) Deduce the number of stereoisomers of compound **C**.
4. [1]
- (iv) Write the equation for the reduction of oleocanthal by $NaBH_4$ to give compound **C**.
Use [H] to represent the reducing agent and use the molecular formula of oleocanthal and compound **C** in the equation.
 $C_{17}H_{20}O_5 + 4[H] \rightarrow C_{17}H_{24}O_5$ [1]
- (v) State the number of moles of $H_2(g)$ that will be evolved when 1 mol of compound **C** reacts with an excess of sodium metal.
1.5 mol [1]

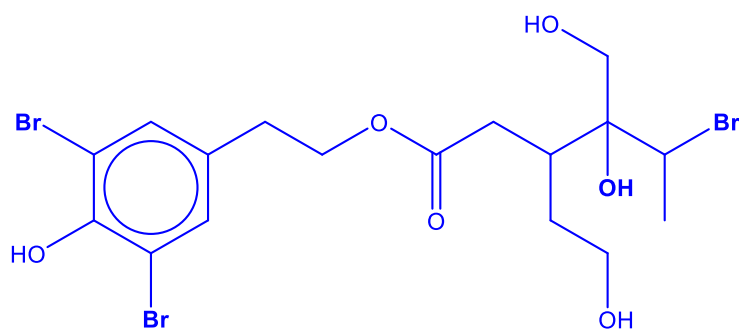
(b) Draw structures of the organic compounds formed when compound **C** is

(i) heated with excess dilute NaOH(aq)

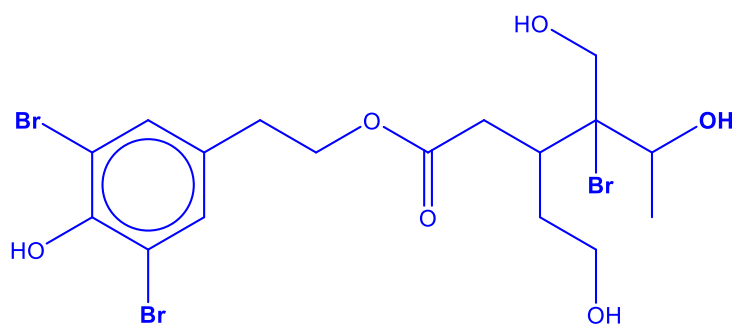


[2]

(ii) reacted with excess Br₂(aq).



OR



[2]

- (c) Hexan-1-ol, $\text{C}_6\text{H}_{13}\text{OH}$, is one of the compounds that contribute to the aroma of olive oil.

A student used the apparatus shown in Fig. 4.2 to carry out an experiment to determine the enthalpy change of combustion of hexan-1-ol.

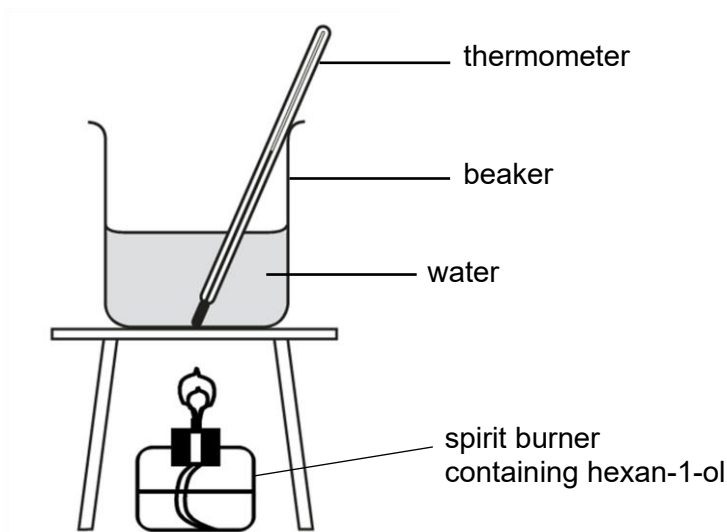


Fig. 4.2

The experimental results obtained are shown in Table 4.1.

Table 4.1

mass of water in beaker / g	250
initial temperature of water / °C	31.0
final temperature of water / °C	44.5
initial mass of spirit burner and hexan-1-ol / g	50.91
final mass of spirit burner and hexan-1-ol / g	50.34

- (i) Using data from Table 4.1, calculate the heat, in kJ, gained by the water in this experiment. The specific heat capacity of water is $4.18 \text{ J g}^{-1} \text{ K}^{-1}$.

$$\begin{aligned}
 \text{Heat gained by water} &= 250 \times 4.18 \times (44.5 - 31.0) \\
 &= 250 \times 4.18 \times 13.5 = 14107.5 \text{ J} = 14.1 \text{ kJ}
 \end{aligned}$$

[1]

- (ii) The enthalpy change of combustion of hexan-1-ol is $-3980 \text{ kJ mol}^{-1}$. Calculate the percentage efficiency of heat transfer in this experiment.

Amount of heat that should be produced by hexan-1-ol assuming no heat loss

$$= \frac{50.91 - 50.34}{6(12.0) + 14(1.0) + 16.0} \times 3980$$

$$= \frac{0.57}{102.0} \times 3980$$

$$= 22.241 \text{ kJ}$$

$$\text{Percentage efficiency of heat transfer} = \frac{14.1075}{22.241} \times 100\% = 63.4\%$$

[2]

- (d) Olive oil primarily contains triesters, which do not vapourise easily. Hence, raw olive oil is unsuitable as a direct fuel for diesel engine as the triesters present will accumulate and clog the engine components. Olive oil can be converted into biodiesel through a chemical process called transesterification. The resulting esters from this process are more suitable for use as fuel in diesel engines.

One transesterification reaction is shown in Fig. 4.3.

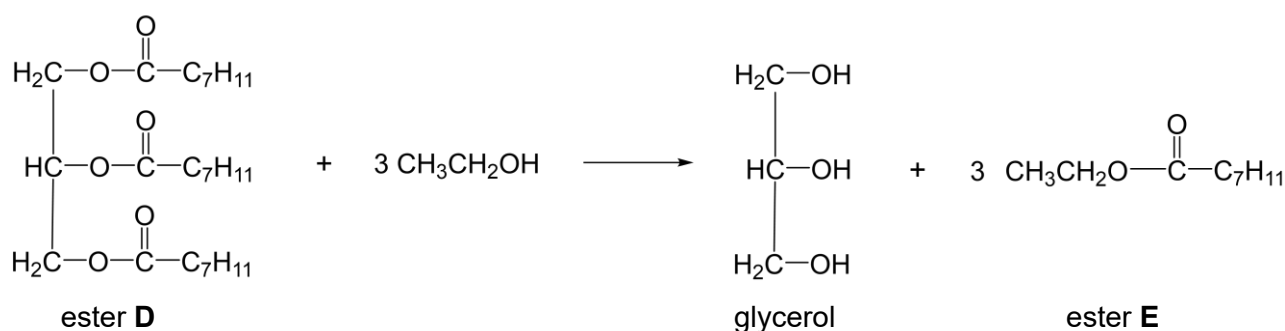


Fig. 4.3

- (i) Explain why ester E is more suitable than ester D to be used as a fuel in diesel engines.

Ester E is more volatile / has a lower boiling point than D because the instantaneous dipole-induced dipole attractions between its molecules are weaker and need less energy to overcome than those of D since E has less number of electrons per molecule.

[2]

A large amount of glycerol is generated as a by-product in the production of biodiesel from natural oils. Efforts are being made to convert glycerol into more useful organic products.

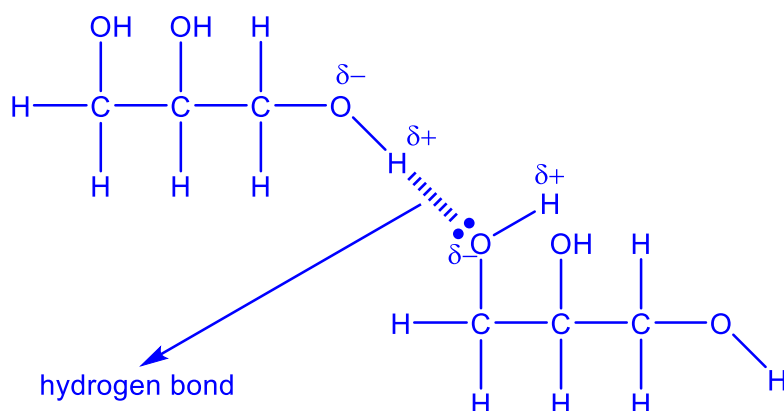
- (ii) Give the systematic name of glycerol.

propane-1,2,3-triol

[1]

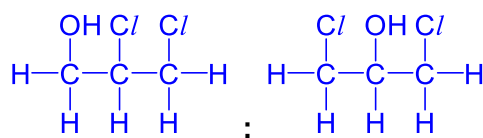
- (iii) The properties of glycerol are affected by the intermolecular forces present between glycerol molecules.

Draw a labelled diagram to name and show the strongest intermolecular force present between two molecules of glycerol.



[1]

- (iv) Glycerol can react with hydrogen chloride to form dichlorinated products. Draw the structures of all possible dichlorinated products from this reaction. **Ignore any stereoisomers.**



[2]

[Total: 18]

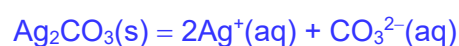
- 5 Silver is known for forming a range of sparingly soluble salts, such as silver carbonate and the silver halides. Their low solubility in water makes them useful in qualitative analysis and photographic processes.

- (a) The values of the solubility products of some silver salts at 298 K are given in Table 5.1.

Table 5.1

salt	K_{sp} value
AgBr	5.0×10^{-13}
Ag_2CO_3	6.3×10^{-12}

- (i) Write an expression for the solubility product, K_{sp} , of Ag_2CO_3 .

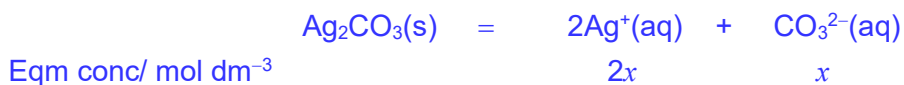


$$K_{sp} = [\text{Ag}^+]^2[\text{CO}_3^{2-}]$$

[1]

- (ii) Ag_2CO_3 solid was stirred in 100 cm^3 of water until no more Ag_2CO_3 solid can dissolve.

Calculate the mass of Ag_2CO_3 that was dissolved in this sample of water.



$$6.3 \times 10^{-12} = (2x)^2(x)$$

$$x = \sqrt[3]{\frac{6.3 \times 10^{-12}}{4}} = 1.16 \times 10^{-4}$$

$$\text{Amount of Ag}_2\text{CO}_3 \text{ dissolved} = \frac{100}{1000} \times 1.16 \times 10^{-4} = 1.16 \times 10^{-5} \text{ mol}$$

$$\begin{aligned} \text{Mass of Ag}_2\text{CO}_3 \text{ dissolved} &= 1.16 \times 10^{-5} \times (2(107.9) + 12.0 + 48.0) \\ &= 3.21 \times 10^{-3} \text{ g} \end{aligned}$$

[3]

- (iii) A solution contains 0.10 mol dm^{-3} each of Br^- and CO_3^{2-} . AgBr and Ag_2CO_3 can be precipitated by adding $\text{AgNO}_3(\text{aq})$ dropwise to the solution.

Which salt will precipitate out first, AgBr or Ag_2CO_3 ? Explain your answer with appropriate calculations.

For first trace of precipitation, Ionic Product = K_{sp}

Minimum concentration of Ag^+ to see first trace of AgBr ppt

$$= \frac{K_{\text{sp}}(\text{AgBr})}{0.10} = \frac{5.0 \times 10^{-13}}{0.10} = 5.00 \times 10^{-12} \text{ mol dm}^{-3}$$

Minimum concentration of Ag^+ to see first trace of Ag_2CO_3 ppt

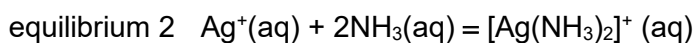
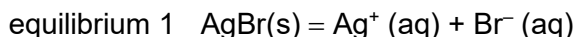
$$= \sqrt{\frac{K_{\text{sp}}(\text{Ag}_2\text{CO}_3)}{0.10}} = \sqrt{\frac{6.3 \times 10^{-12}}{0.10}} = 7.94 \times 10^{-6} \text{ mol dm}^{-3}$$

AgBr will precipitate first since the minimum $[\text{Ag}^+]$ required for precipitation is lower.

[2]

- (b) AgBr is soluble in concentrated $\text{NH}_3(\text{aq})$ but sparingly soluble in dilute $\text{NH}_3(\text{aq})$.

Consider the following two equilibria at 298K.



Use the concepts of Le Chatelier's principle **and** solubility product, as applied to equilibria 1 and 2, explain why AgBr is soluble in concentrated $\text{NH}_3(\text{aq})$ but sparingly soluble in dilute $\text{NH}_3(\text{aq})$.

Calculations are **not** required.

Initial $[\text{Ag}^+]$ is low.

- In dilute NH_3 , there's not enough NH_3
- to complex enough Ag^+ to reduce $[\text{Ag}^+]$ sufficiently (or reduce $[\text{Ag}^+]$ sufficiently through forming stable $\text{Ag}(\text{NH}_3)_2^+$ complex), so ionic product for AgBr is still greater than its K_{sp} .
- In concentrated NH_3 , the high concentration of NH_3 causes the position of equilibrium in equilibrium 2 to shift to the right, to form $[\text{Ag}(\text{NH}_3)_2]^+$ complex
- $[\text{Ag}^+]$ decreases and position of equilibrium in equilibrium 1 shifts to the right.
- The Ionic Product (I.P) for AgBr is now significantly lower until I.P is less than its K_{sp} , hence the POE for Eqm 1 shifts completely to the right, AgBr dissolves completely, forming a colourless solution, $\text{Ag}(\text{NH}_3)_2^+$.

[3]

- (c) Silver chloride and silver bromide can be used in photography.

- (i) In a photographic film, AgBr crystals precipitated into a gelatine base as 'grains'.

Calculate the number of silver ions in a grain of AgBr of mass $2.5 \times 10^{-12} \text{g}$. Give your answer to 2 significant figures.

$$\text{Number of Ag}^+ \text{ ions} = \frac{2.5 \times 10^{-12}}{107.9 + 79.9} \times 6.02 \times 10^{23} = 8.0 \times 10^9$$

[1]

- (ii) In photography, a bromide ion absorbs light of a specific wavelength and loses an electron for the photographic process.



Predict whether it would require more energy or less energy to initiate this process in AgCl compared to AgBr. Explain your answer as fully as you can.

It will require more energy.

Despite Cl^- has a lower nuclear charge, it has less shielding effect since there is less quantum shell of electrons. The electron to be removed is closer to the nucleus and is more strongly attracted to the nucleus.

[2]

Rodinal is used as a photographic developer. It develops a latent photographic image through reducing silver ions in AgBr to silver atoms in alkaline conditions.