2011 Year 6 H2 Chemistry Preliminary Exam – Paper 3 Answers

1 Iron is the cheapest and one of the most abundant of all metals, comprising nearly 5.6% of the earth's crust and nearly the earth's entire core. It exists in a wide range of oxidation states, from −2 to +6, although ferrous (Fe^{2+}) and ferric (Fe^{3+}) compounds are more common.

(a) Acidic solutions containing ferrous ions are *oxidised* to ferric ions in air, with no precipitation seen. On the other hand, ferrous ions give a precipitate in alkaline solutions and the precipitate turns reddish–brown in air.

With reference to the *Data Booklet*, explain the two reactions using relevant E^{θ} values, writing equations where appropriate.

[4]

In acidic solution

$O_2 + 4H^+ + 4e \rightleftharpoons 2H_2O \quad E^{\ominus} = +1.23\ V$
$Fe^{3+} + e \rightleftharpoons Fe^{2+} \quad E^{\ominus} = +0.77\ V$

$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O$

$E^{\ominus}_{cell} = +1.23 - (+0.77) =$ **+ 0.46 V**

In alkaline solution

$Fe^{2+}(aq) + OH^-(aq) \rightarrow Fe(OH)_2(s)$

OR Ferrous ion react with hydroxide ions to form the ppt, $Fe(OH)_2$.

$O_2 + 2H_2O + 4e \rightleftharpoons 4OH^- \quad E^{\ominus} = +0.40\ V$
$Fe(OH)_3 + e \rightleftharpoons Fe(OH)_2 + OH^- \quad E^{\ominus} = -0.56\ V$

$E^{\ominus}_{cell} = +0.40 - (-0.56) =$ **+ 0.96 V**

$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3$

OR The ppt will be oxidised in air to reddish–brown $Fe(OH)_3$.

(b) Ferric ions can catalyse the reaction between $I^-(aq)$ and $S_2O_8^{2-}(aq)$.
By considering relevant E^{θ} values, describe and explain the role of the ferric ions in this reaction, writing equations where appropriate.

Fe^{3+} acts as a catalyst and **reacts with I^-**.

$Fe^{3+} + e \rightleftharpoons Fe^{2+} \quad E^{\ominus} = +0.77\ V$
$I_2 + 2e \rightleftharpoons 2I^- \quad E^{\ominus} = +0.54\ V$

$2I^-(aq) + 2Fe^{3+}(aq) \rightarrow I_2(aq) + 2Fe^{2+}(aq)$

$E^{\theta}_{cell} = +0.77 - (+0.54) =$ **+ 0.23 V >0.** Reaction is feasible.

Fe^{2+} intermediate reacts with $S_2O_8^{2-}$. Fe^{3+} catalyst is regenerated.

Fe^{3+} + e $\rightleftharpoons$ Fe^{2+} $\quad E^{\ominus}$ = +0.77 V

$S_2O_8^{2-}$ + 2e $\rightleftharpoons$ $2SO_4^{-}$ $\quad E^{\ominus}$ = +2.01 V

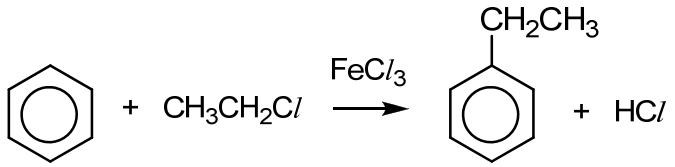
$S_2O_8^{2-}(aq) + 2Fe^{2+}(aq) \rightarrow 2SO_4^{2-}(aq) + 2Fe^{3+}(aq)$

E^{θ}_{cell} = +2.01 – (+ 0.77) = **+ 1.24 V >0**. Reaction is feasible.

[3]

(c) Ferric chloride is an industrial scale commodity inorganic compound which is often used as catalyst in organic synthesis. One example is its use as a Lewis acid for catalysing the alkylation reaction of benzene by chloroethane to form phenylethane. This reaction is similar to the reaction between benzene and chlorine.

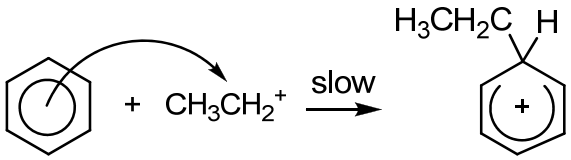
(i) Write a balanced equation for the overall reaction of chloroethane and benzene.



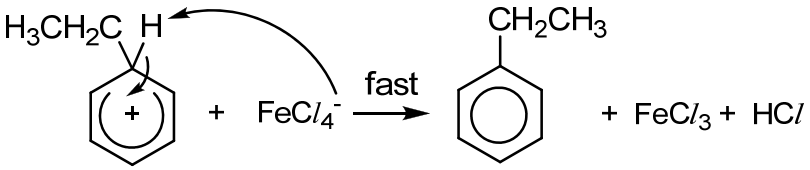
(ii) State and outline the mechanism, with equations only, for the above reaction using ferric chloride as a catalyst.

Electrophilic substitution.

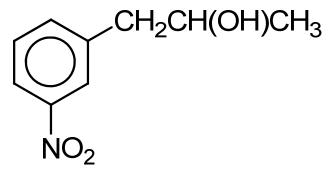
$FeCl_3 + CH_3CH_2Cl \longrightarrow FeCl_4^- + CH_3CH_2^+$



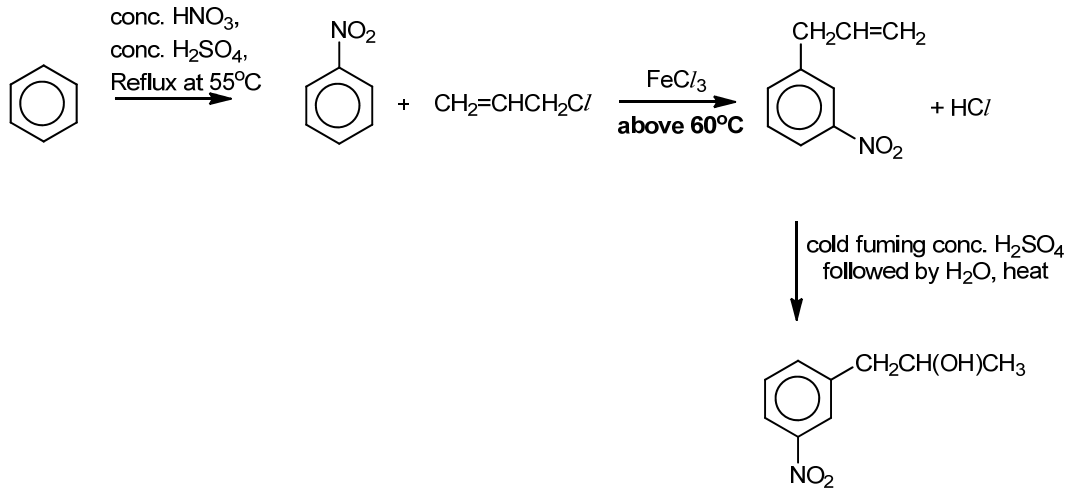
unstable cyclic carbocation



(iii) Hence, or otherwise, suggest how you would synthesise the following alcohol, 1–(3–nitrophenyl)propan–2–ol, starting from a chloroalkene and benzene as your only organic reagents. Your synthesis route should be no more than three steps.



1–(3–nitrophenyl)propan–2–ol



Or H_2O, H_3PO_4 catalyst at 300°C and 70 atm for the last step.

(iv) Explain why 1–(3–nitrophenyl)propan–2–ol exists as enantiomers, and describe how pure samples of the enantiomers can be distinguished by a physical method.

It has a **chiral carbon centre** or carbon atom with four different groups with **no plane of symmetry**;
Pass plane–polarised light through sample and each **enantiomer will rotate the light in opposite/different directions**.

[8]

(d) Consider this iron compound, $NH_4[Fe(SCN)_x(NH_3)_y]$, with the following composition by mass:

Fe	16.4%
S	37.7%
N	28.8%

(i) Define the term *ligand*, and identify the ligands in this complex.

A **ligand** is defined as a molecule/ion which contains **at least one lone pair of electrons** available for forming **dative/coordinate bond** with the central metal atom/ion.

The ligands are **thiocyanate ion (SCN^-)** and **ammonia (NH_3)**

(ii) Calculate the values of x and y in the formula.

Method 1

Fe (Ar = 55.8) is 16.4% of total mass.

$\therefore$ total mass = $100 \times \frac{55.8}{16.4}$

= 340.24

mass of S = $\frac{37.7}{100} \times 340.24$

= 128.27

x = 128.27/Ar

$\boldsymbol{x = 4}$

mass of N = $\frac{28.8}{100} \times 340.24 = 98.00$

$y - 4 - 1 = 98.00/Ar$

$y - 4 - 1 = 7.00$

$\boldsymbol{y = 2}$

Method 2

	Fe	S	N
mol	16.4/55.8 = 0.2939	37.7/32.1 = 1.174	28.8/14 = 2.057
ratio	1	4	7

From $NH_4[Fe(SCN)_x(NH_3)_y]$:

Fe $\equiv x$ S $\equiv (1+x+y)$ N

$\Rightarrow \boldsymbol{x = 4}$

$\Rightarrow 1+x+y = 7$

$\Rightarrow \boldsymbol{y = 2}$

(iii) Calculate the oxidation number of iron in the compound.

Since formula of the anion of complex is $[Fe(SCN)_4(NH_3)_2]^-$,

$4(-1) + 2(0) + Fe = -1$

Fe = 3

Oxidation number of Fe is **+3**

[5]

[Total: 20]

2(a) The Van Slyke's method, named after an Amercian biochemist Van Slyke Donald Dexter, refers to a method to test for primary amino groups. Amino acids can be determined by measuring the volume of nitrogen released from their reaction with nitrous acid. For example, alanine can be reacted as shown in the equation below.

$$CH_3CH(NH_2)COOH + HNO_2 \rightarrow CH_3CH(OH)COOH + N_2 + H_2O$$

Another method to test for primary amino groups consists of reacting amino acids with a volumetric solution of perchloric acid, for example:

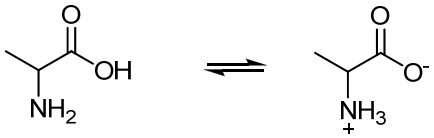
$$CH_3CH(NH_2)COOH + HClO_4 \rightarrow CH_3CH(N^+H_3)COOH + ClO_4^-$$

The above is a weak base and strong acid neutralisation reaction.

The excess perchloric acid is then determined by titration with aqueous sodium hydroxide.

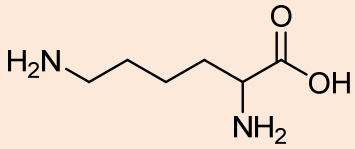
(i) Explain, with the aid of an equation, why alanine is a weaker base than propylamine.

The basic amine ($-NH_2$) group undergoes **internal acid–base reaction** with the acidic –COOH group in alanine to form a **zwitterion**.



Extent of accepting a proton in solution **decreases** $\Rightarrow$ alanine is a weak base.

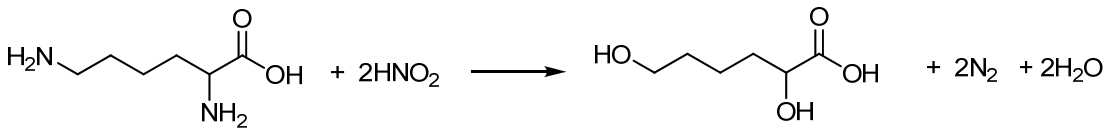
Using the above method to test for primary amino groups in lysine, 50.0 cm^3 of 0.100 mol dm^{-3} perchloric acid is added to a sample of lysine, in glacial acetic acid.



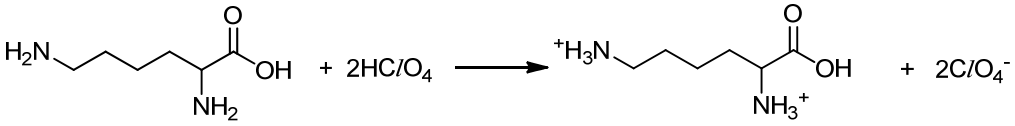
lysine

The excess perchloric acid is determined by titration with 0.150 mol dm^{-3} sodium hydroxide solution. 16.0 cm^3 of sodium hydroxide is needed to complete the titration.

(ii) Write an equation for each of the following reaction between:
(I) nitrous acid and lysine



(II) perchloric acid and lysine



(iii) Calculate the volume of the nitrogen released at a pressure of 103 kPa and a

temperature of 20 °C by the same lysine sample.

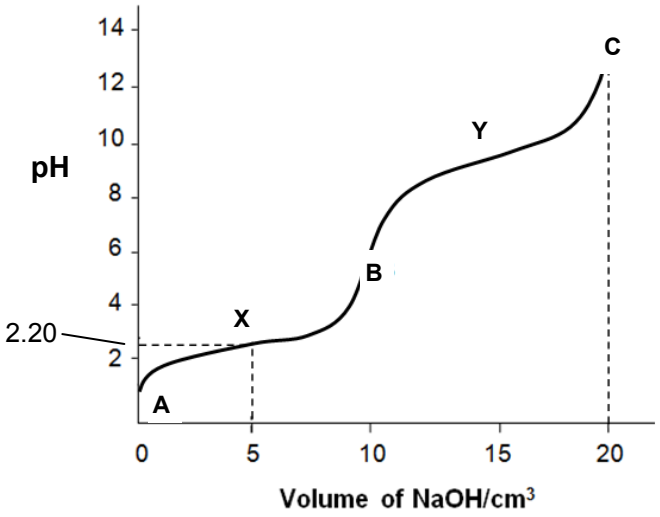
$n(HClO_4)$ added = V x c = 0.0500 x 0.100 = 0.00500 mol
n(NaOH) used for titration = 0.0160 x 0.150 = 0.00240 mol
$n(HClO_4)$ consumed in reaction = 0.00500 – 0.00240 = 0.00260 mol

Since, $2n(HClO_4) = n(\text{lysine}) = 2n(N_2) = 0.00260$ mol

$$V(N_2) = \frac{nRT}{p} = \frac{0.00260(8.31)(273+20)}{103000} = \underline{\textbf{6.17 x 10}^{\textbf{-5}}\ \textbf{m}^{\textbf{3}}} \text{ or } \underline{\textbf{0.0617 dm}^{\textbf{3}}}$$

[6]

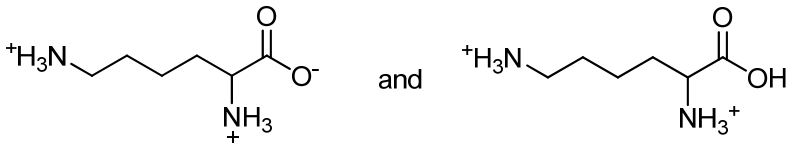
(b) Amino acids like lysine show both acidic and basic properties. In acidic solution, lysine is completely protonated and exists as the conjugate acid. 10.0 cm^3 of completely protonated lysine is titrated with 0.10 mol dm^{-3} NaOH. Its titration curve is shown below.



(i) Calculate the first dissociation constant K_{a1} of lysine.

At pt **X**, pH = pK_{a1}
$K_{a1} = 10^{-2.20} = \underline{\textbf{6.31 x 10}^{\textbf{-3}}\ \textbf{mol dm}^{\textbf{-3}}}$

(ii) Identify the species present at point **X**.



(iii) Calculate the concentration and initial pH of lysine at **A**.

n(NaOH) used to reach 1st endpoint = 0.0010 mol
n(lysine) = 0.0010 mol

[lysine] = 0.0010/0.0100= $\underline{\textbf{0.10 mol dm}^{\textbf{-3}}}$

$$HO_2CCH(NH_3^+)(CH_2)_4NH_3^+ \rightleftharpoons {}^-O_2CCH(NH_3^+)(CH_2)_4NH_3^+ + H^+$$

Eqm	0.10 – x	x	x

$K_{a1} = \dfrac{X^2}{0.10 - X} = 6.31 \times 10^{-3}$

x = $[H^+]$ = 0.02216 mol dm^{-3}

pH of lysine at A = $-\log_{10}(0.028)$ = **1.55 or 1.60 (approx)**

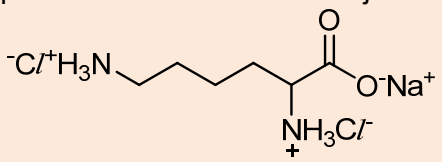
(iv) Explain why the predominant species at point **C** has a high melting point.

The predominant species, $^-O_2CCH(NH_2)(CH_2)_4NH_3^+$, at **C** is a zwitterion, which is **ionic** in nature.

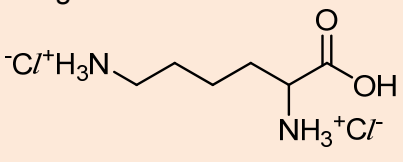
The strong **electrostatic forces of attraction** between the zwitterions require a **large amount of energy** to be overcome, hence the high melting point.

[6]

(c) Equimolar amount of **R** and 0.0151 mol of **S** are mixed and dissolved in a 1 dm^3 of distilled water. The pH of this mixture is then adjusted by adding a suitable amount of solid NaOH.

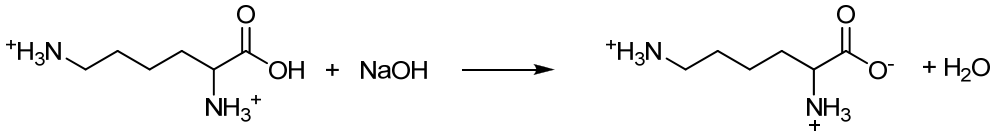


R



S

By means of a balance equation, show how the mixture above can act as a buffer when a few drops of aqueous NaOH are added to it.



S **R**

(d) When 30 cm^3 of 1.0 mol dm^{-3} **R** is added to 25 cm^3 of 1.0 mol dm^{-3} sulfuric acid in a plastic container, the temperature rose by 6.3 °C. The process efficiency is expected to be 90%.

(i) Calculate the standard enthalpy change of the reaction assuming that it takes 4.18 J to increase the temperature of 1 cm^3 of the solution by 1.0 °C.

Apparent amount of heat evolved, **Q'**

= $mc\Delta T$ = (30 + 25) × 4.18 × 6.3 = 1448.4 J

Q' = $\dfrac{90}{100}$ × **Q** (given 90% efficiency)

Actual amount of heat evolved, **Q** = $\dfrac{100}{90}$ × 1448.4 = 1609.3 J

No. of mole of H_2SO_4 = $\dfrac{25}{1000} \times 1.0 = 0.0250$ mol

No. of mole of **R** = $\dfrac{30}{1000} \times 1.0 = 0.0300$ mol

R is the limiting reagent.

Hence, n(H_2O) formed = 0.0300 mol

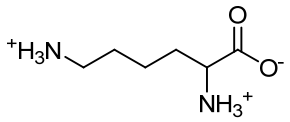
$\Delta H_n^e = -\dfrac{Q}{n(H_2O)} = -\dfrac{1609.3}{0.0300}$ = **– 53.6 kJ mol^{-1}**

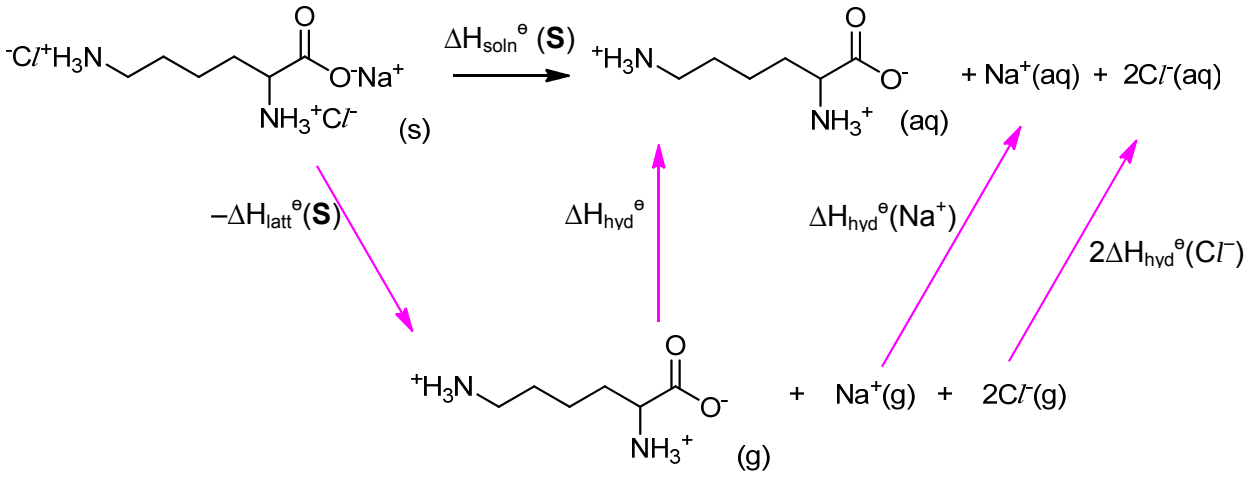
(ii) Predict if the enthalpy change of the reaction will be higher, the same or lower than that calculated in **(i)** if sulfuric acid is replaced by a weak acid. Explain.

Lower/Less exothermic. This is so as **some amount of energy** is required to cause **ionisation** of the **undissociated** weak acid molecules in order for neutralisation to occur.

[4]

(e) One mole of solid **R** in **(c)** dissolves in water to release 930 kJ of energy. Given that the lattice energy of **R** is –234 kJ mol^{-1} and the following enthalpy changes of hydration, draw an energy cycle to determine the enthalpy change of hydration of the $^{-}O_2CCH(NH_3^+)(CH_2)_4NH_3^+$ ion.

ions	ΔH^{θ}_{hyd} /kJ mol^{-1}
Na^+	–499
	?
Cl^-	–381



correct state symbols; labeled energy cycle

By Hess' Law:

$\Delta H_{soln}^{\ominus}$ (**S**) = $-\Delta H_{latt}^{\ominus}$(**S**) + $\Delta H_{hyd}^{\ominus}[^{-}O_2CCH(NH_3^+)(CH_2)_4NH_3^+)]$ + $\Delta H_{hyd}^{\ominus}(Na^+)$ + 2 $\Delta H_{hyd}^{\ominus}(Cl^-)$

–930 = +234 + $\Delta H_{hyd}^{\ominus}[^{-}O_2CCH(NH_3^+)(CH_2)_4NH_3^+)]$ + (–499) + 2(–381)

$\Delta H_{hyd}^{\ominus}[^{-}O_2CCH(NH_3^+)(CH_2)_4NH_3^+)]$ = **+97 kJ mol^{-1}**

[3]

Total: 20]

3(a) An optically active ester, **L**, (11.6 g) with the molecular formula of $C_6H_{12}O_2$, is hydrolysed by heating with an excess of aqueous sodium hydroxide solution. After terminating the hydrolysis, the alkaline reaction mixture is extracted several times with an organic solvent.

The aqueous and organic layers are then collected separately. The aqueous solution is found to be optically inactive.

Anhydrous magnesium sulfate is added to the organic layer. The mixture is filtered and the filtrate distilled. 7.4 g of a liquid **J** is obtained (assume 100 % purity and yield).

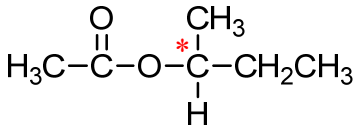
(i) Suggest the role of anhydrous magnesium sulfate in the procedure above.

The anhydrous magnesium sulfate is a **drying agent;** it **removes any remaining traces of water** from the product.

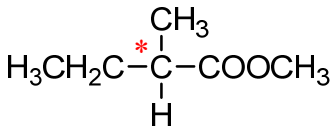
(ii) Calculate the number of moles of ester used and hence calculate the M_r of liquid **J**.

n(ester) = 11.6/116 = **0.100 mol**
n(liquid **J**) = 0.100 mol
M_r (liquid **J**) = 7.4/0.100 = **74.0**

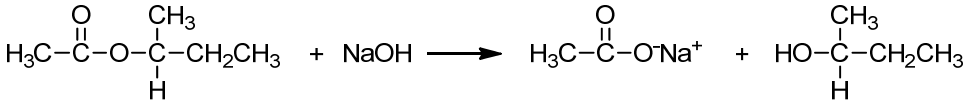
(iii) Propose a possible structural formula of the ester.



(iv) What would be the structure of an isomeric ester that would produce an optically active aqueous layer after hydrolysis?



(v) Write down an equation for the alkaline hydrolysis of one of the esters with sodium hydroxide solution.



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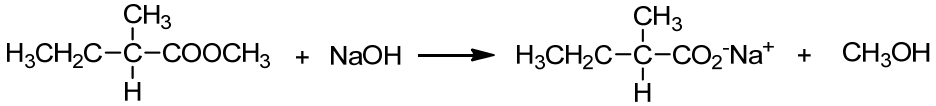
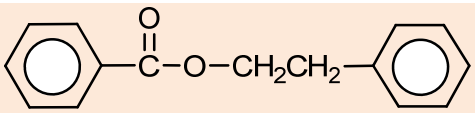


[6]

(b) A food chemist decides to synthesise the ester as shown below, for possible use as a flavouring agent.



The **only** organic compound available is phenylethanal ($C_6H_5CH_2CHO$).

Outline how the food chemist is able to synthesise this ester using only phenylethanal and other appropriate inorganic reagents

[2]

1. **Reflux** phenylethanal with **$KMnO_4/H^+$** to get **benzoic acid**.
2. Reduce phenylethanal with **$LiAlH_4$ in dry ether** to get **2–phenylethanol, $C_6H_5(CH_2)_2OH$**. **Reflux** benzoic acid and 2–phenylethanol with **conc. H_2SO_4** to get the ester.

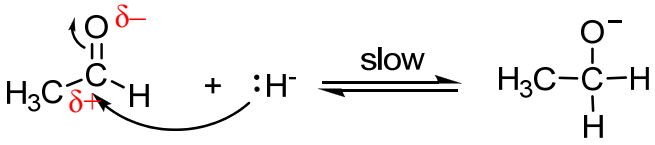
(c) **L** can be reduced to alcohol via an intermediate, ethanal, with the use of lithium aluminium hydride. The attacking species is the AlH_4^- ion which, in effect, is a carrier of hydride ions, H^-. Ethanal is then further reduced in the following two steps.

Step 1 Attack of the hydride ion, H^-, at the carbonyl carbon of ethanal gives a tetrahedral intermediate.

Step 2 The anion reacts with aqueous acid to give the alcohol product.

Describe the mechanism in steps **1** and **2** using only equations. Include relevant charges and curly arrows to show the movement of electrons.

Step 1:



Step 2: $CH_3CH_2O^- + H^+ \longrightarrow CH_3CH_2OH$

[3]

(d) The anhydrous magnesium sulfate from part **(a)** exists as a hydrated salt when dissolved in aqueous sodium hydroxide. Equal volumes of 1.0 mol dm^{-3} hydrated magnesium sulfate and 2.0 mol dm^{-3} aqueous sodium hydroxide are mixed. The resulting mixture produces a white precipitate and has a pH of 10.2.

(i) Suggest the identity of the white precipitate.

$Mg(OH)_2$ / magnesium hydroxide

(ii) Write the expression for the solubility product of this sparingly soluble salt.

$K_{sp} = [Mg^{2+}] [OH^-]^2$

(iii) Calculate the solubility product of the precipitate formed, including its units.

$MgSO_4$ (aq) + 2NaOH (aq) $\rightarrow$ $Mg(OH)_2$ (s) + Na_2SO_4 (aq)
pH = 10.2 $\Rightarrow$ pOH = 3.8
$[OH^-] = 1.58 \times 10^{-4}$ mol dm^{-3}

$K_{sp} = [Mg^{2+}][OH^-]^2 = (\frac{1.58 \times 10^{-4}}{2})(1.58x10^{-4})^2$

$= \mathbf{1.99 \times 10^{-12}\ mol^3\ dm^{-9}}$

$[Mg^{2+}] = \frac{1}{2}[OH^-]$ since $Mg(OH)_2 \rightleftharpoons Mg^{2+} + 2OH^-$.

(iv) Explain, with the aid of equations, the effect on the solubility upon adding aqueous sodium hydroxide in excess to the resulting mixture containing the white precipitate.

$Mg(OH)_2 \rightleftharpoons Mg^{2+} + 2OH^-$ ————(1)

$NaOH \rightarrow Na^+ + OH^-$ ————(2)

Due to **Common Ion Effect**, **position of equilibrium in (1) shifts to the left** as according to **Le Chatelier's principle**. Hence, solubility **decreases**

(v) Magnesium sulfate dissolves in water to give a solution of pH ≈ 6.5.

Explain, with equations only, why this solution formed is slightly acidic.

$MgSO_4 + 6H_2O \rightarrow [Mg(H_2O)_6]^{2+} + SO_4^{2-}$

$[Mg(H_2O)_6]^{2+}(aq) \rightleftharpoons [Mg(H_2O)_5(OH)]^+ + H^+$

[10]
[Total: 20]

4 This question is about the chemistry of Group II elements and carbonyl compounds.

(a) The thermal decomposition of beryllium ethanoate produces its metal carbonate and a carbonyl compound.

$$(CH_3CO_2)_2Be \xrightarrow{\Delta} BeCO_3 + (CH_3)_2CO$$

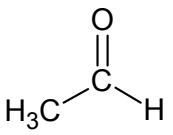
An acidic gas and a mixture of three carbonyl compounds, namely **D**, **E** and **F**, are produced when the reaction mixture of beryllium ethanoate and beryllium methanoate is strongly heated.

(i) Suggest the identity of the acidic gas.

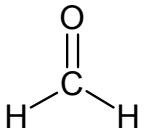
CO_2 / carbon dioxide

(ii) Both **D** and **E** but **not F** decolourise potassium manganate(VII). Both **D** and **F** but **not E** gives a yellow precipitate with alkaline aqueous iodine.

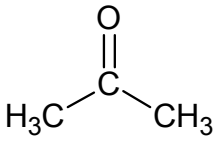
Suggest the structural formulae of **D**, **E** and **F**.



D



E



F

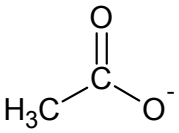
(iii) There is no organic product obtained when **E** is reacted with hot acidified potassium manganate(VII). Account for this observation.

E, which is methanal, undergoes **strong oxidation** to form carbon dioxide gas and water.

[5]

(b) When **D** is warmed with Tollens' reagent and the organic product, **K**, is formed. **K** is then reacted with 2–chloro–2–methylpropane, $(CH_3)_3CCl$, forming a sweet–smelling liquid.

(i) Suggest the structural formula of **K**.

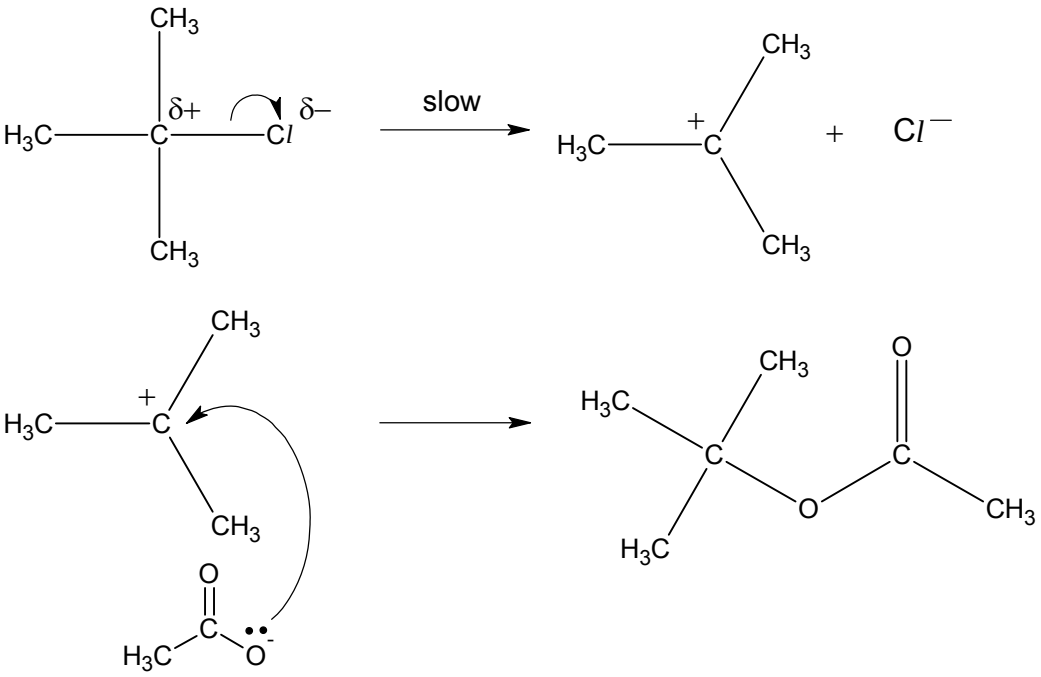


K

(ii) In the formation of the sweet–smelling liquid, **K** reacts with $(CH_3)_3CCl$. Suggest the type of reaction here.

Nucleophilic substitution.

(iii) Propose, with the aid of appropriate equations, the reaction mechanism for the organic synthesis in part **(a)(iv)**.



(iv) Given that the half–life of 2–chloro–2–methylpropane is 1500 s and the rate constant, k has a numerical magnitude of 4.62×10^{-4}, prove that the order of reaction with respect to $[(CH_3)_3CCl]$ is first order.

If the order of reaction with respect to $[(CH_3)_3CCl]$ is first order,
$\Rightarrow t_{1/2} = \ln 2 / k$
$\Rightarrow$ The product of $t_{1/2}$ and k should be equals to ln2 which is approximately 0.693.

$t_{1/2} \times k = 1500 \times 4.62 \times 10^{-4} = 0.693 \approx \ln 2$

(v) Explain the effect of a catalyst on the rate constant.

When a catalyst is used, the **activation energy (E_a) is lowered**.
Hence, **rate constant (k) increases**.

(vi) Predict, with reasoning, the solubility of 2–chloro–2–methylpropane, $(CH_3)_3CCl$ in water.

$(CH_3)_3CCl$ **will not be soluble** in water as it **cannot form hydrogen bonding** with water molecules.

[11]

(c) Calcium ethanoate, one of the Group II salts of carboxylic acids, is also commonly used in the production of propanone.

Predict, with reasoning, if the decomposition temperature of calcium ethanoate will be higher or lower than that of beryllium ethanoate.

Higher. Calcium is further down the group than beryllium. Calcium ion has a lower charge density than beryllium ion hence a lower polarising power. Thus, the polarizing effect of Calcium ion on ethanoate ion is less. So, calcium ethanoate is **more thermally stable** than beryllium ethanoate

[2]

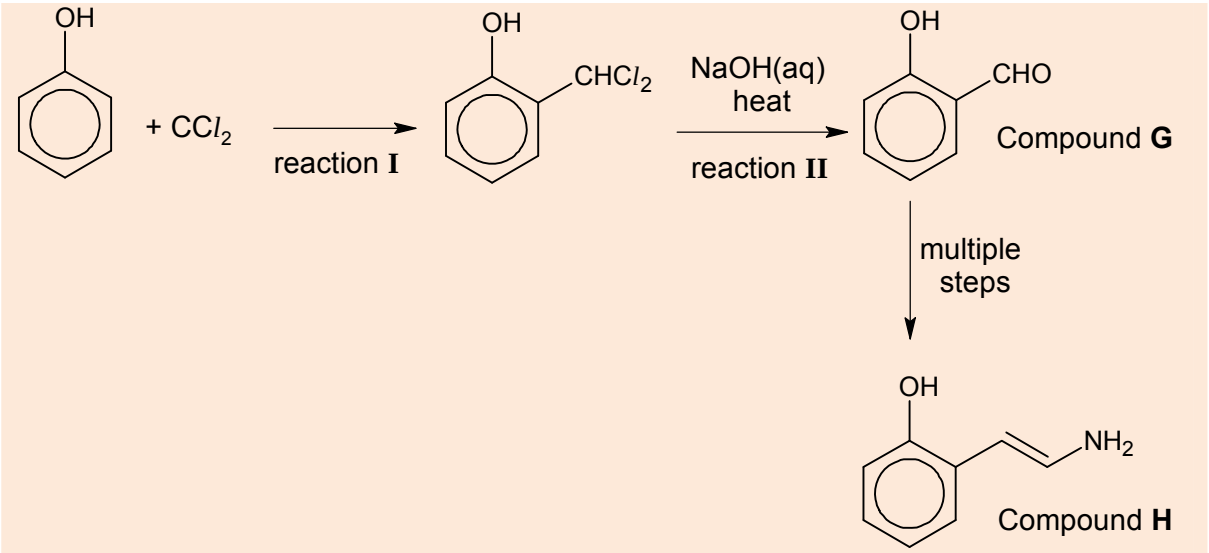
(d) Beryllium is very similar to aluminium in several ways.
State and explain whether beryllium oxide is acidic, basic or amphoteric.

Amphoteric. The small Be^{2+} ion has **high charge density and** it **polarises the O^{2-} anion** to induce a partial covalent character.

[2]
[Total: 20]

5 Aqueous sodium hydroxide is an important reagent used in many chemical reactions whereby the hydroxide ion can either act as a base, or a nucleophile in organic synthesis.

(a) In the production of 2–hydroxybenzaldehyde (Compound **G**), phenol is heated with chloroform ($CHCl_3$) in the presence of aqueous sodium hydroxide. To improve the yield of the product, the formation of a reactive intermediate, CCl_2 is essential. $CHCl_3$ reacts with the hydroxide ions via neutralisation to give the reactive intermediate. A typical synthetic route is shown below.



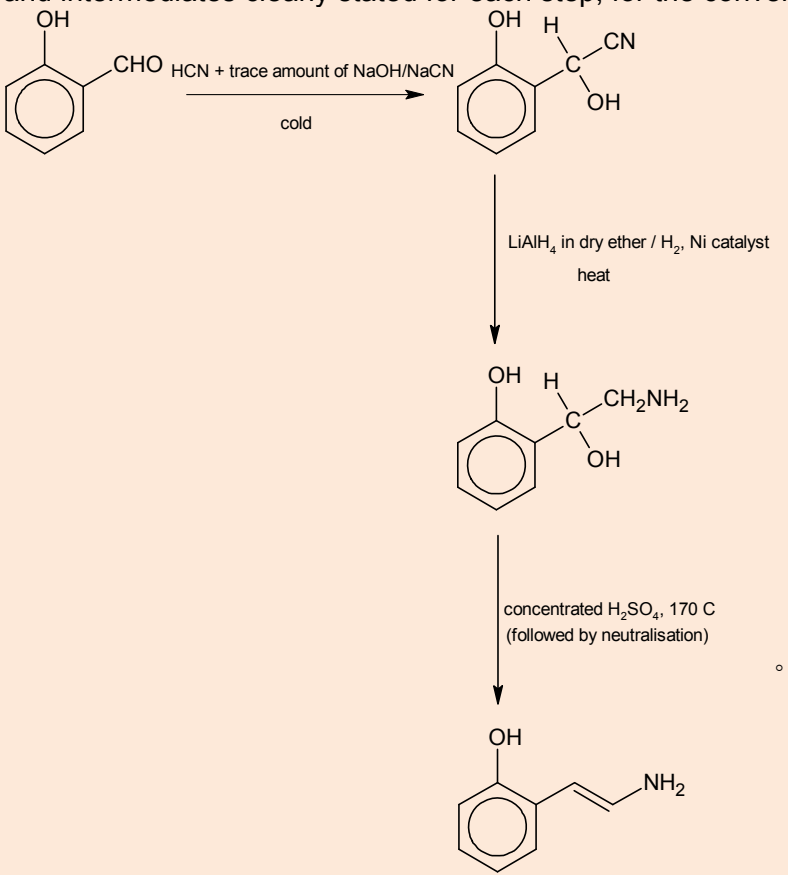
(i) Write the balanced equation for the formation of the reactive intermediate.

$CHCl_3 + OH^- \rightarrow CCl_2 + H_2O + Cl^-$
OR
$CHCl_3 + NaOH \rightarrow CCl_2 + H_2O + NaCl$

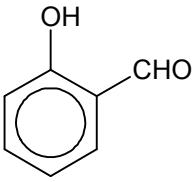
(ii) Explain why CCl_2 attacks phenol readily in reaction **I**.

The carbon atom in CCl_2 is **electron–deficient / electrophilic**.

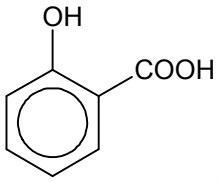
(iii) Suggest an effective synthetic route (within 3 steps), with the reagents, conditions and intermediates clearly stated for each step, for the conversion of **G** to **H**



(iv) State and explain the relative acid strength of **G** and



is **less acidic** than



. The second molecule has a carboxylic acid group and the **carboxylate ion is stabilised** by the **dispersion of negative charge** over two oxygen atoms. The **electron–withdrawing carbonyl** group **increases the withdrawal of electrons** away from the H atom in the hydroxyl group. *OR* **formation of** "**resonance structures**".
OR This causes the **weakening of the O–H bond** which promotes the loss of proton.

[8]

(b) Besides being used as a favourable nucleophile in many organic syntheses, aqueous sodium hydroxide also reacts with halogens, for example chlorine, under different conditions to yield different products, typically NaC*l*O and NaC*l*O_3.

(i) Write the balanced equation when chlorine is reacted with aqueous sodium hydroxide at 10 – 20 °C.

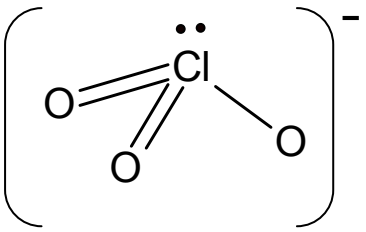
$2NaOH + Cl_2 \rightarrow NaCl + NaClO + H_2O$

Also accepted: balanced ionic equation

(ii) State the type of reaction that chlorine undergoes in **(i)**.

Disproportionation.

(iii) Draw the Lewis structure of ClO_3^- ion, giving its shape and bond angle.



Shape: Trigonal pyramidal **AND** Bond angle: 107°

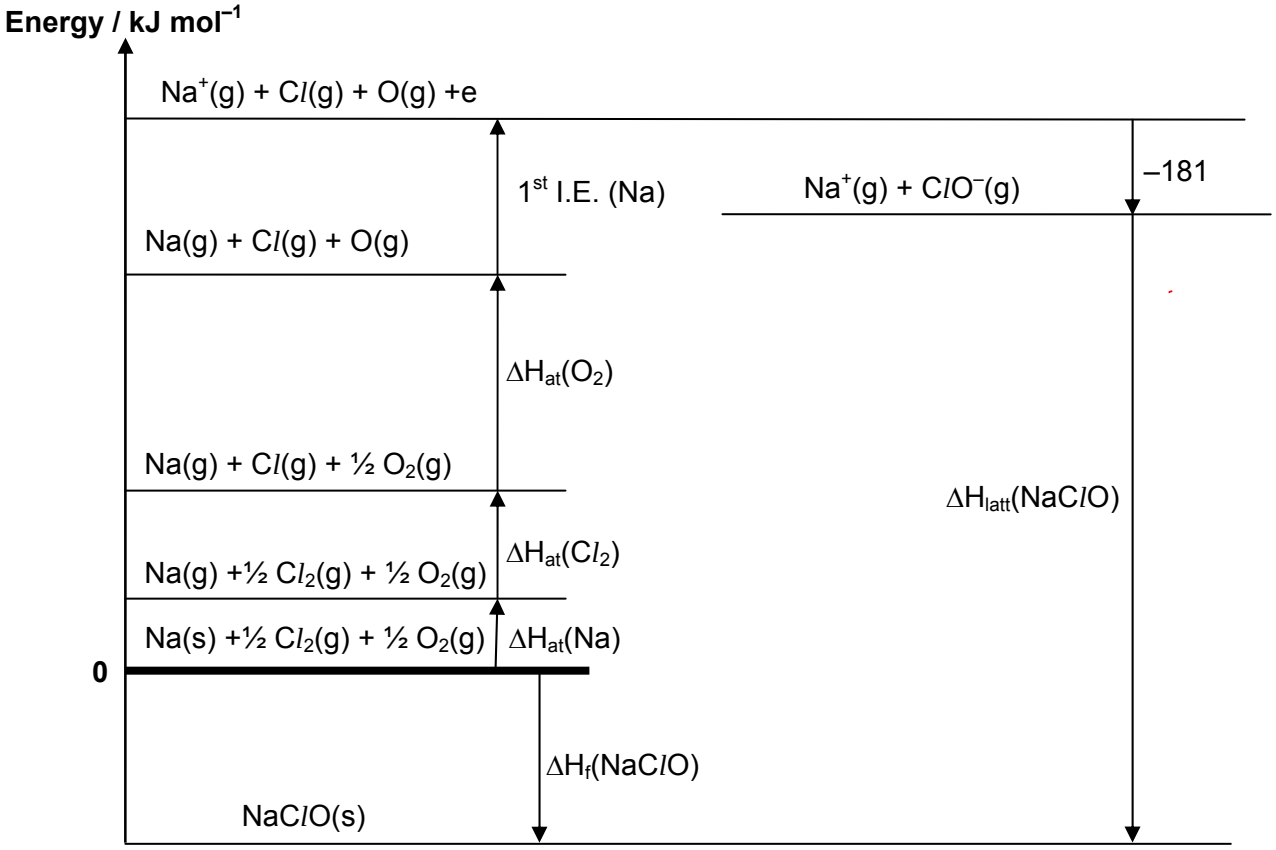
(iv) Predict, with reasoning, the relative volatility of Cl_2 and I_2.

Both are **simple molecular substances**.
Cl_2 has smaller no. of electrons hence **weaker intermolecular van der waals' forces**. **Smaller amount of energy needed to overcome these forces. Hence** Cl_2 **more volatile** than I_2.

[6]

(c) Construct an energy cycle for the formation of solid NaC*l*O from its elements. Use the relevant data from the table below as well as from the *Data Booklet*, calculate the lattice energy of NaC*l*O.

enthalpy term	ΔH / kJ mol^{-1}
standard enthalpy change of formation of NaC*l*O	–619
standard enthalpy change of atomisation of Na	+108
C*l*(g) + O(g) + e$^-$ → C*l*O$^-$(g)	–181



By Hess' law:
ΔH_{latt} = –(–181) – (+494) – ½(+496) ½(+244) – (+108) + (–619) = **–1410 kJ mol^{-1}**

Also accepted: energy cycle with correct labels

[6]

[Total: 20]