NATIONAL JUNIOR COLLEGE
SH2 MID YEAR TIMED PRACTICE
Higher 2

CANDIDATE NAME			
SUBJECT CLASS		REGISTRATION NUMBER	

CHEMISTRY

9476/02

Paper 2 Structured Questions

7 July 2026
2 hours

Candidates answer on Question Paper.
Additional Materials: Data Booklet

READ THE INSTRUCTIONS FIRST

Write your subject class, registration number and name on all the work you hand in.
Write in dark blue or black pen.
You may use a soft 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	**/7**
2	**/19**
3	**/15**
4	**/18**
5	**/12**
6	**/9**
Paper 2 Total	**/80**

This document consists of **24** printed pages.

1 **(a)** Two organic compounds, **A** and **B,** can co-polymerise to produce a polyester. On treatment with hot acidified sodium dichromate(VI), compound **A**, $C_4H_{10}O_2$, is converted into compound **B**. Compound **B** can also be formed from fumaric acid, $HO_2CCH=CHCO_2H$, upon treatment with hydrogen over a nickel catalyst

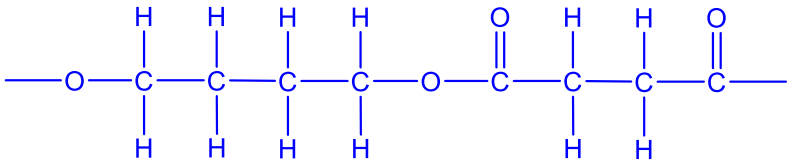
(i) Draw the structures for compounds **A** and **B**.

A	B
$HOCH_2CH_2CH_2CH_2OH$	$HO_2CCH_2CH_2CO_2H$

Examiner's Comment:
Many students cannot recall that H_2 with Ni only reduces C=C and COOH group can only be reduced by $LiAlH_4$ in dry ether.
To solve for **A**, students need to draw structure of **B** first.

[2]

(ii) Draw the structural formula of **one** repeat unit of the polymer formed from compounds **A** and **B**.



[1]

Examiner's Comment:
Students should check if their drawn *repeat unit* to give the polymer when repeated.

Poly(A-B) is a biodegradable plastic and can be used for food packaging like disposable tablewares and paper cups.

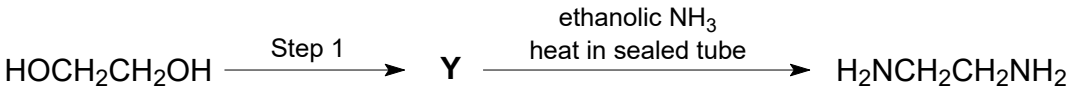
(iii) Suggest why poly(A-B) is biodegradable.

[1]

Poly(A-B) has **ester linkages that can be hydrolysed**.

Examiner's Comment:
Many students did not highlight it is the presence of ester linkages which can be hydrolysed.

(b) Ethane-1,2-diol, $HOCH_2CH_2OH$, has a wide variety of uses including in antifreeze in cars. Ethane-1,2-diol undergo a series of steps to form $NH_2CH_2CH_2NH_2$.



(i) Suggest the structure of **Y** and state the reagents and conditions for step 1.

[2]

Y: $BrCH_2CH_2Br$ / $ClCH_2CH_2Cl$

Step 1: anhydrous PBr_3 / PCl_3 / PCl_5 / $SOCl_2$ or HBr (g) or HCl(g)

(ii) Deduce which compound, $HOCH_2CH_2OH$ or $NH_2CH_2CH_2NH_2$ has a higher boiling point.

…….…….... [1]

$HOCH_2CH_2OH$ can form **stronger H-bonds** between molecules
since **O-H bond is more polar than N-H bond**.
Therefore, **boiling point of $HOCH_2CH_2OH$ will be higher.**

Examiner's Comment:
Many students mistaken N to be more electronegative than O, hence N-H bond is more polar, giving rise to stronger hydrogen bonds.

Many did not realise that both $NH_2CH_2CH_2NH_2$ and $HOCH_2CH_2OH$ have the same extensiveness in hydrogen bonding (consider the no. of lone pairs on O/N and no. of protonic H).

A few highlighted the higher Mr of $HOCH_2CH_2OH$, hence larger electron cloud and stronger idid. While this is correct, the difference in 2 in no. of electrons is not significant.

[Total: 7]

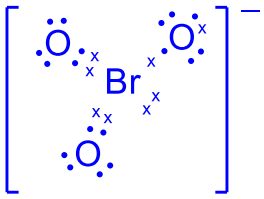
2 Bromine can form several compounds under suitable conditions as shown in Table 2.1.

Table 2.1

Bromine containing species	Oxidation number of Br
Br^-	–1
BrO^-	+1
BrF_4^-	+3
BrO_3^-	+5
BrO_4^-	+7

(a) **(i)** Draw the dot-and-cross diagram for BrO_3^-. [1]

(i)



Examiner's Comment:
O being more electronegative, will attract the extra electron to form the anion. Br is able to expand octet, hence double bonds to O atoms.

(ii) State and explain the bond angle in BrO_3^-. [2]

There are **3 bond pairs (BP) and 1 lone pair (LP) around Br**, electron geometry is tetrahedral. There is stronger r**epulsion between LP -BP than BP-BP**.
thus lone pair presses the bond pairs towards each other resulting in **bond angle to be 107°** < 109.5° and the shape is trigonal pyramidal around Br.

Examiner's Comment:
Many students did not highlight the stronger repulsion of lone pair-bond pairs.

(b) When a sample of 9.909 g of $Br_2(l)$ was reacted with an excess of aqueous NaOH, two different bromine containing ions, **X** and **Y**, are formed. The identities of **X** and **Y** can be found in Table 2.1. The resulting mixture was then made up to 250 cm^3 with deionised water to form solution **Q**.

The following procedures were carried out on solution **Q**.

1. When 25.0 cm^3 of solution **Q** was acidified with an excess of acid, followed by the addition of $AgNO_3(aq)$, a cream precipitate was formed.
2. This precipitate was insoluble in excess $NH_3(aq)$, and its mass was found to be 1.942 g.
3. To a separate 25.0 cm^3 portion of solution **Q**, excess KI solution was added. The I_2 liberated required 24.80 cm^3 of 0.500 mol dm^{-3} $Na_2S_2O_3$ for complete reaction as shown.

$$2S_2O_3^{2-} + I_2 \rightarrow S_4O_6^{2-} + 2\,I^-$$

(i) Given that ion **X** is responsible for the formation of the cream precipitate, state the identity of **X**.

Ion **X**: ..... [1]

Br^-

Examiner's comment:

- Students struggled with extracting the important key words in the question for answering the question.
- Some students gave "AgBr" as answer ignoring the fact that question asks for ion.
- A few students suggest "Ag^+ / I^-" even though question stated that X is bromine containing ions.
- A few students suggest BrO^- as the ion, forgetting that $AgNO_3$ typically test for halides.

(ii) Calculate the amount of **X** in 25.0 cm^3 of solution **Q**.

Amount of Br^- in 25.0 cm^3 of solution **Q** = $\frac{1.942}{79.9+107.9}$ = 0.01034 mol

Examiner's comment:

- Students struggled with this calculation when they failed to recognise that the Br- ion is precipitated as AgBr.
- Some failed to realise that the mass collected in step 2 is that of AgBr not just Br^- ion and definitely not NaBr.

[1]

(iii) Calculate the amount of bromine atoms in 9.909 g of $Br_2(l)$.
Hence, show that there are 0.00206 mol of **Y** in 25.0 cm^3 of solution **Q**.

Amount of Br_2 in 250.0 cm^3 of solution **Q** = $\frac{9.909}{2\times79.9}$ = 0.06201 mol
Total moles of Br atoms in Br^- and Y = (2)(0.06201) = 0.12402

Amount of **Y** in 250.0 cm^3 of solution **Q**
= 0.12402 – $\left(\frac{250}{25.0}\right)$ (0.01034)
= 0.02062 mol

Amount of **Y** in 25.0 cm^3 of solution **Q**
= $\left(\frac{25.0}{250}\right)$ (0.02062) = 0.002062 (shown)

Examiner's comment:

- Students struggled with this calculation when they failed to recognise Br_2 is the reactant that leads to formation of bromine containing ions X and Y.
- Some are confused whether they should calculate the number of Br atoms or moles of bromine atoms. Students are reminded to associate "amount" to moles than the number.
- Some struggled with whether they are calculating moles in 25.0 cm^3 or 250 cm^3.
- Some manage to get the numerical value by working with math instead of using chemistry principles.

[2]

(iv) In step 3, **Y** reacts with KI to form **X**. Deduce the oxidation state of Br in **Y**.

Y reacts with KI to form Br^- (In the process, I- is converted to I_2. I_2 liberated is titrated against $Na_2S_2O_3$ to determine the amount of I_2 formed, and hence amount of KI that reacted with **Y**.)

Amount of $S_2O_3^{2-}$ reacted = $\left(\frac{24.80}{1000}\right)$(0.500) = 0.01240 mol

$2S_2O_3^{2-} : I_2 : 2\ I^-$

Amount of KI reacted with **Y** in step 3 = 0.01240 mol

$\frac{\text{amount of KI}}{\text{amount of Y}} = \frac{0.01240}{0.002062} \approx \frac{6}{1}$

$I^- : e^-$
i.e. Each mol of **Y** gained 6 mol of electrons to form Br^-

Original oxidation state of Br in Y = –1 + 6 = +5

Examiner's comment:

- Students struggled with this calculation when they failed to
  - associate the change in oxidation state with number of electrons transfer.
  - deduce the original oxidation state from the fact that Br atom in Y is reduced to Br^- (which is X) when it reacts with KI.
  - realise that O from polyatomic ion becomes water NOT oxide ion in a redox reaction.

[2]

(v) Using Table 2.1 and your answers in **(iii)** and **(iv)**, construct the balanced equation for reaction between Br_2 and NaOH.

……..……[1]

Y is BrO_3^-,
$5Br^- : BrO_3^-$
$3Br_2 + 6OH^- \rightarrow 5Br^- + BrO_3^- + 3H_2O$

Examiner's comment:

- Most students failed to use the moles of X and Y from parts (ii) and (iii) to deduce their coefficient in this balanced equation.
- Most students have forgotten the fact that an alkaline reactant(NaOH) cannot form acidic products. Hence products such as HBr, HBrO, $HBrO_3$ are not acceptable since they are potential proton donor. Some even forms Na metal as products.
- A few students did not realise that Br_2 and NaOH are the only reactants they can start with.

(c) Br^- reacts with BrO_3^- in acidified medium as shown.

$$BrO_3^- + Br^- + 6H^+ \rightarrow 3Br_2 + 3H_2O$$

A series of kinetic experiments were conducted on this reaction and the data collected were tabulated in Table 2.2.

Table 2.2

Expt	$[BrO_3^-]$ / mol dm^{-3}	$[Br^-]$ / mol dm^{-3}	$[H^+]$ / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	1.20	0.100	1.50	1.00×10^{-2}
2	2.40	0.100	1.50	2.00×10^{-2}
3	1.80	0.200	1.50	3.00×10^{-2}

(i) Use Table 2.2, deduce the order of reaction with respect to $[BrO_3^-]$ and $[Br^-]$.

……..……[2]

Let the rate equation be: Rate = $k[BrO_3^-]^p[Br^-]^q[H^+]^r$

- Comparing experiment 1 and 2:
  When $[BrO_3^-]$ is doubled, and $[Br^-]$ and $[H^+]$ are kept constant, rate of reaction doubles.
  Hence, reaction is 1st order with respect to BrO_3^-.

- Comparing experiments 2 and 3:

$$\frac{(2.4)^1(0.1)^q(1.5)^r}{(1.8)^1(0.2)^q(1.5)^r} = \frac{2.00\times10^{-2}}{3.00\times10^{-2}}$$

$$\frac{(0.1)^q}{(0.2)^q} = \left(\frac{3}{4}\right)\frac{2.00\times10^{-2}}{3.00\times10^{-2}}$$

q = 1
Hence, reaction is 1st order with respect to Br^-.

Examiner's comment:

- Most students are able to deduce the order wrt BrO_3^- using inspection method, however, almost 50% struggled with determining the order wrt Br^-.
- Students are advised to use the mathematical approach to determine the order for both reactants due to lack of clarity in their explanation.
- Some answers lack systematic presentation and difficult to understand. Despite Br^- being the unknown, some students created 4th set of data by changing the concentration of Br^- instead of BrO_3^- to become constant across suitable pair of experiments, thus not accepted as answer

(ii) Given that the reaction is 2nd order with respect to $[H^+]$, calculate the value of rate constant, *k*, for experiment 1. Include its units.

……[1]

From experiment 1:

$1.00 \times 10^{-2} = k(1.20)(0.100)(1.50)^2$

$k = 0.03704$

units: $mol^{-3}dm^9\ s^{-1}$

Examiner's comment:

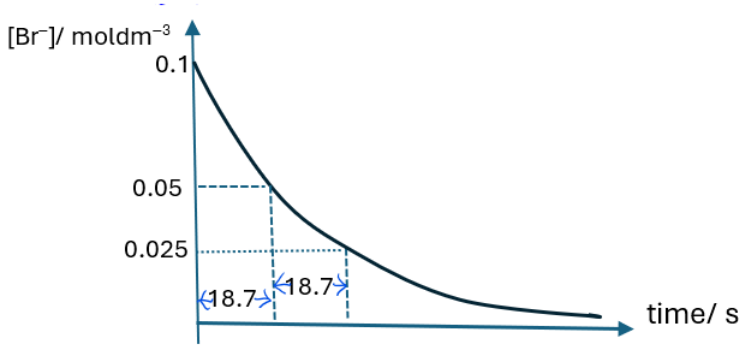
- A handful of students equate k (rate constant) to conc of reactants raised to their powers. i.e. $k = [\ ]^x$
- A handful of students have forgotten that the units for rate is $moldm^{-3}s^{-1}$ while some thought that units for concentration is $moldm^{-3}s^{-1}$.

(iii) The initial rate of experiment 1 is determined from the gradient of tangent at time, *t* = 0 when concentration of Br^- is monitored with time.

Given that the concentrations of BrO_3^- and H^+ remain unchanged during the course of reaction, calculate the half-life of this reaction.

Hence sketch the graph of $[Br^-]$ against time.

Half-life ($t_{½}$) = $\frac{ln2}{0.03704} = 18.7\ s$



Examiner's comment:

- A handful of students plotted product conc time graph instead. Hence their graph shows an increasing trend instead of decreasing one.
- Large % of student did not demonstrate the understanding of first order reaction with respect to Bromide ion in the sketch of $[Br^-]$ vs time graph.

[2]

(d) A bromine compound, Br*Cl* reacts with benzene, in the presence of A*lCl*$_3$, to form a monohalogenobenzene, C_6H_5X.

(i) Suggest whether the product C_6H_5X is chlorobenzene or bromobenzene. Explain your answer.

..... [1]

The product is **bromobenzene.**
C*l* is more electronegative than Br, hence **an electrophile of Br$^+$ is generated** from the reaction between Br*Cl* and A*lCl*$_3$.

Examiner's comment:

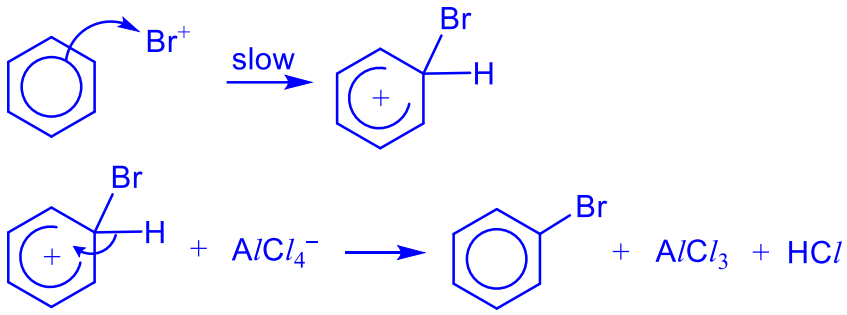
- Many students merely stated that Br is more electronegative, not mentioning **clearly** that the electrophile generated is Br$^+$.
- Many stated that Br is more eletronegative, thus 'it' will be the electrophile. "It" is vague as it could mean Br atom is acting as the electeophile instead of Br$^+$.

(ii) Draw the mechanism of the reaction. Include all the relevant dipoles, curly arrows and charges.

Include the structure of the organic intermediate.

Electrophilic substitution

$$BrCl + AlCl_3 \longrightarrow AlCl_4^- + Br^+$$



[3]

Examiner's comment:

- Generally well done with a number of students failing to do the following:
- Show that the A*lCl*$_3$ funtioning as the catalyst as stated in the question, thus showing the benzene ring directly attacking the Br*Cl* molecule.
- Show regeneration of catalyst
- Naming the mechanism
- Indicating slow step

[Total: 19]

3 **(a)** Chloroform, $CHCl_3$ is commonly used as a solvent for paints, lacquers, adhesives, and floor polishes. It can undergo hydrolysis in basic conditions as follows.

$$CHCl_3(aq) + 4OH^-(aq) \rightleftharpoons HCO_2^-(aq) + 3Cl^-(aq) + 2H_2O(l)$$

At 60 °C, 0.20 mol of $CHCl_3$ is mixed with 0.80 mol of NaOH in 2.0 dm³ of solution and allowed to reach equilibrium. The final concentration of HCO_2^- was found to be 0.098 mol dm^{-3}.

(i) Explain what is meant by the term *dynamic equilibrium*.

..... [2]

A dynamic equilibrium occurs when the **rates of forward and backward reaction are equal** and there is **no net change in concentration of reactants and products** in a **closed system.**.

Examiner's comment:

- Most forgot to state '**closed system'**. A dynamic equilibrium can **only** be established and maintained if no reactants or products can escape into the surroundings. If the system is open (for example, if a gaseous product escapes), the forward and backward reaction rates can never become equal, and the concentrations will never remain constant.

- Some also stated that **equlibrium concentrations** are **equal** which is **incorrect**. **Rates are EQUAL**, **Concentrations are CONSTANT**. Because the forward and backward reactions are happening at the exact same speed, the amounts (concentrations) of the chemicals stop changing.

(ii) Write the expression for the equilibrium constant, K_c, for this reaction and state its units. [1]

$$K_c = \frac{[HCO_2^-][Cl^-]^3}{[CHCl_3][OH^-]^4} \quad \text{units: } mol^{-1}dm^3$$

(MUST include units)

Examiner's comment:

- Generally well done, with only some students including H_2O product into the K_c expression.
- Why H_2O excluded here?
  - *Water is a pure liquid and is the solvent in this aqueous reaction. Its concentration remains essentially constant throughout the reaction, so it is omitted from the equilibrium constant expression.*
  -

(iii) Use these data to calculate the value of K_c.

	$CHCl_3$(aq)	+ $4OH^-$(aq)	⇌	HCO_2^-(aq)	+ $3Cl^-$(aq)	+ $2H_2O$(l)
Initial/ mol/dm^{-3}	$\frac{0.20}{2.0}$ = 0.1	$\frac{0.80}{2.0}$ = 0.4				-
change/ mol/dm^{-3}	–0.098	–4(0.098) = 0.392		+0.098	+3(0.098) = 0.294	-
change/ mol/dm^{-3}	0.002	0.008		0.098	3(0.098) = 0.294	-

$K_c = \frac{(0.098)(0.294)^3}{(0.002)](0.008)^4}$

K_c = **3.04 x 10^8**

[2]

Examiner's comment:

- Many did not read carefully and mistook the concentration of HCO_2^-(aq) given as amt. in moles even though it was stated clearly that it was concentration in mol dm^{-3}.

(iv) Predict and explain the effect on the equilibrium position when the reaction is repeated at a higher pH.

…… [1]

Higher pH implies that [OH^-] concentration increases.

By Le Chatelier's Principle, system wants to partially decrease [OH^-], by shifting the position of the equilibrium to the right.

Examiner's comment:

- Generally well done, although a significant number deduced that pH increases leads to [H^+] increasing.
- Recall that **higher pH → lower [H^+].**
- Hence, higher [OH^-].

(b) A chemical plant has groundwater with contaminated $CHCl_3$ and two other halogenated solvents:

- Methyl iodide, CH_3I
- Benzyl chloride, $C_6H_5CH_2Cl$

The half-lives, $t_{1/2}$, for hydrolysis of the contaminant and solvents in the groundwater at 25°C obtained from environmental monitoring are as provided in Table 3.1.

Table 3.1

Compound	$t_{1/2}$
$CHCl_3$	1.4 years
CH_3I	7 days
$C_6H_5CH_2Cl$	15 hrs

(i) Suggest and explain two reasons for the large difference in hydrolysis rates between $CHCl_3$ and CH_3I.

[2]

Bond enthalpy factors:

- **C-I bond (238 kJ/mol) much weaker than C-Cl bond (338 kJ/mol)**

  OR

- **larger atomic size of I causes poorer effectiveness of orbital overlap between C and I hence C-I bond is longer**.

  OR

- **larger atomic size of I hence C-I bond is longer**

  AND

- Thus **weaker C-I bond breaks more easily**, leading to faster hydrolysis.

Mechanism considerations:

IF considering via S_N2 mechanism:

- $CHCl_3$: **3 bulky Cl atoms attached to electron deficient C-atom**, as compared to only 3 H-atoms in CH_3I.
- So more **steric hindrance** and **nucleophile less able to attack reactive C-atom**, slower rate of hydrolysis.

  OR

IF considering via S_N1 mechanism:

The **carbocation intermediate, $^+CHCl_2$** formed from $CHCl_3$ **has two highly electron withdrawing Cl atoms** which makes the **carbocation highly electron deficient**, thus **highly unstable** as **compared to the $^+CH_3$ formed from CH_3I**. So **much higher E_a** for formation of $^+CHCl_2$, slower rate of hydrolysis for $CHCl_3$.

Examiner's comment:

- **Poorly done** as many failed to see the link between rate and mechanism. **Rate is determined SOLELY by the slowest step. *Regardless of whether a reaction mechanism has 2 steps or 20 steps***, the overall rate of the reaction is dictated entirely by its Rate-Determining Step (RDS) – the slowest step in the mechanism.

- Many students explained that more energy, thus more time is required to break 3 C-Cl bonds than 1 C-I bond during hydrolysis. Shorter half-life implies greater rate of reaction. **During hydrolysis (an SN1 or SN2 reaction), you do NOT break all 3 C-Cl bonds at once.**
  - In **CH_3I**, the reaction involves breaking only **the single C-I bond** (the leaving group leaves).
  - In **$CHCl_3$**, the reaction involves breaking only **the single C-Cl bond** that acts as the leaving group. The other two C-Cl bonds **remain completely intact** throughout the reaction!
  - The molecule is $CHCl_3$ (chloroform). It has *three* chlorine atoms, but only *one* of them leaves and is replaced by an -OH group during hydrolysis (forming $CHCl_2OH$). The other two chlorines stay firmly attached to the carbon.

- A significant number also explained that difference in **intermolecular forces** (i.e. id-id/pd-pd interactions) led to difference in rates.

Why this is **wrong**:

- For CH_3I or $CHCl_3$ to undergo hydrolysis, a **covalent bond inside the molecule must break** (the C–I or C–Cl bond).
- To do this, the molecule must collide with a nucleophile (like H_2O or OH^-) with enough energy (activation energy, E_a) to break that **specific intramolecular covalent bond**.
- **Intermolecular forces** only hold molecules together in a bulk liquid/solid. They do not influence how easily a nucleophile can break a C–X bond. Even if you completely eliminate all IMFs (by turning the substance into a gas), the **intramolecular C–X bond** would still require exactly the same amount of energy to break.

(ii) Benzyl chloride, $C_6H_5CH_2Cl$, hydrolyses rapidly via S_N1 mechanism. Suggest why benzyl chloride is able to undergo S_N1 mechanism despite being a primary halide.

..... [1]

The electron deficient carbon of the carbocation formed, $C_6H_5CH_2^+$ **has p-orbitals that overlap with p-orbitals of benzene ring, thus the positive charge is dispersed/electron deficient is reduced via resonance/delocalisation of electrons**.

Hence the **carbocation is stable enough (accept also if comparison to why this is formed preferentially and preferred to S_N2)** for to form and undergo Sn1 mechanism.

Examiner's comment:

- While many students recognised the need for the carbocation to be stable in order for SN1 to occur preferentially, most missed out or gave incomplete reasoning for the stability. Both 'resonance/delocalisation' and 'dispersion of positive charge' need to be included for the full credit.

Some students explained that the partial double bond character due to chlorine atom donating its lone pair to the benzene as the answer. However, the Cl is not directly bonded to the benzene, there is one alkyl carbon in the middle that prevents it from happening.

(c) **(i)** Compound **X,** $CH_3CH_2CH_2OCH_2CH_3$, is made by reacting 1-chloropropane with ethanol.

Suggest why the yield of this synthesis is improved significantly with the addition of sodium.

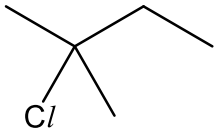
..... [2]

- Addition of sodium to ethanol forms sodium ethoxide. Ethoxide ion is a much **stronger nucleophile** than ethanol, **due to increase in electron density on the O-atom**.
- Hence, the **lone pair of electrons on oxygen are more available**, makes it **more reactive** towards the **electron deficient carbon/the electrophile**.

Examiner's comment:

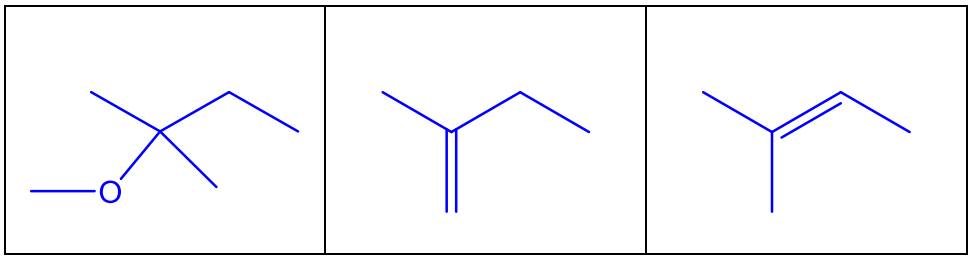
Most students commonly mistaken the increased in nucleophilicity is due to the negative charge of the nucleophile. This is incorrect. Strength of nucleophilicity is dependent on the availability of lone pair for donation during the reaction. A neutral nucleophile can be as stronger or stronger than a negatively charged nucleophile.

(ii) When 2-chloro-2-methylbutane is treated with CH_3CH_2ONa in ethanol at 80°C, a mixture of three organic products is formed from both substitution and elimination reactions.



2-chloro-2-methylbutane

Draw the **skeletal formula** of all the organic products.



Examiner's comment:

Many students missed out the elimination product **C**. There are two sites for elimination giving **C** as the answer.

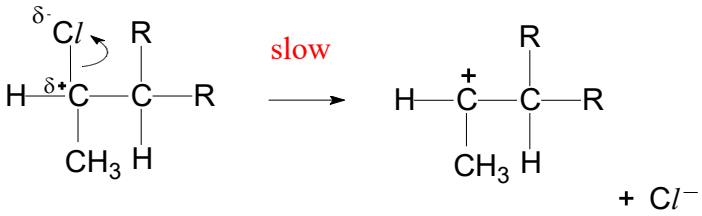
[2]

(iii) When 2-chloro-2-methylbutane undergoes elimination, the $CH_3CH_2O^-$ acts as a base and abstracts a proton from the reactive intermediate

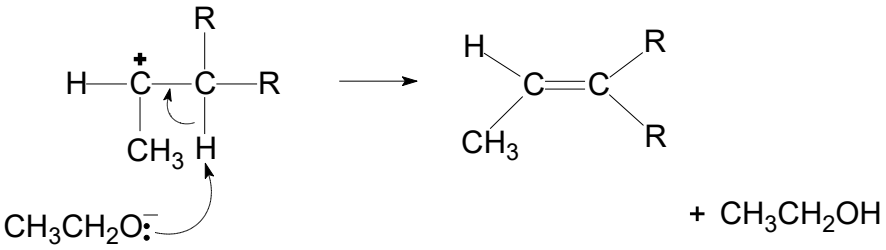
Complete the diagram below to show how elimination takes place. Use curly arrows to show movement of electrons. Include all the relevant dipoles, lone pairs and charges.

[2]

Step 1:



Step 2:



Examiner's comment:

- Many students did not indicate slow or balance the first step.
- Many students drew the arrow from C–H to the C+ atom. This is incorrect as the electrons in the C–H bond is shifted to be shared by the 2 C atoms in the C=C. Hence, the arrows should be drawn to the middle of the 2 C atoms as shown in the answer.

[Total: 15]

4 This question is about the chemistry of Group 2 elements and their compounds.

(a) The carbonates of Group 2 elements are sparingly soluble in water. The carbonates also decompose upon strong heating. Some of the properties of Group 2 carbonates are given in Table 4.1.

Table 4.1

compound	molar mass / g mol^{-1}	solubility at 25 °C / g dm^{-3}	enthalpy change of thermal decomposition / kJ mol^{-1}
magnesium carbonate	84.3	0.18	+117
calcium carbonate	100.1	0.0066	+178
strontium carbonate	147.6	0.0034	+235
barium carbonate	197.3	0.014	+267

(i) Write the equation, including state symbols, for the thermal decomposition of calcium carbonate.

$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

Examiner's comment:
Many students gave combustion instead of thermal decomposition. ($CaCO_3(s) + O_2(g) \rightarrow$

……..[1]

(ii) Describe and explain the trend of the decomposition temperatures of the Group 2 carbonates.

……[3]

- The enthalpy change of decomposition **becomes more endothermic** down group 2 carbonates, implies that the carbonates require increasingly higher temperatures to decompose/Decomposition temperature increases from $MgCO_3$ to $BaCO_3$
  from Mg^{2+} to Ba^{2+} / down the group.
  Ionic radius of metal cation increases
- charge density / polarising power of metal cation decreases from Mg^{2+} to Ba^{2+} / down the group
- Extent of polarisation / distortion of electron cloud of CO_3^{2-} by metal cation
- Extent of weakening of covalent bonds in CO_3^{2-} decreases
- More energy is required for the decomposition of Group 2 carbonates from $MgCO_3$ to $BaCO_3$

Examiner's comment:

Many students did not recognise that the covalent bond C–O is the one broken during decomposition. Instead, many answers suggested stronger ionic bond between the ions for the reason of higher decomposition temperature required.

(iii) Write the solubility product expression for barium carbonate, including the units.

$K_{sp} = [Ba^{2+}][CO_3^{2-}]$ mol^2 dm^{-6}

……..[1]

Examiner's Comment:

(iii) Write the solubility product expression for barium carbonate, including the units.

Many candidates lost the mark here for one of three reasons:

- **Missing units:** They correctly wrote $K_{sp} = [Ba^{2+}][CO_3^{2-}]$ but failed to include the units, or wrote an incomplete unit.
- **Wrong units:** Some wrote units such as mol dm^{-3} or mol^3 dm^{-9}, failing to recognise that the product of two concentrations (mol dm^{-3} × mol dm^{-3}) yields **mol^2 dm^{-6}**.

Wrong expression with a fraction: A significant number of candidates incorrectly included a denominator, writing expressions such as $K_{sp} = \frac{[Ba^{2+}][CO_3^{2-}]}{[BaCO_3]}$ or $K_{sp} = \frac{1}{[Ba^{2+}][CO_3^{2-}]}$, forgetting that the solid is excluded from the equilibrium expression

(iv) Using the data in Table 4.1 and your answer in **(a)(iii)**, calculate the solubility product for barium carbonate.

solubility of $BaCO_3$ = 0.014 ÷ 197.3
= 7.0958×10^{-5} mol dm^{-3}

K_{sp} of $BaCO_3$ = $(7.0958 \times 10^{-5})^2$
= 5.04×10^{-9} mol^2 dm^{-6}

Examiner's Comment:
The most common errors in this calculation were:

- **Did not convert to mol dm^{-3}:** Candidates often divided 0.014 by 197.3 but failed to realise that 0.014 represented 0.014 g dm^{-3} (or 0.014 g per 100 cm^3) and omitted the conversion step, or they did not show the working clearly.
- **Used different solubility for two different ions:** A recurring misconception was assuming that $[Ba^{2+}]$ and $[CO_3^{2-}]$ had different values. Many candidates incorrectly doubled the solubility for one ion (e.g., using $2s$ for one concentration and s for the other), failing to recognise that for $BaCO_3(s) \rightleftharpoons Ba^{2+}(aq) + CO_3^{2-}(aq)$, both ions are produced in a 1:1 ratio and therefore have identical concentrations equal to the molar solubility, s.

[2]

(b) The hydroxides of Group 2 elements are also sparingly soluble in water. Given that the solubility of calcium hydroxide is 0.0139 mol dm^{-3} at 25 °C, calculate the pH of a saturated solution of calcium hydroxide at 25 °C.

$[OH^-]$ = 2×0.0139
= 0.0278 mol dm^{-3}

pOH = –lg 0.0278
= 1.5556

pH = 14 – 1.5556 = 12.4

Examiner's Comment:
The vast majority of candidates lost the mark because they did not multiply by 2 for the concentration of OH^-. They correctly calculated the solubility of $Ca(OH)_2$ as 0.0139 mol dm^{-3}, but then incorrectly used this value as $[OH^-]$ instead of recognising that each mole of $Ca(OH)_2$ produces two moles of OH^- ions. Consequently, they calculated a pH that was too low (around 11.4 instead of the correct 12.4).

[2]

(c) When carbon dioxide was bubbled into a saturated solution of calcium hydroxide, a white precipitate of calcium carbonate was formed. However, upon further bubbling of carbon dioxide into the mixture, the precipitate dissolved and a colourless solution of calcium hydrogencarbonate, $Ca(HCO_3)_2$, was obtained.

(i) Write an ionic equation for the formation of hydrogencarbonate ions.

$CaCO_3(s) + CO_2(g) + H_2O(l) \rightarrow 2Ca^{2+}(aq) + 2HCO_3^-(aq)$
OR $CO_3^{2-}(aq) + CO_2(g) + H_2O(l) \rightarrow 2HCO_3^-(aq)$

.....[1]

Examiner's Comment:

Many candidates **did not read the question carefully**. The question asks for the *formation of hydrogencarbonate ions*, but a large number of candidates wrote the acid-base reaction:

$$CO_3^{2-}(aq) + 2H^+(aq) \rightarrow 2HCO_3^-(aq)$$

or wrote equations producing Ca^{2+} and HCO_3^- from solid $CaCO_3$ without including CO_2 and H_2O. This is incorrect in the context of the experiment described (bubbling CO_2). The correct ionic equation showing the formation of HCO_3^- from the carbonate ion is:

$$CO_3^{2-}(aq) + CO_2(g) + H_2O(l) \rightarrow 2HCO_3^-(aq)$$

(ii) State and explain, using Le Chatelier's Principle, why calcium carbonate dissolves when excess carbon dioxide was bubbled into the mixture.

When excess carbon dioxide was bubbled into the mixture, CO_3^{2-} react with CO_2 to form HCO_3^{2-}.

By Le Chatelier's Principle, the decrease in $[CO_3^{2-}]$ results in the position of equilibrium of "$CaCO_3$ (s)⇌ Ca^{2+} (aq)+ CO_3^{2-}"(aq) to shift to the right (to increase $[CO_3^{2}]$)

Hence, the white precipitate dissolves.

.....[2]

Examiner's Comment:

Candidates frequently gave **generic responses not related to the specific equilibrium**, such as: *"The equilibrium shifts to the right to oppose the change."* This is too vague. To gain full marks, candidates must:

1. State the specific equilibrium involved: $CaCO_3(s) \rightleftharpoons Ca^{2+}(aq) + CO_3^{2-}(aq)$.
2. Explain that adding excess CO_2 removes CO_3^{2-} ions (by converting them to HCO_3^-).
3. Then state that, by Le Chatelier's Principle, the equilibrium shifts to the right (to replace the removed CO_3^{2-} ions), causing the solid $CaCO_3$ to dissolve.

(d) Magnesium chloride is a supplement used to increase dietary magnesium intake.

(i) Describe the reaction of magnesium chloride with water. Write an equation for the reaction and state the pH of the resultant solution.

$MgCl_2$ dissolves in water and Mg^{2+} undergoes **hydrolysis** to give a solution with **pH 6.5**

$[Mg(H_2O)_6]^{2+} + H_2O \rightleftharpoons [Mg(H_2O)_5(OH)]^+ + H_3O^+$

.....[2]

Examiner's Comment:

The most frequent errors were:

- **Writing dissolving instead of hydrolysis:** Many candidates simply wrote the dissolution equation $MgCl_2(s) \rightarrow Mg^{2+}(aq) + 2Cl^-(aq)$ and stated that it dissolves. The question asks for the *reaction with water*, which is the hydrolysis of the hydrated Mg^{2+} ion.
- **Giving pH as 3 instead of 6.5:** Candidates who did write a hydrolysis equation often wrote $Mg^{2+} + H_2O \rightarrow Mg(OH)_2 + 2H^+$, leading them to state a strongly acidic pH of 3. The correct equation is the reversible formation of the hydroxoaqua complex, $[Mg(H_2O)_6]^{2+} + H_2O \rightleftharpoons [Mg(H_2O)_5(OH)]^+ + H_3O^+$, which gives a weakly acidic solution with a pH of approximately 6.5.

Some enthalpy changes relating to magnesium chloride are found in Table 4.2.

Table 4.2

	ΔH / kJ mol^{-1}
lattice energy of $MgCl_2$(s)	–2540
standard enthalpy change of hydration of Mg^{2+}(g)	–1980
standard enthalpy change of hydration of Cl^-(g)	–364

(ii) Using data from Table 4.2, calculate the standard enthalpy change of solution, $\Delta H_{sol}^{\ominus}$, of magnesium chloride, $MgCl_2$(s).

[1]

$\Delta H_{sol}^{\ominus}$ ($MgCl_2$) = –L.E. ($MgCl_2$) + ΔH_{hyd}° (Mg^{2+}) + 2ΔH_{hyd}° (Cl^-)
= –(–2540) + (–1980) + 2(–364)
= –168 kJ mol^{-1}

Examiner's Comment:

The almost universal error here was **forgetting that there are two moles of Cl^- ions**. Candidates used the hydration enthalpy of Cl^- only once in the Born-Haber cycle calculation:

$$\Delta H_{sol}^{\circ} = -L.E. + \Delta H_{hyd}(Mg^{2+}) + \Delta H_{hyd}(Cl^-)$$

This gave an incorrect value. The correct calculation must include **2** × $\Delta H_{hyd}(Cl^-)$ to account for the two chloride ions in $MgCl_2$:

$$\Delta H^{\circ}_{sol} = -(-2540) + (-1980) + 2(-364) = -168 \text{ kJ mol}^{-1}$$

(iii) Given that the standard Gibbs free energy change of solution of magnesium chloride is –126 kJ mol^{-1}, use your answer in **(d)(ii)** to calculate the standard entropy change of solution, $\Delta S_{sol}^{\ominus}$, of $MgCl_2$(s) at 298 K.

[1]

$\Delta G_{sol}^{\ominus} = \Delta H_{sol}^{\ominus} - T\Delta S_{sol}^{\ominus}$
$-126 = -168 - [298 \times \Delta S_{sol}^{\ominus} (MgCl_2)]$
$\Delta S_{sol}^{\ominus} (MgCl_2) = -0.14094$ kJ mol^{-1} K^{-1}
$= -141$ J mol^{-1} K^{-1}

Examiner's Comment:
The main issue here was **no units or wrong units**. Candidates often calculated the numerical value correctly (-0.14094) but failed to include units, or they left the units in kJ mol^{-1} K^{-1}. The mark is awarded for the correct conversion to **J mol^{-1} K^{-1}** (specifically, **–141 J mol^{-1} K^{-1}**)

(iv) Predict, with reasoning, how the spontaneity of the dissolution of magnesium chloride will change with increasing temperature.

When temperature increases, $-T\Delta S_{sol}$ becomes more positive.
Since $\Delta G_{sol} = \Delta H_{sol} - T\Delta S_{sol}$, ΔG_{sol} will become less negative / more positive with increasing temperature.
Hence, the dissolution is less spontaneous at higher temperatures.

……..[2]

Examiner's Comment:
Most student are able to use their answers in (ii) and (iii) to make the correct deduction on how increases in T affect ΔG. However, most students do not receive the full credit as the explanation is effy (there is little suggestion on how changes in $-T\Delta S_{sol}$ affect the sign on ΔG)

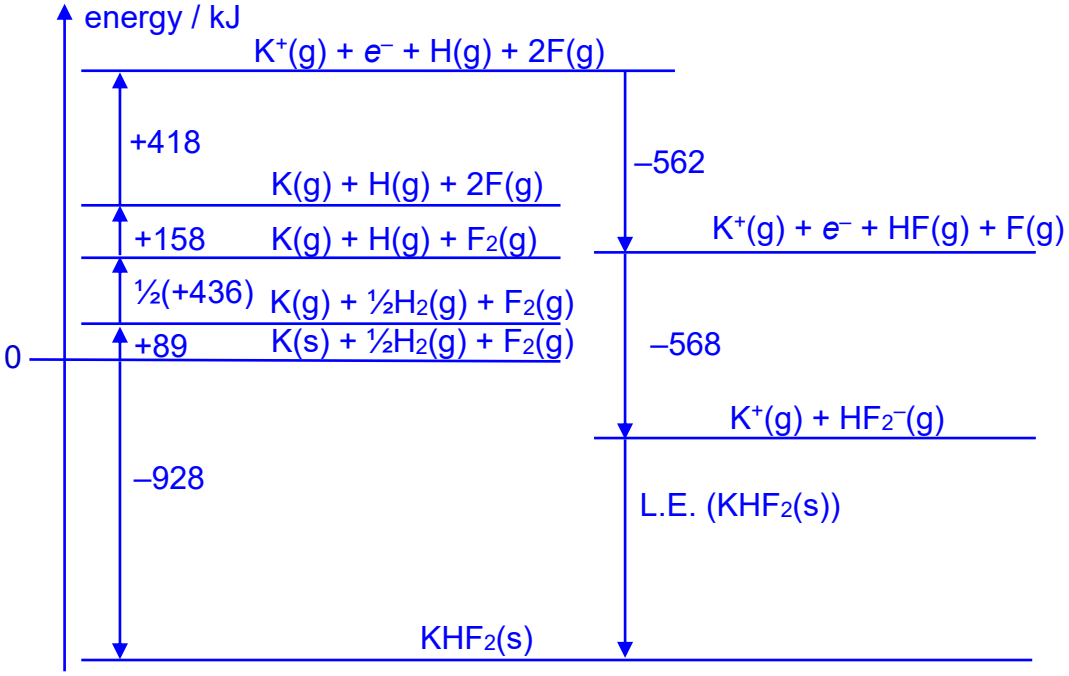
[Total: 18]

5 Fluorine was historically difficult to isolate because it is extremely reactive. It was finally isolated in 1886 by Henri Moissan, who electrolysed a cooled solution of potassium bifluoride (KHF_2) dissolved in anhydrous HF using platinum–iridium electrodes.

(a) (i) Use the data in Table 5.1, together with data from the *Data Booklet*, to calculate a value for the lattice energy of potassium bifluoride, $KHF_2(s)$. Show your working.

Table 5.1

	ΔH / kJ mol^{-1}
enthalpy change for the reaction, $HF(g) + F(g) + e^- \rightarrow HF_2^-(g)$	–568
standard enthalpy change of atomisation of K(s)	+89
standard enthalpy change of formation of $KHF_2(s)$	–928



L.E.($KHF_2(s)$) = +240+328+562–418–158–218–89–928 = **–681 kJ mol^{-1}**

[4]

Examiner's Comment:

This question is generally badly done. Many students have forgotten the various energetic definitions. For Enthalpy change of formation, quite a handful of students forget it is energy released to form a solid from its constituent elements in the standard state. There are also quite a number of students who forget that bond forming (in this context H–F bond) is an exothermic process. Some other common mistakes include the omission of state symbol, and incorrect balance of equations.

(ii) Compare the magnitude of the lattice energy of KHF_2 to that of KF. Explain the difference.

……..…[1]

HF_2^- and F^- have the **same charge**, but **HF_2^- has a larger ionic radius than F^-**. Based on $|\text{L.E.}| \propto \left|\frac{q_+ \times q_-}{r_+ + r_-}\right|$, the **magnitude of lattice energy of KHF_2 is hence smaller** than that of KF.

Examiner's Comment:
This question is generally well done. Most students are able to explain based on the factors affecting Lattice energy $|\text{L.E.}| \propto \left|\frac{q_+ \times q_-}{r_+ + r_-}\right|$, although a few students did not explain that the charge product for these two ionic compounds is the same and hence lose partial credit.

(b) The strength of a carboxylic acid depends on its structure. An example of this is the comparison of ethanoic acid and 2-fluoroethanoic acid.

Acid	pK_a
CH_3CO_2H	4.76
FCH_2CO_2H	2.60

(i) Explain the difference in pK_a values in the above table.

…….. [2]

Compare to CH_3CO_2H, FCH_2CO_2H has a **lower pK_a and hence is a stronger acid** .
The negative charge on its conjugate base, $FCH_2CO_2^-$, is **more dispersed and hence is more stable** due to presence of **electron withdrawing F** atom.
Thus, **acid dissociation occurs to a greater extent** in FCH_2CO_2H and FCH_2CO_2H is a stronger acid.
Examiner's Comment:
Most students received partial credit for this question. Firstly, it is important to recognise the relationship between pKa and acid strength. Next, students should recognise the concept used to compare acid strength: stability of conjugate base. In addition, many students did not include key terms like Fluorine is an electron withdrawing group. Finally, there were also a handful of effy answers which talk about stability and dispersal of charge when it is unclear the focus is on the acid molecule or the conjugate base.

(ii) Calculate the pH of a solution containing 0.200 mol dm^{-3} of FCH_2CO_2H.

$[H^+] = \sqrt{Ka(0.2)}$

$[H^+] = \sqrt{10^{-2.6}(0.2)} = 0.0224$
pH = 1.65

[1]

Examiner's Comment:
Generally well done question. Most student applied the right calculation although a small handful just treat the acid as a strong acid and hence lose the easy mark.

(iii) Calculate the ratio of $\frac{[CH_3CO_2^-]}{[CH_3CO_2H]}$ when CH_3CO_2H is placed in a buffer solution kept at pH 3.8. Give your answer to three significant figures.

$pH = pK_a + \lg \frac{anion}{acid}$
$3.8 = 4.76 + \lg \frac{anion}{acid}$
$\frac{anion}{acid}$ = **0.110**

Examiner's Comment:
Again, an easy mark to score. Question already said that this is a buffer solution. Applying the correct buffer formula should secure this mark easily. A handful of students remember the wrong formula and hence did not score for this question.

[1]

(c) Trifluoroethanoic acid, CF_3CO_2H, is a colourless liquid with a vinegar-like smell. It is produced industrially by electrofluorination of ethanoyl chloride to first give trifluoroethanoyl fluoride, CF_3COF.

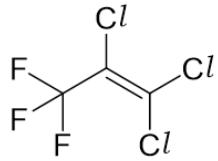
(i) State the type of reaction involved for the conversion of CF_3COF into CF_3CO_2H.

…… **Hydrolysis**……[1]

Examiner's Comment:
Many students failed to recognise that the conversion of CF_3COF to CF_3CO_2H is the hydrolysis of an acyl fluoride. A common misconception was identifying the reaction as nucleophilic substitution instead of nucleophilic acyl substitution.

(ii) An older route to CF_3CO_2H commences from compound **A**.

The synthesis of compound **A** to CF_3CO_2H produces two side products, one of which is a pale-yellow gas.



compound **A**

Suggest the reagents and conditions for the one-step conversion of compound **A** into CF_3CO_2H, and state the identities of the two by-products.

Reagents and conditions	By-products
$KMnO_4$(aq), H_2SO_4(aq), heat	**Cl_2** and **CO_2**

[2]

Examiner's Comment:
Compound A contains three carbon atoms and a C=C double bond, whereas CF_3COF contains only two carbon atoms. The decrease of 1 carbon atoms indicates that the conversion is a step-down reaction involving the oxidative cleavage of the C=C bond. Many students failed to identify the correct reagents, either by omitting the aqueous state symbol for H_2SO_4 or by using NaOH(aq). The latter demonstrates a failure to recognise that NaOH(aq) would hydrolyse CF_3COF to form the corresponding carboxylate salt rather than the carboxylic acid.

The oxidative cleavage of terminal alkene produced CO_2. Since pale yellow gas is produced, Cl_2 is formed as one of the by-products.

[Total: 12]

6 Three compounds, **A**, **B**, and **C**, each containing only carbon, hydrogen, and oxygen, have the same molecular mass of 164. All three compounds are 1,4-disubstituted benzenes and each compound contains exactly one carboxylic acid functional group.

Table 6.1 shows the observations made when separate samples of **A**, **B** and **C** were treated with different reagents under specified conditions.

Table 6.1

Test	Reagents and conditions	Observations with **A**	Observations with **B**	Observations with **C**
1	warm with alkaline aqueous iodine	no change	pale yellow precipitate, **D**, forms	no change
2	add aqueous bromine	no change	no change	orange solution decolourises and white precipitate, **E**, $C_9H_6O_3Br_4$, forms
3	warm with Fehling's solution	brick red precipitate forms	no change	no change
4	add cold alkaline potassium permanganate(VII)	no change	no change	purple solution decolourises
5	add 2,4-dinitrophenylhydrazine	orange precipitate, **F**, forms	orange precipitate forms	no change

(i) For each compound **A**, **B** and **C**, use the information in **Table 6.1** to deduce the functional groups present.

Compound	Functional groups or structures present
A	**aliphatic aldehyde (–CHO)** based on the positive Fehling's and 2,4-DNPH tests.
B	**methyl ketone/carbonyl (–$COCH_3$)** based on the positive iodoform test and 2,4-DNPH Can accept ketone.
C	contains an **alkene (C=C)** based on the cold $KMnO_4$ decolourisation. contains a **phenol** based on the white precipitate with aqueous bromine.

[3]

Examiner's Comment:

Compound A: Some students had the misconception that a positive Fehling's test (brick-red precipitate) indicates the presence of benzaldehyde. In fact, Fehling's solution gives a positive result with aliphatic aldehydes but not with benzaldehyde.

Compound B: A number of students assumed the presence of an aldehyde without considering the results of all the reagent tests. The positive results for both the 2,4-DNPH test and the tri-iodomethane test indicate the presence of a $-COCH_3$ group (a methyl carbonyl group). Students are strongly encouraged to draw the $-COCH_3$ functional group rather than simply stating "ketone", as not all ketones give a positive tri-iodomethane test.

Compound C: Many students identified only one functional group, either phenol or alkene, without recognising that all functional groups present were required.

Common Mistake

Many students failed to note that they were **required to use only the information provided in Table 6.1 to deduce the functional groups**. Consequently, some identified functional groups such as carboxylic acid and arene, even though their presence cannot be established from the information given in Table 6.1.

(ii) Suggest the structures for compounds **A**, **B**, **C, D**, **E** and **F**.

All three compounds have the same molecular mass (164) and contain only C, H, O.

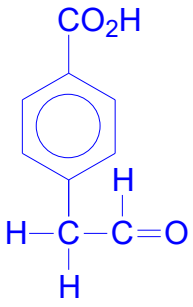
They are 1,4-disubstituted benzenes with exactly one –COOH group.

- Benzene ring with two substituents: C_6H_4 (mass = 76)
- One –COOH (mass = 45)
- Remaining mass for the other substituent = 164 – (76 + 45) = 43

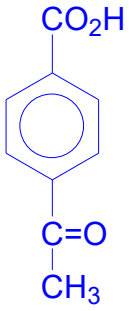
The other substituent has formula C_2H_3O (since 2×12 + 3×1 + 16 = 43).

Structures **A**, **B**, **C**, **D**, **E** and **F:**

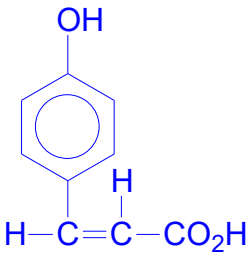
A:



B:



C:



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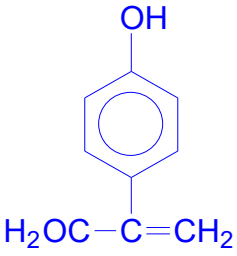
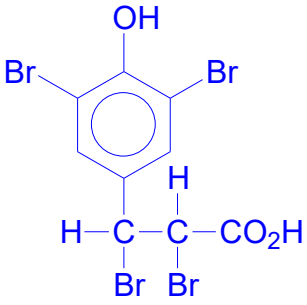


D: CHI_3

E:



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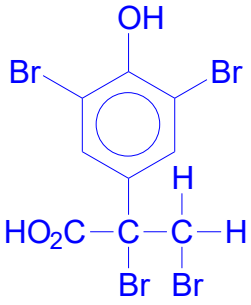
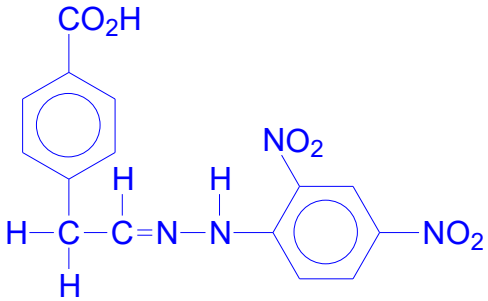


F:



Examiner's Comment:

Compound **A**: Many students failed to recognise that the compound cannot be benzaldehyde. Some also proposed structures with an incorrect number of carbon atoms, resulting in a molecular mass that did not match the value given.

Compound **B**: Most students were able to deduce the correct structure of compound B if they recognised the presence of the $–COCH_3$ group from the reagent tests in Table 6.1.

Compound **C**: Many students failed to recognise the presence of a phenol functional group. Instead, they assumed that compound C had a structure similar to compounds A and B and proposed the presence of a benzoic acid group.

Compound **D**: Students were expected to recognise that the yellow precipitate formed in the tri-iodomethane test is triiodomethane (CHI_3), not the carboxylate salt produced. A common mistake was writing an incorrect chemical formula (e.g. CH_3I instead of CHI_3).

Compound **E**: Many students failed to recognise that bromination occurs at both the phenol ring and the C=C bond. The 2- and 4-positions of the phenol ring are substituted by bromine atoms, while each carbon atom of the C=C bond adds one bromine atom. A common misconception was that all four bromine atoms substitute onto the aromatic ring at the 2-, 3-, 5-, and 6-positions, without recognising that the C=C bond also undergoes addition.

Compound F: The majority of students were unable to draw the structure of compound F. Many were unfamiliar with the structure of 2,4-dinitrophenylhydrazine, while others failed to recognise that the reaction is a condensation reaction between the carbonyl group (C=O) and the hydrazine group ($–NH_2$), forming a C=N bond with the elimination of H_2O.

[6]

[Total: 9]