2024 Y6 H2 Chemistry Term 3 Timed Practice – Suggested Solutions

Section A

Question	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Answer	C	C	A	D	B	C	A	B	D	D	C	D	B	A	A

MCQ worked solutions

1 Ans: C

CO is a neutral oxide which does not react with aq. NaOH.
CO_2 gas is acidic and reacts with aq. NaOH.

$Fe_xO_y + yCO \rightarrow xFe + yCO_2$

Amt of Fe_xO_y = 0.523 mol (given)

Amt of Fe = (146 / 55.8) = 2.616 mol

Since volume of CO_2 was measured at r.t.p., amt of CO_2 = (75.4 / 24.0) = 3.142 mol

	Fe_xO_y	+ yCO	→	xFe	+	yCO_2
Amt/mol	0.523			2.616		3.142
Mole ratio	1			5		6

Hence, x = 5 and y = 6.

2 Ans: C

$5\ X^- + XO_n^- \longrightarrow$ halogen-containing product (either X_2 or XO^- from observing the MCQ options)

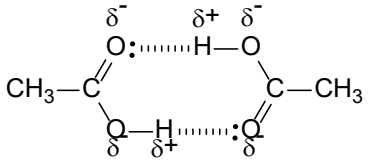
Step 1: Balance X; $5\ X^- + XO_n^- \longrightarrow \underline{3}\ X_2$
OR $5\ X^- + XO_n^- \longrightarrow \underline{6}\ XO^-$
Step 2: Check if amt of electrons gained = amt of electrons lost

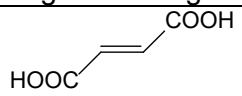
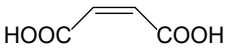
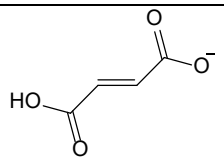
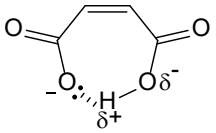
A	$5\ X^- + XO^- \longrightarrow 3\ X_2$ amt of electrons gained by 1 mol of XO^- to form ½ mol X_2 = 1 mol amt of electrons lost by 5 mol of X^- to form $\frac{5}{2}$ mol of X_2 = 5 mol	not balanced
B	$5\ X^- + XO_2^- \longrightarrow 6\ XO^-$ amt of electrons gained by 1 mol of XO_2^- to form 1 mol of XO^- = 2 mol amt of electrons lost by 5 mol of X^- to form 5 mol of XO^-= 10 mol	not balanced
C	$5\ X^- + XO_3^- \longrightarrow 3\ X_2$ amt of electrons gained by 1 mol of XO_3^- to form ½ mol X_2 = 5 mol amt of electrons lost by 5 mol of X^- to form $\frac{5}{2}$ mol of X_2 = 5 mol	balanced
D	$5\ X^- + XO_4^- \longrightarrow 6\ XO^-$ amt of electrons gained by 1 mol of XO_4^- to form 1 mol of XO^- = 6 mol amt of electrons lost by 5 mol of X^- to form 5 mol of XO^- = 10 mol	not balanced

3 Ans: A

Step 1: Write electronic configuration of Fe atom i.e. [Ar] $3d^6 4s^2$
Step 2: Remove electrons from atom to form ion, removing 4s before 3d. For Fe^{3+}, two 4s electrons and one 3d electron are removed from Fe i.e. Fe^{3+} : [Ar] $3d^5$.

4 Ans: D

1	Not a result of hydrogen bonding. $CH_3CH_2CONH_2$ is neutral as the lone pair of electrons on the N atom is delocalised into the C=O bond, making it unavailable for dative covalent bond formation to a proton.
2	A result of hydrogen bonding. In vapour state, CH_3COOH can exist as a dimer which is held by hydrogen bonds:  M_r of dimer = 120
3	Not a result of hydrogen bonding. $(CH_3)_3N$ has more electron-donating alkyl groups than $(CH_3)_2NH$, which increases the electron density on the N atom in $(CH_3)_3N$, thus increasing the availability of the lone pair of electrons on N for dative covalent bond formation to a proton.
4	A result of hydrogen bonding.

Acid		
Conjugate base		
Remarks	Conjugate base is <u>not</u> stabilised by intramolecular hydrogen bond	Conjugate base is stabilised by intramolecular hydrogen bond ⇒ conjugate base of cis-acid is more stable ⇒ cis-acid is more acidic than trans-acid ⇒ K_{a1} of cis-acid is greater than K_{a1} of trans-acid.

Hence, K_{a1} of *trans*-acid is smaller than that of K_{a1} of *cis*-acid.

5 Ans: B

1	Option 1 is correct. According to the slow step (rate-determining step), rate = k[G][F]. However, 1 molecule of G (an intermediate) is formed from 2 molecules of E in the preceding fast step. Hence, the overall rate equation should be rate = $k[E]^2[F]$. Note that intermediates should not appear in the overall rate equation.
2	Option 2 is correct. $2E \rightleftharpoons \cancel{G}$ $\cancel{G} + F \rightarrow \cancel{H}$ $\cancel{H} + F \rightarrow E_2F_2$ By summing up the three equations in the mechanism, the overall equation is: $2E + 2F \rightarrow E_2F_2$.
3	Option 3 is incorrect. The mechanism involves <u>three</u> transition states. Each step has a transition state. The mechanism involves two intermediates (G and H). Recall that an intermediate is a species that is formed in one step of a reaction mechanism and consumed in a subsequent step.

6 Ans: C

The orders of reaction for each reactant are not given. Hence the question is asking for *possible* shapes of graph for different orders.

Option 2: As bromine is a reactant, its concentration will decrease with time. Depending on the orders with respect to the various reactants, the decrease could be linear or as a curve (as shown in the question). Hence, option 2 is possible.

Since absorbance $\propto$ $[Br_2(aq)]$, the above explanation for option 2 holds for a graph of absorbance against time. Hence, option 1 is possible.

The pressure of the system is contributed by its gaseous components. In this reaction, CO_2 (a product) is the only gaseous species. A graph of pressure against time would be show an increasing trend starting from the origin. Hence, option 3 is not possible.

A graph of rate against $[Br_2(aq)]$ would be a horizontal line (if zero order) or show an increasing trend starting from the origin (if 1^{st} or 2^{nd} order). Option 4 is not possible.

7 **Ans: A**

Recall:
A Brønsted-Lowry acid is a proton donor; A Brønsted-Lowry base is a proton acceptor.
A Lewis acid is an electron-pair acceptor; A Lewis base is an electron-pair donor.

A	$2NH_3(l) + 2Na(s) \longrightarrow 2NaNH_2(s) + H_2(g)$ NH_3 is a brønsted-Lowry acid as it donates a proton, H^+, to form NH_2^-. [H^+ then undergoes redox reaction with Na to form Na^+ and H_2]
B	$NH_3(g) + H_2O(l) \longrightarrow NH_4^+(aq) + OH^-(aq)$ NH_3 is a brønsted-Lowry base as it accepts a proton, H^+, from H_2O to form NH_4^+.
C	$4NH_3(g) + 5O_2(g) \longrightarrow 4NO(g) + 6H_2O(g)$ NH_3 is oxidised to NO (oxidation state of N changes from –3 to +2).
D	$4NH_3(aq) + Cu^{2+}(aq) \longrightarrow [Cu(NH_3)_4]^{2+}(aq)$ Each NH_3 donates a lone pair of electrons to form a dative coordinate bond with Cu^{2+} in $[Cu(NH_3)_4]^{2+}(aq)$. Hence, NH_3 is a lewis base.

8 **Ans: B**

Let the weak acid be HA.

Equivalence point (point **B**) is reached when 10.0 cm^3 of 0.100 mol dm^{-3} HA is added. Since n(HA) : n(NaOH) = 1 : 1, HA must be a monobasic acid $\Rightarrow$ option 1 is correct

At equivalence point (point **B**), all the NaOH has reacted with HA to form NaA. The solution contains A^-, the conjugate base of HA. A^- undergoes hydrolysis to form OH^-.

$$A^-(aq) + H_2O(l) \rightleftharpoons HA(aq) + OH^-(aq)$$

Hence, the solution is alkaline (pH >7) $\Rightarrow$ option 2 is correct

At point **A**, only 50% of the NaOH has been reacted with HA to form NaA. The solution contains unreacted NaOH and the salt, NaA formed ($n(OH^-)_{unreacted} = n(A^-)_{formed}$). Since the solution does not contain the weak acid, HA, and its salt, NaA, it is not a buffer solution $\Rightarrow$ option 3 is incorrect
[Note: A buffer solution with maximum buffering capacity is formed at point **D**, where $n(HA)_{excess} = n(A^-)_{formed}$.]

9 **Ans: D**

To prepare a buffer of pH 7.40, choose the acid with pK_a closest to 7.40 i.e. 7.20, which is the pK_a of $H_2PO_4^-$. The species in the buffer would be the weak acid, $H_2PO_4^-$, and its conjugate base, HPO_4^{2-} i.e. option D.

The following options are incorrect for the following reasons.

A	HPO_4^{2-} reacts with NaOH to form PO_4^{3-}. If NaOH is limiting, a mixture of HPO_4^{2-} and PO_4^{3-} i.e. a mixture of an acid with its conjugate base will form. This resultant mixture has a pH of around 12.38.
B	This mixture of an acid (H_3PO_4) and its conjugate base ($H_2PO_4^-$) results in a buffer solution of pH around 2.15.
C	$H_2PO_4^-$ reacts with H^+ from HC*l* to form H_3PO_4. If HC*l* is limiting, a mixture of an acid (H_3PO_4) and its conjugate base ($H_2PO_4^-$) results in a buffer solution of pH around 2.15.

10 Ans: D

<u>[IO_3^-] in solution Z</u>

Solution **Z** is a saturated solution of $Ca(IO_3)_2$.

$$Ca(IO_3)_2 \rightleftharpoons Ca^{2+}(aq) + 2\ IO_3^-$$

Eqm conc/ mol dm^{-3} – s 2s

$K_{sp} = s(2s)^2 = 6.47 \times 10^{-6} \Rightarrow s = 0.01174$ mol dm^{-3}

$[IO_3^-] = 2(0.01174) = 0.0235$ mol dm^{-3}

<u>[Pb^{2+}] when $Pb(IO_3)_2$ just precipitates</u>

$Pb(IO_3)_2$ precipitates when

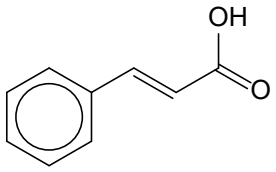
Ionic Product $[Pb(IO_3)_2] \geq K_{sp}[Pb(IO_3)_2]$

$[Pb^{2+}](0.0235)^2 \geq 3.69 \times 10^{-13}$

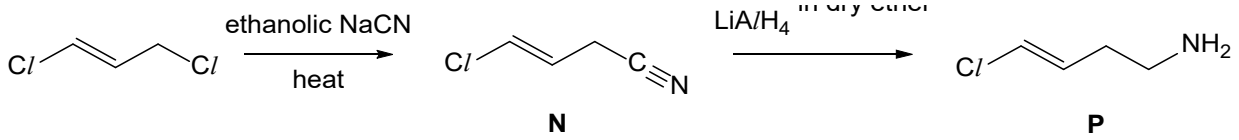
$[Pb^{2+}] \geq 6.68 \times 10^{-10}$ mol dm^{-3}

$Pb(IO_3)_2$ starts to precipitate when $[Pb^{2+}] = 6.68 \times 10^{-10}$ mol dm^{-3}

11 Ans: C

A	Cinnamaldehyde has 9 sp^2 hybridised carbon atoms (6 from benzene ring, 2 from alkene carbons, 1 from carbonyl carbon).
B	Cinnamaldehyde contains an aliphatic aldehyde which gives positive tests for both Fehling's solution and Tollens' reagent.
C	Only the C=C in Cinnamaldehyde reacts with Br_2 in CCl_4.
D	Hot acidified $K_2Cr_2O_7$ only oxidises the aldehyde to the carboxylic acid, forming the following product.  Hot acidified $K_2Cr_2O_7$ is unable to oxidise the benzene side chain or the alkene.

12 Ans: D

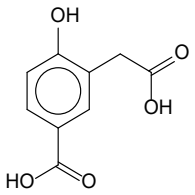


N **P**

Reaction with NaCN	**Reaction with $LiAlH_4$**
The reaction with NaCN is a nucleophilic substitution reaction. The C*l* attached to the C=C does **not** undergo nucleophilic substitution. (Reason: *p orbital of the C*l *atom overlaps with the π electron cloud of the adjacent C=C bond. This allows the lone pair of electrons in the p orbital of the C*l *atom to delocalise into the C=C bond and results in partial double bond character in the C–C*l *bond. This bond is strengthened and is hence not easily broken.*)	$LiAlH_4$ is a reducing agent and reduces the nitrile functional group, –CN, to $–CH_2NH_2$. Alkenes are reduced by H_2, Ni, heat, but not by $LiAlH_4$.

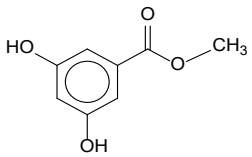
13 Ans: B

A



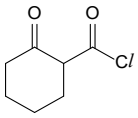
Each mole of this compound has 2 -COOH groups and liberates 1 mole of CO_2 per mole of the compound. The phenol group does not react with Na_2CO_3.

B

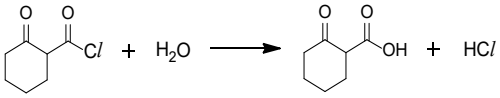


The phenol groups do not react with Na_2CO_3. This compound does not liberate CO_2.

C

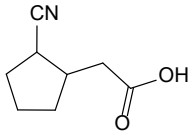


Each mole of this compound has 1 -COC*l* group and reacts with H_2O to form 1 -COOH group and 1 mole of HC*l* in the following reaction:



Both the resultant compound and HC*l* react with Na_2CO_3 to liberate 1 mole of CO_2.

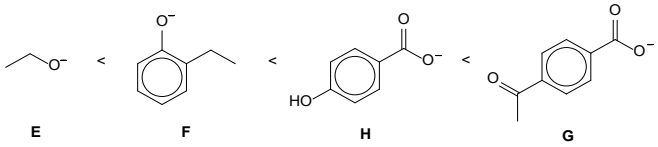
D



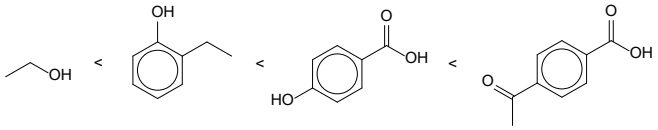
Each mole of this compound has 1 -COOH groups and liberates ½ mole of CO_2 per mole of the compound.

14 **Ans: A**

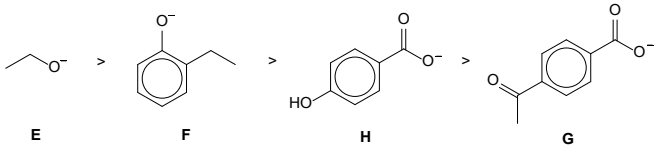
In increasing order of stability:



The more stable the anion (conjugate base), the stronger the acid. Hence, in increasing order of acid strength:

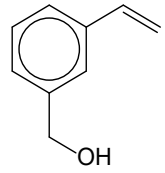
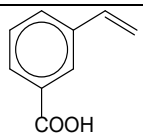
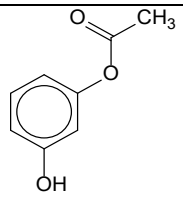


Since the stronger the acid, the weaker its conjugate base, the basicity decreases in the order:



Note: **G** is the most stable as the negative charge is delocalised between 2 highly electronegative oxygen atoms in the carboxylate group and has an electron withdrawing carbonyl group on the 4th position relative to the carboxylate group on the benzene ring, which increases the dispersal of the negative charge further. **H** is less stable than **G**, but is more stable than **F** and **E**, as the negative charge is delocalised between 2 highly electronegative oxygen atoms in the carboxylate group. However, **H** has an electron donating hydroxy group on the 4th position relative to the carboxylate group on the benzene ring, which decreases the dispersal of the negative charge compared to in **G**. **F** is more stable than **E** as the negative charge on the oxygen can be delocalised into the benzene ring. However in **E**, the negative charge is localised on the oxygen atom and intensified by the electron donating alkyl group.

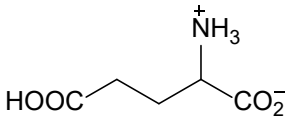
15 **Ans: A**

	properties		
compound	I	II	III
	Contains an alcohol, produces H_2 gas upon reaction with Na.	Contains an alkene group, reacts with and decolourises orange aqueous Br_2.	Contains a primary alcohol which can be oxidised. The orange $K_2Cr_2O_7$ will turn green.
	Contains a carboxylic acid group, produces H_2 gas upon reaction with Na.	Contains an alkene group, reacts with and decolourises orange aqueous Br_2.	Acidified $K_2Cr_2O_7$ does not oxidise alkenes. The -COOH group will not be oxidised. The orange $K_2Cr_2O_7$ will remain orange.
	Contains a phenol group, produces H_2 gas upon reaction with Na.	Contains a phenol group, reacts with and decolourises orange aqueous Br_2. A white ppt will also be formed.	The acidified condition with heat will hydrolyse the ester to form a diphenol and ethanoic acid. Neither products can be oxidised. The orange $K_2Cr_2O_7$ will remain orange.

Only compound 1 will display all 3 properties.

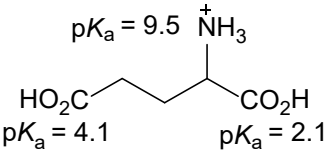
Section B

B1(a)

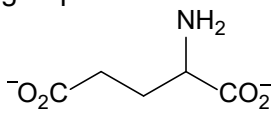


Comments:

- Consider the fully protonated form of glutamic acid and assign the pK_a values.



- The NH_3^+ group being the weakest acid will have the highest pK_a of 9.5 while the COOH group bonded to the alpha carbon has the lowest pK_a as it is the stronger weak acid among the two COOH groups.
- This is so as the negative charge in the COO^- group bonded to the alpha carbon is stabilised to a greater extent by the electron-withdrawing NH_2 group due to proximity, hence the COO^- group bonded to the alpha carbon is stablised to a greater extent.



- At pH 3, the groups with pK_a > 3 will be protonated while those with pK_a < 3 will be deprotonated.

B1(b) Sequence of amino acids in **P**: val-phe-asp-lys-gly-phe-lys-val-arg

Comments:

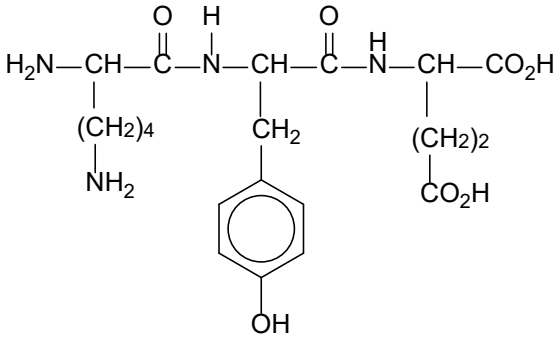
- Generally well done.

B1(c)(i) 6

Comments:

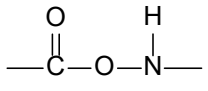
- These are the possible tripeptides that can be formed: BCD, CBD, DBC, BDC, CDB, DCB.
- Students are reminded that peptide bonds are formed by NH_2 and COOH groups that are bonded to the alpha carbon and not by those in the side chain.

B1(c)(ii)

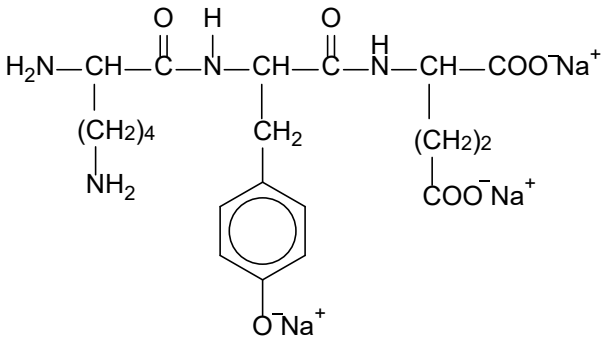


Comments:

- Students are reminded that by convention, the N-terminus of the amino acid residue is written on the left.

- Common mistakes made include drawing:
  -  as a peptide bond
  - side chain bonded to the wrong carbon (carboxyl carbon), resulting in a carbon with 5 bonds
  - polymer representation using $(\ )_n$ when question is asking for **BCD** tripeptide and not **…BCDBCDBCDBCD…** polypeptide.
  - structures with missing CH_2 group in the side chain or missing peptide bonds.

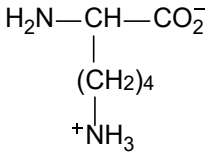
B1(c)(iii)



Comments:
- Since the base used for deprotonation is specified to be NaOH in this question, the product drawn should show the Na^+ counterion.
- Another common mistake involves overlooking the fact that the phenol functional group can react with NaOH as well.

B1c(iv) A zwitterion is an <u>electrically neutral</u> molecule with <u>oppositely charged</u> ends.

zwitterionic form of **B**:



Comments:
- Students are reminded that definitions can easily carry other unintended meanings if certain words are omitted/included or rephrased loosely.
- A common mistake involves omitted the word “electrically” and just stating that it is neutral, which would instead mean neutrality in an acid-base sense.
- Some students defined zwitterions as amino acids which is not necessarily true.

B2(a)(i) Type of reaction involving CO_2: <u>Reduction</u>
The <u>oxidation number of C decreases</u> from <u>+4 in CO_2</u> to <u>+2 in HCOOH</u>.

Comments:
- Based on the question, the type of reaction must be <u>specific to the reaction undergone by CO_2</u>. Hence, the term “redox” should be avoided.

B2(a)(ii) Cathode: $CO_2 + 2H^+ + 2e^- \longrightarrow HCOOH$
Anode: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$

$E^\ominus_{cell} = E^\ominus_{cathode} - E^\ominus_{anode}$
$= -0.61 - (+1.23) = -1.84$ V

$\Delta G^\ominus = -nFE_{cell}^\ominus$
$= -(4)(96500)(-1.84) = +710240 = +710000$ J mol^{-1}

Since $\underline{E^\ominus_{cell} < 0 / \Delta G^\ominus > 0}$, it shows that the reaction in equation 1 is not spontaneous. Thus, a power supply is required for the reaction to occur.

Comments:
- In the equation $\Delta G^\ominus = -nFE^\ominus$, n refers to the <u>no. of moles of electrons transferred</u> in the redox reaction in equation 1, i.e. n = 4.
- The sign (positive or negative) for $E^\ominus_{cell}$ and $\Delta G^\ominus$ should be provided in answer. (The same applies for ΔH, ΔS, ΔG and lattice energy)
- The final answer should be written in 3 s.f. and the correct units must be included.
- Note that the units of ΔG is J mol^{-1} or kJ mol^{-1}

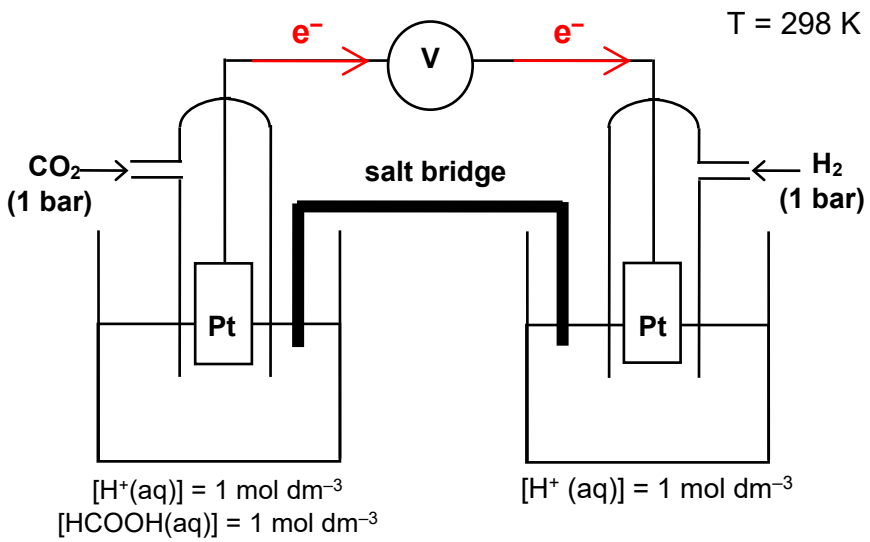
B2(a)(iii) $CO_2 + 2H^+ + 2e^- \rightleftharpoons HCOOH$ $\quad E^\ominus = -0.61$ V

A lower pressure of CO_2 will cause the <u>position of equilibrium to lie more to the left/ favour the backward reaction at the cathode</u>.

This results in a more negative $E(CO_2/HCOOH)$ value and the $\underline{E_{cell}}$ (which is equal to $E(CO_2/HCOOH) - E(O_2/H_2O)$) <u>will become more negative</u>, hence requiring a higher power supply.

Comments:
- Generally well done.
- As E_{cell} can be positive/negative, for clarity of answers, students should <u>avoid writing E_{cell} increase/decrease</u>. Instead, specify if E_{cell} becomes <u>more or less positive/negative</u>. (The same applies for ΔH, ΔS, ΔG and lattice energy).
- E_{cell} should be used instead of $E^\ominus$ as $E^\ominus$ could be referring to standard reduction potential.
- Students should note that the power supply for the electrolytic cell has to be numerically greater than $E^\ominus_{cell}$ (or E_{cell}) for electrolysis to take place.

B2(b)



Comments:

- Recall: Checklist for the general labels to include when drawing the setups:

in each half-cell	connecting 2 half-cells
☐ identity of electrode	☐ external wire with voltmeter
☐ identity and concentration of electrolyte	☐ direction of electron flow
☐ gas jar, identity and partial pressure of gas (if any)	☐ salt bridge
	☐ temperature

Note: Question may also ask for the labelling of anode (–) or cathode(+).

- Recall that at standard conditions:
  - Temperature: 25 °C or 298 K
  - Pressure (of any gases involved): 1 bar
  - Concentration (of all ions/compounds in aqueous solution): 1 mol dm^{-3}
- Students need to note that for an electrochemical cell, all species (both reactants and products) in the half-equation must be present.
- Since the CO_2/HCOOH half-cell has a more negative electrode potential, the CO_2/HCOOH half-cell is the anode and HCOOH is oxidised to CO_2 (and hence electrons flow from the CO_2/HCOOH half-cell to the standard hydrogen electrode).
- As CO_2 is produced at the anode, a common mistake is to draw the arrow direction for CO_2 pointing out of the gas jar. Note that when setting up the standard electrochemical cell, 1 bar of CO_2 gas has to be provided at the anode, and hence the arrow direction for CO_2 should be pointing into the gas jar.

B2(c)(i) To avoid oxidation of useful HCOOH at the anode.

Comments:

- HCOOH is a weak acid and is hence not likely to erode the anode.

B2(c)(ii) CO_2 has low solubility in aqueous solution
OR CO_2(aq) diffuses slower than CO_2(g)

Comments:

- Specific reason needs to be provided for the slower rate of reaction/reduction (e.g. lower concentration due to lower solubility).

- Water cannot be preferentially reduced as it has a more negative $E^{\ominus}$.
  $H_2O + 2e^- \rightleftharpoons H_2 + 2e^-$ $\quad E^{\ominus} = -0.83$ V
  $CO_2 + 2H^+ + 4e^- \rightleftharpoons HCOOH$ $\quad E^{\ominus} = -0.61$ V
- As CO_2 is only slightly soluble in water and even if H_2CO_3 is formed, H_2CO_3 is a weak acid and the $H^+(aq)$ obtained is very low in concentration.

B2(d)(i)

Reduction half-equation: $MnO_4^- + 2H_2O + 3e^- \longrightarrow MnO_2 + 4OH^-$
Oxidation half-equation: $HCOO^- + 3OH^- \longrightarrow CO_3^{2-} + 2H_2O + 2e^-$

$3HCOO^- + 2MnO_4^- + OH^- \longrightarrow 2MnO_2 + 3CO_3^{2-} + 2H_2O$

Comments:
- Note that under alkaline conditions, CO_3^{2-} (NOT CO_2) should be formed.
- An overall balanced equation should not have any electrons present.

B2(d)(ii)

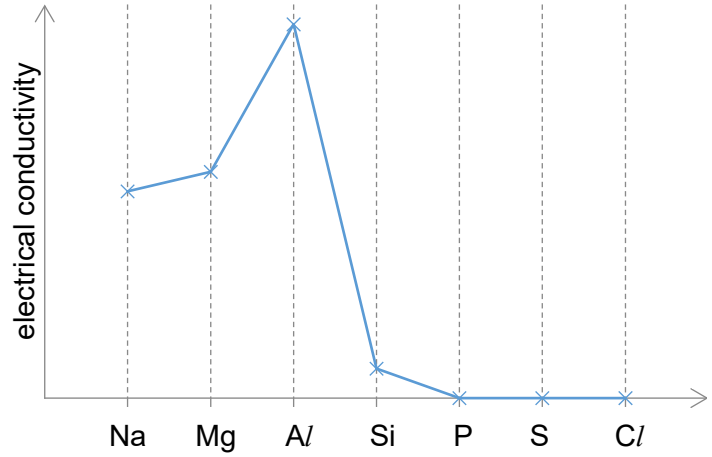
Amount of MnO_2 collected = $\frac{0.45}{86.9}$ = 0.005178 mol

Amount of $HCOO^-$ reacted = $\frac{3}{2}$ x 0.0051784 mol = 0.0077675 mol

Concentration of $HCOO^-$ reacted = 0.0077675 ÷ $\frac{30.00}{1000}$ = 0.259 mol dm^{-3}

Comments:
- Generally well done.

B3(a)



Na, Mg and Al exist as giant metallic structures with delocalised electrons which can act as mobile charge carriers.

Electrical conductivity increases from Na to Al with increasing number of delocalised valence electrons.

Si has a giant molecular structure where strong covalent bonds exist between Si atoms.

It is a metalloid and hence has poor electrical conductivity.

P_4, S_8, Cl_2 exist as simple molecular structures with <u>absence of mobile charge carriers.</u>

Comments:
- Students who studied usually get full credit for this question.
- Si have limited conductivity, and non-metals (P_4, S_8, Cl_2 have zero conductivity, it should be reflected in the graph).
- Students need to know that it is the increase in the number of delocalised *valence* electrons from Na to Al that results in the increase in conductivity.
- A handful of students used the concept of charge density of ions which does not explain changes in conductivity.
- For P_4, S_8, Cl_2, "absence of mobile charge carriers" is required in the answer. It is not enough to say that there is no delocalised electrons as this is just *one* example of a mobile charge carrier (molten ions is another example)
- A handful of students wrongly attributed increase in electrical conductivity to increasing cation charge. Some students also miss the mark when they did not explain the increasing trend for the metals.

B3(b)

Hydration: $MgCl_2(s) + 6H_2O(l) \longrightarrow [Mg(H_2O)_6]^{2+}(aq) + 2Cl^-(aq)$

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

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

pH = 6.5

$PCl_5(s) + 4H_2O(l) \longrightarrow H_3PO_4(aq) + 5HCl(aq)$

pH = 2

Comments:
- The reversible arrow to show the hydrolysis of $[Mg(H_2O)_6]^2$ is required.
- Students should quote a specific value of pH rather than to give a range.

B3(c)

Cationic radii Al^{3+} = <u>0.050</u> nm

Cationic radii Cr^{3+} = <u>0.062</u> nm

Since the cationic radii for Cr^{3+} is <u>bigger</u> than Al^{3+}, the <u>charge density is lower, lower polarising power</u>, less able to distort the electron cloud of the water molecules, <u>weakening the O–H bonds to a smaller extent, the extent of hydrolysis will be lower</u>. pH will be slightly <u>higher</u> than $AlCl_3$ solution.

Comments:
- Students are reminded to read the question carefully so that they could answer as required. "*By using data from the data booklet"*, requires candidates to quote data.
- Incorrect answers included the use of reduction potential values, atomic radius, and ionisation energy.
- Some students go on a tangent to discuss the structures of $AlCl_3$ vs $CrCl_3$, rather than compare the hydrated cations.

B3(d)(i)

$K_{sp} = [Mg^{2+}][NH_4^+][PO_4^{3-}]$ mol^3 dm^{-9}

Comments:
- Generally well done.

B3(d)(ii) Let the solubility of struvite be s mol dm^{-3}

$MgNH_4PO_4(s) \rightleftharpoons Mg^{2+}(aq) + NH_4^+(aq) + PO_4^{3-}(aq)$

$K_{sp} = 4.37 \times 10^{-14} = [Mg^{2+}][NH_4^+][PO_4^{3-}]$

$4.37 \times 10^{-14} = s \times s \times s = s^3$

$s = \sqrt[3]{4.37 \times 10^{-14}} = \underline{\mathbf{3.52 \times 10^{-5}\ mol\ dm^{-3}}}$

Comments:
- Generally well done.

B3(d)(iii) $(NH_4)_2SO_4 \longrightarrow 2NH_4^+ + SO_4^{2-}$

$(NH_4)_2SO_4$: NH_4^+

1 : 2

$[NH_4^+] = 0.200$ mol dm^{-3}

Let the solubility of struvite be s mol dm^{-3}

$K_{sp} = [Mg^{2+}][NH_4^+][PO_4^{3-}]$

$[Mg^{2+}] = [PO_4^{3-}] = s$

Since struvite is sparingly soluble in water and the presence of NH_4^+ ions from $(NH_4)_2SO_4$ further suppresses its solubility, s << 0.200. Thus, (s + 0.200) ≈ 0.200.

$K_{sp} = = 4.37 \times 10^{-14} = s \times 0.200 \times s = 0.2s^2$

$s = \sqrt[2]{\frac{4.37 \times 10^{-14}}{0.2}}$

$s = \underline{\mathbf{4.67 \times 10^{-7}\ mol\ dm^{-3}}}$

Comments:
- Since 1 mole of $(NH_4)_2SO_4$ forms 2 moles of NH_4^+, $[NH_4^+] = 0.200$ mol dm^{-3}. A common incorrect answer used $[NH_4^+] = 0.100$ mol dm^{-3}.
- Students are reminded to present their working clearly in all answers.

B3(d)(iv) When $MgCl_2$ is added to the solution, $[Mg^{2+}]$ increases, position of equilibrium of $MgNH_4PO_4(s) \rightleftharpoons Mg^{2+}(aq) + NH_4^+(aq) + PO_4^{3-}(aq)$ <u>shift left,</u> to partially offset the increase in $[Mg^{2+}]$ by removing some Mg^{2+}.This causes the solid struvite to precipitate out for removal.

Comments:
- Generally well done.
- Students are reminded to quote a reversible equation when discussing a shift in equilibrium position.

B3(d)(v) NaOH(aq)

Comments:
- Generally well done.

B3(d)(vi) Ionic bonds and covalent bonds

Comments:
- Generally well done.

B3(e)(i) Amount of phosphorous in <u>pure</u> struvite = $\frac{85}{137.3}$ = 0.6191 mol

Amount of phosphorous from $Ca_3(PO_4)_2$ = $\frac{5}{310.3} \times 2$ = 0.03223 mol

Total P content = 0.6191 + 0.03223 = 0.6513 mol × 31.0 = **<u>20.2 g</u>**

Comments:
- Incorrect answers did not take into account the phosphorus present in struvite, or the phosphorus present in the impurity.

B3(e)(ii) Mass of fertiliser needed = $\frac{100}{20.19} \times (50 \times 10^3)$ = **<u>2.48×10^5 g or 248 kg</u>**

Comments:
- Generally well done.

Section C

C1(a) Reason 1:
From chlorine to iodine, the size of the halogen atom X increases and the valence orbitals of the halogen atom X become <u>more diffuse</u>. As such, the <u>overlap of (valence) orbitals</u> which forms the C–X bond becomes <u>less effective</u> down the group.

Reason 2:
The <u>electronegativity of the halogen atom X decreases</u> from chlorine to iodine. This causes the <u>polarity / ionic character of the C–X bond to decrease</u> down the group.

Comments:
- Generally well done.
- Note that down the Group, it is the valence <u>orbitals</u> (NOT electron cloud) that become more diffuse.
- Some students showed confusion between covalent bond strength vs intermolecular forces of attraction.
- Given that this is a two-mark question which requires students to provide two reasons in their explanations, students are advised to keep their answers concise. Some students explained at length why electronegativity of halogens fall and/or why valence orbitals become larger and more diffuse down the Group, which are not required for this question. Stating and linking electronegativity difference of C and X down the group to polarity of the C-X bond, and more diffuse valence orbitals to less effective orbital overlap will suffice.

C1(b)(i) The role of nitric acid is to <u>neutralise / remove any remaining NaOH</u> to <u>quench</u> the reaction or to <u>prevent the formation of Ag_2O</u>.

Comments:
- Generally well done.
- Students need to mention both the neutralisation of NaOH and its effect (quenches/stops the reaction or to prevent the formation of the Ag_2O ppt).
- A few students incorrectly thought that nitric acid is the catalyst for the reaction. Students are advised to consider the properties (e.g. acidic/basic) of the chemicals, as well as the design of the experiment (e.g. stopping reaction at a given time), to deduce the role of nitric acid.
- As the experiment involves measuring the mass of ppt AgX ppt formed, students need to state clearly that Ag^+ and OH^- react to form <u>$Ag_2O(s)$,</u> which interferes in the collection of AgX ppt.

C1(b)(ii) Volume of NaOH used to react with 0.05 mol of halogenoalkane
= 0.05 / 2.00 = 0.0250 dm^3 = 25 cm^3
Since NaOH needs to be in excess, 30 cm^3 of NaOH will be used.

Since HNO_3 needs to be in excess (to completely remove any remaining NaOH at t = 2 min), and both NaOH and HNO_3 have the same concentration, 30 cm^3 of HNO_3 will be used.
(This ensures that HNO_3 will be in excess as some NaOH is used up during the reaction with halogenoalkane.)

Volume of $AgNO_3$ used to react with 0.05 mol of halide
= 0.05 / 2.00 = 0.0250 dm^3 = 25 cm^3
Since $AgNO_3$ needs to be in excess to ppt the max amount of AgX (X = C*l*, Br, I) at t = 2 min, 30 cm^3 of $AgNO_3$ will be used.

Procedure:
1) Using a 50 cm^3 measuring cylinder, measure 30 cm^3 of **FA 1**.
2) Place both the conical flask containing 1−chlorobutane and 50 cm^3 measuring cylinder containing **FA 1** into a thermostatically controlled water bath set at 50 °C.
3) Place a thermometer into the conical flask and another thermometer into the measuring cylinder.
4) When the temperature of 1−chlorobutane and **FA 1** both reaches 50 °C, pour **FA 1** into the conical flask containing 1−chlorobutane. Start the stopwatch immediately and swirl the mixture thoroughly to mix its contents while keeping the mixture still immersed in the water bath.
5) At exactly 2 min, use another 50 cm^3 measuring cylinder to add 30 cm^3 of **FA 2** into the conical flask and swirl the mixture thoroughly to mix its contents.
6) Remove the conical flask from the water bath and after the mixture is cooled to room temperature, add 30 cm^3 of **FA 3** until no more precipitate forms.
7) Filter the mixture through a filter funnel lined with a pre-weighed filter paper.
8) Wash the precipitate with cold deionised water.
9) Dry the precipitate with the pre-weighed filter paper in a desiccator.
10) Using an electronic balance, weigh accurately the precipitate and the pre-weighed filter paper.
11) Repeat steps 1 – 10 using samples of 50 cm^3 of 1−bromobutane and 50 cm^3 of 1−iodobutane separately.

Treatment of results:
With mass of the three precipitates obtained, the amount of each precipitate is calculated by dividing the mass over their respective molar mass or M_r.

Comments:
- Majority of students failed to show pre-calculations involving the computation of the volume of excess NaOH, HNO_3 and $AgNO_3$. There must be sufficient HNO_3 to neutralise NaOH, and sufficient $AgNO_3$ to react with halide ion formed (assuming complete nucleophilic substitution).
- Majority of students failed to ensure that both NaOH and 1-halobutane need to be at 50 °C before mixing and starting the reaction. A common error was mixing the reagents before placing the reaction mixture in the hot water bath. This starts the reaction even before the reaction mixture can reach 50 °C.

- Students should take note of the capacity of the apparatus (e.g. 250 cm^3 conical flask) when deciding on the volumes of excess reagents to be added. The total volume of the reaction mixture should ideally not exceed half the capacity of the apparatus used.
- Several students used 10 cm^3 (or a smaller volume) of the halogenoalkanes and placed them into test-tubes/boiling tubes. By doing so, the mass of the ppt collected will be much lower, resulting in greater error in mass measurement. Besides, the capacities of the test-tubes/boiling tubes are very small and will limit the volume of the other reagents (NaOH, HNO_3 and $AgNO_3$) which are to be added in excess.
- Many students did not realise that the goal of the experiment was to determine the amount of AgX precipitate, failing to show calculations for amount of AgX. Students are reminded to read every bullet point before starting the question.
- Students who tried to administer methods involving titration or colourimetry should note that the question clearly states that gravimetry is the method of choice. Note the gravimetry method is the quantitative determination of an analyte based on its mass, and does not necessitate heating with crucible. Silver halides are unstable to heat.
- Students should note that all mixtures should be filtered at the same temperature as solubility of the precipitates vary at different temperatures.
- All mixtures should also be cooled to room temperature before addition of $AgNO_3$ as AgX ppt is thermally unstable.
- Use of infrared lamps or bunsen burners to dry the AgX ppt should not be used as AgX is thermally unstable. It is sufficient to pat dry the ppt between two filter papers.

C2(a)(i) Step 1: dilute HNO_3, room temperature
Step 2: Sn, conc. HC*l*, heat (under reflux), followed by NaOH(aq)

Comments:
- The most common error for Step 1 is 'concentrated HNO_3, concentrated H_2SO_4, heat'. This condition is used for the nitration of benzene to form nitrobenzene instead. Phenol is a stronger nucleophile than benzene because the −OH group is electron-donating and increases the electron density of the benzene ring. Hence, nitration of phenol requires a milder condition than benzene.
- Candidates are encouraged to write down 'room temperature' for the condition required. For step 1, heat is not accepted as it may result in poly-substitution.
- For step 2, candidates need to write clearly that NaOH is only added after the first set of reagent and conditions.

C2(a)(ii) Condensation

Comments:
- Generally well done. Although the reagent looks foreign, candidates are expected to link what they have learnt and apply their knowledge to the unfamiliar context. This is similar to the formation of an amide bond from an amine.

C2(a)(iii) In increasing pK_a: 4-nitrophenol < phenol < ethanol

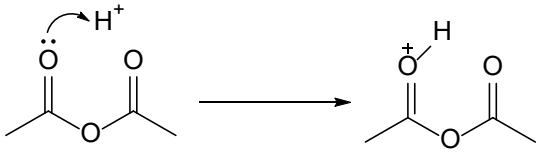
The smaller the pK_a, the stronger the acid.

Ethanol is a weaker acid compared to phenol. The phenoxide ion is more stable as the p-orbital containing the lone pair of electrons on the oxygen atom overlaps with the π electron cloud of the benzene ring and the lone pair of electrons is delocalised into the ring, dispersing the negative charge. Such resonance stabilisation is absent in ethanol. The ethoxide ion is less stable as it has an electron-donating ethyl group, which intensifies the negative charge on the oxygen atom.

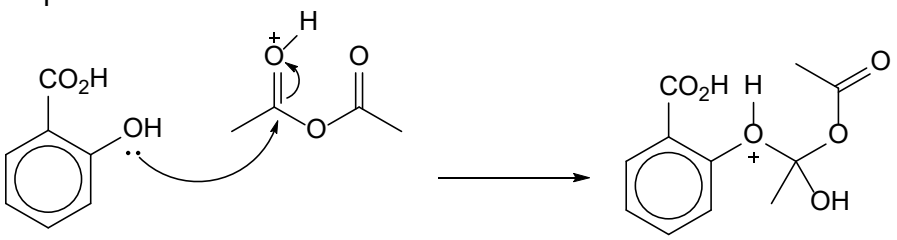
4-nitrophenol is a stronger acid compared to phenol. The presence of electron-withdrawing group, $-NO_2$, on the benzene ring disperses the negative charge on the oxygen atom. Thus, 4-nitrophenoxide ion is more stable than phenoxide ion.

Comments:
- Most candidates remember the relationship between pK_a and strength of acid.
- Some candidates used the wrong inequality sign in the arrangement. Answers such as '4-nitrophenol > phenol > ethanol' implies that 4-nitrophenol has a larger pK_a than phenol and are not accepted.
- Candidates are reminded not to mix up the terminologies. It is correct to use the term 'overlap / interact' for orbitals but incorrect to say that 'electrons from oxygen overlap / interact with the π electron cloud / electrons from oxygen disperse / diffuse into the benzene ring'.
- It is inaccurate to use the term 'phenoxide ion' as the conjugate base of 4-nitrophenol. It is advisable for students to draw out the structure of the conjugate base if they are unsure of the nomenclature.
- While it is acceptable to say that the $-NO_2$ group 'deactivates' the benzene ring, this does not desrcibe the nature of the $-NO_2$ group. Hence, use the term 'electron withdrawing' to describe the nature of the substituents.
- The conjugate base of ethanol is ethoxide, and not ethanoxide.
- The most common point that was left out is 'p-orbital containing the lone pair of electrons on the oxygen atom overlaps with the π electron cloud of the benzene ring'.
- Some candidates only provided explanations for two out of the three compounds. It is important to note that candidates are expected to explain for the three compounds.

C2(b)(i) Step 1:



Step 2:

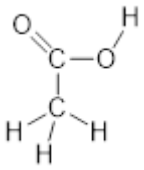


Comments:
- Most students were able to follow the written description.
- The head of the arrow should point towards the atom, and not the charge.
- For Step 2, some students drew the arrow from the lone pair of O in −OH to the positively-charged O. However, in the intermediate given, there is no formation of new bond between 2 oxygen atoms. Students are required to look at the structure of the intermediate and see which bonds are broken/formed.

C2(b)(ii) The protonation of the O in C=O results in the C in C=O to be <u>more electrophilic / more electron deficient</u>.

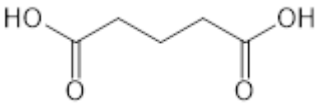
Comments:
- Some candidates gave general answer, stating that the intermediate is positively-charged and thus it can attract nucleophile better. Candidates are expected to look at the diagram and infer that it is the C in C=O that is crucial for the explanation as a new bond is formed between C and O.
- Answers describing the general action of a catalyst such as 'providing an alternative pathway with a lower activation energy' are not accepted as it has no reference to the structure given.

C2(b)(iii)



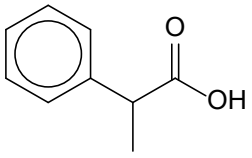
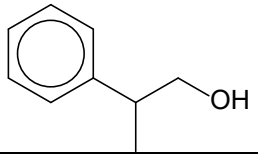
Comments:
- While most candidates can deduce the identity, many were careless and did not show all the atoms and bonds.
- Quite a number of students drew skeletal structure instead of displayed formula.

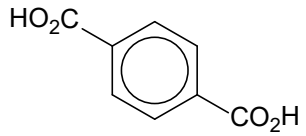
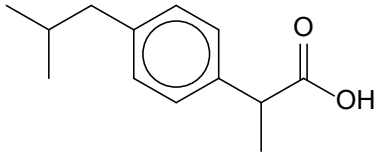
C2(b)(iv)



Comments:
- Generally well done.

C2(c)

evidence / information	deduction
Molecular formula of **P** is $C_9H_{10}O_2$.	ratio of C : H is approximately close to 1 : 1, **P** may contain a <u>benzene ring</u>.
P rotates plane-polarised light.	**P** is <u>chiral</u> / <u>contains chiral carbon</u> / <u>does not have a plane of symmetry</u>
P reacts with lithium aluminium hydride to form **Q**, $C_9H_{12}O$.	**P** undergoes <u>reduction</u> to form **Q**. As the number of oxygen atoms are reduced by 1, <u>**P** contains $-CO_2H$ group</u> and <u>**Q** is a primary alcohol</u>. **P:**  **Q:** 

P reacts with $(CH_3)_2CHCH_2Cl$ in the presence of anhydrous $AlCl_3$ to form **R**.	**P** undergoes <u>electrophilic substitution</u> to form **R**. **P** contains a benzene ring.
R reacts with hot acidified potassium manganate(VII) to form **S**, $C_8H_6O_4$.	**R** undergoes <u>oxidation / side-chain oxidation</u> to form **S**. **S** is a <u>dicarboxylic acid</u>, hence **R** contains <u>2 alkyl side chains.</u>
Only one mono-brominated product is formed when **S** undergoes bromination.	**S** undergoes <u>electrophilic substitution.</u> The <u>two $-CO_2H$</u> groups in **S** are on <u>positions 1 and 4.</u> **S**:  **R**: 

Comments:

- Students are advised to write down evidences for their deductions which are meaningful. Deductions that will lead to the elucidation of the structures are considered meaningful.
- The type of reaction should often be accompanied with the structural features, such as functional groups present in reactants and products, position(s) of substituents.
- Some students missed out the information on 'rotate plane-polarised light' and proposed a structure of P that has a plane of symmetry / no chiral carbon.
- One common error is to suggest that P contains aldehyde or ketone. The reduction of aldehyde/ketone does not result in a decrease in the number of oxygen atom. Students are reminded to track the change in the molecular formula. Answers such as 'P contains C=O' is also not accepted as it is ambiguous.
- When there is a decrease in the number of carbon atoms after reacting with hot, acidified $KMnO_4$, many students proposed that there is oxidative cleavage of C=C and were not able to draw the correct structures subsequently. When the benzylic carbon contains H/O atoms, the side-chain can also undergo oxidation and resulting in loss of carbon atoms in the form of CO_2.
- Another common area is to put the 2 −COOH groups in S on positions 1 and 3. This results in the formation of major/minor products, instead of ONLY 1 product upon bromination.
- Students are strongly encouraged to present their answers succinctly as taught during lessons, with a clear logical flow. This will definitely assist the markers in understanding their trend of thoughts.

C3(a)(i) Either Trigonal planar

Comments:

- Generally well answered.

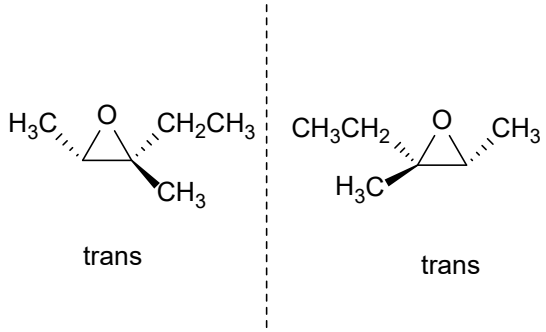
C3(b)(i) Enantiomerism

Either

Comments:
- The epoxide formed contains 2 chiral carbons with no internal plane of symmetry and hence exhibits enantiomerism.

C3(b)(ii)

Either



Comments:
- Both enantiomers are of the '*trans*' form (-CH_3 substituents on opposite sides). A good majority of students gave *cis-trans* products, ignoring the information stated in the question.
- Drawing of 3D diagrams seems to be a challenge for many students. For cyclic compounds, it may be easier to put the ring on the plane and project the substituents using wedged and hashed bonds.

C3(b)(iii) The two enantiomers are present in equal amount (or a racemic mixture is formed) because the

Either peroxy acid can attack from either face/side of the alkene with equal likelihood.

Comments:
- Most students recognised the formation of a racemic mixture and hence, the lack of optical activity. But the explanation is not always present or fully explained. The idea of 'equal likelihood of attack from either side of the plane is not clear in some answers, resulting in loss of marks.

C3(c)(i) The carbon atoms in the ring have a partial positive charge (or are electron-deficient) as they are

Either bonded to highly electronegative O. This makes the epoxide susceptible to attack by the nucleophile, OH^-.

Comments:
- Answers must be clear about which carbon is carrying the partial positive charge, i.e. the carbon directly bonded to O. Those who wrote 'positive charge' were penalised.
- A minority cited 'ring strain' as the answer and this is not accepted. 'Ring strain' can be used to explain the reactivity of the ring but it does not account for the susceptibility to nucleophilic attack.

C3(c)(ii) Carbon-2 has two/ more methyl (alkyl) groups attached and hence experiences more steric

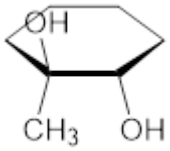
Either hindrance. Carbon-3 is less hindered for the nucleophile to carry out backside attack.

The two methyl groups are also electron-donating, hence decreases the magnitude of partial positive charge on carbon-2 / carbon-2 is less electron deficient, making it less susceptible to nucleophilic attack.

Comments:

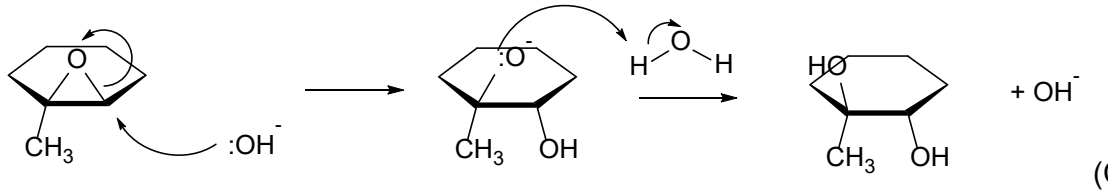
- The question asked for two reasons so there should be two parts to this. First reason is steric hindrance and the second reason is electronic factor. The phrasing of the question asks for some form of comparison between carbon-2 and carbon-3 and this comparison is not always present in the answers.

C3(c)(iii)
Either



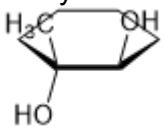
Comments:

- This part seems to be difficulty for majority – understanding that the attack by the nucleophile on the less hindered carbon and showing inversion on the site of attack.



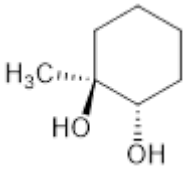
(Correct)

- Many students changed the chirality of the carbons involved, resulting in wrong structure.



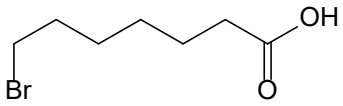
(Incorrect)

- Answers showing top view with wedged and hashed bonds shown correctly are accepted:



(Correct)

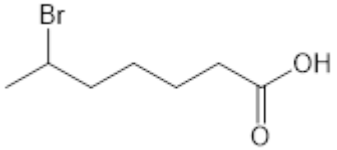
C3(a)(i)
Or



ethanolic NaOH, heat/heat under reflux
followed by $H_2SO_4(aq)$

Comments:

- Some students wrongly put the Br on the 6th carbon, instead from the 7th carbon



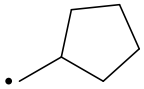
- The question states clearly that **U** gives only ONE product upon elimination. Putting Br on the 6th carbon will end up with more than one product:

- Ethanolic medium must be used to ensure elimination reaction takes place preferentially. If NaOH(aq) is used, nucleophilic substitution will take place.

C3(a)(ii) Reaction **I**: H_2, Ni, heat or H_2, Pd/Pt
Or Reaction **II**: LiA/H_4 in dry ether

Comments:
- Reaction **I**: Heating is required for H_2, Ni, unless Pd/Pt is used as the catalyst.
- Reaction **II**: Some students used $NaBH_4$ but this is not strong enough to reduce the carboxylic acid group. $NaBH_4$ is specific for reduction of carbonyls.

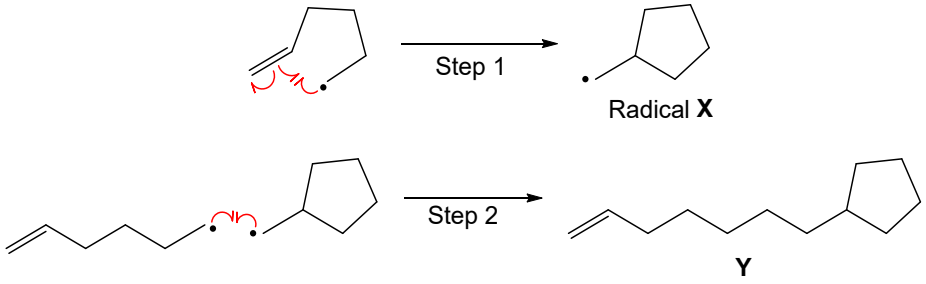
C3(b)(i)
Or



Radical **X**

Comments:
- Generally well answered.
- Some students were careless and drew a radical structure with too many C atoms.

C3(b)(ii)
Or



Comments:
- Many students lost marks in step 1 for not showing the homolytic fission of the pi bond in alkene with two half-headed (representing movement of 1 electron) arrows. Many used the full-headed arrows (representing movement of 2 electrons) which are wrong in this context.
- Many students did not show the meeting of the two half-headed arrows to form a new bond in both step 1 and step 2.

C3(b)(iii)
Or

$$n_e = \frac{It}{F} = \frac{3.0 \times 30 \times 60}{96500} = 0.05596 \text{ mol}$$

$$\text{Amount of product formed} = \frac{0.05596}{2} = 0.02798 \text{ mol}$$

$$\text{Mass of } \mathbf{W} \text{ formed} = \frac{63}{100} \times 0.02798 \times 166.0 = \underline{\mathbf{2.93\ g}}$$

Comments:
- A small number of students forgot to convert minutes to seconds in applying Q = It = neF.
- A good number of students forgot to factor in the correct stoichiometry, i.e. 2 mol of V form 1 mol of product (W or Y), resulting in loss of marks.
- Some students did not make use of the '% mass of product obtained' information in the question to solve for the mass of W formed.