1(a) $\mathbf{B}^{6+}(g) \longrightarrow \mathbf{B}^{7+}(g) + e^-$

Comments:
- Generally well done.

1(b) **C**

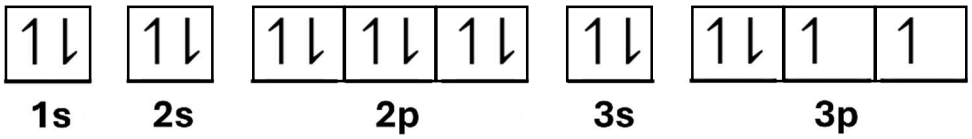
There is a large jump between the 8th and 9th ionisation energies.
This indicates that significantly more energy is needed to remove the 9th electron.
Thus this 9th electron is located in an inner electron shell that is nearer to the nucleus, experiencing less shielding and is attracted more strongly by the nucleus.
Therefore, there are 8 valence electrons.
Hence **C** belongs to Group 18 of the Periodic Table and is a noble gas.

Comments:
- Most students were able to correctly identify **C** as the noble gas.
- A common error was the incorrect use of the term "inner subshell". A subshell refers to s, p, d, f. The large jump in ionisation energies is due to the change in principal quantum number, n, of the electron shell from which the electron is removed from (from 3 to 2) and not because of the subshell.

1(c)(i) Sulfur

Comments:
- Generally well done.

1(c)(ii)



Comments:
- This question was well answered

1(d) $\mathbf{D}^+$: $1s^2\,2s^2\,2p^6\,3s^2\,3p^6$
C: $1s^2\,2s^2\,2p^6\,3s^2\,3p^6$

$\mathbf{D}^+$ and **C** are isoelectronic species and hence their outermost electrons experience the same shielding effect.
However, $\mathbf{D}^+$ has a larger nuclear charge than **C** and so there is stronger electrostatic attraction between the nucleus and the outermost electrons in $\mathbf{D}^+$.

Hence the 2nd ionisation energy of **D** is more positive than the 1st ionisation energy of **C**.

Comments:

- Most students understood the concept in this question but had missing key terms, used incorrect terms or demonstrated misconception in their answers.
- Many students had the misconception that only the inner electrons contribute to the shielding effect. This is not true, because the outer electrons also contribute to shielding effect (though comparably less). Therefore, there is a need to mention that both D^+ and C contain the same number of electrons and hence the outermost electron for both D^+ and C experience the same shielding effect.
- The 2nd I.E. of **D** refers to removal of the outermost electron from $\mathbf{D}^+$ and the 1st I.E. of C refers to the removal of the outermost electron from **C**.
    - Some students were not aware that the outermost electron were being removed from $\mathbf{D}^+$ and **C**.
    - Writing the electronic configuration of **D** is irrelevant to this question since the 2nd I.E of D refers to the removal of outermost electron from $\mathbf{D}^+$ (instead of **D**).

1(e)(i) The electronegativity of an atom in a molecule is a relative measure of its ability to attract bonding electrons.

Comments:

- A significant number of students did not specify "bonding" electrons in their answers.

1(e)(ii) 2.5

Comments:

- Generally well done.

1(f)(i) The B–H_a bond is longer.

Since two electrons are shared between three atoms in B−H_a−B, there is an average of one shared electron per B−H_a bond, which is less than the two shared electrons per B–H_b bond. This decrease in electron density between the B and H_a atoms causes the B−H_a bond to be weaker and therefore longer.

Comments:

- Students are required to clearly show the comparisons between B−H_a and B−H_b bond. This includes the number of shared electrons, bond strength and hence the bond length.
- Students are also required to demonstrate understanding of the term "three-centre two-electron bond" for the B−Ha−B as having an average of one shared electron per B−H_a bond.

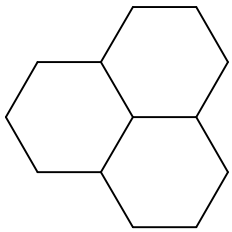
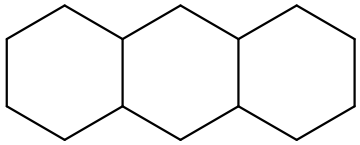
1(f)(ii) 122°

Since the electron density of the B–H_b bond is greater than that of the B–H_a bond, the repulsion between two B–H_b bonds is greater than that of the repulsion between B–H_a and B–H_b, which is greater than that between two B–H_a bonds. Hence H_b–B–H_b bond angle is greater than 109.5°.

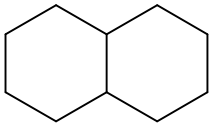
Comments:

- The explanation required in question was challenging for most students.
- The concept tested here is the VSEPR theory, but students are required to adapt and apply it to the context of this question. It is analogous to the idea of "repulsion of lone pair-lone pair > lone pair-bond pair > bond pair-bond pair". However, there are no lone pair of electrons about the B atom, but only bond pairs of B–H_a and B–H_b which differ in their electron density. Hence, students are expected to recognise that the B–H_b bond pair, which has greater electron density, exerts greater repulsion compared to the B–H_a bond pair. As a result, repulsion between B–H_b and B–H_b > B–H_a and B–H_b > B–H_a and B–H_a.

2(a)(i)

 or 

Comments:

- Generally well done.
- Some candidates incorrectly gave  as the answer – note that only 10 carbons are present.

2(a)(ii) Each carbon atom has an unhybridised p orbital which overlaps side-on with the other p orbitals on adjacent carbon atoms. This continuous side-on overlap of the p-orbitals allows the π electrons to be delocalised and shared equally across all carbon atoms, resulting in all bond lengths to be equal.

Comments:

- Many students described the σ bond involvement when it was explicitly mentioned in the question **not** to do so.
- There is one electron per carbon atom involved in the delocalisation – **not** one *pair* of electrons.
- Most students were not able to accurately bring out the equal / even distribution of electron density between carbon atoms.
- Citing "intermediate" bond length between that of C−C and C=C bond just means the bond length is in between these two. It does not necessarily mean that any two given such bonds are equal in length e.g. 0.4 and 0.6 are both intermediate between 0.3 and 0.8 but they are not equal.

- "Partial double bond character" does not mean that any two bonds having such a characteristic are equal in bond length.

2(a)(iii) sp^3

Each carbon atom has <u>four bond pairs / regions of electron densities</u> and <u>no lone pairs</u> and exhibits a tetrahedral molecular geometry (shape). Each bond pair must thus be located in an sp^3 hybrid orbital.

Comments:

- Hybridisation cannot be determined solely based on the number of bonds since the presence of lone pairs or lone electrons must also be accounted for i.e. the **total number of regions of electron densities** involved should be clear.
- Shape alone is insufficient as well since the same shape can be the outcome for different hybridisations.
- Students are reminded to use proper convention in science, sp_3 is **not** an acceptable representation of hybridisation.

2(a)(iv) <u>Allotrope **F** is a non-conductor</u> of electricity while <u>graphite is a conductor</u> of electricity.

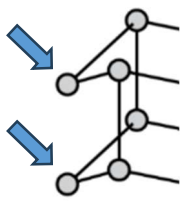
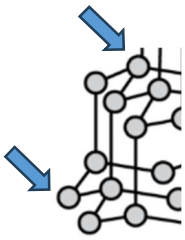
All four valence electrons on each C atom in allotrope **F** are used to form σ bonds, and <u>no electrons</u> are available for <u>delocalisation</u> / <u>no mobile charge carrier</u> to conduct electricity. In graphite, three of the valence electrons on each C atom are used to form σ bonds. The last electron on each C atom in graphite delocalises across the whole layer, acting as a mobile charge carrier. Hence, graphite is a conductor of electricity.

Comments:

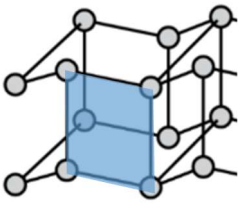
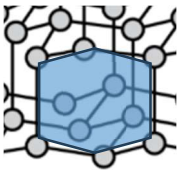
- Students are reminded to always **answer the question** as some students did not clearly state the difference in difference in conductivity.
- **F** is a **non**-conductor and should not be described as though there is *some* level of conductivity.
- For graphite, electricity is conducted **along** the layers, not **between** the layers.

2(a)(v) The researcher is <u>incorrect</u>.

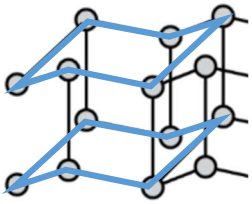
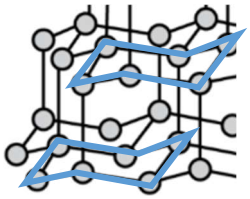
The two structures are different because

 **Fig. 2.1**	 **Fig. 2.2**
These two carbons point in the same direction.	These two carbons point in different / opposite directions.

OR

 **Fig. 2.1**	 **Fig. 2.2**
There are “rectangular” faces. There are 4-carbon rings on the sides.	There are hexagonal faces. There are 6-carbon rings on the sides.

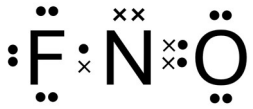
OR

 **Fig. 2.1**	 **Fig. 2.2**
Chair structures are stacked directly on top of each other.	Chair structures are staggered between the layers.

Comments:

- Many other interesting and valid answers were given.
- Students should not assume that the structures given are drawn to scale, hence any reference to different bond lengths cannot be validated.
- The same hybridisation of carbon atoms in the two structures does not mean that the atoms must be connected in the same way.
- Many students did not realise that only a **part** of the structure is given and that the drawing can be extended by repeating the given pattern (same for allotrope **F**). Therefore, it is not correct to say that some atoms only have 2 or 3 bonds.

2(b)(i)



Comments:

- Some students did not draw the lone pairs of electrons which were required as part of the dot-and-cross diagram.
- Some students drew the structures with lone electrons even though it was not necessary for this molecule.
- Some students incorrectly drew N as having a dative covalent bond to O, resulting in N being electron-deficient.

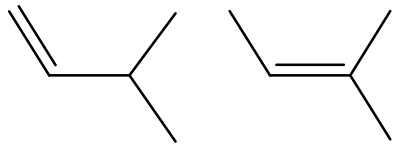
2(b)(ii) see-saw / distorted tetrahedral

Comments:
- Generally well done.

2(c)(i) ethanolic NaOH and heat

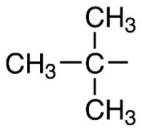
Comments:
- Some students wrote KOH even though the context given was NaOH.

2(c)(ii)



Comments:
- Generally well done.
- A small number of students mistakenly thought *cis-trans* isomerism existed in the alkene shown on the right.
- The question required the **skeletal formulae** of **L** and **M** and not displayed formulae or other structures.
- A small number of students did not count the number of carbons in their structures and gave more or less than five-carbon compounds as answers.

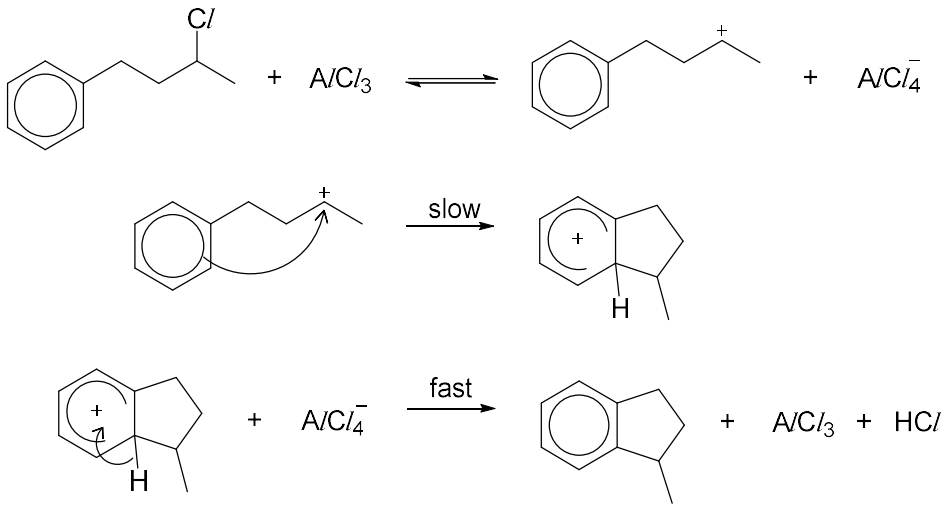
2(c)(iii) S_N1 does not occur because **N** is a 1° bromoalkane and the carbocation formed is not stable enough.



The bulky group hinders the backside attack by the OH^- nucleophile on the electron-deficient carbon and hence S_N2 does not occur.

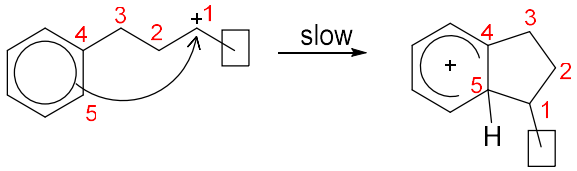
Comments:
- Students must clearly state which mechanism, S_N1 or S_N2, that their answer is referring to.
- There is only ONE group (as shown above) that is attached to the carbon bearing the Br – **not** three methyl groups.
- For S_N2, some students were not clear in describing which carbon is the one being attacked by the nucleophile – it is the **carbon bonded to Br**. Some students mistook the attack to be on the carbon bearing the three methyl groups (see above).
- Any reference to a "central" carbon is ambiguous as there is more than one such carbon.

3(a)(i) Electrophilic Substitution



Comments:

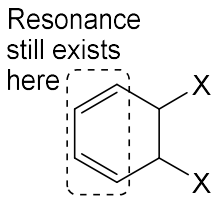
- A handful of students missed out on the regeneration of the $AlCl_3$ and the formation of the HCl product, as well as labelling the slow and fast steps. As a matter of habit, students should also name the mechanism.
- A handful of students did not manage to draw the correct structure of the product. A helpful hint here: number the carbons in the side chain when connecting the ring, so that the fused ring has the correct number of carbon atoms, with the substituent on the correct position.



3(a)(ii) The delocalisation of the six π electrons in the ring structure of benzene causes resonance stabilisation. Addition reactions disrupt the delocalisation of the six π electrons in benzene while substitution reactions restores the resonance stabilisation after temporarily disrupting it.

Comments:

- Some students did not explicitly mention both sides of the explanation – that addition reactions disrupt the delocalisation, as well as how substitution reactions restore the resonance stabilisation.
- Many students simply stated that resonance is disrupted through the addition reaction, or that resonance is lost. This is incorrect as the benzene will still have resonance with the remaining 4π electrons in the product.



The more accurate explanation is the loss of aromaticity or the disruption of the delocalisation of the six π electrons.

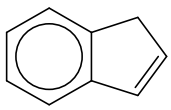
3(a)(iii) A*l*C*l*$_3$ acts as a Lewis acid catalyst in the reaction.

Comments:
- Some students only identified the "Lewis acid" role or the "catalyst" role. Both roles are required in the answer.

3(a)(iv) With reference to the mechanism, the electrophile is planar about the positively charged carbon in the carbocation. Hence, the π electrons from the benzene ring will attack the positively charged carbon on either side of the plane with equal probability. Hence, a racemic mixture is formed, and the product is unable to rotate plane-polarised light.

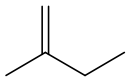
Comments:
- Most students were able to infer that a racemic mixture had been formed, but were unable to articulate clearly where the "trigonal planar" part of the molecule was, or what were the nucleophile and electrophile.
- A handful of students incorrectly stated that the carbon attached to chlorine was trigonal planar in **S**. Instead, it is the positively charged carbon in the carbocation that is trigonal planar.
- Some students suggested that benzene was an electrophile, or that an unspecified electrophile had attacked the positively charged carbon.
- A handful of students referred to benzene as having a trigonal planar structure (note that benzene is simply planar) and that the electrophile attacked benzene from above and below the (benzene) plane with equal probability. This was accepted as this would also form a racemic mixture for the same reason.

3(b)(i)

U: 

Comments:
- Generally well done
- Incorrect responses usually omitted the C=C in the structure or the wrong number of carbon atoms in the 5-carbon ring.

3(b)(ii)

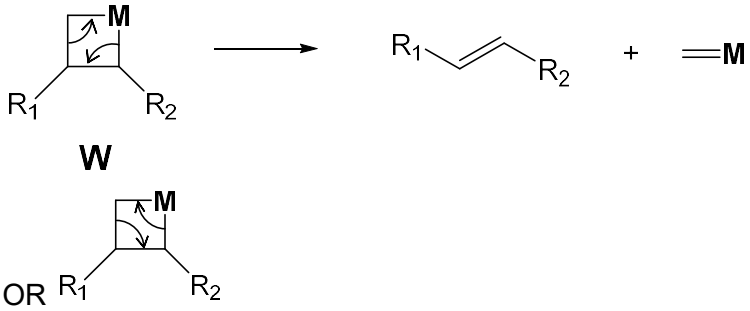
V: 

Comments:
- Generally well done.

3(b)(iii) Free radical substitution reaction may result in <u>produce multiple alternative monosubstituted products / major product is another monosubstituted product / multiple substitutions</u>

Comments:
- Many students mentioned "unwanted side-products" being formed without being more specific about the nature of the side-products.
- A handful of students suggested that the unwanted products were formed in the termination step. Note that the alkane formed by the combination of two alkyl radicals are formed in trace amounts only, and hence does not affect the reaction much.

3(c)



W

Comments:
- Generally well done.
- Some students may have omitted this question by mistake. Do read each question carefully.
- Arrows that pointed ambiguously at M or another C atom were not accepted as the reaction involves the formation of π bonds.

3(d) Test: To each compound in separate test-tubes, add <u>H_2SO_4(aq),</u> a few drops of <u>$KMnO_4$ and heat</u> in hot water bath

Observation(s):
For **X**, there is <u>decolourisation</u> of purple $KMnO_4$.
For **Y**, there is <u>decolourisation</u> of purple $KMnO_4$ and <u>evolution</u> of a colourless <u>gas</u> (CO_2) which gives a <u>white precipitate with limewater</u>.

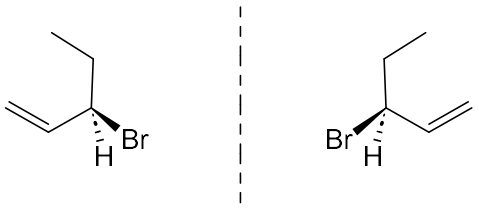
Comments:
- Some students combined multiple distinguishing tests, such as reacting with $KMnO_4$, H_2SO_4 and heat, followed by 2,4-DNPH or Na_2CO_3. The excess H_2SO_4 from the oxidation will give a false positive with Na_2CO_3 and the $KMnO_4$ and/or H_2SO_4 may interfere with the condensation reaction with 2,4-DNPH. Students should use only one set of distinguishing test and reagent, unless no single test is possible.

- Many students suggested the correct reagents but did not give complete observations. Most incorrect answers omitted the decolourisation of purple $KMnO_4$.
- A handful of students used "heat with reflux". This is not accepted for simple chemical tests which should be just test-tube reactions.

3(e)(i) 3-bromopent-1-ene

Comments:
- Generally well done.
- Some incorrect answers named the carbon chain incorrectly (e.g. hexene or heptene), or misspelled the pentene as penta-1-ene.
- A number of students omitted the position of the double bond. Pentene may be pent-1-ene or pent-2-ene.

3(e)(ii)



Comments:
- A number of students who drew the tetrahedral structure using the chemical formula made careless mistakes such as writing the formula incorrectly ($-CH_2CH_3$ and CH_3CH_2- are correct, whereas H_3CH_2C- is incorrect).
- Students are reminded to refer to the "Introduction to Organic Chemistry" notes for the rules on writing and drawing chemical structures.

4(a)(i) In 1 m^3, mass of air is 1 kg.

mass of $O_3 = \frac{2 \times 10^{-5}}{100} \times 1$
$= 2 \times 10^{-7}$ kg
$= 2 \times 10^{-7} \times 10^3 \times 10^6$
$= 200$ μg

Hence, concentration of O_3 is <u>200</u> μg m^{-3}

Comments:
- A number of students overlooked the % sign in the given data (2×10^{-5} % by mass of O_3). The % must first be divided by 100, giving 2×10^{-7} kg as the mass of O_3 in 1 m^3 of air.
- Note that 1 kg = 10^3 g = $10^3 \times 10^6$ μg

4(a)(ii) PSI of $O_3 = \frac{200 - 100}{235 - 157} (200 - 157) + 100$
$= \underline{155}$ (3 s.f.)

Comments:
- Since concentration of O_3 (200 μg m^{-3}) lies between 157 and 235 μg m^{-3}, students should have referred to the legend provided and used data in rows i = 2 and 3 when applying the equation to determine PSI.

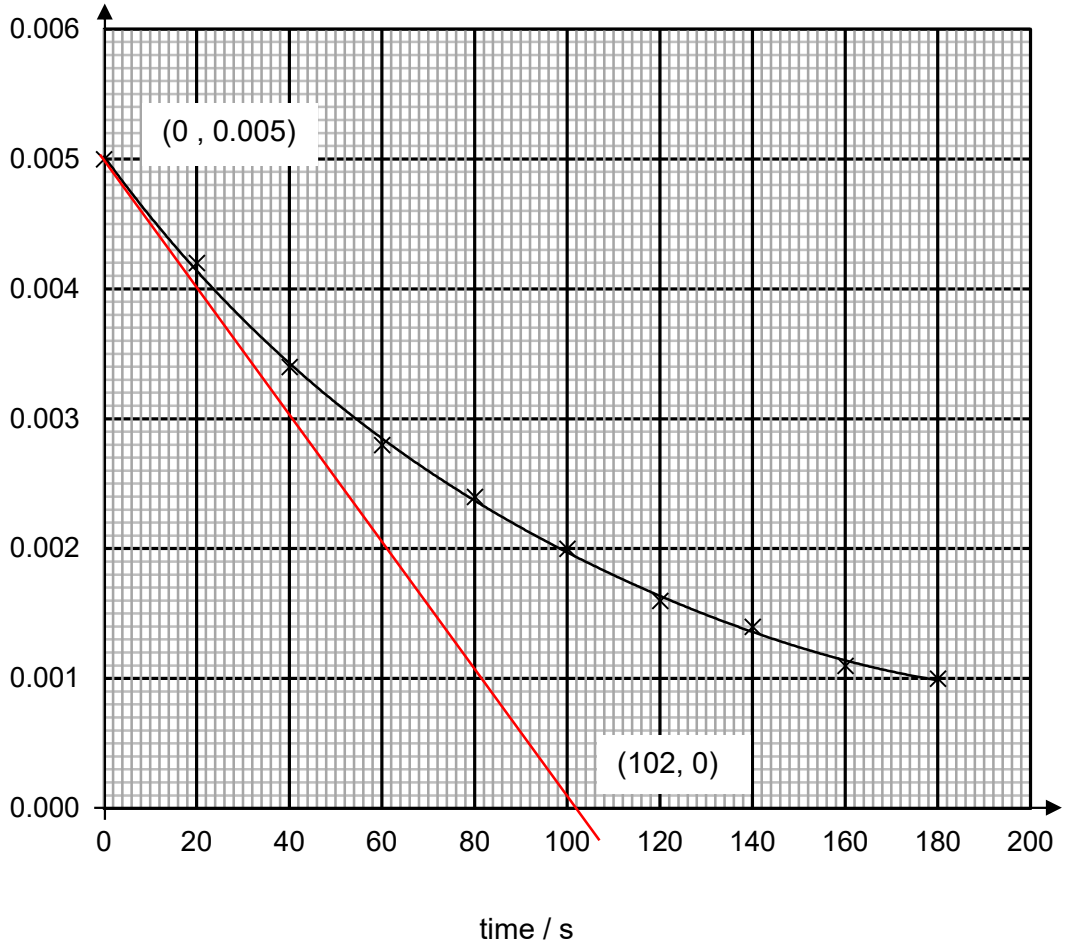
4(b)(i) Vehicular emissions are a significant source of NO_2. When the lockdown measures were implemented, there were fewer vehicles on the road, and concentration of NO_2 decreased.

Comments:
- Generally well done.

4(b)(ii) NO_2 is a radical and can react with O_3. During the Circuit Breaker, the concentration of NO_2 decreased, leading to less reaction with O_3. Therefore, the concentration of O_3 increased.

Comments:
- Given information about radicals destroying O_3, the increase in [O_3] during Circuit Breaker can be accounted by a decrease in [radicals].
- Many students did not recognise NO_2 to be a radical species. The N atom contains an unpaired electron.
- Many students who suggested that decreased [CFCs] during Circuit Breaker led to decreased [C*l*●] did not justify why [CFCs] would have decreased (e.g. reduction in industrial activities). Students should note that CFCs are no longer used in modern appliances like air-conditioners, refrigerants and aerosol sprays, and therefore should not justify by suggesting a reduction in their usage during Circuit Breaker.
- Note that radicals are not greenhouse gases and greenhouse gases do not trap UV light to facilitate the breakdown of CFCs into C*l*●.

4(c)(i) $[O_2]$ / mol dm^{-3}



Draw a tangent at t = 0 s

Initial rate = −gradient
= −[(0.005 – 0) / (0 − 102)]
= 4.90 x 10^{-5} mol dm^{-3} s^{-1}
= **z**

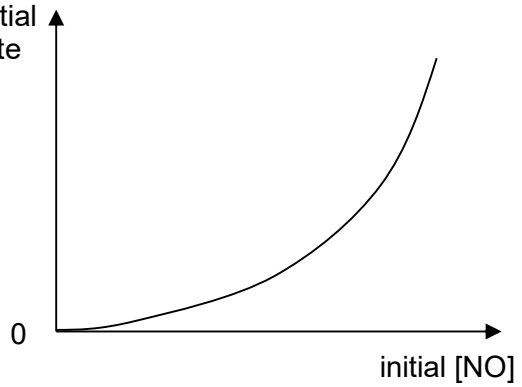
Comments:

- To find initial rate from a concentration-time graph, a tangent line has to be drawn at time = 0.
- A correct tangent at time = 0 should only touch a small portion of the graph at the starting point.
- Students should note that rate of reaction is positive by convention, therefore initial rate = **−** gradient.

4(c)(ii) Comparing experiments 1 and 2, when [O_2] x 3, initial rate x 3. [O_2] α rate.
Hence, reaction is first order with respect to O_2.

Comments:
- Generally well done.

4(c)(iii)



Comments:
- Given that reaction is second order with respect to NO, when initial [NO] x2, rate x2^2 = x4. The rate–[reactant] graph is a curve through the origin, upward-sloping with increasing steepness. Students should be familiar with the different characteristic shapes of kinetics graphs.

4(c)(iv) rate = $k[NO]^2[O_2]$

Comments:
- Mistakes like writing NO_2 instead of NO and leaving out [O_2] (order previously determined in **(c)(ii)**) should be avoided.

4(c)(v) The half-life of a reaction is the time taken for the concentration of a reactant to decrease to half its initial value.

Comments:
- As reaction rates are typically described as a function of concentration, the half-life of a reaction should be defined in terms of concentration, not amount.
- The species involved (reactant or product) should be clearly specified.

4(c)(vi) rate = $k[NO]^2[O_2]$

Using large excess of NO, reaction becomes pseudo first order.
rate = $k'[O_2]$ where $k' = k[NO]^2$

$t_{½} = \frac{\ln 2}{k'}$

$= \frac{\ln 2}{k[NO]^2}$

Since [NO] in experiment 3 is doubled that of experiment 1,
$t_{½}$ of experiment 3 = $\frac{74}{2^2}$ = 18.5 s

Comments:

- Looking at the significantly higher initial [NO] compared to $[O_2]$ used in experiments 1 to 3, students should realise this is a pseudo-order reaction and manipulate the rate equation obtained in **(c)(iv)** to arrive at the pseudo-order rate equation: rate = $k'[O_2]$ where $k' = k[NO]^2$. A common mistake was to consider $k' = k[NO]$ or $k' = k[O_2]$.
- Since this is a pseudo-order reaction, k' is in the denominator for the half-life equation, $t_{½} = \frac{\ln 2}{k'}$, not $t_{½} = \frac{\ln 2}{k}$. Half-life is dependent on [NO].
- Some students attempted to solve without using the half-life information for experiment 1 and were not given credit. Such calculations which relied on the rate value obtained in **(c)(i)** are less accurate due to errors associated with the tangent line drawn.

4(c)(vii) $N_2O_2 + O_2 \longrightarrow 2NO_2$

Comments:

- Most students knew to involve the intermediate N_2O_2 in the 2nd step. However, a handful of students did not ensure that the 2nd step, when summed up with the 1st step, gives the overall reaction equation. This is an essential condition for a valid proposed mechanism.

$2NO \longrightarrow N_2O_2$

$N_2O_2 + O_2 \longrightarrow 2NO_2$

$2NO + O_2 \longrightarrow 2NO_2$

4(d)(i) Homogeneous catalysis

Comments:

- In homogeneous catalysis, the catalyst and reactants are in the same phase, in this case, the gaseous phase.
- Since there is no mention of how the rate of reaction changes over time, the reaction cannot be described as autocatalytic.

4(d)(ii)

$NO_2 + SO_2 \longrightarrow SO_3 + NO$ (I)

$NO + ½ O_2 \longrightarrow NO_2$ (II)

Comments:

- Clue was given in the question about NO_2 catalysing the oxidation of SO_2. So, students should consider the oxidation of SO_2 to SO_3 by NO_2.
- Since NO_2 is a catalyst, it should be regenerated.
- Catalytic oxidation of atmospheric sulfur dioxide by atmospheric oxides of nitrogen is an important example of homogeneous catalysis in the syllabus.

4(e)

$n(S_2O_3^{2-})$ reacted $= \frac{15.60}{1000} \times 4.00 \times 10^{-4}$

$= 6.24 \times 10^{-6}$ mol

$n(I_2)$ formed $= 6.24 \times 10^{-6} / 2$

$= \underline{3.12 \times 10^{-6}}$ mol

$n(SO_2)$ in 1 m^3 sample of air = $3.12 \times 10^{-6} \times 5$
$= 1.56 \times 10^{-5}$ mol
mass in 1 m^3 sample of air = $1.56 \times 10^{-5} \times 64.1$
$= 0.00099996$ g
mass concentration of SO_2 = <u>0.00100 g m^{-3}</u> (3 s.f.)

Comments:
- The mole ratio of $I_2 : S_2O_3^{2-}$ is 1 : 2, not 1 : 1.
- The sample of air used for analysis is 1 m^3, not 1 dm^3. Read the question carefully.
- Mass = no. of moles x molar mass, not ÷ molar mass.
- 0.00099996 when rounded to 3 s.f. is 0.00100 (or 1.00×10^{-3} or 10.0×10^{-4}). Many students made careless mistakes in the final answer.

5(a) $Zn^{2+} + 4OH^- \longrightarrow [Zn(OH)_4]^{2-}$

Comments:
- Generally well done.
- Note that the oxidation state of zinc in Zn^{2+} and $[Zn(OH)_4]^{2-}$ are both +2. Hence, this is a complexation reaction, not a redox reaction. Students who attempted to balance the equation using electrons invariably used the wrong reactants.

5(b)(i) At high $[OH^-]$, $[Zn(OH)_4]^{2-}$ is produced, causing <u>$[Zn^{2+}]$ to decrease</u>. This causes the <u>position of equilibrium of $Zn^{2+} + 2e^- \rightleftharpoons Zn$ to shift to the left</u>. Hence, $E(Zn^{2+}/Zn)$ becomes more negative.

Comments:
- Students should explicitly state the effect of complexation on the **concentration** of Zn^{2+}, instead of stating that Zn^{2+} is depleted (this is ambiguous as it could mean amount and not concentration).
- Students should also write the correct half-equation using the ⇌ equilibrium arrow.
- Students should also reference the appropriate reaction when stating that the "position of equilibrium shifts left/right".
- Stating that the cell is not operating at standard conditions is not sufficient to explain the difference in value for *E*. Use the concept of Le Chatelier's Principle to explain how *E* is more negative.

5(b)(ii) $O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^-$
$Zn^{2+} + 2e^- \rightleftharpoons Zn$

When $E_{(Zn^{2+}/Zn)} = -1.25$ V, $E(O_2/OH^-) = +0.34$ V
$E_{cell} = +0.34 - (-1.25) =$ <u>+1.59 V</u>
$\Delta G = -nFE_{cell}$
$= -(4)(96500)(+1.59)$
$= -613740$ J mol^{-1}
= <u>–614 kJ mol^{-1}</u>

Comments:

- Some students missed the question prompt to use the reduction potential values provided. Using *E* values from the Data Booklet would yield an incorrect ΔG value.
- Some relevant equations for this question:
  - $E_{cell} = E_{cathode} - E_{anode}$,
  - $\Delta G = -nFE_{cell}$ (note: the units of the final answer is J mol^{-1}, and don't forget to include the – sign)
- Some errors were due to an incorrect value of *n*. Evaluate the overall equation to determine the number of mole of electrons transferred per mole of reaction. Since 2 moles of electrons were released for every mole of Zn oxidised, and the overall equation contains 2 moles of Zn, the total number of electrons transferred per mole of reaction is 2 × 2 = 4.

5(b)(iii) With a lower $[OH^-]$, $Zn(OH)_2$ is less able to dissolve to form $[Zn(OH)_4]^{2-}$. The insoluble $Zn(OH)_2$ forms a non-conducting layer on the electrode surface, preventing the electrode from coming into contact with the electrolyte. Hence, the electrode is not able to conduct electricity, and the oxidation of active zinc cannot occur.

Comments:

- This question was challenging, likely due to the lack of understanding of the context of the question. As a data-based question, students should evaluate the significance of the big decrease in $[OH^-]$ and associate it to the process of discharge at the anode. As stated in the question stem, "highly concentrated potassium hydroxide solution" was required for zinc hydroxide to dissolve to form zincate. Using this information, consider why a lower concentration of hydroxide ions will impact the discharge process at the anode.
- Students were also prompted to **not** refer to *E* values. Hence, answers that considered shifts in equilibrium positions affecting *E* values were not given credit.
- Some answers considered the limiting amount of OH^- causing the reaction to stop. When OH^- runs out, the battery will stop functioning because the capacity of the battery had been used up. This does not answer the question of why the discharge stopped *prematurely*.
- Below are a few other misconceptions commonly seen in some answers:

Misconceptions	Reason why they are wrong
Zn anode cannot react with the hydroxide ions in the electrolyte, hence oxidation does not occur.	During the discharge process, Zn is oxidised in its half-cell, by releasing electrons. Zn does not react with the OH^- in the electrolyte.
Zn anode cannot react with oxygen molecules.	For an electrochemical cell to work, the reactants at the two electrodes should not be reacting with each other. Instead, they are separately oxidized/reduced to transfer electrons through the wire, to generate electricity. That is why a separator is necessary

		to prevent the two reactants from both sides from coming together.
	The pores of the separator are clogged by the formation of $Zn(OH)_2$, which prevents the movement of electrons through the electrolyte.	This is incorrect as electrons flow through the wire connecting the anode and cathode, not the electrolyte solution. Conducting ions flow through the electrolyte and the separator to maintain electrical neutrality.

5(c) Reactant molecules diffuse towards the catalyst surface and become adsorbed onto the active sites. This increases the concentration of reactants at the catalyst surface and weakens the covalent bonds within the molecules which lowers activation energy. Reactants molecules also come in close contact with orientation to react and form products. The product molecule desorbs and diffuse away from the catalyst surface.

Comments:

- Many students did not include the increase in concentration of reactants on the catalyst surface as part of the mode of action.
- There were quite a number of answers with misspelled "adsorbed" and "desorbed." Note that the noun forms of adsorbed is adsorption, and of desorbed is desorption. There's no such word as "deadsorbed."
- Secondly, adsorb and absorb have different meanings. The former means that the reactants are "attached" to the surface, while the latter means that the reactants are "going into" the catalyst, which does not happen.
- Students should refrain from using layman or less accurate words to describe the mode of action. For instance, "straining" a bond as opposed to "weakening", "break away" as opposed to "desorb".
- There is a difference between "weakens the covalent bonds between the molecules" and "weakens the covalent bonds within the molecules". There are no covalent bonds between the H_2O and O_2 molecules.

5(d)

- Use of air as reactants at the cathode means less harmful chemicals are used in the making of the cell.
- Rechargeable feature reduces the amount of chemicals wasted in production of batteries as compared to single-use batteries.
- Rechargeable batteries reduce electronic waste caused by the disposal of single-use batteries.
- Lower cost of purchasing batteries repeatedly.

Comments:

- Some answers were poor in quality without sufficient reason to substantiate their claims: e.g. "more sustainable" or "more environmentally friendly."
- Answers that stated the obvious, "e.g. rechargeable batteries can be reused" were not accepted.
- Students are also encouraged to answer the question directly and address the advantage of rechargeable batteries over single-use batteries, instead of why single-use batteries are less preferred.

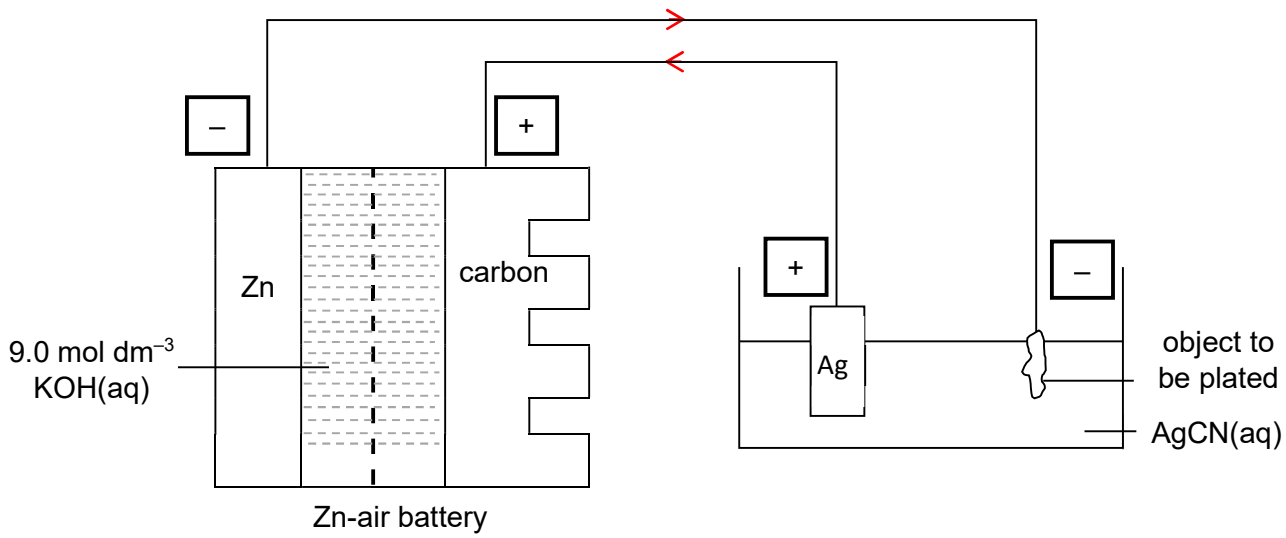
5(e)(i) The amount of active zinc <u>decreased</u>.

Comments:
- Generally well done

5(e)(ii) $H_2(g)$

Comments:
- Students are encouraged to think through the process and the reactants present in the cell and how they could impede on the discharge of the battery. Losing active zinc would mean that the zinc electrode is reacting with something in the electrolyte (that can be reduced), causing it to be oxidised even when the circuit is not closed.
- A common wrong answer was O_2 gas. Oxygen gas <u>may</u> be formed by the oxidation of OH^-, but that does not explain losing active zinc.
- Answers such as ZnO or CO_2 were poor guesses: ZnO is not a gas, and there are no carbon-containing species in direct contact with Zn.

5(f)(i)



Zn-air battery

Comments:
- This question was challenging, with many students unable to label the electrode polarities correctly.
- To answer this question accurately, students need to first identify the electrochemical cell (i.e. battery, which is on the left) and the electrolytic cell (on the right).
- Electrons in a battery flow from the anode (the negative electrode), which is the zinc electrode as explained in the question stem, to the cathode (the positive electrode).
- The polarity of the electrolytic cell is dependent on the polarity of the electrode of the electrochemical cell it is attached to. Hence, the object, connected to the zinc anode with negative polarity, will also adopt a negative polarity.

5(f)(ii) $Ag^+ + e^- \longrightarrow Ag$

amount of Ag = 1.75 / 107.9 = 0.01621 mol
amount of e^- = <u>0.0162 mol</u>

Comments:
- Generally well done.

5(f)(iii) $Zn \longrightarrow Zn^{2+} + 2e^-$

amount of Zn reacted = 0.01621 / 2 = 8.109×10^{-3} mol
mass of Zn lost = $8.109 \times 10^{-3} \times 65.4$ = <u>0.530 g</u>

Comments:
- Generally well done.
- Students who did not obtain the correct answer usually missed the mole ratio of the Zn oxidation reaction.

5(f)(iv) $Q = It = n_eF$

$1.5t = 0.01621 \times 96500$
t = <u>1040 s</u> (or 17.4 min)

Comments:
- Generally well done.
- Some students were confused between the n_e in this equation, and the n in $\Delta G = -nFE_{cell}$.
  - The n in $\Delta G = -nFE_{cell}$ refers to the amount of electrons transferred in <u>1 mole of reaction</u>, while
  - The n_e in $Q = n_eF$ refers to the specific amount of electrons transferred within the time in which the battery was discharged/the electrolytic cell was operated.