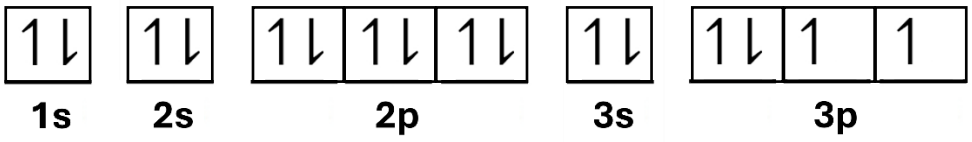
1(a) $\mathbf{B}^{6+}(g) \longrightarrow \mathbf{B}^{7+}(g) + e^-$

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.

1(c)(i) Sulfur

1(c)(ii)



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**.

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

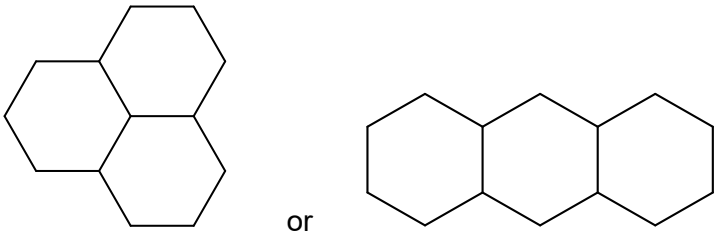
1(e)(ii) 2.5

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.

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°.

2(a)(i)



or

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.

2(a)(iii) sp^3

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

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

All four valence electrons on each C atom in allotrope **F** are used to form σ bonds, and no electrons are available for delocalisation / no mobile charge carrier 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.

2(a)(v) The researcher is incorrect.

The two structures are different because

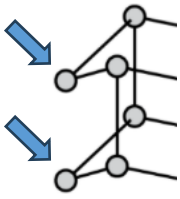
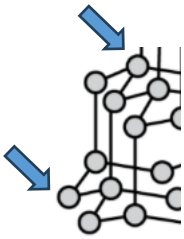
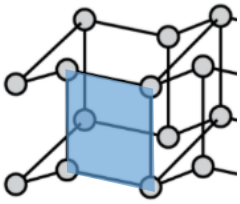
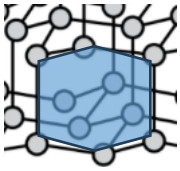
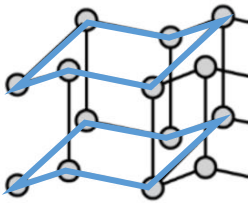
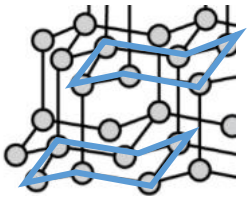
	

Fig. 2.1	**Fig. 2.2**
These two carbons point in the same direction.	These two carbons point in different / opposite directions.

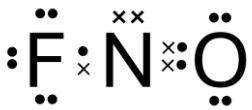
OR

 **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.

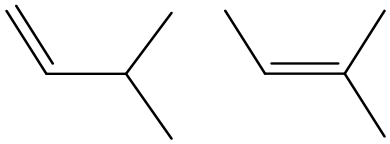
2(b)(i)



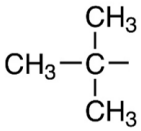
2(b)(ii) see-saw / distorted tetrahedral

2(c)(i) ethanolic NaOH and heat

2(c)(ii)

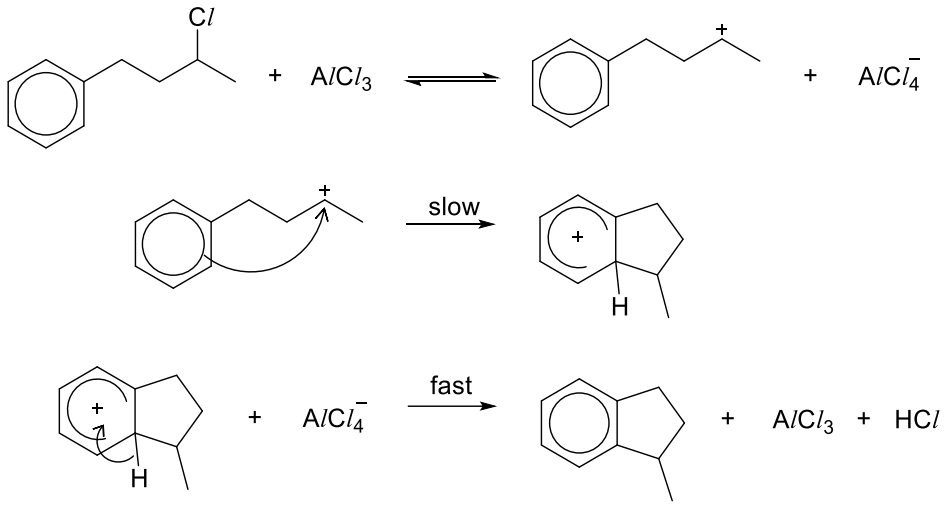


2(c)(iii) S_N1 does not occur because **N** is a 1° bromoalkane and the carbocation formed is not stable enough.



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

3(a)(i) Electrophilic Substitution



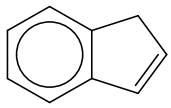
3(a)(ii) The delocalisation of the six π electrons in the ring structure of benzene causes resonance stabilisation. Addition reactions disrupt the delocalisation of the six π electrons in benzene while substitution reactions restores the resonance stabilisation after temporarily disrupting it.

3(a)(iii) $AlCl_3$ acts as a Lewis acid catalyst in the reaction.

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.

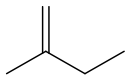
3(b)(i)

U:



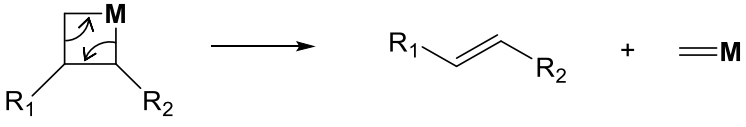
3(b)(ii)

V:

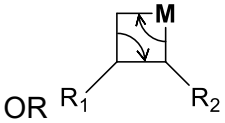


3(b)(iii) Free radical substitution reaction may result in produce multiple alternative monosubstituted products / major product is another monosubstituted product / multiple substitutions

3(c)



W

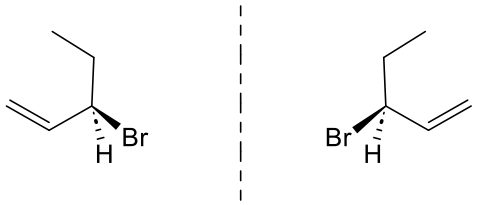


3(d) Test: To each compound in separate test-tubes, add $H_2SO_4(aq)$, a few drops of $KMnO_4$ and heat in hot water bath

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

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

3(e)(ii)



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

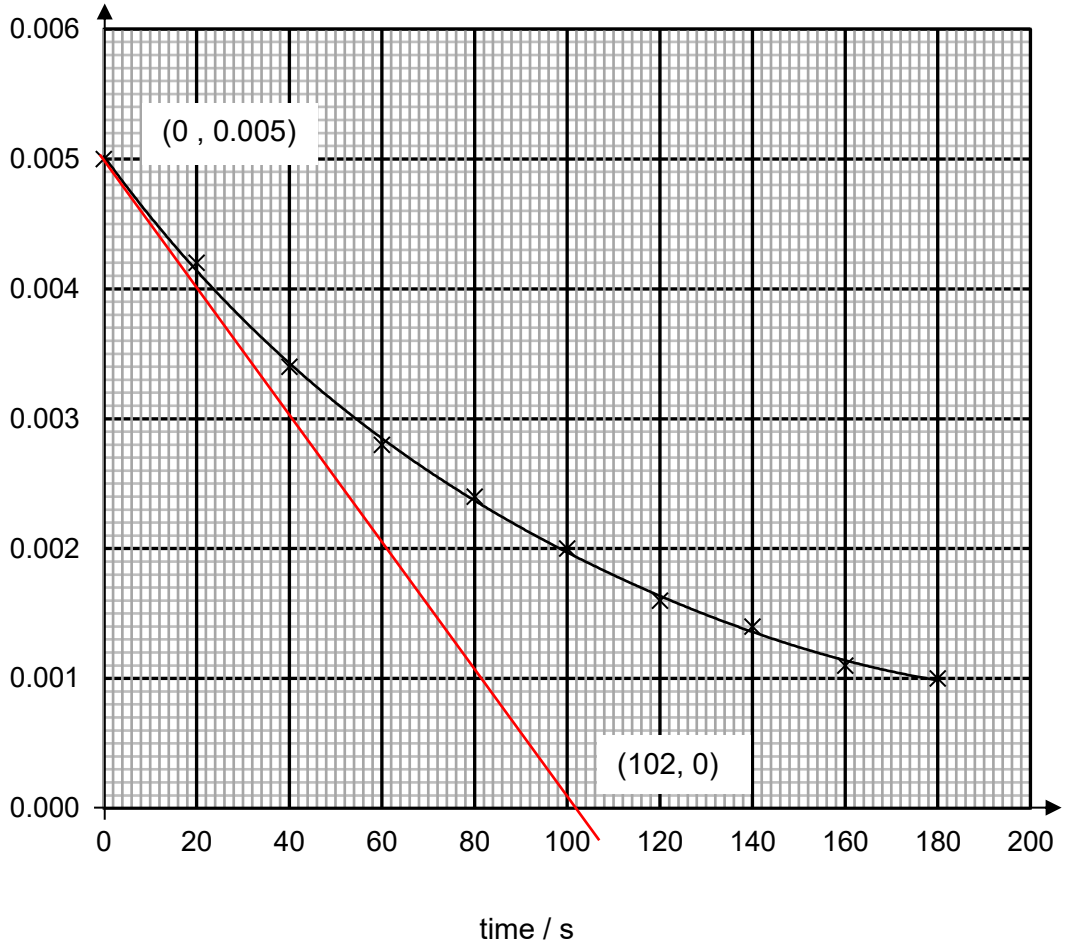
Hence, concentration of O_3 is 200 μg m^{-3}

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

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.

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.

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

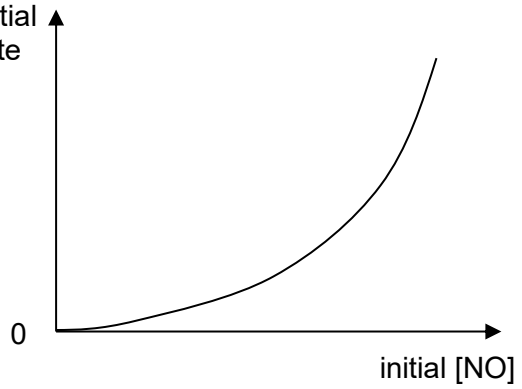


Draw a tangent at t = 0 s

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

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.

4(c)(iii)



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

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.

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

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

4(d)(i) Homogeneous catalysis

4(d)(ii) $NO_2 + SO_2 \longrightarrow SO_3 + NO$ (I)
$NO + ½\ O_2 \longrightarrow NO_2$ (II)

4(e) $n(S_2O_3^{2-})$ reacted = $\frac{15.60}{1000}$ x 4.00×10^{-4}
$= 6.24 \times 10^{-6}$ mol
$n(I_2)$ formed = $6.24 \times 10^{-6} / 2$
$= 3.12 \times 10^{-6}$ 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 = 0.00100 g m^{-3} (3 s.f.)

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

5(b)(i) At high $[OH^-]$, $[Zn(OH)_4]^{2-}$ is produced, causing $[Zn^{2+}]$ to decrease. This causes the position of equilibrium of $Zn^{2+} + 2e^- \rightleftharpoons Zn$ to shift to the left. Hence, $E(Zn^{2+}/Zn)$ becomes 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
$E_{cell} = +0.34 - (-1.25) = +1.59$ V
$\Delta G = -nFE_{cell}$
$= -(4)(96500)(+1.59)$
$= -613740$ J mol^{-1}
$= -614$ kJ mol^{-1}

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.

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.

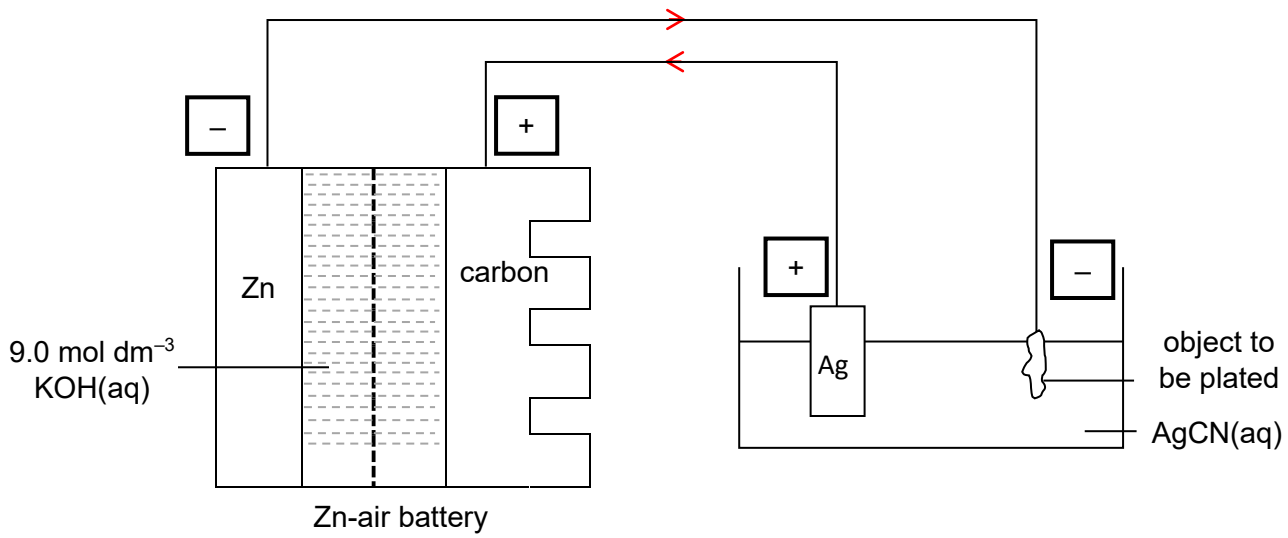
5(d)

- 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.

5(e)(i) The amount of active zinc decreased.

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

5(f)(i)



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>

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>

5(f)(iv) $Q = It = n_e F$

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