Section A

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

Question 1 (C)

From the question, combustion of CS_2 and H_2S gives CO_2 and SO_2; the hydrogen in H_2S would be converted to H_2O, i.e.

$$CS_2 + H_2S + O_2 \longrightarrow SO_2 + CO_2 + H_2O$$

Balancing the equation gives

$$CS_2 + H_2S + {}^9/_2O_2 \longrightarrow \underline{3}SO_2 + \underline{1}CO_2 + H_2O$$

Question 2 (B)

From period 7 of the Periodic Table,

104	105	106	107
Rf	Db	Sg	Bh
rutherfordium	dubnium	seaborgium	bohrium
–	–	–	–

Assuming the ions have a nucleon number of 267,

ion	no. of protons	no. of e^-	no. of neutrons = 267 – proton no.	no. of neutrons – no. of e^-
Rf^{2+}	104	104 – 2 = 102	163	61
Db^{3+}	105	105 – 3 = 102	162	60
Sg^{4+}	106	106 – 4 = 102	161	59
Bh^{5+}	107	107 – 5 = 102	160	58

Question 3 (B)

A

3rd IE of Na : $Na^{2+}(g) \longrightarrow Na^{3+}(g) + e^-$
$[He]2s^22p^5$ $[He]2s^22p^4$

3rd IE of Ne : $Ne^{2+}(g) \longrightarrow Ne^{3+}(g) + e^-$
$[He]2s^22p^4$ $[He]2s^22p^3$

Incorrect. Na^{2+} and Ne^{2+} have the same number of electron shells.
Na^{2+} has a higher IE due to greater nuclear charge and approximately constant shielding compared to Ne^{2+}.

B

Correct. The following equations show the 4th IE of the five elements.

$O^{3+}(g) \longrightarrow O^{4+}(g) + e^-$
$[He]2s^22p^1$ $[He]2s^2$

$F^{3+}(g) \longrightarrow F^{4+}(g) + e^-$
$[He]2s^22p^2$ $[He]2s^22p^1$

$Ne^{3+}(g) \longrightarrow Ne^{4+}(g) + e^-$
$[He]2s^22p^3$ $[He]2s^22p^2$

$Na^{3+}(g) \longrightarrow Na^{4+}(g) + e^-$
$[He]2s^22p^4$ $[He]2s^22p^3$

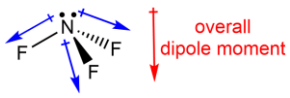
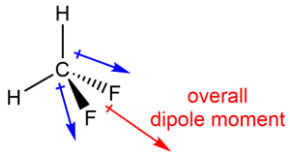
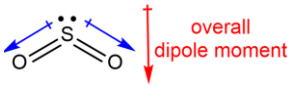
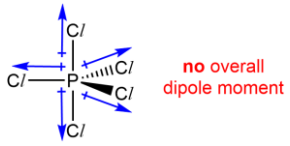
$Mg^{3+}(g) \longrightarrow Mg^{4+}(g) + e^-$
$[He]2s^22p^5$ $[He]2s^22p^4$

The **4th** electrons were all removed from the 2p subshell.

D

Incorrect. Successive IE involve successive removal of electrons from the same element, hence the nuclear charge does not change.

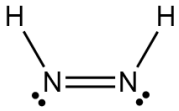
Question 4 (D)

molecule	shape	polarity
NF_3  4 regions of e^- density + 1 lone pair	trigonal ~~planar~~ **pyramidal**	polar
CH_2F_2  4 regions of e^- density + 0 lone pair	tetrahedral	~~non~~-**polar**
SO_2  3 regions of e^- density + 1 lone pair	~~linear~~ **bent**	polar
PCl_5  5 regions of e^- density + 0 lone pair	trigonal bipyramidal	non-polar
	(The dipole pointing up is cancelled out by the dipole pointing down. The remaining 3 dipoles lie on a trigonal plane and cancel each other out exactly)	

Question 5 (D)

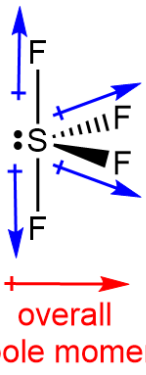
1 Incorrect. $NaHF_2$ is an ionic compound which dissolves in water to form aqueous ions. These ions form **ion-dipole interactions** with water.

2 Incorrect.

structure		
no. of lone pairs	4	2
no. of H	2	2
average no. of hydrogen bonds	2	2

H_2O_2 and N_2H_2 form the same average number of hydrogen bonds i.e. they have the same extensiveness of hydrogen bonding.

3 Correct.



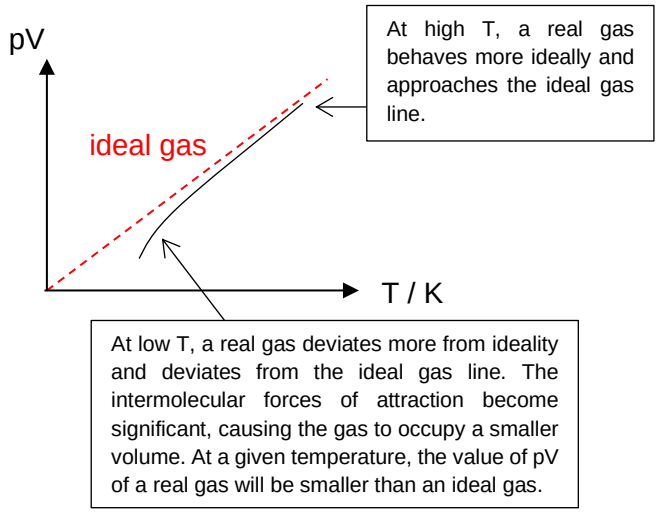
SF_4 is polar which allows it to form permanent dipole – permanent dipole interactions with other polar molecules.

4 Correct. Despite the presence of the –OH groups which allows the molecules to form intermolecular hydrogen bonds, $CH_3(CH_2)_{17}OH$ has a very long alkyl chain with a very large and polarisable electron cloud, causing its predominant intermolecular force to be instantaneous dipole-induced dipole interactions.

Question 6 (D)

$$pV = (nR)T$$
$$y = (m)x$$

For an ideal gas, the graph of pV against T gives a straight line with a positive gradient passing through the origin.



Question 7 (C)

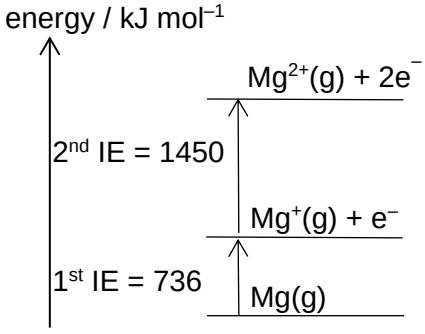
$^1/_2H_2SO_4 + NaOH \longrightarrow \frac{1}{2}Na_2SO_4 + H_2O$

0.04 mol of NaOH requires 0.02 mol of H_2SO_4 for reaction. Hence, H_2SO_4 is in excess and NaOH is limiting.

Heat change, $q = mc\Delta T = (20 + 20)(4.2)(14)$
$= 2352$ J

Enthalpy change of neutralisation
$= -\frac{q}{n_{water}} = -\frac{q}{n_{NaOH}} = -\frac{2352}{0.04}$
$= -58800$ J mol^{-1}
$= -58.8$ kJ mol^{-1}

Question 8 (C)

1	
	Incorrect. Since $Mg^+(g)$ is at a lower energy than $Mg^{2+}(g)$, $Mg^+(g)$ is more stable than $Mg^{2+}(g)$.
2	Since Mg^{2+} has a higher charge and a smaller cationic radius than Mg^+ (resulting in a smaller interionic distance for $MgCl_2$), $MgCl_2$ has a more negative lattice energy than $MgCl$.
3	Since $MgCl_2$ is the more stable form, the standard enthalpy change of formation of $MgCl_2$ is more negative than that of $MgCl$.

Question 9 (A)

For the forward reaction to be spontaneous, $\Delta G^\ominus < 0$ i.e. $\Delta H^\ominus - T\Delta S^\ominus < 0$.

$$(-197) - T_0\left(-\frac{189}{1000}\right) < 0$$
$$T_0 < \frac{197}{0.189} = 1040 \text{ K (to 3sf)}$$

As T increases, the positive $-T\Delta S^\ominus$ term outweighs the negative $\Delta H^\ominus$. Hence, the value of $\Delta G_r^\ominus$ becomes less negative i.e. increases with increasing temperature.

Question 10 (A)

This is a clock reaction.

- Volume of reactant α [reactant]
- Rate α $\frac{[I_2]}{t}$ (given) α $\frac{\text{volume of } I_2}{t}$

Calculating the rates of each experiment

experiment	rate
1	$\frac{4}{1} = 4$
2	$\frac{2}{0.5} = 4$
3	$\frac{4}{2} = 2$
4	$\frac{8}{8} = 1$

Hence, option 3 is incorrect. The rates of experiments 1 and 2 are equally fast.

Comparing experiments 1 and 2, when volume of iodine x 2, rate is constant i.e. order of reaction wrt I_2 is 0.

Comparing experiments 1 and 3, when volume of propanone x 2, rate x 2 i.e. order of reaction wrt propanone is 1.

Comparing experiments 1 and 4, when volume of sulfuric acid x 4, rate x 4 i.e. order of reaction wrt sulfuric acid is 1. **Note**: while volume of iodine is also halved, the order of reaction wrt iodine is 0 and does not affect the rate.
Rate = k[propanone][H_2SO_4]

Hence, option 2 is incorrect.

Units of rate constant
$= \frac{\text{mol dm}^{-3}\ \text{s}^{-1}}{(\text{mol dm}^{-3})(\ \text{mol dm}^{-3})}$
$= \text{mol}^{-1}\ \text{dm}^3\ \text{s}^{-1}$
Hence, option 1 is correct.

Question 11 (B)

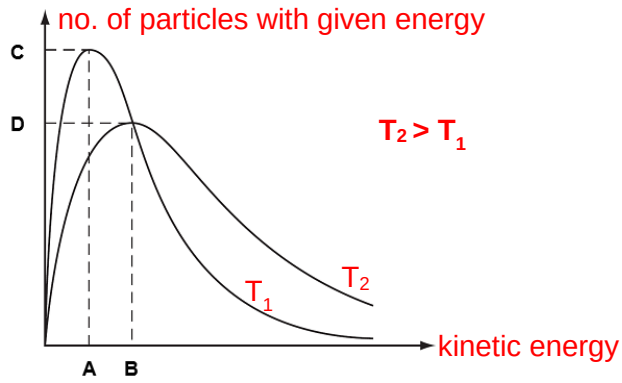
The initial rate of this reaction is very low (near 0) – option **A** is incorrect. Since this is an autocatalytic reaction, as time passes, more Mn^{2+}, which acts as the catalyst, is formed. This causes the reaction rate to increase. The reaction rate increases until a maximum before decreasing. This is because, while there is a high [Mn^{2+}], the concentration of the reactants decrease, causing a decrease in the reaction rate.

The graph in option **D** describes what happens if a heterogeneous catalyst is present, but Mn^{2+} is a homogeneous catalyst.

The gradient of the graph in option **C** is proportionate to the rate of reaction. The rate initially starts slow (near 0 gradient) and increases all the way to the end of reaction. This is unlikely as the rate would slow down (i.e. the gradient should become more gentle) when the concentration of reactants such as MnO_4^- are very low.

Question 12 (A)

This question tests students on their knowledge of the axes of the Boltzmann distribution curve.



Question 13 (A)

p / atm	2Z(g)	⇌	X(g)	+	2Y(g)	p_{total}
Initial	0.86		0		0	
Change	–2x		+x		+2x	
Eqm	0.86–2x		x		2x	1.11

At eqm, 0.86–2x + x + 2x = 1.11 ⇒ x = 0.25

Degree of dissociation $= \frac{\text{amt of Z dissociated}}{\text{initial amt of Z}}$
$= \frac{2x}{0.86}$ since p α n
$= \frac{2(0.25)}{0.86}$
= 0.581

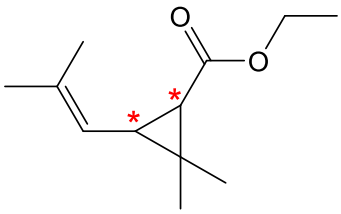
Option **1** is correct.

Option **2** is incorrect. Addition of a catalyst increases both the forward and backward rate, resulting in the same value of K_p i.e. the position of equilibrium does not shift with the addition of a catalyst. The equilibrium partial pressure of X does not change.

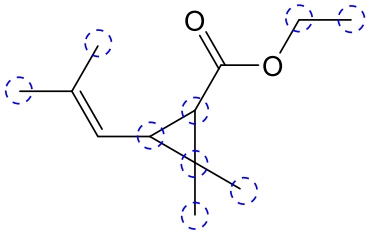
Option **3** is incorrect. The inert gas is added at constant volume, causing an increase in pressure that is proportional to the amount of inert gas added. The partial pressures of Z, X and Y do not change with the addition of the inert gas, resulting in no change to the position of equilibrium.

Question 14 (C)

Option **1** is incorrect. Compound **A** has 2 chiral centres and no double bond that undergoes cis-trans isomerism. Hence, it has 2^2 stereoisomers.



Option **2** is correct. sp^3 hybridised atoms have 4 regions of electron density and the nine sp^3 hybridised carbons are indicated in the following diagram.



Option **3** is correct. A double bond consists of 1 σ bond (with 2 e^-) and 1 π bond (with 2 e^-). Since there two double bonds (1 C=C and 1 C=O), there are a total of 4 π e^-.

Question 15 (B)

Option **1** is incorrect. From the information provided, CCl_2F_2 forms free radicals in the atmosphere. Formation of free radicals from CCl_2F_2 requires their breaking of the C–Cl bond to form Cl● radicals or breaking of the C–F bond to form F● radicals.

Since the C–Cl bond (bond energy = 340 kJ mol^{-1}) is weaker and require less energy to break than the C–F bond (bond energy = 485 kJ mol^{-1}), Cl● radicals are formed more readily than F●.

Option **2** is correct. The two steps in the chain reaction provided shows that X● is consumed in the first step and regenerated in the second step, showing X● to be a homogeneous catalyst.

Option **3** is correct. In the termination steps, two radicals (such as the halogen radicals) collide and react, removing radicals from the reaction mixture.

Section B

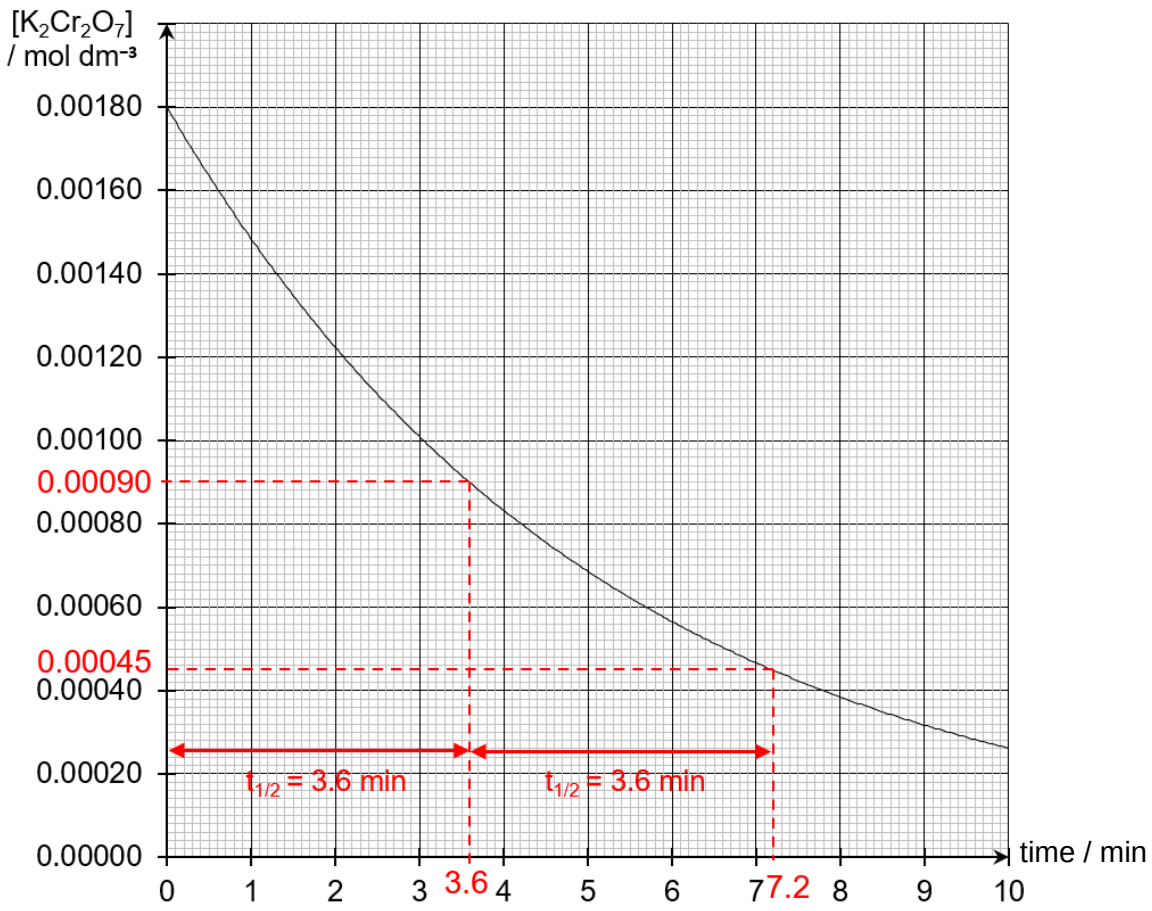
B1 (a) (i) Comparing experiments 1 and 2,
when initial $[H_2SO_4]$ x 2, initial rate x (0.00035/0.00009 ≈) 4.
The order of reaction wrt H_2SO_4 is 2.

Examiners' Comments
- This was generally very well done.

(ii) Draw a tangent at time = 0 min and obtain its gradient.
The initial rate of the reaction is −gradient.

Examiners' Comments
- There were many candidates who were unable to use the proper terminology: it is the gradient of the *tangent*, **not** the gradient of the *curve*.
- The context is the *initial* rate, hence the reference should be made w.r.t. **time** i.e. t = 0 min. Making references to a particular *point* plotted on a graph e.g. "tangent at (0,0.00180)" does not convey the same meaning explicitly.
- Not many candidates were able to show a clear understanding that the initial rate in this case was the *negative* of the gradient.

(iii)



1st half-life
= time taken for $[Cr_2O_7^{2-}]$ to decrease from 0.00180 to 0.00090 mol dm^{-3}
= 3.6 min

2nd half-life
= time taken for $[Cr_2O_7^{2-}]$ to decrease from 0.0009 to 0.00045 mol dm^{-3}
= 7.2 – 3.6
= 3.6 min

Since the half-life is constant, the reaction is first order with respect to $Cr_2O_7^{2-}$.

Examiners' Comments
- Many students did not indicate, on Fig 1.1, the values that were read off from the graph e.g. "0.00045", "7.2" etc. Such clearly written values constitute part of the entire working.
- The emphasis should be that the half-life is "constant", which does **not** have the same meaning as "equal". A first order reaction has a constant half-life, not an *equal* half-life. So stating "1st half-life = 2nd half-life = 3.6 min" is **not** the same as saying "half-life is constant".
- The value of the calculated half-life e.g. "3.6 min" should be clearly shown in the working.

(iv) rate = $k[CH_3CH_2OH][Cr_2O_7^{2-}][H_2SO_4]^2$

Examiners' Comments
- When asked for the rate equation, students should always give the overall rate equation which does **not** involve any pseudo-orders, but many candidates rewrote the rate equation as "rate = $k'[Cr_2O_7^{2-}]$, where $k'=[CH_3CH_2OH][H_2SO_4]^2$". More often than not, pseudo-order

treatments are specific to particular experiments (e.g. when an experiment involves one reactant being in large excess over the others). When asked for the rate equation, it is the overall, entire "law" which governs the reaction, not particular experiments.

- The following are **not** rate equations.
  - "k[CH_3CH_2OH][$Cr_2O_7^{2-}$][H_2SO_4]^2"
  - "k = [CH_3CH_2OH][$Cr_2O_7^{2-}$][H_2SO_4]^2"
  - "r = k[CH_3CH_2OH][$Cr_2O_7^{2-}$][H_2SO_4]^2"
  - "rate *equation* = k[CH_3CH_2OH][$Cr_2O_7^{2-}$][H_2SO_4]^2"
- Many forgot the "[H_2SO_4]^2" from part **(i)**. It is important to understand that the information from all the previous parts contribute information about the order of reaction of each reactant. This is common in reaction kinetics questions and students should be mindful of this.

(v) Since ethanol and H_2SO_4 are in large excess over $Cr_2O_7^{2-}$,
the rate equation can be written as
rate = k'[$Cr_2O_7^{2-}$] where **$\underline{k' = k[\text{ethanol}][H_2SO_4]^2}$**.

From (a)(ii),
half-life in expt 1 = ln 2 / k'
= ln 2 / [k(0.050)(4.0)^2] = 3.6 min

$\therefore$ half-life in expt 3 = ln 2 / [k(0.025)(4.0)^2] = (0.050/0.025) $\times$ 3.6
= 7.2 min

Examiners' Comments
- Many did not show any meaningful working i.e. simply writing "half-life = 3.6 $\times$ 2" was hardly adequate.

(b) **(i)** When absorbance = 0.25, [$Cr_2O_7^{2-}$] = 0.00068 mol dm^{-3}

Examiners' Comments
- Most candidates were able to read the value correctly from the graph.

(ii) amount of $Cr_2O_7^{2-}$ reacted = (0.003)(8.5 x 10^{-4} – 0.00068)
= 5.100 x 10^{-7} mol

Since $Cr_2O_7^{2-}$ and ethanol react in a 1:3 ratio,
amount of ethanol in 50 cm^3 of breath = 3(5.100 x 10^{-7})
= 1.53 x 10^{-6} mol

Examiners' Comments
- Many candidates forgot to carry out the subtraction of "0.00068".
- Candidates are advised to leave their answers in standard form, as some wrote the incorrect number of zeroes, which often led to incorrect calculations subsequently.
- Units should always be included at the end of every intermediate and final answers (see above).
- Some candidates still had issues with showing the correct number of significant figures, often wasting time writing a long string of numbers at different stages of a calculation, or rounding off incorrectly.

(iii) amount of ethanol in 1 cm^3 of blood = $(2100/50)(1.53 \times 10^{-6})$
= 6.426×10^{-5} mol

amount of ethanol in 100 cm^3 of blood = $(100)(6.426 \times 10^{-5})$
= 6.426×10^{-3} mol

mass of ethanol in 100 cm^3 of blood = $(6.426 \times 10^{-3})(46.0)$
= 0.296 g

BAC = 0.296% > legal BAC i.e. the driver is guilty of drink-driving.

Examiners' Comments

- Proper statements are needed for **all** working; simply writing down mathematical calculations with no accompanying statements is not sufficient e.g. "1+2=3" is meaningless without any statements.
- Many candidates did not calculate the BAC as specified in the question, but went on to do their own calculations so to arrive at the conclusion. While they may get the mathematics or conclusion correct, candidates must ultimately answer what the question wants, which, in this case, is "Calculate the BAC of the driver".
- Some missed out the data given and wasted time computing the M_r of ethanol.
- The conclusion i.e., whether the driver is guilty or not, should still be written. Just calculating the BAC alone is not sufficient – the conclusion must still be stated.

(c) Volumes of **A** required to prepare five 100 cm^3 diluted solutions.

Let c be the concentration of 100 cm^3 of one of the diluted solutions of **A**.
Amount of $K_2Cr_2O_7$ in diluted solution of **A** = $(100/1000)(c) = 0.1c$ mol
Volume of solution **A** required for dilution = $(0.1c / 0.00500)$ dm^3
= $(100c / 0.00500)$ cm^3

concentration of diluted solution **A** / mol dm^{-3}	volume of solution **A** required for dilution / cm^3
1.00×10^{-3}	20.00
0.800×10^{-3}	16.00
0.600×10^{-3}	12.00
0.400×10^{-3}	8.00
0.200×10^{-3}	4.00

Mass of $K_2Cr_2O_7$ required to prepare 250 cm^3 of 0.00500 mol dm^{-3} acidified $K_2Cr_2O_7$
Amount of $K_2Cr_2O_7$ in solution **A** = $(250/1000)(0.00500)$ = 0.00125 mol
Mass of $K_2Cr_2O_7$ required = 0.00125(294.2) = 0.3678 g

Preparation of solution **A**

1. Using an electronic balance, **weigh** accurately about 0.37 g of $K_2Cr_2O_7$ in a clean and dry weighing bottle.

2. **Dissolve** the solid in some 1.00 mol dm^{-3} sulfuric acid in a 100 cm^3 beaker. Transfer the solid quantitatively from the weighing bottle to the beaker by rinsing the weighing bottle a few times with 1.00 mol dm^{-3} sulfuric acid and transferring all the washings into the beaker.

3. **Transfer** the solution in the beaker quantitatively into a **250 cm^3 graduated flask** with the aid of a funnel and a glass rod. Rinse the beaker a few times with 1.00 mol dm^{-3} sulfuric acid and transfer all the washings into the graduated flask.

4. **Fill** the graduated flask to the 250 cm^3 mark with more **1.00 mol dm^{-3} sulfuric acid**. Use dropper to add the 1.00 mol dm^{-3} sulfuric acid drop by drop when nearing the mark.

5. **Stopper** the graduated flask and **shake** the solution thoroughly to ensure that it is homogeneous. Label the solution solution **A**.

Prepare diluted solutions of **A**

6. Using a **burette**, transfer 20.00 cm^3 of solution **A** into a **100 cm^3 graduated flask**.

7. **Fill** the graduated flask to the 100 cm^3 mark with **1.00 mol dm^{-3} sulfuric acid**. Use dropper to add the 1.00 mol dm^{-3} sulfuric acid drop by drop when nearing the mark.

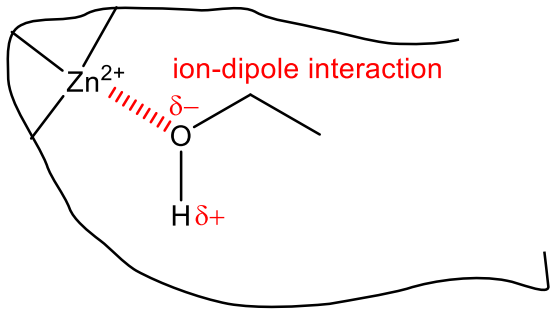
8. **Stopper** the graduated flask and **shake** the solution thoroughly to ensure that it is homogeneous.

9. Repeat steps 6 to 8 using different volumes of **A** as shown in the table.

Examiners' Comments

- **Pre-experimental calculation** – many students were unable to perform the simple calculation for dilution to fill up the table. Do read the question carefully to understand the volumes and concentrations involved.
- **Preparation of solution A** – most students who attempted this question were able to write the procedure but missed crucial steps such as dissolving the solid in a beaker before transferring (quantitatively) into the graduated flask, or the last step to stopper *and* shake the flask.
- **Dilution of solution A** – dilution must be carried using volumetric glassware, i.e. burette and graduated flask. A pipette cannot be used due to the varying volumes of A required. Measuring cylinders are not accurate enough for this purpose.
- Note that according to the question, both solution A and the dilution solutions are prepared using sulfuric acid. Hence, sulfuric acid should be used in all steps where normally, DI water would be used (dissolving, rinsing, filling up).
- A number of students calculated the amount/volume of sulfuric acid required (according to the redox reaction) but this is unnecessary as the sulfuric acid is present in (great) excess and the instructions provided was to prepare solutions using sulfuric acid. Hence, the solution is *acidified*. There is no need to measure the volume of sulfuric acid separately when preparing the solutions.

(d) **(i)**



Examiners' Comments

- To draw a complete ion-*dipole* interaction, answers must show the *dipole* on the ethanol molecule accurately, with the $\delta+$ and $\delta-$ charges on the H and O atoms, respectively.
- Many students also added $\delta+$ on the Zn^{2+} which is redundant, since Zn^{2+} is fully charged.
- Many students did not label the interaction formed. Do read the question carefully to understand the requirements.

(ii) From the graph, the rate of removal of ethanol is constant (i.e. the rate of removal is zero order with respect to ethanol).

This is because the concentration of ethanol in the body was sufficiently high such that the active sites on ADH are saturated **OR** there are insufficient ADH enzymes to remove the high amount of ethanol present.

Examiners' Comments

- BAC (blood alcohol content) is a measure of the concentration of ethanol in the body. Hence, the graph (Fig. 4.1) is a concentration vs time graph. The gradient of the graph, thus, shows the *rate* of the reaction. Most students were able to recognise this.
- However, many students described the action of enzymes in general without answering the question specifically, which is, why is the rate of removal constant?
- Answers which contradicted themselves or contradicted the data from the graph were not awarded full credit. For example, the reaction was initially first order wrt ethanol until the active sites of ADH were saturated, then the reaction became zero order wrt ethanol.

B2 (a) (i) From Fig. 2.1, % conversion of CO decreases as temperature increases. This means that the equilibrium position shifts left, favouring the backward endothermic reaction which absorbed heat to counteract the increase in temperature. Hence, the forward reaction is exothermic.

Examiners' Comments

- While most students were able to present their analysis of Fig 2.1 by stating the trend of the graph, a handful of students misinterpreted what % CO conversion meant.
- % CO conversion is the % of CO that is converted to the products, i.e. a low % CO conversion would mean a small amount of CO is converted to the products. Conclusion from the analysis of the graph should be: since % CO conversion decreases as temperature increases, less CO is converted to the products, position of equilibrium shifts to the left as temperature increases.
- A handful of students erroneously stated that the rate of forward reaction decreases as temperature increases. Students are reminded that an increase in temperature always causes an increase in the rate of reaction. In the case of an equilibrium reaction, increase in temperature causes both the forward and backward rates of reaction to increase until a new equilibrium at a faster rate is formed.

(ii) $$K_c = \frac{[CO_2(g)][H_2(g)]}{[CO(g)][H_2O(g)]}$$

Examiners' Comments

- Generally well done.
- Students are reminded that K_c is written in terms of concentration i.e. [X], and not partial pressure i.e. P_x.

(iii) From Fig. 2.1, % CO conversion is 35.0%.

Let x be the initial amount of H_2O and CO and V be the volume of sealed container.

	$CO(g)$	+	$H_2O(g)$	$\rightleftharpoons$	$CO_2(g)$	+	$H_2(g)$
Initial amt / mol	x		x		0		0
Change in amt / mol	−0.35x		−0.35x		+0.35x		+0.35x
Equilibrium amt / mol	0.65x		0.65x		0.35x		0.35x

$$K_c = \frac{[CO_2(g)][H_2(g)]}{[CO(g)][H_2O(g)]} = \frac{(\frac{0.35x}{V})(\frac{0.35x}{V})}{(\frac{0.65x}{V})(\frac{0.65x}{V})} = 0.290 \text{ (3 s.f.)}$$

Examiners' Comments
- While most students were able to correctly read off from Fig 2.1 the % CO conversion at 1000 K, a handful of students misinterpreted what % CO conversion meant.
- 35% CO conversion meant that 35% of the initial CO is converted to the products, i.e. if initial amount of CO is x mol, 0.35x mol of CO would be converted (change in amount of CO = −0.35x mol). 35% CO conversion does not mean that equilibrium amount of CO is 0.35x mol.
- Students are strongly encouraged to present their working fully to show that K_c is expressed in terms of concentration (number of moles/volume).

(iv) Since the equilibrium constant at 1000 K is less than 1, it means that the position of equilibrium lies more to the left, in which reactants are favoured over products.
Thus, the sign for $\Delta G^{\ominus}$ at 1000 K is positive.

Examiners' Comments
- This question tests students' understanding that the position of equilibrium is dependent on the $\Delta G^{\ominus}$. In reactions where $\Delta G^{\ominus} < 0$, $K > 1$;
  $\Delta G^{\ominus} > 0$, $K < 1$.
  Note the reference point for K is 1, not 0.
- Students are reminded to be specific in their answer. Merely stating that "K is very small" or "K is small" without stating the reference point for K is not sufficient.
- When $K < 1$, the position of equilibrium lies more to the left and reactants are favoured over products.
- The sign of $\Delta G^{\ominus}$ should be explicitly stated as 'positive', instead of merely '$\Delta G^{\ominus} > 0$'.

(b) **(i)** Let x be the change in amount.

	$CO(g)$	+	$H_2(g)$	$\rightleftharpoons$	$CH_2O(g)$
Initial amt / mol	0.500		0		0.600
Change in amt / mol	+ x		+ x		−x
Equilibrium amt / mol	0.500 + x		x		0.600 − x

Since the partial pressure of H_2 and CH_2O is the same, the mole fraction and thus the equilibrium amount of H_2 and CH_2O is the same.

Hence, 0.600−x = x

x = 0.300 mol.

Thus, equilibrium amount of H_2 = CH_2O = 0.300 mol and equilibrium amount of CO = 0.500 + 0.300 = 0.800 mol.

P_{CO} = (0.800 / 1.400) x 2.80 x 10^5 Pa

= 160000 Pa

$$K_{p1} = \frac{P_{CH_2O}}{P_{CO}\,P_{H_2}}$$

$$= \frac{1}{160000} = 6.25 \times 10^{-6}\ Pa^{-1}$$

Examiners' Comments

- This question was poorly attempted.
- $K_p = \frac{P_{CH_2O}}{P_{CO}\,P_{H_2}}$. Note that $K_p \neq \frac{n_{CH_2O}}{n_{CO}\,n_{H_2}}$. Since the equilibrium partial pressures of H_2 and CH_2O are the same, $K_p = \frac{1}{P_{CO}}$. Students should work towards determining P_{CO}.
- Some students constructed an unnecessarily complicated I.C.E table. Since the equilibrium partial pressures of H_2 and CH_2O are the same, the mole fraction and thus the equilibrium amount of H_2 and CH_2O is the same. It would be most convenient to construct an I.C.E table in terms of amounts, let the change be x mol, solve for x, then solve for the P_{CO} where $P_{CO} = \frac{n_{CO}}{n_{total}} \times P_{total}$. P_{total} at equilibrium is 2.80 x 10^5 Pa.
- Some students misread the information as 0.600 mol to be the amount of H_2 placed in the vessel. Note that for this experiment, there is no H_2 in the vessel initially, the backward reaction takes place until equilibrium is reached. Therefore, the 'change in amount' in the I.C.E table is positive for CO and H_2 and negative for CH_2O.

(ii) $K_p = K_{p1} \times K_{p2}$

Examiners' Comments

- Students should approach this question by writing out the K_{p1} and K_{p2} expressions and see how they can be combined to give the K_p expression.

$$K_{p1} = \frac{P_{CH_2O}}{P_{CO}\,P_{H_2}} \qquad K_{p2} = \frac{P_{CH_3OH}}{P_{CH_2O}\,P_{H_2}}$$

$$K_p = \frac{P_{CH_3OH}}{P_{CO}\,P_{H_2}^{\,2}}$$

$$= \frac{P_{CH_2O}}{P_{CO}\,P_{H_2}} \times \frac{P_{CH_3OH}}{P_{CH_2O}\,P_{H_2}}$$

$$= K_{p1} \times K_{p2}$$

- Some students did not read the question carefully to express K_p in terms of K_{p1} and K_{p2}, instead they expressed K_p in terms of partial pressure.

(iii) Increase in pressure OR use a smaller volume of container.
At higher pressure, the position of equilibrium will shift to the right to produce fewer moles of gas.

Examiners' Comments
- Answers related to temperature change are not accepted since there is no information on enthalpy change given in the question.
- Answers related to removal or addition of species are not accepted these are not changes to *reaction conditions*.
- Students have to specify that the reaction that produces a smaller amount of **gaseous** particles are favoured to counteract the increase in pressure.

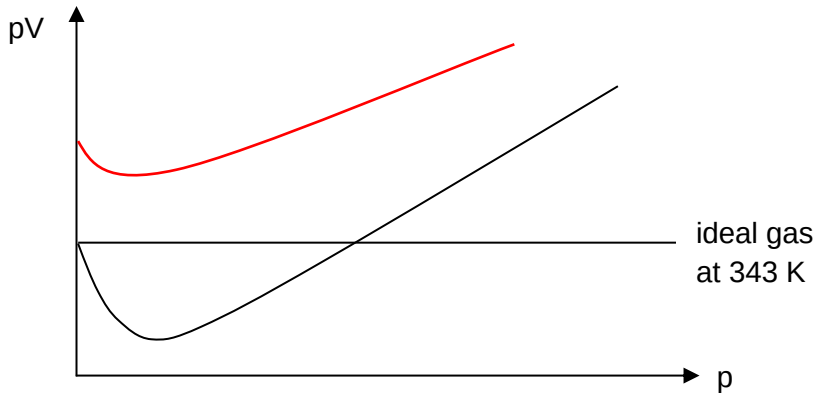
(iv) oxidation number of C in formaldehyde: 0
oxidation number of C in methanol: –2

Examiners' Comments
- Since there is only 1 C atom in CH_2O and CH_3OH, the oxidation number of C can be determined by applying this rule: In a compound, the algebraic sum of the oxidation numbers of the atoms is 0.

  For CH_2O,
  (oxidation number of C) + 2(+1) + (–2) = 0
  Oxidation number of C = 0

  For CH_3OH,
  (oxidation number of C) + 4(+1) + (–2) = 0
  Oxidation number of C = –2

(c)

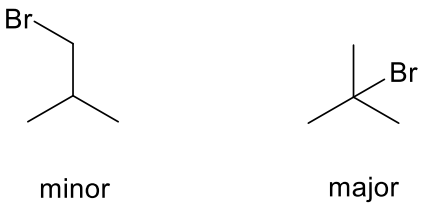


At 500 K, pV has a greater magnitude since pV = nRT.
Also, the gas particles possess sufficiently high kinetic energy to overcome the intermolecular attractive forces, thus behaving more ideally.

Examiners' Comments
- Majority of students failed to sketch a graph with a higher y-intercept. Note the pV value increases when T increases (pV = nRT, n and R are constants).
- Also, there is less negative deviation from ideality at a higher T (i.e. less curvature). Students are expected to explain why this is so based on their understanding of how a real gas approaches ideality at high temperature.

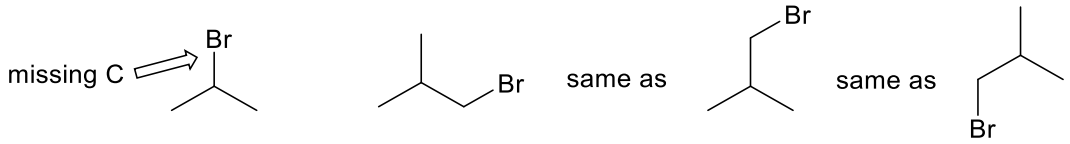
Section C

C1 (a) (i)



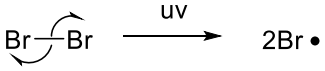
Examiners' Comments

- Most students were able to give the correct skeletal formulae of the two products.
- Common mistakes include drawing the displayed formulae (instead of the required skeletal formula), mistaking the root name "propane" to have 5 carbons (instead of 3) or drawing C*l* instead of Br.
- A handful of students who identified only one product drew two repeats, not recognising that the nine primary hydrogens are equivalent.
- Examples of wrong structures:

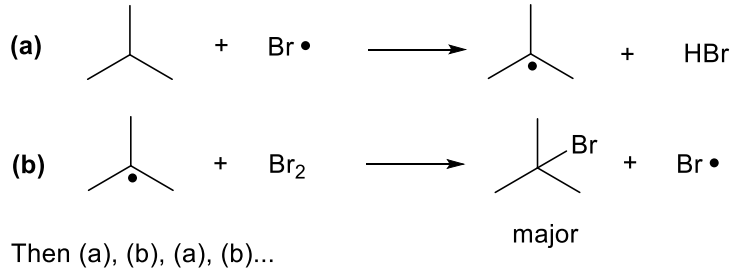


(ii) Free Radical Substitution Mechanism

Initiation:

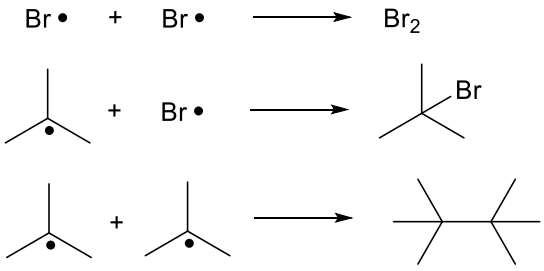


Propagation:



Then (a), (b), (a), (b)...

Termination:



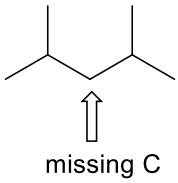
The following points must be clearly shown.

- Three steps clearly labelled: Initiation, Propagation, Termination
- Indicate uv light on the reaction arrow of initiation step
- 2 fishhook arrows to show homolytic fission in step 1 to generate two Br radicals
- Correct major product in step (b) of propagation
- Correct set of propagation reactions (a) and (b). Propagation steps should always generate a radical in one of the products in order to keep the chain reaction going.
- Termination steps involving reaction of two radicals.

Examiners' Comments

- This question was generally well done.
- Answers that lacked full mechanism details received partial credit. Common mistakes include:
  - Using double-headed arrows in the initiation step instead of the correct half-headed arrows (fishhook arrows) to illustrate homolytic fission of the Br–Br bond

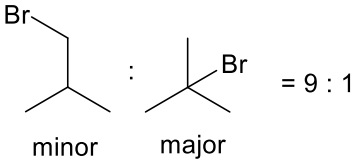
- Wrongly using Br radical for step (b) to form product instead of abstracting the Br from a Br_2 molecule, and hence failing to regenerate a Br radical in propagation.
- Wrongly identified the major product in step (b) of propagation
- Missing bonds in organic compound formed in the termination step, e.g.



- A handful of students described the mechanism in prose instead of using equations and curly arrows, hence receiving no credit for their answer.

- Students should note that curly arrows are only required in the initiation step of the free-radical mechanism unless stated otherwise.

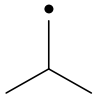
(iii)

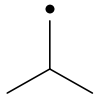


Examiners' Comments

- Many students were able to state the correct 9 : 1 ratio but failed to make reference to the respective products they were referring to, thus receiving no credit due to ambiguity.
- A handful of students were unable to recognise that the 9 primary hydrogens in 2-methylpropane are equivalent, thus wrongly stating a ratio of minor:major = 6 : 1 or 3 : 1.

(iv)

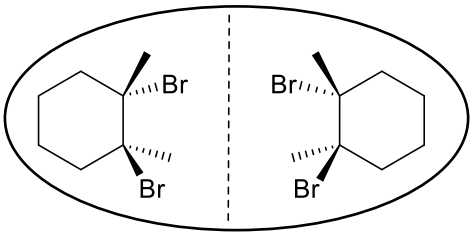
The minor product is formed from  radical while the major product is formed from  radical.

Tertiary radical  is more stable than primary radical  due to the presence of more electron-donating alkyl groups. Hence, 2-bromomethylpropane is formed as the major product.

Examiners' Comments

- Many students failed to compare the relative stabilities of the primary and tertiary ***radicals***.
- Some students simply stated that the "tertiary *hydrogen* is more reactive than the primary *hydrogen*" without showing understanding that this is a result of tertiary *radicals* being more stable than primary *radicals*.
- A significant number of students wrongly wrote that "the *major product (or tertiary carbon)* is more stable than the *minor product (or primary carbon)* due to its greater number of alkyl groups." This is an incorrect understanding. The structures of both the major and minor products are stable which is why both can exist. Major product simply means it is present in greater proportion which is due to the greater stability of the tertiary radical intermediate and not due to the stability of the product itself.
- Students should substantiate their explanation of why tertiary radicals are more stable than primary radicals by clearly stating the "electron-donating" nature of alkyl groups
- A handful of students wrongly identified the *tertiary* radical as a *secondary* radical.
- A handful of students wrongly used the term *carbocations* instead of *radicals*.

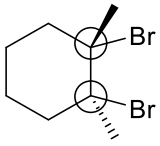
(b) **(i)**



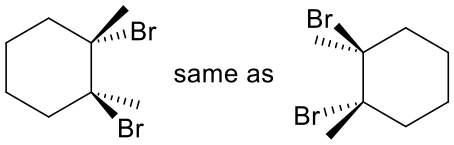
enantiomers

a *meso* compound

Examiners' Comments

- This question was poorly done, showing that many students have challenges visualising and representing 3D structures of compounds. More practice needed!
- Many students entirely missed out on the methyl groups in their drawings or mistakenly replaced these methyl groups with hydrogens, while some others did not draw bromine atoms in their products at all. Students should be drawing stereoisomers of the product 1,2-dibromo-1,2-dimethylcyclohexane, and not the reactant **A**.
- Students should ensure that they use dashed and wedged bonds correctly to illustrate stereochemistry. No credit was given for incorrect 3D drawings. Examples of incorrect structures are shown below.
- 

(It is not possible to have 3 groups lying on the same plane as represented by the three solid lines as each of the circled C is tetrahedral in shape)



(These are not a pair of enantiomers. Flipping the structure on the right by 180 degree clockwise will give the structure on the left)

- Some students wrongly labelled the mirror as "plane of symmetry". The plane of symmetry of a compound should be found within the molecule itself.
- Many students wrongly circled a pair of meso compounds as the pair of enantiomers.

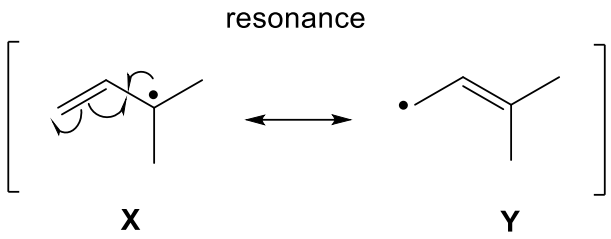
(ii) Even though there are two chiral centres with expected number of stereoisomers to be 4 (2^2), there are only 3 stereoisomers formed because the cis isomer <u>has an internal plane of symmetry</u> (meso compound).

Examiners' Comments

- Common wrong answers identified "reactant **A** as the meso compound" and it is clear from the structure of **A** given that it is in trans configuration and not a meso compound. A meso compound has more than 1 chiral centre **and** an internal plane of symmetry.
- Others simply stated "the molecule is a meso compound" without reference to any particular stereoisomer/structure. Such generic and vague answers received no credit.

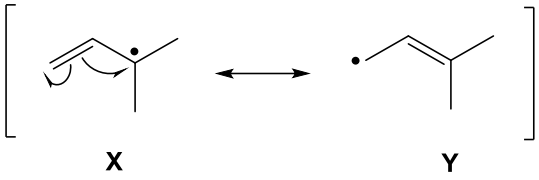
- Some students identified the meso compound but failed to explain the main reason why a meso compound is not optically active – it has an internal plane of symmetry.
- Some students wrote contradictory statements such as "the *enantiomers* are *meso* compounds" or "the *enantiomers are superimposable mirror images of each other* hence they are meso compounds" showing poor understanding of terminology in chemistry. Note that enantiomers are defined to be a pair of *non-superimposable* mirror images. Meso compounds are not optically active and are hence not enantiomers.

(c) **(i)**



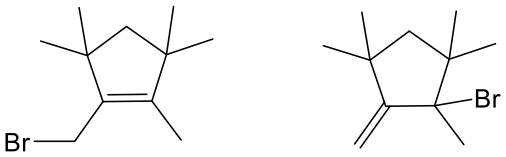
Examiners' Comments

- Only a handful of students got this question correct.
- A useful way of solving this question is by remembering that each fishhook arrow represents the movement of *one electron*, and that each bond consists of two electrons. To form the resonance structure **Y** from **X**, the C–C π bond in **X** has to undergo homolytic fission (2 fishhook arrows splitting in opposite direction) and the new C–C π bond in **Y** is formed with the lone electron on the tertiary C radical (2 fishhook arrows meeting each other). This leaves a lone electron on the leftmost C of **Y**.
- Many students drew a mix of double-headed arrows and single-headed arrows (fishhook arrows). For mechanisms in H2 chemistry, the arrows must either be all fishhook arrows, or all double-headed arrows. There should not be a mix.
- A common incorrect answer with a missing fishhook arrow:



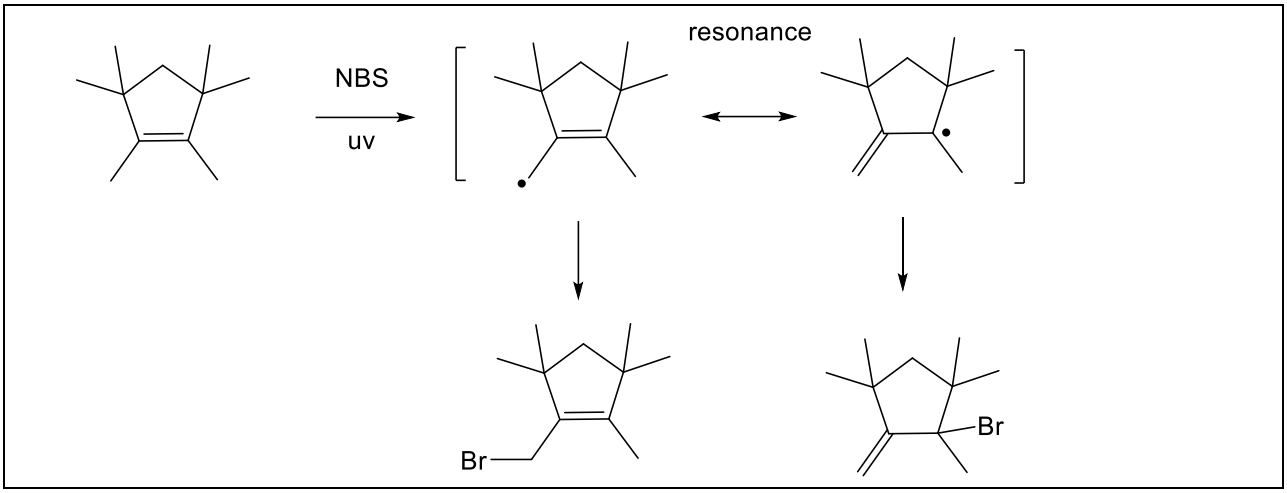
A third fishhook arrow must be drawn from the lone electron on the tertiary C radical to show its movement in forming the new C-C pi bond in **Y**.

(ii)

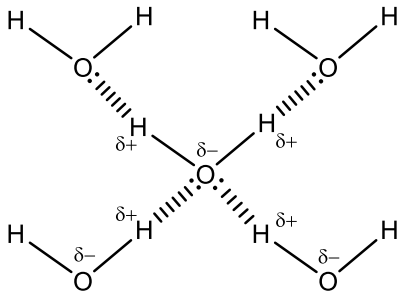


Examiners' Comments

- Only a handful of students received full credit for this question.
- This question tests students' ability to recognise the pattern in the given context and apply it accordingly.
- Applying the pattern observed to the new compound:



C2 **(a)** **(i)**



IIIIII represents a hydrogen bond

Examiners' Comments
- This is a fundamental question that covers the requirements of a hydrogen bond. As such, the three main features must be clearly shown in the diagram:
  - Partial charges on O and H
  - Lone pair of electrons on O
  - Dashed line labelled as hydrogen bond
- A handful of students failed to differentiate the hydrogen bond between water molecules and the covalent bonds within water.
- An appalling number of students also misrepresented H_2O as HO_2.

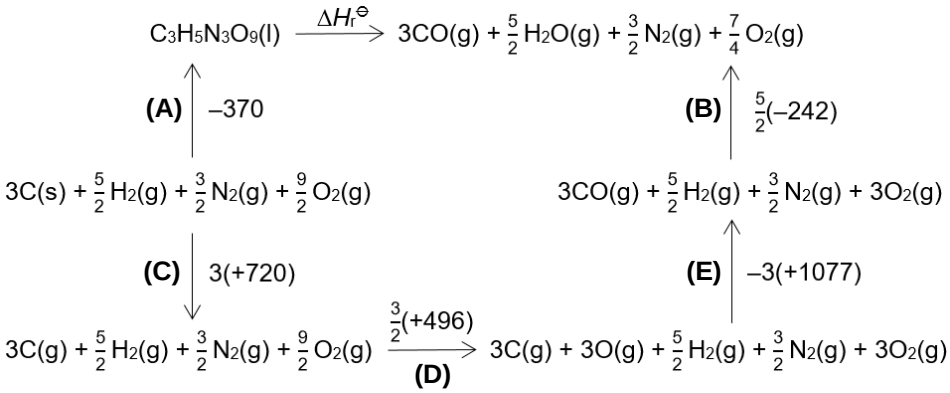
(ii) Glycerol forms extensive <u>hydrogen bonds with water molecules</u>, which <u>prevents the formation of regular hydrogen bonds between H_2O molecules</u>.

Examiners' Comments
- This part was generally well done. There are, however, a handful of students who made reference to the energy of the hydrogen bonds formed between glycerol and water versus between water molecules instead of referring to the disruption of the rigid regular structure of ice.

(b) **(i)** $\Delta H_{decomposition}^{\ominus} = 3(-394) + \frac{5}{2}(-293) - (-370) = -1544.5 \text{ kJ mol}^{-1}$

Examiners' Comments
- This part was generally well done. Common mistakes include omission of coefficients for –394 and –293 and calculation errors.

(ii)



$\Delta H_r^\ominus = -(-370) + 3(+720) + \frac{3}{2}(+496) - 3(+1077) + \frac{5}{2}(-242)$

$= -562 \text{ kJ mol}^{-1}$

Examiners' Comments
- This part is poorly attempted.
- Most students were able to write only the equations for the formation of nitroglycerin and steam from their respective elements, as well as the atomisation of carbon.
- Many missed out on forming of gaseous O atoms using BE(O=O) and applied the BE(C≡O) directly. This is incorrect as the application of bond energy produces gaseous atoms, not molecules.
- The coefficients of the enthalpies applied were missing or incorrect for many as well.

(iii)
- Highly exothermic decomposition reaction
- Large increase in the number of gaseous molecules leads to generation of high pressures
- The increased temperature leads to further expansion of gas.

Examiners' Comments
- This part was fairly well done. Many students could recognise that there were huge amounts of heat released, along with the increase in amount of gaseous molecules from the decomposition reaction, thus accounting for the explosive nature.
- A key feature of an explosion involves rapid outward spreading of energy – not all highly exothermic reactions cause an explosion. Due to the large amount of gas and heat produced, the rapid expansion of gas due to higher temperature is substantial. This allows the gas to carry the energy away from the point of explosion rapidly.
- A spontaneous reaction does not mean that the reaction will be explosive in nature, as a good number of students incorrectly thought.

(iv) Nitroglycerin is more safely handled at low temperatures due to the lowering of average kinetic energy of molecules, causing fewer molecules to have sufficient energy to overcome the E_a / decreasing the rate of reaction.

The reaction, with a negative ΔH and positive ΔS, is spontaneous/leads to a negative ΔG at all temperatures.

Examiners' Comments
- This part was not well attempted.
- Many students were able to address the spontaneity component with ΔG, using ΔH and ΔS, but missed out on the safety component at lower temperatures. Students should note that temperature is related to kinetic energy and possessing sufficient energy to overcome the activation energy. Having a less negative ΔG still suggests that the reaction is spontaneous without explaining why it is safer.

C3 **(a)** **(i)** Al^{3+} and N^{3-} have the same same electronic configuration and hence their outermost electrons experience the same shielding effect.

Al^{3+} has a higher nuclear charge than N^{3-}.

The outermost electrons in Al^{3+} experience a greater effective nuclear charge and are more strongly attracted by the nucleus, resulting in a decrease in the size of the electron cloud.

Hence the ionic radius of Al^{3+} is smaller than that of N^{3-}.

Examiners' Comments

- Some students erroneously compared ionic and atomic radii. This caused their explanations to be confusing and incorrect.
- There was also an obvious lack of clear thoughts when students simply quoted 'keywords' and presented points that were not linked to each other. A good answer requires all concepts to be connected logically.
- Others wrote excessively (half a page long) for a 2m question. It is important to answer all questions succinctly.
- Many students who answered the question wrongly failed to recognise that both ions are isoelectronic and have the same electronic configuration, and incorrectly justified the difference in radii with the difference in number of shells.
- Many students used the phrase 'valence electrons of Al^{3+} and N^{3-}'. The term 'valence electrons' refer to the outermost electrons of an **atom** involved in chemical bonding. Hence, students should rephrase their answer to 'outermost electrons of Al^{3+} and N^{3-}'.

(ii) B and N in α-BN are sp^2 hybridised. B and N in β-BN are sp^3 hybridised.

Examiners' Comments

- The question was well answered. Most students understood the hint provided in the question and applied their knowledge of the shapes about C in diamond and graphite, thus determining the right hybridisation.
- A significant number of students assume that N is sp^3 hybridised in α-BN. In this case, it will not be possible for N to possess an unhybridised 2p orbital with a lone pair of electrons that can be delocalised within the layer of BN.

(iii) While there is a π-electron cloud across each layer, N is more electronegative than B. Hence the lone pair of electrons in the unhybridised 2p orbitals is more localised around the N atoms/ less delocalised. Thus, there is limited electrical conductivity in α-BN.

Examiners' Comments

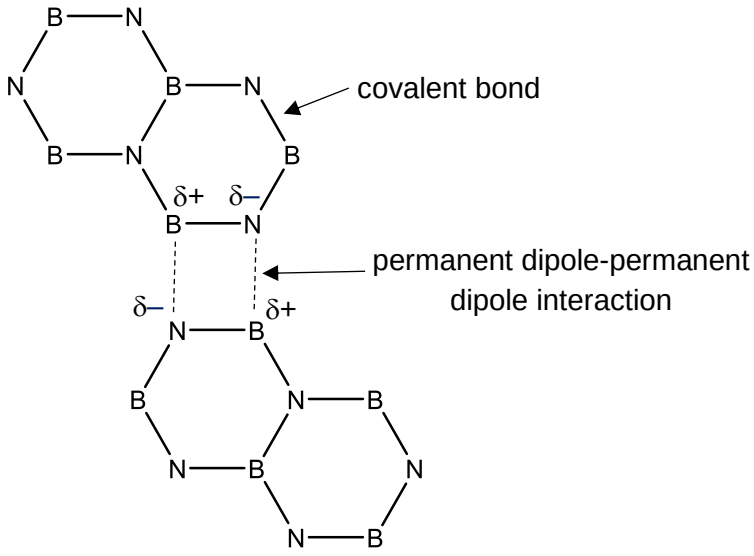
- Many students wrongfully claimed that graphite has more delocalised electrons than α-BN. It should not be difficult to realise that graphite and α-BN have the same number of electrons in the unhybridised 2p orbitals within each layer.
- Ambiguous answers were not given any credit. One such example is 'delocalisation of π-electrons is less extensive in graphite'. This answer did not clearly relate the reduced extensiveness to the electronegative nature of N.

(iv) The absence of a π-electron cloud / delocalised electrons causes β-BN to be an electrical insulator. Note: The lone pair of electrons in the sp^3 hybrid orbital of N is donated to the sp^3 hybrid orbital of B.

Examiners' Comments

- Common terms such as 'free electrons' and 'mobile charge carriers' are not specific enough to illustrate the fact that the π-electrons in the unhybridised 2p orbitals are delocalised throughout the entire layer. It is time for students to update their own understanding to one that is expected of an H2 Chemistry curriculum.

(v)



Examiners' Comments
- Many students labelled the interaction between the layers as instantaneous dipole-induced dipole interaction. Please read the question carefully.
- Others carelessly identified the interaction between $B^{\delta+}$ of one layer and $B^{\delta+}$ of another layer as permanent dipole-permanent dipole interaction. Students should show an attractive interaction which would be between oppositely charged centres.
- Many used solid line to indicate pd-pd interactions, which is wrong. Weak interactions are represented by dotted lines. Some even used arrow, which should have been used for dative bonding, not intermolecular forces of attraction.

(b) **(i)** $2BN(s) + \frac{3}{2}O_2(g) \rightarrow B_2O_3(l) + N_2(g)$

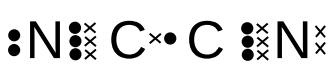
Examiners' Comments
- Many students were unable to relate that B and A*l* are elements in Group 13. Hence, the formula of boron oxide is analogous to that of aluminium oxide.
- Others identified NO as the inert diatomic gas without realising that NO is a radical which is not inert.
- Some missed the information from the question that a **diatomic** gas was produced, and gave NO_2 (which is triatomic) as the inert gas. Similar to NO, NO_2 is not inert.

(ii) Gradient = $\frac{-1178-(-1191.8)}{1470-1070} = +0.0345$ kJ mol^{-1} K^{-1}

$\Delta S^{\ominus} = -0.0345$ kJ mol^{-1} K^{-1}

There is a <u>decrease in the number of gaseous molecules</u>, resulting in a decrease in disorder of the system. Change in entropy is negative.

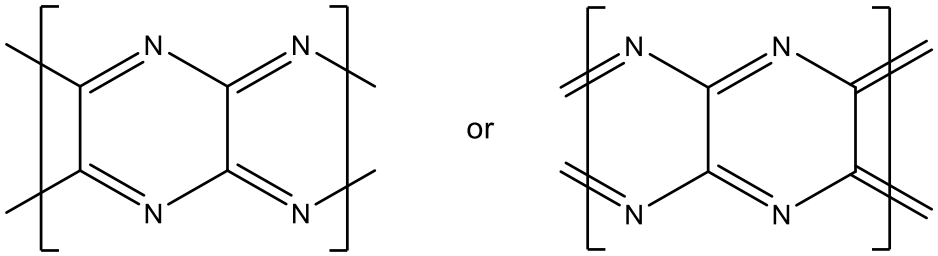
Examiners' Comments
- Some students did not realise that the gradient of a graphical plot of $\Delta G^{\ominus}$ against T corresponds to $-\Delta S^{\ominus}$. Please recall the formula: $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$.
- Others identified two points on the graph and used their GC to easily solve for $\Delta S^{\ominus}$. This method was also acceptable.
- Many students lost marks to having the wrong units kJ mol^{-1}, instead of kJ K^{-1} mol^{-1}.

(c) **(i)** 

Examiners' Comments
- Generally well done for students who read the question carefully and realised that there is a carbon-carbon single bond in C_2N_2.
- Many students were careless and did not put in the lone pairs of electrons on N atoms.
- Students must ensure that their dot-and-cross annotations on C and N are clear.

(ii) More energy is needed to overcome the <u>stronger hydrogen bonds between C_2H_5OH molecules</u> than the <u>weaker instantaneous dipole induced dipole interaction between C_2N_2 molecules</u>. Hence, C_2N_2 has a <u>lower</u> boiling point than C_2H_5OH.

Examiners' Comments
- Many students did not correctly identify the interaction between ethanol molecules as hydrogen bonding. This shows a lack of effort in revising lecture notes and tutorial questions.
- Despite identifying the correct intermolecular forces of attraction, many did not <u>compare the strengths</u> of the respective interactions and simply conclude with the energy required to overcome them.

(iii) 

Examiners' Comments
- Other structures that fulfilled the criteria were also accepted.
- Many students did not recognise that upon polymerising, the NCCN pattern should still remain intact. (Please recall the dimerisation of $AlCl_3$ to form Al_2Cl_6.)