2022 H2 Chemistry Y5 Term 3 Common Test Suggested Solutions

Section A

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

Question 1 (D)

A	Amount of $N_2 = \frac{2.80}{28.0} = 0.100$ mol 1 mol of N_2 has 2 mol of N atoms Amount of N atoms = 2(0.100) = 0.200 mol No. of atoms = $0.200 \times 6.02 \times 10^{23}$ $= 1.204 \times 10^{22}$
B	Amount of Ar = $\frac{3.60}{39.9} = 0.09023$ mol No. of atoms = $0.09023 \times 6.02 \times 10^{23}$ $= 5.431 \times 10^{22}$
C	Amount of $C_2H_2 = \frac{950}{24000} = 0.03958$ mol 1 mol of C_2H_2 has 4 mol of C and H atoms. Amount of atoms = 4(0.03958) = 0.1583 mol No. of atoms = $0.1583 \times 6.02 \times 10^{23}$ $= 9.530 \times 10^{22}$
D	No. of $CO_2 = 5.10 \times 10^{22}$ 1 mol of CO_2 has 3 mol of C and O atoms No. of atoms = $3(5.10 \times 10^{22})$ $= 1.53 \times 10^{23}$

Question 2 (C)

$Cl_2 + 2e^- \longrightarrow 2Cl^-$ -- (1)

$Cl_2 \longrightarrow Cl$–containing product -- (2)

The 0.05 mol of Cl^- formed in (1) came from $(\frac{0.05}{2})$ = 0.025 mol of Cl_2. Since 0.03 mol of Cl_2 was used, there is (0.03 – 0.025) = 0.005 mol of Cl_2 involved in (2).

The amount of Cl_2 used in equation (1) : equation (2) = 0.025 : 0.005 = 5:1.

Therefore, equations (1) and (2) can be written as

5Cl_2 + **10**$e^- \longrightarrow$ **10**Cl^- -- (3)

1$Cl_2 \longrightarrow Cl$–containing product -- (4)

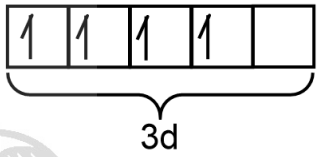
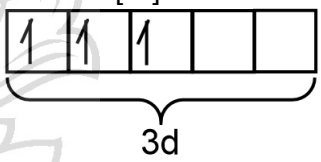
The 10 mol of e^- from equation (3) must be given out in equation (4). So equation (4) becomes

1$Cl_2 \longrightarrow Cl$–containing product + **10**e^-

Since **1**Cl_2 gave **10**e^-, 1 Cl gives 5 e^- to become the chlorine-containing product i.e. the final oxidation state of the Cl in the product is +5.

Question 3 (2&3)

As 2&3 was not provided as an option, all students were awarded one mark for this question.

1	Incorrect. Electronic configuration of Cr = [Ar] $3d^5$ $4s^1$ $\Rightarrow$ electronic configuration of Cr^+ = [Ar] $3d^5$
2	Correct. All electrons in [Ar] are paired. Cr^{2+} electronic configuration = [Ar] $3d^4$  Cr^{3+} electronic configuration = [Ar] $3d^3$  For Cr^{2+} and Cr^{3+}, there are no paired electrons.
3	The equation describes the 3rd IE of Cr which, from the Data Booklet, is +2990 kJ mol^{-1}.

Question 4 (D)

Since there is a large jump between the 5th and 6th IE for element X, the 6th electron is removed from an inner shell i.e. X has 5 valence electrons and is from group 15.

Since W, X, Y and Z are consecutive elements, W is from group 14, X is from group 15, Y is from group 16 and Z is from group 17.

The group 17 element has the highest first IE as it has the highest nuclear charge while having approximately constantly shielding effect as in W, X and Y.

Question 5 (B)

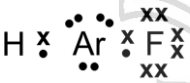
The cation of J

- is polyatomic (made up of many atoms)
- has overall charge of 2+
- contains Pt in a +4 oxidation state
- dative bonded to 6 species (NH_3 or Cl^-)

If J is made up of 2 Cl and 4 NH_3 dative bonded to Pt, then the overall charge of the cation
= O.S. of Pt + 2(charge of Cl^-) + 4(charge of NH_3)
= +4 + 2(−1) + 4(0)
= 2+
This satisfies the above criteria i.e. cation of J has formula $[PtCl_2(NH_3)_4]^{2+}$.

J has a number of monoatomic anions e.g. Cl^-.
The 2+ charge of the cation needs to be balanced by a 2– from 2 Cl^-. The formula of J should be $[PtCl_2(NH_3)_4]Cl_2$ i.e. $Pt(NH_3)_4Cl_4$.

Question 6 (C)

A	Incorrect.  Ar has 5 regions of electron density (electron pair geometry of trigonal bipyramidal) and 3 lone pairs which gives a molecular <u>shape of linear</u>.
B	Incorrect. Since F is more electronegative than H, F pulls electron density towards itself causing a $\delta-$ on F and $\delta+$ on H. Hence, HF is polar.
C	Correct. From the dot-and-cross diagram, Ar in HArF has 10 electrons around itself in its valence shall.
D	Incorrect. Hydrogen bonds exist between compounds with H–F, H–O and H–N bonds. Since there are no H–F bonds in HArF, there are no hydrogen bonds between HArF.

Question 7 (A)

1	Incorrect. Hydrogen bonds exist between compounds with H–F, H–O and H–N bonds. PH_3 consists only of 3 P–H and is unable to form hydrogen bonds with other PH_3 molecules.
2	Incorrect. NH_3 has a higher bp than CH_4 due to the ability of NH_3 to form stronger intermolecular hydrogen bonds (compared to the weaker instantaneous dipole-induced dipole interactions between CH_4 molecules) which require more energy to overcome.
3	Incorrect. NH_3 has a higher bp than CH_4 due to the ability of NH_3 to form stronger intermolecular hydrogen bonds (compared to the weaker permanent dipole-permanent dipole interactions between PH_3 molecules) which require more energy to overcome.

Question 8 (C)

A	Incorrect. From the data booklet, Ba has a larger atomic radius compared to K, but this does not relate to the strength of the metallic bonds in Ba and K.
B	Incorrect. Ba, having a larger molar mass, is heavier than L. However, this does not relate to the strength of the metallic bonds in Ba and K.
C	Correct. With a higher charge in Ba^{2+}, there is stronger attraction between the lattice of Ba^{2+} cations and the sea of delocalised electrons (compared to that in K^+), resulting in stronger metallic bonds in Ba which require more energy to overcome, leading to a higher melting point.
D	Incorrect. Ba^{2+} has more electrons than K^+. However, this does not relate to the strength of the metallic bonds in Ba and K.

Question 9 (D)

M_r of CO_2 = 12.0 + 2(16.0) = 44.0

Amount of $CO_2 = \frac{4.4}{44.0} = 0.100$ mol

$pV = nRT$

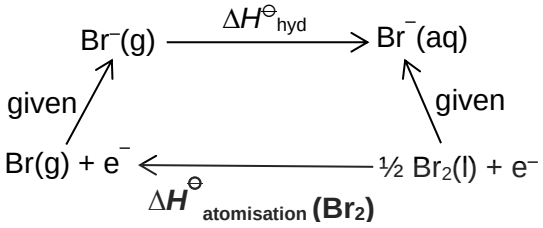
p of $CO_2 = \frac{nRT}{V} = \frac{(0.100)(8.31)(90+273)}{1.00 \times 10^{-3}}$
= 301700 Pa
= 3.017 bar (since 1 bar = 10^5 bar)

Final pressure in bottle = $p_{air} + p_{carbon\ dioxide}$
= 1 + 3.017
= 4.02 bar

Question 10 (C)

1	Correct. This is Avogadro's law.
2	Correct. For a fixed mass of gas, the no. of moles of gas is also fixed. $pV = nRT$ $p = (\frac{nR}{V})T$ $\frac{nR}{V}$ is a constant since n, R and V are constant in this case. Hence, p is directly proportional to T.
3	Incorrect. $p = (\frac{nR}{V})T$ p is <u>inversely</u> proportional to V.

Question 11 (D)



The other information provided do not form a useful part of the energy cycle to determine $\Delta H^{\ominus}_{hyd}$ of Br^-.

Question 12 (A)

$H_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + 2H_2O$ − (1)

$CH_3COOH + NaOH \longrightarrow CH_3COONa + H_2O$ – (2)

If x mol is the amount of water released from (2), then (1) releases 2x mol of water (since the volume and concentrations of H_2SO_4 and CH_3COOH are the same i.e. the amounts of H_2SO_4 and CH_3COOH are the same)

Since $\Delta H_{neutralisation} = -\frac{\text{heat change}}{\text{amount of water}}$,

for (1), $\Delta H_{neutralisation}(1) = -\frac{p}{2x}$

for (2), $\Delta H_{neutralisation}(2) = -\frac{q}{x}$

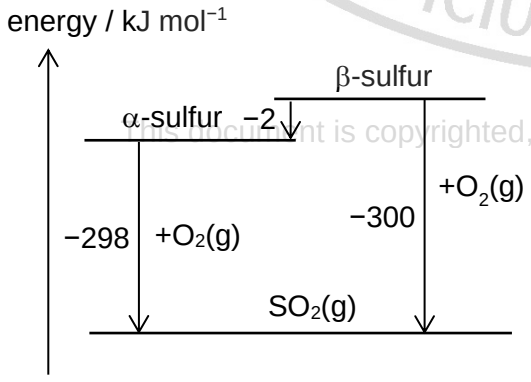
(1) involves the reaction of a strong acid with a strong base, while (2) involves the reaction of a weak acid with a strong base. Therefore, $|\Delta H_{neutralisation}(1)| > |\Delta H_{neutralisation}(2)|$ i.e.

$\frac{p}{2x} > \frac{q}{x}$

$\Rightarrow p > 2q$

Question 13 (B)

Since the two allotropic forms of sulfur undergo combustion to give a common product, SO_2, the following energy level diagram can be drawn to visualise the difference in energy of α-sulfur and β-sulfur.



A	Incorrect. The standard enthalpy change of formation is the energy change when 1 mole of the pure substance in a specified state is formed from its constituent elements in their standard states under standard conditions. The standard state of a substance is its **most stable form** under standard conditions. From the energy level diagram, the most stable form is α-sulfur as it is lower in energy. Hence, $\Delta H_f^{\ominus}$ of β-sulfur = +2 kJ mol^{-1} since it involves converting α-sulfur to β-sulfur.
B	Correct. As mentioned in **A**, the standard enthalpy change of SO_2 involves SO_2 being formed from its constituent elements i.e. O_2 and S in their most stable form. Since the most stable of S is α-sulfur, the $\Delta H_f^{\ominus}$ of SO_2 is −298 kJ mol^{-1}.
C	Incorrect. α-sulfur has a lower energy and is, therefore, more stable than β-sulfur.
D	Incorrect. As shown in the energy level diagram, energy is released (−2 kJ mol^{-1}) to convert from β-sulfur and α-sulfur.

Question 14 (C)

1	Correct. Since 1 mol of CH_4 reacts with 1 mol of steam to form carbon monoxide and gas **R**, **R** has to be H_2 in order to balance the chemical equation. $CH_4 + H_2O \longrightarrow CO + 3\mathbf{H_2}$ Since **R** = H_2 gas, **R** is flammable.
2	Incorrect. Students will obtain −5 kJ mol^{-1} if they forgot to convert 1000 °C to 1273 K. ΔG at 1000°C = $\Delta H^{\ominus} - T\Delta S^{\ominus}$ = $210 - (1000 + 273)(\frac{215}{1000})$ = −63.7 kJ mol^{-1}
3	For reaction to be spontaneous, $\Delta G < 0$. $\Delta H^{\ominus} - T\Delta S^{\ominus} < 0$ $210 - T(\frac{215}{1000}) < 0$ T > 976.7 K = 703.7 °C Therefore, minimum temperature for reaction to be spontaneous is 704 °C.

Question 15 (A)

The graphs shown in the question are graphs of ΔG against T and can be derived from the equation $\Delta G = \Delta H - T\Delta S$.

Rearranging the equation, we obtain

$\Delta G = (-\Delta S)T + \Delta H$

y = m x + c

Hence, the gradient of lines is $(-\Delta S)$ while the y-intercept is ΔH.

T < 900 K, $2Mg\mathbf{(s)} + O_2(g) \longrightarrow 2MgO(s)$ – (1)

T> 900 K, $2Mg\mathbf{(l)} + O_2(g) \longrightarrow 2MgO(s)$ – (2)

The ΔS of both reactions are negative, since there is a decrease in the amount of gaseous species in the system. Since the gradient is $(-\Delta S)$, we are expecting the lines to have a positive gradient, reject options **C** and **D**.

$\Delta S_{(2)}$ is more negative than $\Delta S_{(1)}$ because liquid Mg has a greater entropy than solid Mg, there is greater decrease in entropy for reaction (2) when liquid Mg is reacted compared to when solid Mg is reacted in reaction (1). This means that, the gradient when T > 900 K i.e. $(-\Delta S_{(2)})$ is greater than the gradient when T < 900 K i.e. $(-\Delta S_{(1)})$.

General Comments for Sections B and C

- If there is a need to use the extra writing pages, students are reminded to
  - write a note to direct the examiners to the extra pages and
  - label the question parts with their answers!
- There is unnecessary mark loss due to incorrect number of significant figures or incorrect units used in your answers. Please give all answers to 3 sf unless otherwise instructed by the question.

Section B

B1

General Examiner's Comments

B1 is a simple question that awards marks for recall and knowing your content in depth. Students who were unfamiliar with the content were unable to use correct scientific terms. Hence, they did not score well.

(a) (i)

element	He	Ne	Ar
r / nm	0.140	0.160	0.190

Examiner's Comments

- A handful of students misidentified the data from the Data Booklet as the d_v, hence wrongly dividing by two to obtain 0.070, 0.080 and 0.095 nm The data from the Data Booklet already shows the atomic *radii*, not diameter.

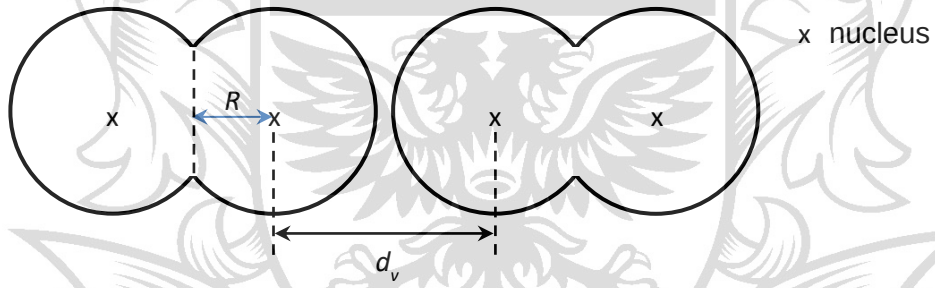
(ii) *r* increases down Group 18.

Down the group,
- the number of electronic shells increases, and
- distance between the nucleus and the valence electrons increases.

Despite the increasing nuclear charge,
- electrostatic attraction between the nucleus and the valence electrons decreases, resulting in an increase in the size of the electron cloud and hence *r* increases.

Examiner's Comments
- This is a simple recall question adapted to a new context known as the van der Waals' radius.
- Students are expected to use correct scientific terminology to account for the trends observed. The trend should be clearly stated, and if a symbol was used, then it should be the same as that given in the question, i.e., "*r*".
- Students should note that the correct term to use is "electronic shells", and not (just) "shells" or "principal quantum shells". It is also incorrect to say that the "number of *valence* shells increases". There exist only principal quantum numbers and the number of valence shells remain at 1.
- Some students were able to clearly, and correctly, relate the increase in electron shells (and increase in electron cloud size) to the repulsion between the two molecules, and hence the impact on van der Waals radius.
- Note that "effective nuclear charge" is usually not used when discussing the trend down a group. This is because shielding is not constant down a group (different orbital types provide different effectiveness of shielding), and a more detailed treatment needs to be done. Such generalisations using "effective nuclear charge" down a group may not always be accepted.
- An increase in distance between the nucleus and the valence electrons does not imply an increase in shielding; some students incorrectly phrased this as a cause-and-effect statement.

(b)



Examiner's Comments
- Refer to lecture notes on Atomic Structure (p. 21). "The covalent radius of an atom is half the inter–nuclear distance between two covalently bonded atoms."

(c) When atoms combine to form a covalent bond, their valence orbitals overlap, causing the nuclei to come closer together, hence decreasing the inter-nuclear distance, and so the covalent radius will always be smaller.

OR Shared electrons experience electrostatic attraction to both nuclei resulting in a shorter covalent radius compared to van der Waals radius.

OR Repulsion between the two molecules results in a longer van der Waals radius compared to covalent radius.

Examiner's Comments

- Quite a number of students wrote confusing phrases like "electron clouds overlap" without realising that electrons are negatively charged, and they repel one another instead of overlapping.
- Those who correctly used the term "orbital overlap" failed to elaborate how an orbital overlap caused the nuclei to come closer together.
- Many students justified their point by explaining that the "covalent bond is stronger than van der Waals forces of attraction", without explaining that the covalent bond results in an orbital overlap, which is the main reason for a smaller radius. Some also simply used the idea of "chemically bonded vs. not chemically bonded" but did not elaborate in greater detail as to what that idea meant in terms of the impact to the two radii.

B2 (a) (i) Graphite has a giant molecular structure.

A large amount of energy is required to break the strong covalent bonds between C atoms, resulting in graphite having a high melting point.

Examiner's Comments

- This is a simple recall question. Despite the fact that the question began with the phrase "In terms of structure and bonding", many students focused only on the presence of covalent bonds in graphite.
- Many students compared the difference between the melting points of graphite and buckminsterfullerene. The question did not ask for why graphite has a "higher" melting point.
- It is important to read the question carefully in order not to waste time providing unnecessary information which will not be given credit.
- Some candidates, in their lengthy description of the covalent bonds in graphite, showed that they were in fact confused with the structures in diamond and graphite, making incorrect references like "tetrahedrally bonded". Other phrases like "sea of delocalised electrons" in graphite were also used, which left the examiners wondering if the students were inappropriately borrowing terminology more suited to describe metallic bonds.
- Note: the weak id-id interactions between the layers in graphite allow the layers to slide over one another, but when graphite is melted, a lot of energy is needed to break the covalent bonds between the carbon atoms in every layer.
- Students need to correctly describe interactions: e.g., are the interactions between atoms or molecules, are the interactions between or within molecules.

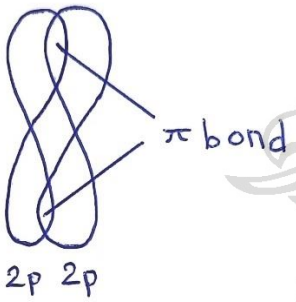
(ii) The energy released in forming the weaker instantaneous dipole–induced dipole forces between C_{60} & water molecules cannot compensate for the energy needed to break the stronger hydrogen bonds in water. Hence C_{60} is insoluble in water.

Examiner's Comments

- Some students erroneously identified that buckminsterfullerene, C_{60}, has a giant molecular structure. This claim is not supported by the data given in Table 2.1.
- A number of students superficially stated that C_{60} is non-polar while water is polar. This statement does not fully explain why C_{60} is insoluble in water.
- Many students were unable to identify the solute-solvent interaction (weak id-id).
- Credit was not given for mentioning the breaking of the "solute-solute interactions" without identifying the specific interactions between C_{60} molecules i.e. id-id interactions. Some students who mentioned the solute-solute interactions wrongly identified them as covalent bonds within C_{60}. Note that dissolving C_{60} in a solvent does not result in the formation of C atoms, but that the solute particles (discrete C_{60} molecules) are now surrounded by solvent molecules.
- A handful of students reasoned that C_{60} was insoluble in water due to its inability to form "ion-dipole interactions" or H-bonds with water.

- Many students simply mentioned that the id-id interactions were weaker than the H-bonds, without referring to energy compensation. Some who mentioned energy compensation confused the interactions that were broken and formed.
- Please spell all terms correctly e.g., “instantaneous”.

(b) **(i)**



Examiner’s Comments

- Students are expected to label their diagram to indicate the side-on overlap of the *2p orbitals* in carbon (read question carefully) resulting in the formation of a π bond.
- Answers showing the outcome of the overlap (merged p-orbitals) were not accepted, as the question was asking for the overlapping process (“how”).
- A handful of students mistakenly thought / indicated that there are two π bonds present. As shown, the two overlapping regions between the two p orbitals make up one π bond, and each π bond holds up to a maximum of two electrons.
- A number of students drew sigma bonds instead.
- Each p orbital can basically be drawn like how one may draw the number “8”, and students should avoid other less accurate representations.

(ii) Each C forms 3 σ bonds
$\Rightarrow$ each C must have 1 electron left for π bond.
$\therefore$ There is a total of 60 such electrons per C_{60} molecule, and since each π bond requires 2 electrons $\Rightarrow$ there are <u>30</u> π bonds.

Examiner’s Comments

- Many students were unable to correctly interpret this question. Please refer to the answer above.

(iii) The bond between any two carbon atoms shared by a pentagon and a hexagon is a single bond (longer bond length), hence no π bonds can be drawn within the pentagons. Hence the proposed method is not possible.

OR

There can only be a maximum of two π (double) bonds per pentagon.
Since there are only 12 pentagons, there is only a maximum of 24 π bonds, which is less than 30 [from **(ii)**].
Hence the proposed method is not possible.

Examiner’s Comments

- Many students were unable to see that a shorter bond length implied the presence of a double bond.
- Many students’ answers implied that more than 2 double bonds can be included in one pentagon, demonstrating poor understanding of the framework of carbon in pentagon and the ability of carbon to form a maximum of 4 bonds.
- Those who understood this question had a hard time expressing their thoughts succinctly. Markers found it challenging to decipher students’ understanding.

- Clear justification or reasoning should always be given to support one's answers; simply stating that there could be also π bonds in the hexagons without further / relevant elaboration is insufficient.

(iv) Any 6 (or others)

Examiner's Comments

- Students' incorrect understanding of the structure prevented them from answering the question well. Some students drew more than 4 bonds connected to one carbon.
- The handful of students who understood that the bond shared between a pentagon and a hexagon is a single bond would have identified the correct locations of the carbon–carbon double bonds.

B3 **(a)** pV=nRT

$10^5 \times (1 \times 10^{-3}) = n(8.31)(-50 + 273)$

n = 0.05396 mol

Amount of gases in 1 dm^3 = 0.05396 mol

Atmospheric concentration of CCl_2F_2 = 530 ppb

⇒ 530 CCl_2F_2 molecules in 10^9 gaseous molecules of air.

Amount of CCl_2F_2 in 1 dm^3 of air = $(\frac{530}{10^9}) \times 0.05396$

$= \underline{2.86 \times 10^{-8} \text{ mol}}$

Examiner's Comments

- Many students were unable to obtain full credit for this question. While most were able to calculate the total amount of gas using the ideal gas equation, many were unable to obtain the amount of CCl_2F_2, which require the use of the atmospheric concentration (i.e. 530 ppb) and the definition of ppb given in the question. Students should note that the total amount of gas is not entirely CCl_2F_2.
- A handful of students also made careless mistakes that mainly include an incorrect R value (e.g. 8.13, 3.81 instead of the correct 8.31 which is in the Data Booklet) and an incorrect units used for volume in the ideal gas equation (i.e. V should be in m^3 instead of dm^3).

(b) **(i)** H_2 is has no permanent dipole moment and does not contribute to the greenhouse effect.

CCl_2F_2, N_2O and NF_3 have a permanent dipole moment they are greenhouse gases.

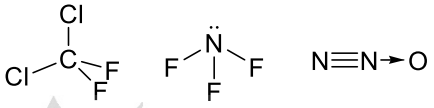
Due to the low atmospheric concentration of NF_3 it is a minor contributor to the greenhouse effect.

Due to the high atmospheric concentrations and long atmospheric lifetimes of CCl_2F_2 and N_2O, they are major contributors to the greenhouse effect.

Examiner's Comments

- This question was poorly done.

- Firstly, many students were unable to identify whether the molecules have a permanent dipole moment using the concept of polarity. Students should consider the structures of the molecules when determining the overall polarity.



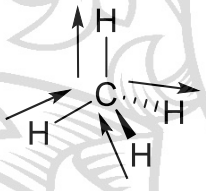
- Secondly, many students attributed the contribution to the greenhouse effect to how polar the molecule is. However, the question only mentioned that molecules with permanent dipole moment absorb IR without stating a correlation between polarity and extent of absorption. As guided in the question, students should instead utilise the data presented in the table to evaluate the contribution, i.e. how much of each gas is present (given by the concentration) and how long they stay in the troposphere (given by the lifetime). Since both concentration and lifetime are presented, students should consider both factors in making a sound evaluation.
- Some students also made irrelevant mentions of how there are permanent dipole-permanent dipole interactions between polar molecules and/or instantaneous dipole-induced dipole interactions between non-polar molecules. The context of this question did not suggest that molecules form intermolecular interactions with IR for absorption to occur.

(ii) During asymmetric stretching, a bond is lengthened and the other bond is shortened. The dipole moments do not cancel out / the molecule has an overall dipole moment.

Examiner's Comments

- This part was poorly done. Most students were aware that the ability to absorb IR was due to the presence of a net dipole moment and tried to explain how this dipole arose in a non-polar molecule of CO_2. However, the explanation mostly lacked references to asymmetric stretching and compressing phenomenon set out in the question, which should be in terms of bond length increasing and decreasing, and as a result, the dipole moments do not cancel out.
- Answers which suggested *'the dipole moments were unequal after asymmetric stretching and hence, a net dipole moment exist'* were not accepted as it lacked references to the direct observed effect on bond lengths of asymmetric stretching.
- A small handful of students did not realise that CO_2 is linear and concluded that there was a net dipole present due to its bent shape.

(iii)



or others

Examiner's Comments

- This question was generally well done.
- Other acceptable answers should show at least 1 C-H bond shortening/lengthening whilst the other C-H bonds do the opposite.

(c) **(i)** $\Delta H^{\ominus}$ of the reaction = (−538.8) + (−8.4) – 2(−132.1)
= −283 kJ mol^{-1}

Examiner's Comments

- This question was surprisingly not as well done.
- $\Delta H_r^{\ominus} = \Sigma n \Delta H_f^{\ominus}$ (products) $-$ $\Sigma m \Delta H_f^{\ominus}$ (reactants)
  The above formula can be applied to solve this question.
- Common careless mistakes include students forgetting to multiply the enthalpy changes with the respective stoichiometric coefficient or using the wrong sign.

(ii) Negative. There is a decrease in the number of moles of gaseous particles (from 2 moles to 1 mole).

Examiner's Comments

- This question was generally well done.
- A small handful of students chose the sign of $\Delta S^{\ominus}$ that will make $\Delta G^{\ominus}$ negative, given that $\Delta H^{\ominus}$ was calculated in **(c)(i)** to be negative. This is incorrect since the question did not mention that $\Delta G^{\ominus}$ is negative or the reaction is spontaneous to begin with.

(iii) At a low temperature, the negative $\Delta H^{\ominus}$ outweighs the positive $-T\Delta S^{\ominus}$. $\Delta G^{\ominus}$ is negative, hence reaction is spontaneous.

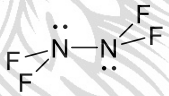
Examiner's Comments

- Many students struggled with explaining this part. Students are expected to be able to compare the magnitude of $\Delta H^{\ominus}$ and $-T\Delta S^{\ominus}$ to show how a low T enables the negative $\Delta H^{\ominus}$ term to dominate, leading to a negative $\Delta G^{\ominus}$.
- Students should also clearly articulate the significance of a negative $\Delta G^{\ominus}$, i.e. reaction is spontaneous.

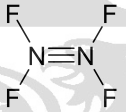
(iv) There are 3 bond pairs and 1 lone pair around each N atom. To minimise repulsion, the electron pairs are arranged as far apart as possible in space.

N_2F_4 has a trigonal pyramidal shape about each N atom.

Examiner's Comments



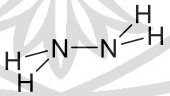
- Most students were able to state the shape correctly. The inability to obtain full credit for this part mainly stems from the omission of the key idea behind VSEPR theory - to minimise repulsion. Please learn the entire explanation required for such questions.
- Students who stated the incorrect shape likely drew structures of N_2F_4 that are invalid.

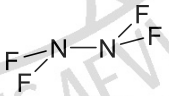


For example, (N is in period 2 and therefore cannot expand octet)

(v) More energy is needed to overcome the stronger hydrogen bonding between N_2H_4 molecules compared to the weaker permanent dipole–permanent dipole interactions between N_2F_4 molecules. Therefore, N_2F_4 is a gas whereas N_2H_4 is a liquid at room temperature.

Examiner's Comments

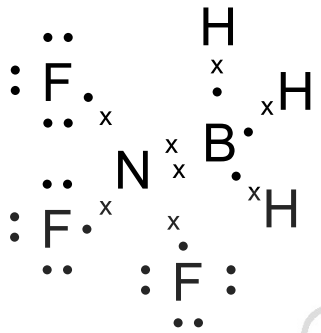




- Many students did not realise N_2H_4 was capable of intermolecular hydrogen bonding. Similarly, many students thought N_2F_4 was non-polar and only forms instantaneous dipole-induced dipole interactions between molecules. Students are should always draw out the structures of the molecules before concluding polarity and type of intermolecular forces present between molecules.

- A small handful of students thought the N-H bond in N_2H_4 was the hydrogen bond that breaks during phase change. Please note that intramolecular bonds are not broken during phase change.

(d) **(i)**



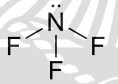
Examiner's Comments

- Most students were aware that there is a dative bond formed between N and B atoms since BH_3 is electron deficient and NF_3 has a lone pair of electrons available for donation.
- A significant number of students did not show the all the valence electrons around F or drew bonds instead of dot and cross.
- As the question requires the drawing of a 'dot-and-cross' diagram, the pair of electrons in the dative bond should be represented with dot/cross and not an arrow (N $\longrightarrow$ B).

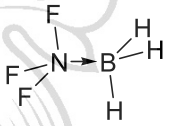
(ii) 107° to 109.5°

Examiner's Comments

- This question was not well done.
- Students must be familiar with the various shapes of molecules and bond angles (See Table 1 in Section 4.4 of Chemical Bonding I lecture notes).



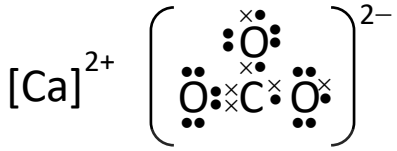
About N: 3 bond pairs, 1 lone pair,
trigonal pyramidal
F-N-F bond angle: 107°



About N: 4 bond pairs, tetrahedral
F-N-F bond angle: 109.5°

Section C

C1 (a) (i)



Examiner's Comments

- Students are reminded to present their answers clearly and in pen, especially for the 'dot' electrons. Otherwise, they may be lost among the 'dotted' lines of the question paper.
- A lot of mistakes in the CO_3^{2-} ion had either more than 8 electrons around C or fewer than 8 electrons. Some students also left out the lone pairs on the O atoms.
- Do not draw electron shells around the atoms in dot-and-cross diagrams.

(ii) Calcium carbonate is hard because it has a structure of a giant ionic lattice with strong electrostatic attraction between the calcium ions and carbonate ions throughout the lattice structure.

However, it is not as hard as quartz or diamond, which has a structure of a giant molecular lattice. The strong covalent bonds between the carbon atoms in diamond, or between the silicon and oxygen atoms in quartz, are stronger than the ionic bonds in calcium carbonate.

Note: It does not mean that ionic bonds are *always* stronger than covalent bonds. It depends on the substances being compared.

Examiner's Comments

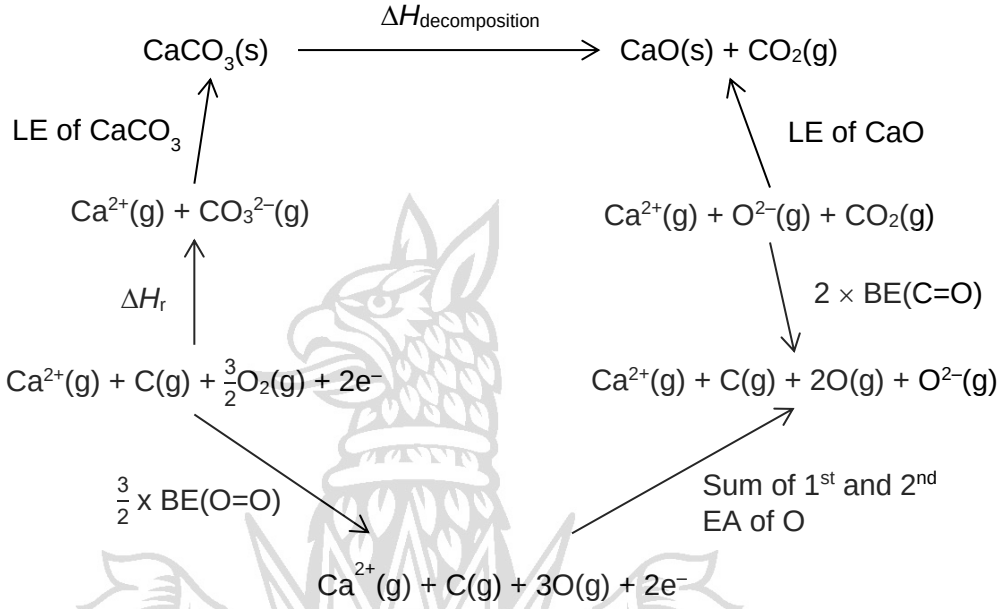
- Good answers should describe the structure **and** bonding of **both** $CaCO_3$ and diamond (or quartz) and compare them in this context. Answers which did not describe the bonding clearly were not awarded full credit.
- Poor answers made general statements such as, "since covalent bonds are stronger than ionic bonds…"

(b) (i) The lattice energy of an ionic compound is the energy released when 1 mole of the solid ionic compound is formed from its constituent gaseous ions under standard conditions (i.e. 1 bar and 298 K).

Examiner's Comments

- The state of the ionic compound (solid) and its constituent ions (gaseous) are required in the definition.

(ii)



Using Hess' Law,

$\Delta H_r = \frac{3}{2}(496) + (-142+844) - 2(805) + (-3505) - (178) - (-2810)$

$= -1037$ kJ mol^{-1} $= -1040$ kJ mol^{-1} (3 sf)

Examiner's Comments

- Many students who attempted this question were able to obtain partial credit by paying close attention to the states of the species at each step of the energy cycle.
- A common mistake was using the wrong value of bond energy for CO_2. It clearly states in the Data Booklet that the C=O bond in CO_2 is 805 kJ mol^{-1} (and not 740).

C=O	740
C=O in CO_2	805

- When including electron affinity in the energy cycle, you should also include the electrons at the correct step.

(iii) The oxide ion is smaller than the carbonate ion.

Since the magnitude of lattice energy is inversely proportional to the inter-ionic distance, the smaller the anion radius, the greater the magnitude of the lattice energy.

Examiner's Comments

- This question was generally well done with most students recognising that the oxide ion is smaller than the carbonate ion, and explaining how this difference affects the magnitude of lattice energy.
- Some common mistakes include referring to the oxide ion as oxygen ion or just oxygen, and using incorrect terms such as inter-ionic *radius* (instead of inter-ionic *distance* of an ionic compound).
- Some students incorrectly correlated lattice energy with charge density of ions, which is inconsistent with the lattice energy expression. Some also incorrectly stated that lattice energy is equal to $\left|\frac{q_+ q_-}{r_+ + r_-}\right|$, instead being directly proportional.

- Students should also specify the ions they are comparing, rather than just state that CaO has a smaller inter-ionic distance than $CaCO_3$.

(iv) The bonding in the calcium carbonate lattice has some covalent character due to the polarisation of the large carbonate anion by the smaller and highly charged calcium cation.

Examiner's Comments

- Students should describe the polarisation of the electron cloud of the carbonate anion by the calcium cation, instead of just stating that the carbonate ion has a large electron cloud which is easily polarisable. This is because both the cation and anion need to possess the suitable properties in order for polarisation to be significant.
- Some students were confused between lattice energy and bond energy.
- Answers which revolved around generic ideas such as "loss of heat to surroundings" and "average values from the *Data Booklet*" were irrelevant to the discussion.

(c) **(i)** $4H_2(g) + CaCO_3(s) \longrightarrow CH_4(g) + H_2O(g) + Ca(OH)_2(s)$

This is a redox reaction.
H_2 is oxidised as H increases in oxidation number from 0 to +1 while $CaCO_3$ is reduced as C decreases in oxidation number from +4 to –4.

Examiner's Comments

- Most students were able to write the balanced equation from the information given.
- A common mistake was writing the formula of calcium hydroxide as CaOH, which was surprising given that this is a formula of a conventional ionic compound.
- A large majority of students were able to recognise that H_2 is oxidised but they were not able to deduce the correct oxidation number of H in CH_4 and gave it as –1 instead of +1.
- A large number of students also mistakenly wrote that there was no reduction and did not realise that the oxidation number of C has decreased.
- Do note that to explain why a redox reaction is present, both the oxidation and reduction of the relevant species must be described, and not just stating one and leaving the examiner to assume that the other half is implied.

(ii) Amount of $CaCO_3$ = 20.0 / 100.1 = 0.1998 mol

Amount of CH_4 formed = $0.1998 \times 0.80 = 0.1598$ mol

Volume of CH_4 formed = $0.1598 \times 24 = 3.84$ dm^3

Examiner's Comments

- This question was well done.
- Some common mistakes include not factoring in the 80% yield, and taking the amount of CH_4 formed (0.1598 mol) as the actual amount rather than the theoretical amount.
- Students should also use the *Data Booklet* to obtain the A_r of Ca as 40.1 and not 40.

C2 **(a)** **(i)** $1s^2\ 2s^2\ 2p^6\ 3s^2$

Examiner's Comments

- This question was well done.

(ii)

(I) Mg has higher first ionisation energy than Na.

The Mg atom has one proton more than the Na atom and hence has a higher nuclear charge. The Mg atom also has one electron more than the Na atom but this electron is added to the same outermost electronic shell and hence shielding effect remains approximately constant. Consequently the valence electrons in Mg experience a higher effective nuclear charge, hence electrostatic attraction between the nucleus and the valence electrons of Mg is stronger, resulting in a greater amount of energy required to remove the valence electron from an Mg atom.

Examiner's Comments

- This question requires students to "state and explain which element has the higher 1st IE". Hence direct reference should be made to the elements being compared, Na and Mg, instead of just quoting the trend in 1st IE across the period.
- Students should read through their written explanations to ensure they sound coherent in a concise manner, instead of just randomly joining terms together.
- Some answers were not sufficiently specific in their description. Instead of just writing "electrostatic attraction is stronger", it should be "electrostatic attraction **between** the nucleus and valence electrons is stronger".
- Students should address effective nuclear charge only after weighing the effects of shielding effect **and** nuclear charge. A common mistake was to directly conclude that effective nuclear charge for Mg was higher due to Mg having 1 more proton, without mentioning shielding effect.

(II) Mg has higher first ionisation energy than A*l*.

The 3s electron to be removed from Mg is at a lower energy level than the 3p electron to be removed from A*l* and is hence more strongly attracted by nucleus. Hence more energy is needed to remove the 3s electron in Mg.

Examiner's Comments

- The principal quantum number and subshell of the electron to be removed from Mg and A*l* should be specified.
- Answers which were not accepted included discussion of the shielding effect of electrons in the 3s orbital, comparison of the distance of 3s and 3p orbitals from the nucleus.
- Some students wrongly stated that the 3p electron was at a lower energy level than 3s electron.

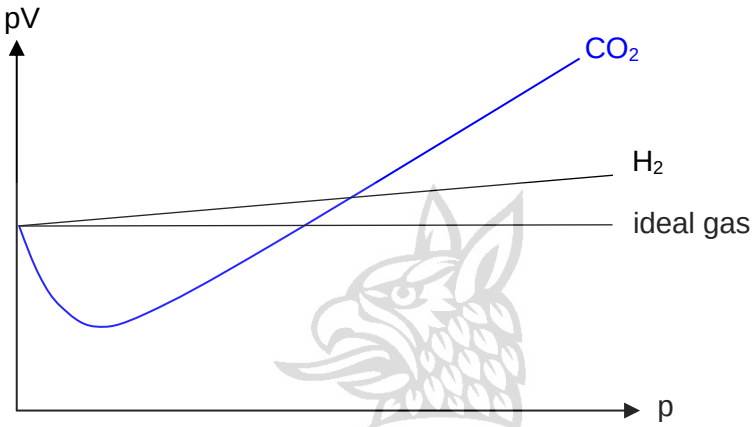
(b) **(i)** The gas particles exert negligible intermolecular attractive forces on one another.

The volume of gas particles is negligible compared to the volume of container.

Examiner's Comments

- Note that the question requires "two **main** assumptions of the kinetic theory", hence only the above two assumptions would be accepted as the answer.
- For the second assumption, students are required to specify "volume of gas **particles**" and "volume of the **container**" for a complete answer. This assumption basically means that ideal gas **particles** are so negligible in size that the **volume occupied by the gas** is the same as the volume of the container the gas is in.
- The incomplete phrase "negligible intermolecular forces" was not accepted.

(ii)



Explanation:
CO_2 has a greater electron cloud/ number of electrons compared to H_2. Thus, CO_2 forms stronger instantaneous dipole–induced dipole interactions as its electron cloud is more polarisable.

The molecular size (molecular volume) of CO_2 molecules is significantly larger than that of H_2. **OR** The size of electron cloud for CO_2 is bigger than that of H_2. This results in stronger repulsive forces between CO_2 molecules compared to H_2 molecules.

Examiner's Comments
- The graph for CO_2 should be labelled.
- Many answers were long and repetitive, and failed to address the question directly. The question required the explanation for the differences in extent of deviation from ideality for CO_2 compared to H_2. So the required answer should explain the differences in characteristics between CO_2 and H_2, and how these violate the two main assumptions stated in **(b)(i)**.
- Note that "instantaneous dipole-induced dipole interactions" should always be spelt out in full.
- A number of students wrongly thought CO_2 was polar - CO_2 is a linear molecule, hence the net dipole of the molecule is zero.
- A number of students wrongly thought that H_2 has no instantaneous dipole-induced dipole interactions.
- Some students wrongly attributed the stronger repulsive forces of CO_2 to larger molecular mass, instead of electron cloud size.

(c) **(i)**

Amount of Mg = $\frac{0.0382}{24.3} = 1.572 \times 10^{-3}$ mol

$\therefore$ Amount of H_2 = amount of Mg = 1.57×10^{-3} mol

Examiner's Comments
- Students are reminded to leave their final numerical answer in 3sf with unit.
- Students are reminded that the unit for amount is "mol" or "moles". There is no such unit as "mols".
- Several students did not realise that the question asked for amount of H_2 Students are reminded to read the question carefully. Some incorrectly thought that "amount" meant "volume". Students are reminded that "amount of X" means "number of moles of X".
- Some students erroneously used 24 as the relative atomic mass of Mg – it should be 24.3. Students are reminded to quote the correct exact values from Data Booklet.

(ii) $p_{atm} = p_{H_2} + p_{H_2O}$

$p_{H_2} = p_{atm} - p_{H_2O}$

$= 101 - 3.77 = 97.23 \text{ kPa} = 97.2 \text{ kPa}$

Examiner's Comments

- Students should use the data given for atmospheric pressure in the lab instead of making own assumption that atmospheric pressure is 101325 Pa .
- Students are reminded to read the question properly. The total pressure of the gas is the sum of the partial pressure of hydrogen gas and the partial pressure of water vapour in the measuring cylinder.
- Some students struggled with this part because they had memorised a few "standard" ways of obtaining partial pressure. Students should ready the question and work with the information (clues) provided.

(iii) $pV = nRT$

$R = \frac{pV}{nT} = \frac{97230 \times 37.0 \times 10^{-6}}{1.572 \times 10^{-3} \times (273 + 28)} = 7.602 = \underline{7.60} \text{ J mol}^{-1} \text{ K}^{-1}$

Examiner's Comments

- Students are expected to know the units of each term in the ideal gas equation and be able to do proper conversion of the values. Pressure is in Pa, volume is in m^3, amount is in mol, T is in K while R is in J mol^{-1} K^{-1}.
- Many incorrect answers arose from using the wrong units, particularly in the volume of 37 cm^3. 37 cm^3 = 37 x 10^{-6} m^3
- Many students used total pressure of gas to calculate R without realising that doing so will require the use of total amount of gas consisting of hydrogen and water vapour.
- Some students attempted to calculate a "partial volume of H_2" as if H_2 gas occupies only a portion of the 37 cm^3. Students must be aware the H_2 (and any other gas in that space) occupies the entire 37 cm^3. It is not possible that the gas occupies only a part of it because gaseous particles move freely within the volume of space they occupy.
- The most convenient method to calculate R would be to use the partial pressure of hydrogen gas, amount of hydrogen gas, volume occupied by hydrogen gas (which is the volume of gas in the measuring cylinder) and temperature at which the experiment was conducted.

(d) **(i)** $q = mc\Delta T = (25)(4.18)(34.4 - 28.6) = +606.1 = +606 \text{ J (3 sf)}$

Examiner's Comments

- Many students did not use the correct mass. Students are reminded that the mass used in the calculation of heat change is the mass of solution.
- Some students converted ΔT from ^oC to K without realising that the ΔT in ^oC is the same as ΔT in K.
- Some students were confused with the sign of q. The sign of q follows that of ΔT.

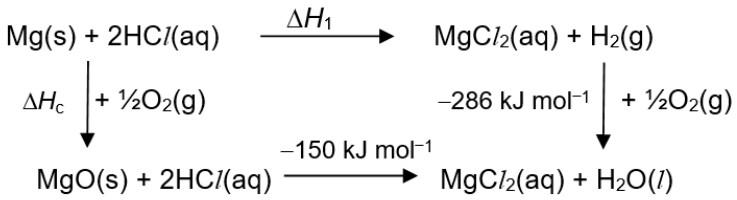
(ii) Amount of Mg reacted = $\frac{0.032}{24.3} = 0.001317 \text{ mol}$

$\Delta H_1 = -\left(\frac{606.1}{0.001317}\right) = -460.2 \text{ kJ mol}^{-1} = \underline{-460 \text{ kJ mol}^{-1}}$

Examiner's Comments

- Most students realised through calculation that Mg is the limiting reactant. Hence, calculation of ΔH_1 is based on the amount of Mg.
- Students are reminded to include the negative sign in the formula to calculate enthalpy change from heat change, $\Delta H = -\left(\frac{q}{n}\right)$.
- The units of ΔH is J **mol^{-1}** or kJ **mol^{-1}** which can be derived from $= -\left(\frac{q}{n}\right)$. Some students omitted the "**mol^{-1}".**

(iii)



By Hess' Law,
$\Delta H_c = \Delta H_1 + (-286) - (-150) = -460.2 - 286 + 150$
$= -596$ kJ mol^{-1}

Examiner's Comments

- Many students mistakenly added $H_2(g)$ into the energy cycle without realising that $H_2(g)$ is produced in the reaction between Mg and HC*l*.
- In drawing an energy cycle, students are reminded to ensure that
  - every chemical equation is balanced,
  - state symbol of all species is displayed,
  - all arrows are labelled with the corresponding energy change, including the one in question,
  - direction of the arrows is correct.

(iv) Since HC*l* was used in excess in the reaction with Mg, doubling the volume of HC*l* used will not affect heat change, *q*.

q = mass of solution × *c* × Δ*T*. However, since the mass of solution is doubled, with constant *q* and *c*, Δ*T* should be halved.

Examiner's Comments

- Many students merely stated that "Δ*T* would decrease" or "Δ*T* would be smaller". Students are reminded that such answers are not specific enough for questions where the volume was **doubled** (not simply "increased"). Δ*T* should be halved, not just "decreased".