Section A

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

MCQ worked solutions

Q1 (D)

Relative molecular mass is the ratio of the average mass of a molecule to $\frac{1}{12}$ the mass of a carbon-12 atom.

Q2 (A)

Mass of SO_2 molecules in 1 m^3 of air
= 0.570 x 1 = 0.570 mg = 0.000570 g

Amount of SO_2 molecules in 1 m^3 of air
= 0.000570 g ÷ (32.1 + 16 × 2) = 0.00000889 mol

Number of SO_2 molecules in 1 m^3 of air
= 0.00000889 × 6.02 × 10^{23} = 5.35 x 10^{18}

Q3 (C)

% abundance of ^{62}Ni = 100 − 69.51 − 26.78
= 3.71%
Relative atomic mass of Ni in sample
= (69.51 × 58 + 26.78 × 60 + 3.71 × 62) ÷ 100
= 58.68

Relative formula mass of $Ni^{35}Cl_2$
= 58.68 + 35+ 35 = 128.68

Q4 (B)

1 is correct: Mg: [Ne] $2s^2$ P: [Ne] $2s^2$ $2p^3$
Same number of electron pairs

2 is correct: As: [Ar] $3d^{10}$ $4s^2$ $4p^3$
Ge: [Ar] $3d^{10}$ $4s^2$ $4p^2$
Same number of electron pairs

3 is incorrect: Ba: [Xe] $6s^2$
Pb^{2+}: [Xe] $4f^{14}$ $5d^{10}$ $6s^2$
Different number of electron pairs

Q5 (C)

Option A is incorrect as **X** has a higher nucleon number of 36 while **Y** has a smaller nucleon number of 32.

Option B is incorrect as **X** has (33 − 14) = 19 neutrons while **Y** has (36 − 18) = 18 electrons.

Option C is correct as it fulfils all 3 criteria.

Option D is incorrect as **X** has 14 – 4 = 10 electrons while **Y** has 18 electrons.

Q6 (B)

$\left|\text{Angle of deflection}\right|$ is proportional to $\left|\frac{q}{m}\right|$.

$^2H^+$: $\left|\frac{q}{m}\right| = \frac{1}{2}$ $^{18}O^{2-}$: $\left|\frac{q}{m}\right| = \frac{2}{18} = \frac{1}{9}$ $^9Be^{2+}$: $\left|\frac{q}{m}\right| = \frac{2}{9}$

Statement 1 is incorrect as $^2H^+$ particles are deflected to the largest extent.

Statement 2 is correct as the $\left|\frac{q}{m}\right|$ of $^9Be^{2+}$ is larger than that of $^{18}O^{2-}$, hence $^9Be^{2+}$ particles are deflected to a larger extent than $^{18}O^{2-}$ particles.

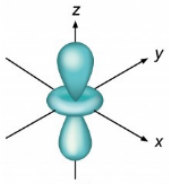
Statement 3 is incorrect as $^9Be^{2+}$ particles are attracted and, hence, deflected towards the negatively charged plate.

Statement 4 is correct as $^{18}O^{2-}$ particles are attracted and, hence, deflected towards the positively charged plate.

Hence, option B (2 and 4 only) is correct.

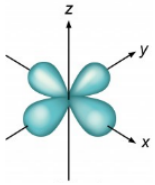
Q7 (D)

Option A is incorrect as $3d_{z^2}$ orbital consists of a dumb-bell surrounded by a small doughnut-shaped ring at its waist and aligned along the z axis.



Option B is incorrect as $3d_y$ orbital does not exist.

Option C is incorrect as the lobes of $3d_{x^2-y^2}$ orbital are aligned along the x and y axes.



Option D is correct as $3d_{xz}$ orbital has a 4-lobed shape and its lobes are pointing between the x and z axes.

Q8 (A)

Real gases deviate from ideal gas behaviour as the intermolecular attractive forces between the gas particles are significant. Ammonia has the strongest intermolecular forces of attractions (hydrogen bonding) and, hence the greatest deviation from ideality, amongst the 4 gases. The other 3 gases are non-polar simple covalent molecules with smaller electron cloud size than ammonia, thus they have weaker instantaneous dipole-induced dipole interactions.

Q9 (C)

For an ideal gas, $pV = nRT$.
For a fixed mass of gas, n is constant.

Option 1 is incorrect as $V = \frac{nRT}{p}$, since T is constant, nRT is constant, thus $V = k\left(\frac{1}{p}\right)$.
Graph of V against $\frac{1}{p}$ should be a straight line passing through the origin.

Option 2 is correct as $p = \frac{nRT}{V}$, since T is constant, nRT is constant, thus $p = k\left(\frac{1}{V}\right)$. Graph of p against $\frac{1}{V}$ will be a straight line passing through the origin.

Option 3 is correct as $V = \frac{nRT}{p}$, since p is constant, $\frac{nR}{p}$ is constant, thus $V = k(T) = k\left(\frac{1}{\frac{1}{T}}\right)$. Graph of V against $\frac{1}{T}$ will be of the same shape as $y = k\left(\frac{1}{x}\right)$.

Option 4 is incorrect. as $p = \frac{nRT}{V}$, since V is constant, $\frac{nR}{V}$ is constant, thus $p = k(T)$. Graph of p against T should be a straight line passing through the origin since T is measured in K.

Q10 (A)

$$pV = nRT = \frac{m}{M}RT$$

$$m = \frac{28.0 \times (p \times 10^5) \times (V \times 10^{-6})}{(273 + T) \times R}$$

Since 1 mol of an ideal gas occupies 22.7 dm^3 at s.t.p (1 bar = 10^5 Pa, 0 °C = 273 K), R can be derived from $pV = nRT$.

Substituting $R = \frac{10^5 \times 22.7 \times 10^{-3}}{1 \times 273}$,

$$= \frac{28.0 \times (p \times 10^5) \times (V \times 10^{-6}) \times 273}{(273 + T) \times 10^5 \times 22.7 \times 10^{-3}}$$

$$= \frac{28.0 \times pV \times 273}{(273 + T) \times 22700}$$

Q11 (D)

Center atom	No. of bond pair electrons	No. of lone pair electrons	Electron pair geometry	Shape	Bond angle
N	3	1	Tetrahedral	Trigonal pyramidal	107°
C (of CH_2)	4	0	Tetrahedral	Tetrahedral	109.5°
C (of C=O)	3	0	Trigonal planar	Trigonal planar	120°
O	2	2	Tetrahedral	Bent	105°

Order of increasing angles: d<a<b<c.

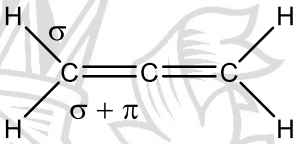
Q12 (B)

Statement 1 is correct. More energy is required to overcome the strong C−C covalent bonds in diamond than the weak intermolecular forces between the layers in graphite.

Statement 2 is correct. The freedom of the layers of carbon in graphite to slide results in greater entropy.

Statement 3 is incorrect. Delocalised electrons from continuously overlapping p orbitals are required to conduct electricity. Graphite can conduct electricity while diamond cannot.

Q13 (C)



The C-H single bonds each comprise of a σ bond. The C=C double bonds each comprise a σ bond and a π bond. Thus there is a total of 6 σ bonds and 2 π bonds.

Q14 (D)

Given that the solution turns cold, this is an endothermic reaction and $\Delta H^{\ominus}$ is positive.
Also, $\Delta G^{\ominus}$ is negative since dissolution is spontaneous. Since $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$, $\Delta S^{\ominus}$ needs to be positive in order for $\Delta G^{\ominus}$ to be negative.

Q15 (A)

Option A is correct as the reaction results in an increase in the number of moles of gaseous particles (from 0 mol to 1 mol) in the system, causing entropy to increase.

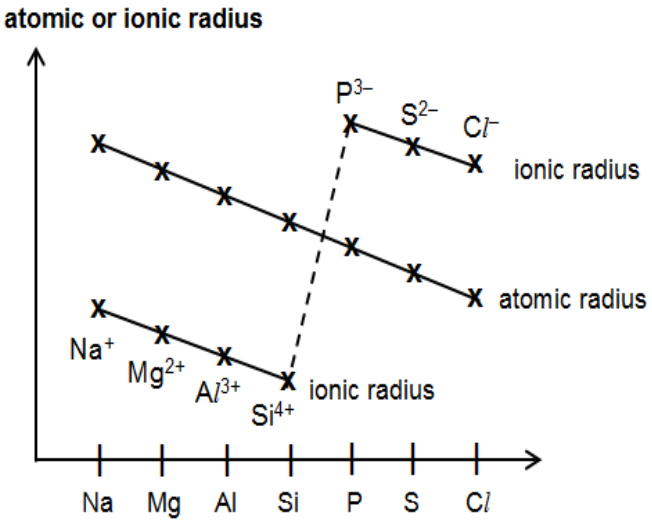
Option B is incorrect as the reaction results in an decrease in the number of moles of gaseous particles (from 1 mol to 0 mol) in the system, causing entropy to decrease.

Option C is incorrect as there is no change in the number of moles of gaseous particles in the system, so the entropy change is less than other options.

Option D is incorrect as the reaction results in an decrease in the number of moles of gaseous particles (from ¼ mol to 0 mol) in the system, causing entropy to decrease.

Section B

B1(a)(i)



Comments:

- Students should follow the requirement of the question and label both graphs.
- As the question only required a sketch of the graphs, students should not waste time drawing the graphs to scale.
- Note that the atomic and ionic radii of the Period 3 elements are given in the *Data Booklet*.

B1(a)(ii) P: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^3$ P^{3-}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$

Both P^{3-} and P have the same nuclear charge. However, P^{3-} has more electrons than P leading to greater electron–electron repulsion and hence the electrostatic attraction between the nucleus and the outermost electron is weaker.

Comments:

- Students should note that both P and P^{3-} have the same number of electronic shells.

B1(a)(iii) Na^+: $1s^2\ 2s^2\ 2p^6$ Mg^{2+}: $1s^2\ 2s^2\ 2p^6$

Na^+ and Mg^{2+} have the same number of electrons/ are isoelectronic and hence their outermost electrons experience the same shielding effect. However, Mg^{2+} has a higher nuclear charge than Na^+. Consequently, the outermost electrons in Mg^{2+} are more strongly attracted by the nucleus.

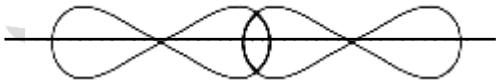
Comments:

- Several students erroneously compared the charges of the two ions, instead of their nuclear charge / proton number. Note that nuclear charge ≠ charge on the ion (e.g. K^+ has a higher nuclear charge than Na^+, K^+ has a higher nuclear charge than Mg^{2+}).
- Students should also note that effective nuclear charge ≠ nuclear charge. Effective nuclear charge is the resultant positive charge experienced by the outermost electrons in a multi-electron atom after taking into consideration shielding effects.
- Students should state clearly that Na^+ and Mg^{2+} are isoelectronic or have the same number of electrons. It is insufficient to state that Na^+ and Mg^{2+} have the same number of outermost electrons or the same number of electronic shells. Having the same number of outermost electrons suggests that the two ions have the same number of outermost electrons but they need not be in the same period; having the same number of electronic shells suggests that the two ions are in the same period but they need not have the same number of outermost electrons.
- A handful of students erroneously wrote that the two ions have approximately/relatively the same shielding effect. Note that the shielding effect is the same as both ions have the same number of electrons.

B1(b)(i) Phosgene, $Cl_2C=O$, has 3 bond pairs and 0 lone pairs of electrons around the central C atom. To minimise electronic repulsion between the bond pairs, the shape of the phosgene molecule is trigonal planar.

Comments:
- Students should clearly state the number of bond pairs AND lone pairs around the central C atom. It is insufficient to write '3 regions of electron density' or '3 bond pairs' as it is unclear if there are any lone pairs around the central C atom.

B1(b)(ii) σ (sigma) bond

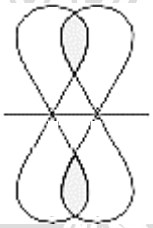


p p

head-on overlap of p orbitals

(show head-on overlap of either s/p orbitals)

π (pi) bond



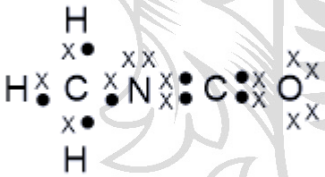
p p

side-to-side overlap of p-orbitals

(accept dotted overlap)

Comments:
- Students should follow the requirements of question and label the diagrams (e.g. type of orbitals and how the orbitals overlap, i.e. head-on or side-to-side).
- As this is a general question on how orbitals overlap to form σ and π bonds, there is no need to refer to the C=O bond in phosgene.

B1(b)(iii)



Comments:
- Students should read the question carefully and draw the dot-and-cross diagram of CH_3NCO, and not any other structures.
- Use only dots '•' and crosses '×' to represent the electrons. Unless otherwise stated by the question, please do not use other symbols e.g. circles, triangles etc.
- Please alternate the use of dots and crosses to represent the electrons of adjacent atoms. For example, in the above answer, '•' is used to represent the electrons on the C atom on the right, and hence '×' should be used to represent the electrons on the N and O atoms bonded to this C atom.
- The dot-and-cross diagram must include all lone pair of electrons in the outermost shell of all atoms in the molecule, e.g N and O.

B2(a)(i) $4H_2O + CrO_4^{2-} + 3e^- \longrightarrow Cr(OH)_3 + 5OH^-$

Comments:
- Students need to recognise that the question clearly stated alkaline medium and only OH^-, not H^+, can appear in the half-equation.
- Students need to be clear on what is the reactant and product in the half equation. Many students ignored the formula of sodium chromate(VI) given in the question and wrongly used Cr^{6+} as the reactant. The product given in the question is solid $Cr(OH)_3$, students should not assume that it is soluble and separate the ionic solid into aqueous ions.

B2(a)(ii) Amount of vanadium reacted = $\frac{0.890}{50.9}$ = 0.01749 mol

Amount of chromate reacted = $\frac{0.230}{1000} \times 50.0$ = 0.0115 mol

amount of vanadium	:	amount of electron	:	amount of chromate
0.01749	:	3	:	1
3		2 x 3 = 6		0.0115
1		2		2

Since 1 mol of vanadium loses 2 mol of electrons, the final oxidation state is <u>+2</u>.

Comments:
- Students should use data to first find amount from the information given in the question, followed by the ratio between the reactants and electrons. This is so as the total amount of electrons lost and gained are the same.
- Students need to recognise that when V loses electrons, the oxidation state increases.

B2(a)(iii)

Element	K	Cr	O
% composition	26.5	35.5	38.0
Molar mass/ g mol^{-1}	39.1	52.0	16.0
Amount in 100 g of sample /mol	$\frac{26.5}{39.1}$ = 0.6777	$\frac{35.5}{52.0}$ = 0.6827	$\frac{38.0}{16.0}$ = 2.375
Mole ratio	1	1	3.5

Hence the ratio of K:Cr:O = 2:2:7

The empirical formula of compound P is <u>$K_2Cr_2O_7$</u>.

Comments:
- Students need to recognise that potassium is represented by symbol K, not P.
- Students should not round up 3.5 to 4 as the difference is too great.
  For eg, x.333 should be multiplied by 3
  eg x.5 should be multiplied by 2

B2(b)(i) Volume of CO_2 = 100 cm^3

Volume of O_2 unreacted = 330 – 100 = 230 cm^3

Hence, volume of O_2 reacted = 400 – 230 = 170 cm^3

Comments:
- Students need to recognise that after reaction, the only gases left are CO_2 and unreacted O_2, as both methane and methanal are burnt completely. Thereafter, the volume of unreacted O_2 and hence the volume of reacted O_2 can be calculated.

B2(b)(ii) $CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$
$HCHO + O_2 \longrightarrow CO_2 + H_2O$

Let x be the volume of methane in cm^3, hence the volume of O_2 reacted with methane is 2x.
Volume of methanal = 100 – x, hence the volume of O_2 reacted with methanal is 100-x

Sum of volume of oxygen reacted = 170 cm^3
$2x + (100 - x) = 170$ cm^3
Solving x = 70 cm^3

Percentage by volume of methane = $\frac{70}{100} \times 100\% = 70.0\%$

Comments:
- Many students wrongly assumed that methane and methanal are equimolar (present in the same number of moles) and wrongly deduced that the 2/3 of the O_2 reacted with methane.

B2(c) Amount of SCN^- = $0.100 \times \frac{22.0}{1000}$ = 0.00220 mol
Amount of Ag^+ unreacted = 0.00220 mol

Amount of Ag^+ reacted with 25.0 cm^3 of H_3AsO_4 = $(1.00 \times \frac{50.0}{1000}) - 0.00220$
= 0.0478 mol

Amount of H_3AsO_4 in 25.0 cm^3 = 0.0478/3 = 0.01593 mol

Amount of H_3AsO_4 in 250 cm^3 = 0.01593 x 10 = 0.1593 mol

Mass of solid H_3AsO_4 = 0.1593 x 141.9 = 22.6 g

Comments:
- Students should not overlook that only 25.0 cm^3 of the original 250 cm^3 H_3AsO_4 solution was used to react with $AgNO_3$.

B3(a) An ideal gas consists of <u>particles of negligible volume compared to the volume of container</u>. The gas particles exert <u>negligible attractive forces</u> on one another.

Comments:
- Students are required to state the two <u>main</u> assumptions of the kinetic theory applied to an ideal gas.
- Students are to mention clearly that the gas <u>particles</u> are of negligible volume. An ideal gas does not have negligible volume, its volume will be the volume of the container.
- Students are reminded to use the generic term “particles” instead of “molecules” as noble gases do not exist as molecules.

B3(b)(i) Total pressure = 0.940 + 0.0729 = <u>1.013 atm</u> > 1 atm
Gas unit <u>will expand</u>.

Comments:
- The question mentioned that the gas bubble contains only $CO_2(g)$ and $H_2O(g)$.
- Students are required to obtain the partial pressures of $CO_2(g)$ and $H_2O(g)$ at 313 K from Table 3.1 to determine the total pressure in the gas bubble and compare to the atmospheric pressure of 1 atm.
- Students should pick up the clue from the question that the gas unit will expand when the total pressure in the gas bubble exceeds that of the atmospheric pressure.

B3(b)(ii) mole fraction of H_2O = 0.0729 / 1.013 = 0.0720

Comments:
- As the gas bubble contains only $CO_2(g)$ and $H_2O(g)$, to find the mole fraction of $H_2O(g)$, students are required to divide the partial pressure of $H_2O(g)$ by the total pressure of $CO_2(g)$ and $H_2O(g)$ present.
- A small number of students wrongly used relative molecular masses in their calculation of mole fraction and should revisit the formula for mole fraction.
- Answer for mole fraction should be expressed in decimals.

B3(b)(iii) $P_{H_2O}\,V = nRT = (m/M)RT$

$m/V = M\,(\frac{1}{RT})\,P_{H_2O}$

$\rho = M(\frac{1}{RT})\,P_{H_2O}$

$= (18)(\frac{1}{8.31 \times 300})(0.0313)(101325)$

$= 22.9\ g\ m^{-3}$

Comments:
- Students are required to convert the values to be used in the ideal gas equation into SI units. The pressure of $H_2O(g)$ given in atm needs to be converted to Pa by multiplying the factor of 101325 (given on the 2nd page of the *Data Booklet*).

B3(b)(iv) mass of CO_2 in gas bubble at 313 K = $1611 \times 2.78 \times 10^{-11} = 4.478 \times 10^{-8}$ g
mass of CO_2 in gas bubble at 300 K = $1736 \times 2.36 \times 10^{-11} = 4.096 \times 10^{-8}$ g

decrease in mass of CO_2 in dough = $4.478 \times 10^{-8} - 4.096 \times 10^{-8} = 3.82 \times 10^{-9}$ g

OR

$m = M(\frac{1}{RT})\,P_{CO_2}V$

mass of CO_2 in gas bubble at 313 K

$= (44)(\frac{1}{8.31 \times 313})(0.940)(101325)(2.78 \times 10^{-11}) = 4.479 \times 10^{-8}$ g

mass of CO_2 in gas bubble at 300 K

$= (44)(\frac{1}{8.31 \times 300})(0.971)(101325)(2.36 \times 10^{-11}) = 4.098 \times 10^{-8}$ g

decrease in mass of CO_2 in dough = $4.479 \times 10^{-8} - 4.098 \times 10^{-8}$
$= 3.81 \times 10^{-9}$ g

Comments:
- To determine the decrease in mass of CO_2 in dough, students need to find the increase in mass of CO_2 in gas bubble, as given in the question.
- To determine the mass of CO_2 at both 300 K and 313 K, students are required to use the density and volume of $CO_2(g)$ at the two temperatures. Then, find the increase in mass of CO_2 in gas bubble.
- Students who did not use the given density and volume had to go through tedious calculations to arrive at the answer for a 1 mark question.

- Students are reminded to use more significant figures and include units in their workings and the final answer should not have a negative sign as the question asked for the "decrease" and not the "change" in mass.
- Certain calculator models showed the calculated answer for the first method to be "0.00000000381" and students should not assume the value is exact as it is likely to have additional decimal places.

B3(c)(i) $\frac{(n_{CO_2})}{(n_{CO_2})_o}$ and hence, (n_{CO_2}) decreases from time = 0 to t min. As more CO_2 diffused into the gas bubble, the amount of $CO_2(g)$ in the gas bubble increases.

Comments:
- From the graph, the dashed line representing $\frac{(n_{CO_2})}{(n_{CO_2})_o}$ is decreasing. Hence, n_{CO_2} in the dough decreases which leads to the increase in the amount of $CO_2(g)$ in the gas bubble.
- Students should note that the command verb of the question is "deduce" and not "state" or "describe". Hence, a brief explanation of how to arrive at the conclusion must be included.

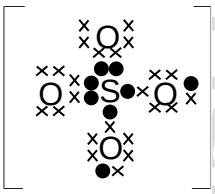
B3(c)(ii) $\frac{(n_{CO_2})}{(n_{CO_2})_o}$ and hence, (n_{CO_2}) remains relatively constant from time = t min onwards.
Since the gas bubble comprises only $CO_2(g)$ and $H_2O(g)$, this implies that the increase in P_T is due to $H_2O(g)$ diffusing into the gas bubble.

Comments:
- From the graph, the dashed line representing $\frac{(n_{CO_2})}{(n_{CO_2})_o}$ remains relatively constant. Hence, n_{CO_2} in the dough remains relatively constant and the increase in the amount of $CO_2(g)$ in the gas bubble becomes negligible.
- Since the volume of the gas bubble remains relatively constant as well, the increase in P_T can only be due to the increase in the amount of $H_2O(g)$ that has diffused from the dough into the gas bubble.
- Students should note that the question required a reason "other than temperature changes" and should not suggest temperature increase or effect of heat on the gases.

Section C

C1(a)(i) Covalent bonds and ionic bonds

Comments:
- Most students recognised that ionic bonds are present in Na_2SO_4 but a significant number of students did not include covalent bonds in their answers. Students are reminded that covalent bonds are found in polyatomic ions such as SO_4^{2-}, NO_3^- and NH_4^+ ions.

C1(a)(ii) $2[Na]^+$  $2-$

Comments:
- Unless otherwise stated in the question, students should only use the symbols "•" and "x" to represent electrons in a 'dot-and-cross' diagram.
- For metal cation, valence electrons initially present in the metal atom have been removed to form the metal cation. Hence, students should not draw any electrons around the metal cation.

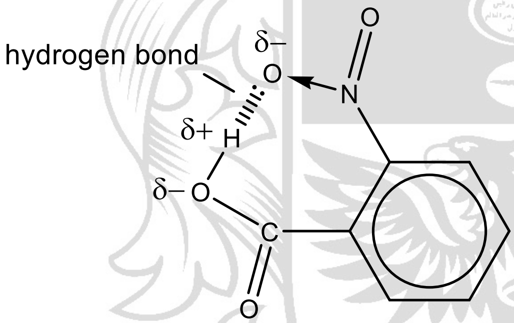
- In SO_4^{2-}, two O atoms accept one electron each, carrying one negative charge each and form single bonds to the central S atom. The other two O atoms each form a double bond to the central S atom. The 'dot-and-cross' diagram is as shown above.
- Use a different symbol to represent the additional electron gained by O to form O^-. For example, if electrons in O is represented by 'x', then use "•" to represent electron gained by O and vice versa.
- As S is in period 3, S can expand octet and accommodate more than 8 outermost electrons. Since a double bond is stronger than a single bond, S forms a double bond with O atom rather than donate a lone pair to O atom to form a dative covalent bond.
- Some students still drew circles for orbits in dot-and-cross diagram. This should not be done.

C1(a)(iii) Both **A** and **B** are ionic compounds with the same cation. In **A**, SO_4^{2-} has the same charge but larger ionic radius than S^{2-} in **B**.

Since $|LE| = k\left|\frac{q_+ \times q_-}{r_+ + r_-}\right|$, |LE| of **B** has a larger magnitude than that of **A**, and more energy is required to overcome the stronger ionic bonds in **B**.

Comments:
- Students need to recognise that for ionic compounds, the first thing to consider for comparing ionic bond strength should be lattice energy (LE).
- Some students spend considerable amount of time to describe LE in words when it can be succinctly expressed as an equation.
- As LE has a negative value, it is ambiguous to use higher or lower to compare LE. Instead, state whether the magnitude of LE is higher/ lower or whether LE is more/ less exothermic when comparing LE of different compounds.
- Note that LE is inversely proportional to interionic distance or sum of ionic radii of the cation and anion. Thus, LE is not directly related to charge density. Students should compare LE based on the charges and radii of the ions and not charge densities of the ions.

C1(b)(i)



To illustrate H-bond, need to show:
- δ+ on protonic H
- δ− on O which the protonic H is attached to
- δ− and lone pair on O interacting with the protonic H
- Dotted line between the protonic H and lone pair on O, labelled as H−bond

Unlike compound **C**, compound **D** has intramolecular hydrogen bonding as the NO_2 and COOH groups are close together.
Thus, it has less extensive intermolecular hydrogen bonding compared to compound **C** and has a lower melting point as less energy is required to overcome these intermolecular hydrogen bonds.

Comments:
- Many students did not show δ− on O which the protonic H is attached to and/or lone pair on O interacting with the protonic H.
- Many students did not specifically draw out the O-H group and use the H atom in the hydrogen bond, and instead vaguely pointed the hydrogen bond to the whole group or even to the O atom, which is incorrect.
- A number of students did not recognise that the N atom in $-NO_2$ has no lone pair of electrons.
- A significant number of students also did not include the proximity of the −COOH and $-NO_2$ groups in **D** in their answers. This is an important point as it explains why intramolecular H bonding occurred in **D** and not in **C**.

- Students are reminded to be concise in their explanations e.g. "**D** has less extensive intermolecular hydrogen bonding while **C** has more extensive intermolecular hydrogen bonding" can be shortened to "**D** has less extensive intermolecular hydrogen bonding than **C**".

C1(b)(ii) Since there is less intermolecular hydrogen bonds to overcome in **D**, it is easier to overcome the solute-solute interactions and solubility is higher.

Comments:
- The dissolution process involves breaking solute–solute and solvent–solvent interactions and forming solute-solvent interaction. As **D** has less extensive intermolecular H bonding, it has weaker solute–solute interactions. Despite the fact that the interactions between **D** and water are weaker than that between **C** and water, the weaker solute–solute interactions in **D** result in **D** having a higher solubility.
- Quite a number of students do not adequately compare and differentiate **C** and **D.** Simply focusing on **D** (solute-solvent bond formation compensates for solute-solute bond breaking) does not explain why **D** is more soluble than **C,** and only serves to explain why **D** is soluble. When answering a question comparing two cases, arguments that make comparison(s) and differentiate the two cases should be used. Commonly, comparative terms like "more/less" and "easier/harder" should be used for this purpose.

C1(c)(i) The electron clouds of molecules can be temporarily distorted, creating instantaneous dipoles. This in turn induces nearby molecules to have oppositely charged induced dipoles, and causes a short-lived electrostatic attraction, which is the instantaneous dipole-induced dipole interaction.

Comments:
- This question was generally well answered, although a number of students only mentioned how the dipoles came about without going on to mention about the attraction between the dipoles.
- A number of students were not able to explain clearly that asymmetry or temporary distortion of electron cloud creates instantaneous dipoles. The inadequate phrasing used might not convey the concept correctly or might be too verbose.

C1(c)(ii) Polarity of Group 17 hydrides: HI < HBr < HC*l* < HF
Going up Group 17, the halogen atoms are increasingly electronegative. Since the H-X electronegativity difference increases going up group 17, the polarity increases as well.

Comments:
- The question required students to arrange the group 17 hydrides in increasing polarity but some students arranged the group 17 hydrides in decreasing polarity instead.
- The group 17 hydrides are covalent and have simple molecular structure. Hence, they do not contain anions/ halide ions but contain halogen atoms covalently bonded to hydrogen atoms.
- Students are reminded to be concise in their answers. There is no need to explain why the electronegativity decreases down the group as the question did not ask for it. Such explanations are required only in questions asking specifically about trends/comparison of electronegativities.

C1(c)(iii) From HC*l* to HBr to HI, the size of the electron cloud of the halogen atom increases significantly, and the strength of instantaneous dipole-induced dipole interactions increase significantly, hence, requiring more energy to overcome. HF has stronger intermolecular hydrogen bonds which require more energy to overcome.

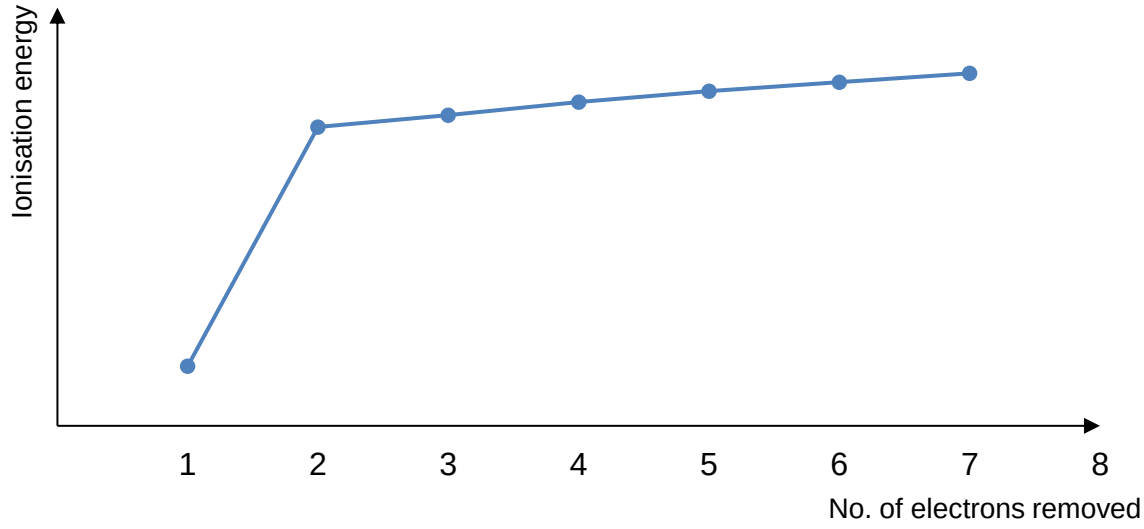
Comments:
- The group 17 hydrides are covalent and have simple molecular structure. Hence, they do not contain anions/ halide ions but contain halogen atoms bonded to hydrogen atoms.

- The strength of instantaneous dipole-induced dipole interactions (id-id) is dependent on number of electrons/ electron cloud size and not dependent on relative molecular mass.
- HC*l*, HBr and HI have both pd-pd interactions and id-id interactions. From HC*l* to HI, while pd-pd interactions decrease (due to decreasing polarity), id-id interactions increase (due to increasing electron cloud size). Since the boiling points increases from HC*l* to HI, this means that the increase in id-id interactions is more significant than the decrease in pd-pd interactions.
- Some students wrote that H bonding occurs between H and F atoms. This is incorrect as the bonding between H and F in a HF molecule is covalent bond. Hydrogen bonding is formed between HF molecules.

C2(a)(i) It is the energy required to remove 1 mole of electrons from 1 mole of gaseous atoms to form 1 mole of singly positively charged gaseous ions.

Comments:
- Some students included the word 'metal' in the definition, implying that only metals can lose electrons. Ionisation energy is applicable to all elements.
- Some students mistakenly left out the word 'gaseous'.
- A small number of students referred ionisation energy as 'energy change'. This is not accurate as ionisation energy is always endothermic.
- There is no need for standard conditions for defining ionisation energy.
- Some students mistakenly wrote 'one mole of singly negatively charged gaseous ions'.

C2(a)(ii)



(Graph showing big increase between 1st and 2nd electron removed, and a general increase over the 7 ionisation energies)

There is a large jump in the 1st and 2nd ionisation energies. This indicates that significantly more energy is needed to remove the 2nd electron. This is because the 2nd electron is located in an inner electronic shell that is nearer to the nucleus and is attracted strongly by the nucleus.

There is an increasing trend as successive electrons are being removed from a more positively charged ion. The more positively charged ion would hold on to the electron more strongly and hence more energy is required for the removal of the electron.

Comments:
- Most students were able to sketch the graph well.
- A small number of students drew log(IE) against number of electrons. They are reminded to read the question carefully.
- A small number of students had the misconception that "With an increasing positive ion, the size of the cation becomes smaller, resulting in stronger electrostatic forces of attraction

between the nucleus and the electrons." This is an example of a wrong cause-and-effect. The size of the electron cloud is smaller due the increase in electrostatic attraction, and not the other way round.

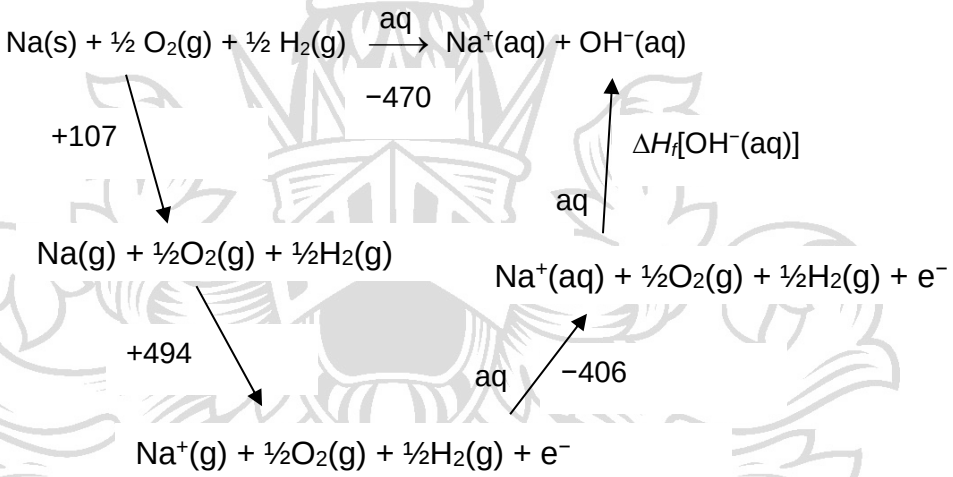
- Students should note that valence electrons refer to electrons in the outermost electronic shell of <u>an atom</u>. Thus, for ions, the electrostatic force of attraction should be described as between the nucleus and outermost electrons. A significant proportion of students did not mention that the increasing trend of ionisation energy is due to the removal of an electron from an <u>increasingly positive charged</u> ion.

C2(a)(iii) O^{2-} : $1s^2\,2s^2\,2p^6$

Comments:

- This question was generally well answered.

C2(b)



Using Hess' Law,
$-470 = +107 + 494 + (-406) + \Delta H_f[OH^-(aq)]$
$\Delta H_f[OH^-(aq)] = -665\ kJ\ mol^{-1}$

Comments:

- Many students left out the electron in the equation for the 1st IE of Na.
- Many students found it challenging to write a balanced equation to represent $\Delta H_f[OH^-(aq)]$. Instead of the correct equation $\frac{1}{2}H_2(g) + \frac{1}{2}O_2(g) + e^- \rightarrow OH^-(aq)$, many students mistakenly wrote it as $H(g) + O(g) + e^- \rightarrow OH^-(aq)$. This is incorrect as hydrogen and oxygen do not exist as atoms in their standard states.
- Students are reminded that it is extremely important to know the definitions of the enthalpy changes well.
- Many students included in their calculations the atomisation energies of oxygen and hydrogen. This is not required as the formation of $OH^-(aq)$ requires the elements to be in their standard states.

C2(c) Amt of NaOH(s) = 1.66/(23.0 + 16.0 + 1.0)
= 0.04150 mol

$q = mc\Delta T$
$= 50 \times 4.18 \times (36.6 - 28.5)$
$= +1692.9$ J

$\Delta H = -q/n$
$= -1692.9 / 0.04150$
$= -40.8$ kJ mol^{-1}

Comments:
- A number of students erroneously included the mass of NaOH in the calculation of q.
- Some students used the wrong equation "$\Delta H = mc\Delta T$" in their calculations, without realising that the units of ΔH is kJ mol^{-1} or J mol^{-1} whereas the units for $mc\Delta T$ is kJ or J.
- Some students overlooked that the reaction releases heat and is thus exothermic. Hence, the sign for ΔH should be negative.
- Students should note that temperature change is the same whether in Celsius or Kelvin and '273' should not be added to try to convert ΔT to Kelvin.

C2(d)(i) $NH_3(g) + \frac{3}{4}O_2(g) \longrightarrow \frac{1}{2}N_2(g) + \frac{3}{2}H_2O(l)$

Comments:
- Many students wrote equations where the coefficient of $NH_3(g)$ is not 1. The definition of standard enthalpy change of combustion is the energy released when one mole of substance is completely burnt in excess oxygen under standard conditions of 298 K and 1 bar.
- A small number of students mistakenly used (g) as the state symbol for H_2O when H_2O is a liquid under standard conditions.

C2(d)(ii) $\Delta H_c^{\ominus} = \frac{3}{2} \times (-285.8) - (-45.9)$
$= -382.8$ kJ mol^{-1}
$= -383$ kJ mol^{-1}

Comments:
- A number of students spent a lot time to draw a complicated energy cycle for this 1 mark question despite not being required by the question.
- There were students who tried to use 'energy taken in to break bond – energy released to form bond', ignoring the standard enthalpy change of formation data given immediately before. This cannot work for this question as H_2O is in liquid state. Recall that the bond energy of a X–Y bond is the average energy required to break 1 mole of the X–Y bonds in the gaseous state.
- Some students did not use the coefficients for H_2O and NH_3 when calculating ΔH_c.
- A significant number of candidates did their calculations using $\Delta H_c^{\ominus} = -45.9 - \frac{3}{2} \times (-285.8)$. They would then obtain a positive value of ΔH_c, which would not make sense as ΔH_c is always exothermic.

C2(d)(iii)

fuel	$H_2(l)$	$NH_3(l)$
temperature at which it is liquified at 1 bar / °C	−253	−33
density / kg m^{-3}	71	682
enthalpy change of combustion / kJ mol^{-1}	−241	−316

In 1 m^3 of $NH_3(l)$, there is 682 kg of $NH_3(l)$.
Amt of $NH_3(l) = 682 \times 10^3 \div 17 = 4.012 \times 10^4$ mol
Energy produced per unit volume from complete combustion of $NH_3(l)$
$= 4.012 \times 10^4 \times 316 \div 1 = 1.27 \times 10^7$ kJ m^{-3}

Comments:
- A number of students did not seem to know how to manipulate the data provided to answer this question.
- Some students used the $\Delta H_c[NH_3(g)]$ calculated in C2(d)(ii) instead of the value given in the table. This is incorrect as the two enthalpy changes involve ammonia in different states.

C2(d)(iv) $NH_3(l)$ produces more energy per unit volume of fuel than $H_2(l)$.

Easier to liquefy gaseous NH_3 as compared to H_2.

$NH_3(l)$ does not ignite readily/ much less flammable than $H_2(l)$ and hence is safe.

World-wide storage and delivery systems are already in place for $NH_3(l)$ since it is used in fertilizer applications. (It is in the top three chemicals transported annually.)

Comments:
- Some students erroneously stated that liquid ammonia releases more energy per unit mass. With some careful calculations, liquid hydrogen releases 120.5 kJ g^{-1} while liquid ammonia releases 18.6 kJ g^{-1}.
- Answers that associated the enthalpy change of combustion (kJ mol^{-1}) with the higher energy efficiency of ammonia were not given credit. The mass or volume of fuel should be considered for practical reasons like storage etc.

C2(e)(i) $NH_2Cl(g) + NH_3(g) \longrightarrow N_2H_4(g) + HCl(g) \qquad \Delta H = -31$ kJ mol^{-1}

$-31 = [BE(N–Cl) + BE(N–H)] – [BE(N–N) + BE(H–Cl)]$
$-31 = [310 + 390] – [BE(N–N) + 431]$

$BE(N–N) = 700 – 431 + 31$
$= +300$ kJ mol^{-1}

Comments:
- This question was generally well answered.

C2(e)(ii) $3N_2H_4(l) \longrightarrow N_2(g) + 4NH_3(g)$

Comments:
- A significant number of students did not read the question carefully and mistakenly wrote an equation involving $N_2H_4(g)$.

C2(e)(iii) The decomposition of hydrazine produces large volumes of gases (from a small volume of liquid hydrazine), leading to the build-up of pressure that can propel the rocket.

Comments:
- A significant number of students did not appreciate the fact that a substance is suitable to be used as a propellent only if there is a large volume of gases produced which causes a build-up of pressure. Many gave environmental concerns which were irrelevant reasons.