

# ASSESSMENT REPORT 2022

## CHM415115 - Chemistry

### Section A

#### Criterion 5

### GENERAL COMMENTS

This section was well-answered by the majority of students.

Most students attempted all questions in this section.

### QUESTION 1

Most students answered this question well, although given the large number of components there were many small errors. A surprising number of students did not answer Question 1 a)

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
1 a)	Anode (-): Cu(s), Cathode (+): Pt(s)  Ions present Anode half-cell: $\text{Cu}^{2+}_{(\text{aq})}$ , $\text{Cl}^{-}_{(\text{aq})}$ Cathode half-cell: $\text{Fe}^{3+}_{(\text{aq})}$ , $\text{Fe}^{2+}_{(\text{aq})}$ , $\text{Cl}^{-}_{(\text{aq})}$  Electron flow: anode to cathode  Ion flow: $\text{Na}^{+}_{(\text{aq})}$ towards cathode $\text{NO}_3^{-}_{(\text{aq})}$ towards anode  Voltmeter placed in external circuit	1  1   1  1  1	1 mark was awarded for each dot point listed. Marks could be awarded for error carried forward in some instances.  Many students did not label all 5 dot points as listed in the question.  Marks were not awarded to students who simply wrote "cations" and "anions" rather than identifying the ions ( $\text{Na}^{+}_{(\text{aq})}$ , $\text{NO}_3^{-}_{(\text{aq})}$ )
1 b)	Anode: $\text{Cu}_{(\text{s})} \rightarrow \text{Cu}^{2+}_{(\text{aq})} + 2\text{e}^{-}$ Cathode: $\text{Fe}^{3+}_{(\text{aq})} + \text{e}^{-} \rightarrow \text{Fe}^{2+}_{(\text{aq})}$ Overall: $\text{Cu}_{(\text{s})} + 2\text{Fe}^{3+}_{(\text{aq})} \rightarrow 2\text{Fe}^{2+}_{(\text{aq})} + \text{Cu}^{2+}_{(\text{aq})}$	1  1	Generally well-answered.  Error carried forward in many instances.



### QUESTION 3

Items a) and b) of this question were generally very well-answered. Most students referred to relative oxidising strength of  $\text{H}_2\text{O}(\text{l})$  and  $\text{Al}^{3+}(\text{aq})$  in their answers to 3 b). In answering item c), the majority of students neglected to nominate an anion for their “salt”. Answers such as “iron salt” were common, or even “Fe(s) salt”.

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
3 a)	Galvanic cells produce electrical energy. Electrolytic cells require/consume/use electrical energy.	1	Students needed to compare the two cell types to receive full marks. Many students only listed the properties of one of the two cells.
3 b)	In an aqueous solution of $\text{Al}^{3+}$ both $\text{Al}^{3+}$ and $\text{H}_2\text{O}$ are present. Water is a stronger oxidant than $\text{Al}^{3+}$ and so it will be reduced in preference to $\text{Al}^{3+}$ . Thus $2\text{H}_2\text{O}(\text{l}) + 2\text{e}^- \rightarrow 2\text{OH}^-(\text{aq}) + \text{H}_2(\text{g})$ will occur at the cathode instead of $\text{Al}^{3+}(\text{aq}) + 3\text{e}^- \rightarrow \text{Al}(\text{s})$ .	1 1 1	Generally very well answered. Students needed to include relevant half-equations for full marks.
3 c)	Identify appropriate salt (e.g. $\text{CuBr}_2$ )  The cation in the salt needs to be a stronger oxidant than water, e.g. $\text{Cu}^{2+}$ .  The anion needs to be a stronger reductant than water, e.g. $\text{Br}^-$ .	1 1 1	Generally poorly answered. Most students neglected to identify a suitable anion. $\text{NaCl}$ was a common, incorrect answer. No marks were deducted for nominating an insoluble salt.

### QUESTION 4

This question was generally not well-answered. Many students were unable to correctly identify the anode and cathode products of the two forms of  $\text{NaCl}$  in item a). In item b), a concerning number of students stated that  $\text{Na}^+(\text{aq})$  would be reduced to  $\text{Na}(\text{s})$  at the cathode in the presence of water.

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
4 a)	Molten $\text{NaCl}$ Anode product: $\text{Cl}_{2(\text{g})}$ Cathode product: $\text{Na}(\text{s})$ or $\text{Na}(\text{l})$  Dilute aqueous $\text{NaCl}$ Anode product: $\text{O}_{2(\text{g})}/\text{H}^+(\text{aq})$ Cathode product: $\text{H}_{2(\text{g})}/\text{OH}^-(\text{aq})$	1 1 1 1	1 mark for each correct answer.  1 mark (maximum) was deducted for any missing/incorrect symbols of state in items a) and b).

4 b)	Anode: $2\text{Cl}^-_{(\text{aq})} \rightarrow \text{Cl}_{2(\text{g})} + 2\text{e}^-$	0.5	Many students incorrectly stated that $\text{Na}^+_{(\text{aq})}$ was reduced at the cathode. i.e.: $\text{Na}^+_{(\text{aq})} + \text{e}^- \rightarrow \text{Na}_{(\text{s})}$
	Cathode: $2\text{H}_2\text{O}_{(\text{l})} + 2\text{e}^- \rightarrow 2\text{OH}^-_{(\text{aq})} + \text{H}_{2(\text{g})}$	0.5	
	Net ionic equation: $2\text{Cl}^-_{(\text{aq})} + 2\text{H}_2\text{O}_{(\text{l})} \rightarrow \text{Cl}_{2(\text{g})} + \text{H}_{2(\text{g})} + 2\text{OH}^-_{(\text{aq})}$	1	However, this mistake led to fairly straightforward net ionic and balanced chemical equations, so students were still able to score up to 2.5/3 on this question, even with such a fundamental error.
	Balanced chemical equation: $2\text{NaCl}_{(\text{aq})} + 2\text{H}_2\text{O}_{(\text{l})} \rightarrow \text{Cl}_{2(\text{g})} + \text{H}_{2(\text{g})} + 2\text{NaOH}_{(\text{aq})}$	1	

## QUESTION 5

Item a) of this question was straightforward and generally answered well. Most students received at least 1-2 marks for item b), although few students received full marks for this question. The most common mistakes were not indicating the electrolyte that was used or selecting an inappropriate material for the anode. Item c) was generally well-answered with most students recognising that the scenario involved differential aeration. It was pleasing to see that most students included relevant equations with their answers.

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
5 a)	Galvanised	1	Marks were not awarded for "sacrificial anode".



## Section B

### Criterion 6

## GENERAL COMMENTS

Overall students performed very well on this section of the Chemistry paper. The marks were generally very high, indicating that students have a firm grasp of this criterion.

As outlined in the individual question comments, improved precision/detail in answering questions may have helped some students. Simple things such as closer attention to reading the question, reading graphs and sketching charts would all help.

## QUESTION 6

Item a) was well-answered by almost all students.

Item b) most gained 1 mark for predicting the correct direction, but to gain a second mark students needed to provide a more detailed answer.

Item c) again most students gained 1 mark for predicting the forward reaction is endothermic, but detail was needed to gain the second mark.

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
6 a)	$K_c = \frac{[\text{NO}_{(g)}]^2[\text{Cl}_{2(g)}]}{[\text{NOCl}_{(g)}]^2}$	2	Writing the fraction upside down – maximum 1 mark  Missing index - maximum 1 mark.
6 b)	The forward reaction favours maximum entropy.  The RHS has more moles of gas, hence there is more <u>disorder</u> on the RHS, and therefore more entropy.	1  1	Similar wording accepted.  Identifies that the forward reaction favours maximum entropy = 1 mark only.  Answer must include a brief explanation of entropy and mention the difference between the number of moles of gas on either side of the equation.  Credit given for mentioning the mole ratio of products to reactants is 3:2.
6 c)	Since the forward reaction favours maximum entropy, the reverse reaction must favour minimum enthalpy.	1  1	Answer of 'endothermic' scores no marks without an attempted explanation.

	Therefore, the reverse reaction is exothermic, meaning the forward reaction is endothermic.		The correct explanation without 'forward reaction is endothermic' scores 1 mark.  Explanations relating to breaking or forming bonds scores no marks.
--	---	--	---

## QUESTION 7

Overall, a challenging question testing a student's understanding of both kinetics and equilibrium in one important reaction.

Item a) most students gained 2 marks out of 4 marks total for predicting the increased reaction rate and the reduced yield. However, gaining full marks required a detailed explanation.

Item b) the concept of using a moderate temperature was missing from many answers. Using the term 'compromise' without outlining that this referred to temperature, and why this was important, scored no marks.

Item c) a fairly straightforward graphing question that gained many marks for most students. Some detail missing or incorrect included not drawing the curves to scale (using the x, 2x and 3x terminology must be complemented with relative scale on the diagram).

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
7 a) i	Higher temperature increases the kinetic energy ( $E_k$ ). Higher $E_k$ means more collisions and a faster reaction.  Any two of the following <ul style="list-style-type: none"> <li>- Since <math>E = \frac{1}{2}mv^2</math>, increased <math>E_k</math> means more collisions.</li> <li>- The higher <math>E_k</math> means more particles with <math>E &gt; E_a</math> and more effective/successful collisions</li> </ul>	1  1	
7 a) ii	Since the forward reaction is exothermic, increased temperature will reduce the yield.  According to LCP, an increase in temperature will favour the reverse/endothermic reaction in order to partially counteract the temperature change.	1  1	A general explanation without reference to LCP or equilibrium quotient will score a maximum of 1 mark.  The extra mark is awarded for answers that demonstrate reasons for the equilibrium favouring the endothermic direction.
7 b)	In practice a compromise / moderate / middle temperature is	1	1 mark for selecting <u>both</u> the compromised temperature and

	chosen which maximises output by combining a high rate at lower yields.		the reason of fast rate at reduce yield. Alternate wording accepted.
7 c)	N <sub>2</sub> – Rapid increase followed by a curved decrease (by x), but not reaching or finishing below the original amount H <sub>2</sub> – Curved decrease 3 times greater than the N <sub>2</sub> reduction (by 3x) NH <sub>3</sub> – Curved increase 2 times greater than the N <sub>2</sub> decrease (by 2x) Flat lines from all three curves from B to C.	1  1  1	Curves need to approximate the increase of decrease by the relevant factors. Simply writing x, 2x or 3x without an approximately correct graph will score 2 of the first 3 marks.

## QUESTION 8

It was unusual to see a calculation question in the C6 paper. This was coupled with an experimental understanding (C2) question. However, most students attempted this question very well.

Item a) was well answered, where most students followed the path of finding the energy, the moles and then the  $\Delta H$ . Some students missed converting it to a negative value.

Item b) was a fairly standard bond energy question, but unfortunately few gained full marks. Most students made at least one error in their calculations. The most common included CO<sub>2</sub> has C=O bonds not C-O bonds, butanol has 3 C-C bonds not 4, the reactant energies must include the oxygen O=O bonds.

Item c) most students answered the first part well, indicating that energy is lost to the surroundings. Unfortunately, most did not know the limitations of the bond energy method, which is based on average energies.

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
8 a)	Heat energy absorbed by water: $E = m\Delta T$ $E = 100 \times 4.184 \times 6.5 = 2720 \text{ J}$	1	Error carried forward accepted within the question.
	Moles of fuel consumed: $n = m/M_r = 0.152/74.12 = 2.051 \times 10^{-3} \text{ mol}$	1	
	Energy change per mole of fuel burnt $\Delta H = E/n = 2720/0.002051$ $= 1326163 \text{ J mol}^{-1}$ $\Delta H = 1326 \text{ kJ mol}^{-1}$	1	



			1 mark for correct equation and 1 mark for correct inclusion of $\Delta H$ .
9 b)		<p>1 Products have lower enthalpy than reactants.</p> <p>1 High activation barrier</p> <p>1 <math>\Delta H</math> Labelled <u>including</u> correct value. No deduction for missing units as they are on the axis already.</p> <p>1 Labelled products and reactants 0.5 marks were deducted for missing states in 9b and 9a.</p>	
9 c)		<p>1</p>	
9 d)	<p>No change to <math>\Delta H</math> as catalyst just lowers activation energy/provides different reaction path/is not consumed.</p> <p><math>\Delta H</math> is related to difference between reactant and product enthalpy and the reaction pathway makes no difference</p> <p>Or <math>\Delta H</math> is independent of reaction pathway as outlined by Hess's law.</p> <p>Or The bonds formed and broken are not different between reactant and products</p>	<p>1 No <math>\Delta H</math> change plus a sensible reason for 1 mark</p> <p>1 Several answers accepted for second mark.</p>	
9 e)	<p>Catalysts increase reaction rate by lowering activation energy.</p> <p>A catalyst provides an alternative mechanism with a lower activation energy, therefore</p>	<p>1 Increased reaction rate plus a sensible reason for 1 mark.</p> <p>1 A detailed explanation is required to achieve the second mark. A distribution curve diagram showing a lower energy</p>	

	<ul style="list-style-type: none"> <li>More particles collide with E greater than or equal to new, lower <math>E_A</math></li> </ul> <p>the frequency of successful/effective collisions increases, increasing the reaction rate</p>		<p><math>E_a</math> and more particles with <math>E &gt; E_a</math>, is an acceptable explanation.</p>
--	--	--	--

## QUESTION 10

Well answered by most students.

Item a) most students gained this mark.

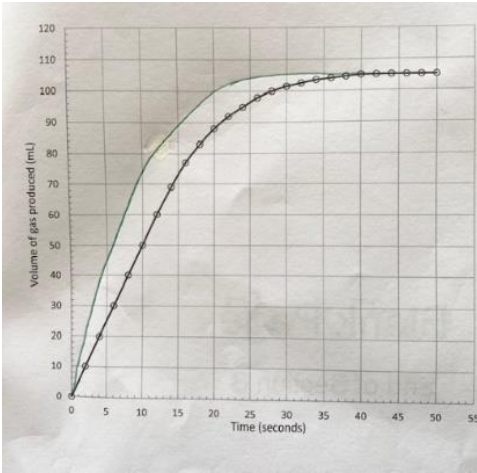
Item b) most students gained this mark. Markers accepted very little variation from the correct value, so those not accurately reading the chart lost an easy mark.

Item c) many students gave an excellent answer relating to increased surface area by crushing the  $\text{CaCO}_3$ . A few students failed to read the question and gave answers relating to temperature and pressure, both scoring zero marks.

Item d) well answered by students.

Item e) was a challenging last question for students. Those students that recognised that the ethanoic acid was a dilute weak acid that poorly ionised gained an immediate 2 marks. It was more challenging to gain the other 2 marks where students needed to relate the acid strength to pH.

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
10 a)	40 seconds	1	
10 b)	Rate = $5.0 \text{ mL s}^{-1}$ Rate = slope = $25/5.0 = 5.0 \text{ mL s}^{-1}$	1	Minor chart reading errors accepted (rate = 4.8 – 5.2) provided clear calculations of slope are shown. 0.5 marks were deducted for missing or incorrect units
10 c)	Reduce particle size/Crushing $\text{CaCO}_3$ into small pieces  This will increase the <u>surface area</u> . This will result in <u>more</u> frequent collisions with the acid, and hence will increase the rate of reaction.  Other alternate answers Increase the concentration of ethanoic acid. <u>More particles per unit volume</u> , <u>more collisions</u> and	1  1	Any wording relating to making smaller pieces accepted.  Explanation must include surface area increase and more collisions (or implied more collisions) to gain the mark.  Three key points needed for 1 mark.

	<p><u>more effective/successful</u> collisions and faster reaction.</p> <p>Add more <math>\text{CaCO}_3</math> and acid. This increases the quantity of gas produced in the same time, <math>\therefore</math> increasing collisions &amp; effective collisions and reaction rate.</p>		<ul style="list-style-type: none"> <li>• Reduce container volume or increase pressure score 0.</li> <li>• Increase temperature score 0.</li> <li>• If this method was chosen, the graph in 10d needed to reflect this choice.</li> </ul>
10 d)	<p>Straight line drawn with steeper slope</p> <p>Endpoint of new line reaches a maximum of 105 mL</p> 	<p> </p> <p> </p>	
10e	<p>Student B is correct since</p> <ul style="list-style-type: none"> <li>• ethanoic acid is a <u>weak dilute</u> (<math>0.1 \text{ mol L}^{-1}</math>) acid.</li> <li>• Ethanoic acid does not fully <u>dissociate /ionise</u> and</li> <li>• the <math>[\text{H}^+] &lt; 0.1 \text{ mol L}^{-1}</math> meaning pH will be <math>&gt; 1</math>.</li> </ul> <p>Student A's calculation is based on a strong acid since</p> <ul style="list-style-type: none"> <li>• <math>\text{pH} = -\log_{10}(0.1) = 1</math></li> </ul>	<p> </p> <p> </p> <p> </p> <p> </p>	<p>Suggesting student A is correct (i.e. ethanoic acid has <math>\text{pH} = 1</math>) scores a maximum of 2 marks.</p> <p>Credit (minor) given to identifying ethanoic acid is monoprotic.</p>

## GENERAL COMMENTS

Overall, most students were able to access parts of most questions. When answering questions, especially those requiring explanation and reasoning, students who did well communicated their knowledge and understanding by addressing the focus or stimulus of the question and using detailed language.

- Students should refrain from using acronyms to answer questions [e.g., Fe (not in relation to iron), IMF, EFOA] etc. In many responses students were using very unusual and unfamiliar acronyms and expecting markers to understand what they were meant to represent.
- Students should avoid the use of personification when addressing trends in the Periodic Table e.g., Al wants/desires/is desperate to lose an electron to become stable. Students are encouraged to read the question carefully and ensure they address the question in their answer by using specific relevant language.
- Students are encouraged to use s, p, d notation rather than shorthand when asked to give electron configurations.
- Students are reminded of the expectation that they must always draw hydrogens to complete structural formula. C- is not the same as C-H.
- Chemistry 415 students should be able to identify specific intermolecular forces e.g., dispersion forces, H-bonding rather than using generic term such as weak intermolecular forces or all-inclusive van der Waals forces.
- Polymer chemistry was not well-understood.

## QUESTION 11

Most students were able to engage with items (a) and (b) (i). However, students found determining the electron configuration for a transition element (ii) challenging.

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
11 a)	$1s^2 2s^2 2p^6 3s^2 3p^5$	1	Writes the correct ground state electron configuration using s, p, d notation.
11 b) i	Copper or Cu	1	Identifies the element as copper.
11 b) ii	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^9$	1	Identifies the electron configuration of $Cu^{2+}$ using s, p, d notation.  Given that the syllabus requires electron configuration of simple ions only rather than transition

			metals, marks were given for $1s^2 2s^2 2p^6 3s^2 3p^6 3d^8 4s^1$
I 1c	<p>These species are all isoelectronic, with the electron configuration <math>1s^2 2s^2 2p^6 3s^2 3p^6</math> hence shielding is constant.</p> <p>Therefore, the radius of these ions only depends on the nuclear charge – the higher the nuclear charge the stronger the electrostatic attraction between the nucleus and the outer electron shell and the smaller the radius.</p> <p>Since calcium has the highest number of protons (20) and sulfur has the least (16), the order of increasing ionic radius is <math>Ca^{2+} &lt; K^+ &lt; Cl^- &lt; S^{2-}</math>.</p>	I I I	<p>Correctly arranges the species in order of increasing ionic radius and explains the order in terms of electron configuration and nuclear charge.</p> <p>Clearly identifies calcium with highest number of protons and sulfur with the least.</p>

## QUESTION 12

Most students were able to engage with items (a) and (b). However, some students did not convert temperature to Kelvin in item (b).

Items (c) polarised students – they either received full marks **or** they did not know how to address the question.

Item (d) – many students misinterpreted the graph as meaning that with increasing pressure the volume of a gas does not change. Many students presented a few statements about properties of an ideal gas **but** did not arrive at a position of whether the gas was ideal or real.

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
I2a	$P_1V_1 = P_2V_2$ $210 \times 12.2 = 1.0 \times V_2$ $V_2 = 2562 \text{ L}$	I	Correctly calculates the volume of air at 1 atm.
I2b	$P_1/T_1 = P_2/T_2$ $210/(273+30) = P_2/(273+16)$ $P_2 = 200 \text{ atm}$	I	Correctly calculates the pressure at 289K.
I2c	$P(O_2) = \%(O_2)/100 \times P_T$ $P(O_2) = 0.21 \times 5.5 = 1.2 \text{ atm.}$ This is less than 1.6 atm, so the diver is not at risk of oxygen toxicity.	I I	<p>Calculates the partial pressure of oxygen gas in air at 5.5 atm <i>and</i> identifies that diver would not be at risk of oxygen toxicity.</p> <p>-0.5 marks for numbers appearing without context.</p>

12d	<p>Particles of an ideal gas have negligible volume and intermolecular forces, and P is inversely proportional to V for an ideal gas (Boyles Law). As a result, the PV product is constant regardless of P for an ideal gas. If the gas shown were ideal then the PV line would be horizontal across the whole range of P values. The gas behaves ideally until very high pressures are reached, then the PV product decreases, indicating that the volume of the gas is lower than expected. The gas is therefore a real gas (not an ideal gas) with intermolecular forces that become significant as pressure increases.</p>	<p>I</p> <p>I</p> <p>I</p>	<p>Identifies that the gas shown is not an ideal gas, referring to:</p> <ul style="list-style-type: none"> <li>• properties of ideal gases, especially negligible intermolecular forces</li> <li>• the relationship between P and V for an ideal gas</li> <li>• referring to the graph, the V decreased disproportionately as P increases for the gas shown at high pressures</li> <li>• the increasing intermolecular forces as P increases for the gas shown</li> </ul> <p>Note that the definition of an ideal gas does not include negligible mass.</p>
-----	--	----------------------------	---

### QUESTION 13

Item a) was mostly answered well.

Item b) was not answered well – students did not recognise atom has to be in gaseous state nor did they refer to the units given in the stimulus table.

Item c) most students did not reference the difference in nuclear charge when explaining the ionisation energy trend anomaly.

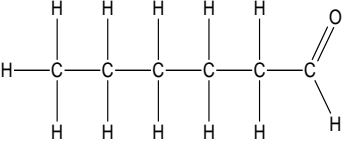
Item d) was answered well.

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
13 a)	<p>Moving from Na to Cl the number of protons in the nucleus increases. Electrons are added to the same valence shell, and the number of full shells between the nucleus and the valence shell is constant, thus shielding of the nuclear charge is (mostly) constant. The electrostatic attraction between the nucleus and the valence shell therefore increases moving across the period, and</p>	<p>I</p> <p>I</p>	<p>Full marks were awarded if student identified that from Na to Cl,</p> <ul style="list-style-type: none"> <li>• the number of protons in the nucleus increases, AND</li> <li>• shielding was ~constant as electrons are being added to the same valence shell.</li> </ul>

	hence the valence shell is pulled closer to the nucleus, reducing the atomic radius moving from Na to Cl.		
13 b)	First ionisation energy is the energy required to remove one mole of electrons from a mole of (neutral) atoms in the gas phase.	1	0.5 marks were awarded if the student referenced gaseous atom OR first electron removed.
13 c)	The electron configuration of Mg is $1s^2 2s^2 2p^6 3s^2$ and the nucleus contains 12 protons. The electron configuration of Al is $1s^2 2s^2 2p^6 3s^2 3p^1$ and the nucleus contains 13 protons. Despite the increase in proton number, the effect of the 3s electrons is to increase the shielding of the 3p electron which is also at a higher energy level, and thus it is easier to remove than expected. As a result, the first ionisation energy for Al is lower than that of Mg.	1  1	Part marks awarded for Identifies the electron configuration (using s, p, d notation) of Al and Mg.  Part marks were awarded for discussion of increased shielding of the 3p electron OR relative stability of the full 3s subshell of Mg.
13 d)	Moving down Group I, while there is an increase in nuclear charge, there is also an increase in the number of full, inner shells between the nucleus and the valence shell. As a result, valence electrons are increasingly shielded from the nuclear charge moving down the Group. This reduces the electrostatic attraction between the nucleus and the valence shell, reducing the first ionisation energy moving down the Group (i.e. the first electron is easier to remove moving down the Group).	1  0.5  0.5	NB: Students are discouraged from attempting to explain ionisation energy using electronegativities.

## QUESTION 14

Most students were able to engage with the naming and drawing of structural formula. Some minor inconsistencies in naming. However, **most** students could not write the empirical formula which was quite surprising/concerning!

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
14		1	
14	1,2-dimethylcyclopentane	1	-0.5 if prefix “di-“ or position of methyl groups was missing
14	Empirical formula: CH <sub>2</sub>	1	Poorly done by most students e.g. C <sub>7</sub> H <sub>14</sub> or CH <sub>7</sub>

### QUESTION 15

Most students recognised the immediate decolouration with Br<sub>2</sub> indicated an unsaturated compound or concluded an alkene. Some students failed to note the molecular formula given meant it could not be an alkyne. However, **many** students did not recognise the significance of the additional stimulus to locate the position of the double bond. Carry through errors were applied to minimise the loss of marks for students further in the question.

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
15 a)	As both isomers react rapidly with Br <sub>2</sub> , an addition reaction must have occurred. Therefore, both isomers are alkenes (unsaturated).	1	Identifies that A and B are unsaturated hydrocarbons, alkenes or contains a double bond.
15 b)	<p>Isomer A gives <b>two products</b> when water is added, so it must be <b>asymmetrical</b> around the double bond. i.e. the double bond is not in the middle of the carbon chain.</p> <p>Isomer B gives <b>one product</b> when water is added, so the double bond must be in ‘the middle’ of the chain, i.e. the chain is <b>symmetrical</b> around the double bond.</p>	1 1	NB: many students repeated the stimulus material to identify an alcohol being formed but not relating any discussion back to the position of the double bond.
15 c)	Isomer A: But-1-ene	1	Draws and names Isomer A – full marks

	$  \begin{array}{ccccccc}  & \text{H} & & \text{H} & & \text{H} & \\  &   & &   & &   & \\  \text{H} & - \text{C} = & \text{C} - & \text{C} - & \text{C} - & \text{H} & \\  & &   & &   & & \\  & & \text{H} & & \text{H} & & \text{H}  \end{array}  $	I	<p>NB: carry through errors from part (b) if location of double bond was incorrect</p> <p>AND carry through errors if structure is incorrect BUT named correctly.</p>
15 c)	<p>Compound D: Butan-2-one (butanone)</p> $  \begin{array}{ccccccc}  & \text{H} & & \text{O} & & \text{H} & & \text{H} & \\  &   & &    & &   & &   & \\  \text{H} & - \text{C} - & \text{C} - & \text{C} - & \text{C} - & \text{H} & & & \\  &   & & & &   & &   & \\  & \text{H} & & & & \text{H} & & \text{H} &  \end{array}  $	I  I	<p>Draws and names Isomer D – full marks</p> <p>NB: carry through errors from item (b) if location of double bond was incorrect</p> <p>AND carry through errors if structure is incorrect BUT named correctly.</p>

## QUESTION 16

Students are encouraged to familiarise themselves with information from their information booklet.

Item (a) was not well-answered with many students incorrectly using the formula for sodium carbonate or identifying the sodium salt of ethanoic acid. Students often ignored states all together.

Item (b) too many students did not give close enough attention to the stimulus information given in item (a) (**in bold**) which informs students that the carboxylic acid had been removed from the product mixture leaving only ethanol and ethyl ethanoate as the **only** organic compounds.

Item (c) was generally answered well. However, of interest was that few students recognised the need for an acid catalyst **or** recognised esterification is an equilibrium reaction. Minor structural irregularities in diagrams were noted.

Item (d) was generally well done. However, some responses suggested that students have a misconception about what constitutes a hydrogen bond. Van der Waals forces were often used to label all intermolecular forces without specific reference to either dispersion forces or hydrogen bonding.

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
16 a)	$  \text{Na}_2\text{CO}_{3(\text{aq})} + 2\text{C}_2\text{H}_4\text{O}_{2(\text{l})} \rightarrow \text{CO}_{2(\text{g})} + \text{H}_2\text{O}_{(\text{l})} + 2\text{NaC}_2\text{H}_3\text{O}_{2(\text{aq})}  $	2	<p>2 marks:</p> <p>Writes a balanced chemical equation, using molecular formulas, for the reaction</p>

			<p>between sodium carbonate solution and ethanoic acid, including states.</p> <p>1 mark: Writes a balanced chemical equation</p> <p>-0.5 mark for no subscripts.</p> <p>NB: Structural formulae was also accepted given many students did not use molecular formulas.</p>
16 b) i	<p>Spectrum A: The compound that gave this spectrum was (unreacted) ethanol. The spectrum contains the characteristic broad absorption around <math>3200-3600\text{ cm}^{-1}</math> of an alcohol OH group (as per information sheet)</p>	<p>1</p> <p>1</p>	<p>Students needed to identify ethanol as the compound and relate characteristic absorption to wavenumber e.g., simply stating -OH grouping was insufficient given their information sheet clearly aids them in determining if it is an alcohol -OH OR carboxylic acid -OH.</p>
16 b) ii	<p>Spectrum B: The compound that gave this spectrum was ethyl ethanoate. The spectrum contains the characteristic C=O absorption at around <math>1750\text{ cm}^{-1}</math>.</p>	<p>1</p> <p>1</p>	<p>Students struggled to correctly identify the ester, with many responses identifying the spectrum as that of a carboxylic acid or an aldehyde/ketone (completely disregarding the stimulus).</p>
16 c)	<p>(See equation below this table)</p> <p>Full marks given for: using structural formulas for all organic compounds, writes an equation for the formation of methyl propanoate and water, AND includes a <math>\text{H}_2\text{SO}_4</math> catalyst.</p>	<p>1</p> <p>1</p> <p>1</p>	<p>-0.5 mark for each error or omission.</p> <p>NB: equilibrium arrows were expected but single arrow was accepted.</p> <p>Part marks were awarded if students incorrectly used methanol and propanoic acid.</p>
16 d)	<p>Alkanes are <b>non-polar</b> molecules with dispersion forces as the only intermolecular force present. These are <b>weak</b> forces, and require little energy to be overcome. Hence ethane has a low boiling point.</p> <p>Alcohols are <b>highly polar</b>, with <b>hydrogen bonding</b> between molecules (in addition to dispersion forces). These</p>	<p>1</p> <p>1</p>	<p>NB: marks were deducted if the response inferred the H-bond was the bond between the O and H within a molecule.</p> <p>Diagrams that showed the formation of hydrogen bonds between hydroxyl groups strengthened the students' responses.</p>



## Section D

### Criterion 8

#### GENERAL COMMENTS:

Overall, this section was well-answered by the majority of students, with about a third of students achieving scores of 36- 45 out of a possible 45 marks.

It was clear that some students had run out of time attempting this as their final section.

Throughout this section, students were penalised -0.5 marks for lack of units in their final answer.

Minor deviations in significant figure use were not penalised in this section. Significant misuse of significant figures were penalised -0.5 marks. Question 19 b) ii was the exception to this, as “to the correct number of significant figures” was stated in the question.

Some students still need to work on logical setting out of their calculations to gain full marks or appropriate part marks for their work.

Students should not skip recording steps in their calculations as these can be vital to gain full marks according to the set mark scheme for the exam.

Combining multiple calculation steps can save time and will gain full marks; however, many errors were seen in doing so.

#### QUESTION 18

The vast majority of students achieved full marks for item a) by employing Hess' Law, but used the wrong  $\Delta H$  value in item b) to find the heat released during combustion.

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
18 a)	Equation 2 was reversed $6 \text{CO}_{2(g)} + 3 \text{H}_2\text{O}_{(l)} \rightarrow \text{C}_6\text{H}_6 + 15/2 \text{O}_{2(g)}$ $\Delta H = + 3267 \text{ kJ}$ Equation 3 multiplied by 3 $3 \text{H}_2(g) + 1 \frac{1}{2} \text{O}_{2(g)} \rightarrow 3\text{H}_2\text{O}_{(l)}$ $\Delta H = 3 \times -286 \text{ kJ} = -858 \text{ kJ}$ Equation 4 multiplied by 6 $6 \text{C}_{(s)} + 6 \text{O}_{2(g)} \rightarrow 6\text{CO}_{2(g)}$ $\Delta H = 6 \times -394 \text{ kJ} = -2364 \text{ kJ}$ $\Delta H = +3267 + -858 + -2364$ $\Delta H = +45 \text{ kJ mol}^{-1}$ .	$\frac{1}{2}$        $\frac{1}{2}$	Students must communicate how they are manipulating their equations either in words, equations or algebraically.
18 b)	$n(\text{C}_6\text{H}_6) = m / M$ $= 39.00/78.11$ $= 0.4993 \text{ mol}$ $E = n \times \Delta H_{\text{combustion}}$		Avoid early rounding 0.04993 <sup>1</sup> 0.500

	$= 0.4993 \times 3267$ $= 1631 \text{ kJ released}$	I	Most students used the heat of formation from a) instead of the heat of combustion as stated in the question.
--	---	---	---

## QUESTION 19

Item (a) Some students were thrown as this was not a combustion empirical formula question as expected/practiced.

Item (b) ii Many students got muddled with the volumes used for sample dilution and did not recognise that the amount of  $\text{Fe}^{2+}_{(\text{aq})}$  in 100.0mL of the diluted sample was the same as in the 10.0 mL of the original water sample.

Students would benefit from drawing a flow-chart or diagram to assist with mole ratios, aliquot fractions, and/or dilutions.

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
19 a)	$\begin{array}{ccccccc} \text{Fe} & : & \text{C} & : & \text{H} & : & \text{O} \\ \text{m} & 24.49 & : & 5.36 & : & 5.40 & : & 64.30 \\ \text{n} & \frac{24.49}{55.85} & : & \frac{5.36}{12.01} & : & \frac{5.40}{1.008} & : & \frac{64.40}{16.00} \\ & 0.4466 & : & 0.4463 & : & 5.357 & : & 4.019 \\ \text{ratio} & \frac{0.4466}{0.4463} & : & \frac{0.4463}{0.4463} & : & \frac{5.357}{0.4463} & : & \frac{4.019}{0.4463} \\ & 1 & : & 1 & : & 12 & : & 9 \end{array}$ Empirical formula = $\text{FeCH}_{12}\text{O}_9$ = $\text{FeCO}_3 \cdot 6 \text{H}_2\text{O}$	I I I	About a quarter of students got the correct empirical formula but were unable to convert this to show the waters of crystallisation/degree of hydration.
19 b) i	$V(\text{average}) = \frac{24.44+24.40+24.42}{3}$ $= 24.42 \text{ mL}$ $n(\text{MnO}_4^-) = c \times V$ $= 0.01053 \times (24.42 \times 10^{-3})$ $= 2.571 \times 10^{-4} \text{ mol}$	I I	4 significant figures in this question
19 b) ii	<b>2 common approaches:</b> $n(\text{Fe}^{2+})_{\text{aliquot}} = 5 \times n(\text{MnO}_4^-)$ $= 1.2857 \times 10^{-3} \text{ mol}$ $n(\text{Fe}^{2+})_{100\text{mL}/\text{simple}} = 1.2857 \times 10^{-3} \times \frac{100}{20}$ $= 6.429 \times 10^{-3} \text{ mol}$ $[\text{Fe}^{2+}]_{\text{simple}} = n / V_{\text{sample}}$ $= 6.429 \times 10^{-3} / 10.0 \times 10^{-3}$ $= 0.643 \text{ mol L}^{-1}$ <b>OR</b> $n(\text{Fe}^{2+})_{\text{aliquot}} = 5 \times n(\text{MnO}_4^-)$ $= 1.2857 \times 10^{-3} \text{ mol}$ $[\text{Fe}^{2+}]_{\text{aliquot}/ 100 \text{ mL}} = n / V_{\text{aliquot}}$ $= 1.2857 \times 10^{-3} / 20 \times 10^{-3}$ $= 0.06428 \text{ mol L}^{-1}$	I I I I (s.f)	Either approach accepted for full marks  Many students ignored either <ul style="list-style-type: none"> <li>the factor of 5 between the aliquot and 100 mL volumetric flask</li> <li>the factor of 10 dilution</li> <li>confused both the above and used them in the incorrect context.</li> </ul> This question should be answered to 3 significant figures

	$[\text{Fe}^{2+}]_{\text{simple}} = 0.06428 \times 100/10$ $= 0.643 \text{ mol L}^{-1}$	          (s.f)	(from the river water sample). This was the 4 <sup>th</sup> mark in this response.
--	---	--------------------------------	---

## QUESTION 20

Item 19 (b) ii Less than 5% of students recognised that the amount of hydrogen ions present in the products was unchanged from the amount in the reactants. The simplest approach to this question.

Most students chose to either calculate the excess sulfuric acid present **or** the moles of nitric acid produced, rather than the sum of both.

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
20 a)	$[\text{AgNO}_3] = 3.26 \text{ g}/100\text{mL}$ $= 32.6 \text{ g/L}$ $= 32.6 / 169.9 \quad (n=m/M)$ $= 0.192 \text{ mol L}^{-1} \quad (3 \text{ s.f.})$ $\approx 0.2 \text{ mol L}^{-1}$		In “show that” questions, students <b>must</b> show their answer to the appropriate number of significant figures <b>before</b> showing it is close to the approximation in the question.
20 b)	$n(\text{H}_2\text{SO}_4) = c \times V$ $= 0.255 \times (25 \times 10^{-3})$ $= 6.38 \times 10^{-3} \text{ mol} \quad (3\text{s.f.})$ $\approx 6 \times 10^{-3} \text{ mol}$		As per above.
20 c)	$n(\text{AgNO}_3)_{\text{given}} = c \times V$ $= 0.192 \times (50 \times 10^{-3})$ $= 9.59 \times 10^{-3} \text{ mol}$ $n(\text{AgNO}_3)_{\text{needed}} = n(\text{H}_2\text{SO}_4)_{\text{given}} \times 2$ $= 6.38 \times 10^{-3} \times 2$ $= 1.275 \times 10^{-2} \text{ mol}$ <p>As <math>n(\text{AgNO}_3)_{\text{given}} &lt; n(\text{AgNO}_3)_{\text{needed}}</math>  <math>\text{AgNO}_3</math> is limiting</p> $n(\text{Ag}_2\text{SO}_4) = n(\text{AgNO}_3)_{\text{limiting}} \times \frac{1}{2}$ $= 9.59 \times 10^{-3} \times \frac{1}{2}$ $= 4.797 \times 10^{-3} \text{ mol}$ $m(\text{Ag}_2\text{SO}_4) = n(\text{AgNO}_3)_{\text{limiting}} \times M$ $= 4.797 \times 10^{-3} \times 311.9$ $= 1.50 \text{ g}$	       	<p>It was necessary to determine the limiting reagent to achieve full marks.</p> <p>Error carried forward was when sulfuric acid was deemed limiting.</p>
20 d)	<p><b>2 approaches:</b></p> $n(\text{H}_2\text{SO}_4) = 6.38 \times 10^{-3} \text{ mol} \quad (\text{from b)})$ $n(\text{H}^+) = 2 \times n(\text{H}_2\text{SO}_4)$ $= 2 \times 6.38 \times 10^{-3}$ $= 1.28 \times 10^{-2} \text{ mol}$		The amount of hydrogen ions in the products is the same as in the reactions as any sulfuric acid that reacted produced nitric acid.

<p>As <math>H^+ + OH^- \rightarrow H_2O</math>  <math>n(OH^-) = n(NaOH) = n(H^+)</math>  <math>= 1.28 \times 10^{-2} \text{ mol}</math>  <math>m(NaOH) = n \times M</math>  <math>= 1.28 \times 10^{-3} \times 39.988</math>  <math>= 0.510 \text{ g}</math></p> <p><b>OR</b>  <math>n(H_2SO_4)_{\text{excess}} = n(H_2SO_4)_{\text{given}} - n(H_2SO_4)_{\text{needed}}</math>  <math>= 6.38 \times 10^{-3} - \frac{9.59 \times 10^{-3}}{2}</math>  <math>= 1.583 \times 10^{-3} \text{ mol}</math>  <math>n(H^+)_{\text{excess}} = n(H_2SO_4)_{\text{excess}} \times 2</math>  <math>= 3.166 \times 10^{-3} \text{ mol}</math>  <math>n(HNO_3)_{\text{produced}} = n(AgNO_3)_{\text{given}}</math>  <math>= 9.59 \times 10^{-3} \text{ mol}</math>  <math>n(H^+)_{\text{total}} = (3.166 \times 10^{-3}) + (9.59 \times 10^{-3})</math>  <math>= 1.276 \times 10^{-2} \text{ mol}</math></p> <p>As <math>H^+ + OH^- \rightarrow H_2O</math>  <math>n(OH^-) = n(NaOH) = n(H^+)</math>  <math>= 1.28 \times 10^{-2} \text{ mol}</math>  <math>m(NaOH) = n \times M</math>  <math>= 1.28 \times 10^{-3} \times 39.988</math>  <math>= 0.510 \text{ g}</math></p>	<p> </p> <p> </p> <hr style="width: 50%; margin: 0 auto;"/> <p> </p> <p> </p> <p> </p> <p> </p>	<p>Full 3 marks were given for EITHER:</p> <ul style="list-style-type: none"> <li>excess <math>H_2SO_4</math> + product <math>HNO_3</math> considered in answer</li> <li>all <math>H^+</math> present in the reagents would be present in the products</li> </ul> <p>2 marks <u>maximum</u> were given for EITHER:</p> <ul style="list-style-type: none"> <li>only excess <math>H_2SO_4</math> considered</li> <li>only <math>HNO_3</math> product considered</li> </ul> <p>Some students incorrectly used <math>K_w</math> in this question. This is not relevant to this question.</p>
---	---	--

## QUESTION 21

Most students were able to write the correct expression for the equilibrium constant. To get full marks, students needed to calculate the concentrations of all species at equilibrium.

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
21 a)	<p>mol.    <math>3A \rightleftharpoons 2B + C</math></p> <p>I        1.2            0            0</p> <p>C       -0.45    (+0.45x2/3) (0.45x1/3)</p> <p>E        0.75            0.3        0.15</p> <p><math>[A] = n/V = 0.75/2 = 0.375 \text{ mol L}^{-1}</math>  <math>[B] = n/V = 0.3/2 = 0.150 \text{ mol L}^{-1}</math>  <math>[C] = n/V = 0.15/2 = 0.075 \text{ mol L}^{-1}</math></p> <p><math>K_c = \frac{[B]^2[C]}{[A]^3}</math></p> <p><math>K_c = \frac{0.150^2 \times 0.075}{0.375^3}</math>  <math>= 0.032 \text{ (no units) @T } ^\circ\text{C}</math></p>	<p>2</p> <p> </p> <p> </p>	<p>“ICE” diagram not required for full marks. Many students would have benefitted from using a technique like this to get their equilibrium values correct.</p> <p>Concentrations could be calculated within the <math>K_c</math> expression solving.</p> <p>Although using the ratio of moles gave the same value (due to the chosen system), this did not receive full marks.</p>
21 b)	<p><math>Q = \frac{[B]^2[C]}{[A]^3}</math></p>		<p>Equilibrium constant and equilibrium quotient are not the same. The expression must be Q not <math>K_c</math> in this response.</p>

$Q = \frac{0.126^2 \times 0.153}{0.600^3}$ $= 0.0112 \text{ (no units) @T } ^\circ\text{C}$ <p><math>Q \neq K_c</math> so the system was not at equilibrium.  <math>Q &lt; K_c</math> indicates that the system would favour the forwards reaction.</p>	<p> </p> <p> </p> <p> </p>	<p>Students should read the question carefully. Some made up their own question in the final part and omitted what was asked – “Is the mixture at equilibrium?” and “predict whether the forward or reverse reaction is favoured”.</p>
---	----------------------------	--

## QUESTION 22

A worrying number of students gave answers to 6 or more significant figures which lost them half a mark. Some others rounded to a single digit. Students need to reflect the number of significant figures used in the question, using scientific notation or changing units where appropriate.

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
22 a)	$n(\text{Cu}) = m/M$ $= 1.87 / 63.55$ $= 0.0294 \text{ mol}$ $n(e^-) = 2 \times n(\text{Cu})$ $= 2 \times 0.0294$ $= 0.0589 \text{ mol}$ $n(e^-) = \frac{It}{F}$ $t = \frac{n(e^-)F}{I}$ $t = \frac{0.0589 \times 96500}{1.55}$ $t = 3660 \text{ s (61 min) (1 h 1 min)}$	<p> </p> <p> </p> <p> </p>	<p>Students who chose to use the formula:</p> $m = \frac{A_r I t}{z F}$ <p>Did not gain full marks unless they showed how they determined z.  Most students who attempted to use this formula recalled it incorrectly.</p>
22 b)	<p>As <math>Q_1 = Q_2</math> when cells are in series</p> $n(e^-)_{\text{cell 1}} = n(e^-)_{\text{cell 2}}$ $= 0.0589 \text{ mol}$ $n(\text{Au}) = n(e^-) / 3$ $= 0.0589 / 3$ $= 0.0196 \text{ mol}$ $M(\text{Au}) = n \times M$ $= 0.0196 \times 197.0$ $= 3.86 \text{ g}$	<p> </p> <p> </p>	<p>Students didn't need to use electrolytic cells in series <math>Q_1 = Q_2</math>. The question could be completed by completing the calculation the same was as in 22 a), just with gold rather than copper.</p> <p>There was a regular 3/2 fraction error when determining the amount of gold directly from amount of copper.</p>

## QUESTION 23

This question was generally well attempted; however, full answers (not the rounded approximation value) from 'show that' questions **must** be used in subsequent questions for full marks

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
23 a)	$n(\text{CO}_2) = m/M$ $= 400.0/44.01$ $= 9.089 \text{ mol}$ $\approx 9 \text{ mol}$	1	For full marks, the answer cannot just be 9 mol from the question. Show the more accurate value determined.
23 b)	$T = 25 + 273$ $= 298 \text{ K}$ $PV = nRT$ $P = \frac{nRT}{V}$ $P = \frac{9.089 \times 8.31 \times 298}{0.605}$ $P = 3.7 \times 10^4 \text{ kPa}$	1	<p>Some students are still forgetting to convert from degrees Celsius to Kelvin.</p> <p>Some students used the incorrect ideal gas constant.</p> <p>Students who gave five or more significant figures lost half a mark.</p>
23 c)	$N(\text{CO}_2) = n \times N_A$ $= 9.089 \times (6.02 \times 10^{23})$ $= 5.47 \times 10^{24} \text{ molecules}$	1	A surprising number of students could not attempt this standard Physical Science calculation.

## QUESTION 24

This is a limiting reagent question and should be approached as such.

Question	Sample answer	Marks	Comments/ considerations for 2022 exam
24 a)	$n(\text{HCl}) = c \times V$ $= 1.086 \times (35 \times 10^{-3})$ $= 0.03801 \text{ mol}$ $\approx 0.04 \text{ mol}$	1	Students should have been working to 4 significant figures in these questions.
24 b)	$n(\text{Ba}(\text{OH})_2) = c \times V$ $= 1.225 \times (25 \times 10^{-3})$ $= 0.03063 \text{ mol}$ $\approx 0.03 \text{ mol}$	1	
24 c)	$n(\text{Ba}(\text{OH})_2)_{\text{needed}} = n(\text{HCl}) / 2$ $= 0.03801 / 2$ $= 0.01901 \text{ mol}$ $n(\text{Ba}(\text{OH})_2)_{\text{excess}} = n(\text{Ba}(\text{OH})_2)_{\text{given}} -$ $n(\text{Ba}(\text{OH})_2)_{\text{needed}}$ $= 0.03063 -$ $0.01901$ $= 0.01163 \text{ mol}$ $\approx 0.01 \text{ mol}$	 ½  ½	Most students purely subtracted the answers from a) and b); however, this was incorrect.

