2022 VCE Chemistry external assessment report

General comments

In Section A, 10 questions elicited 50 per cent or less correct responses. Many of these questions, which required greater depth in understanding of supplied information and the electrochemical series, were redox-based.

In Section B, the questions that were well answered were the question types typically seen on prior examinations. However, it was clear that a number of the questions presented in novel or unfamiliar contexts posed significant problems for many students. A typical example of this type of question was Question 5cii., where only a small number of students were able to make the link between the m/z values and the relative peak heights of the two parent ion peaks, and thus link this information back to the relative molecular mass of the compound.

There were three instances in Section B in which students were specifically directed to provide their response ‘in the box’ indicated.

It became difficult for marks to be awarded when multiple ‘answers’ were provided outside of the box.

Experimental design caused significant issues when presented in unfamiliar/unexpected contexts or situations. A typical example of this is Question 8, where the experimental data indicated that increasing the concentration of a reactant showed a decrease in the quantity and rate of product being formed. When faced with this, many students struggled to think their way through the process and information, and to come up with viable explanations.

This was again shown when students were asked in Question 6c. to state the two factors that could have affected the results obtained. In this situation, it was common to see students falling back on rote-learned responses, which, in light of the information provided in the stem of the question, were not applicable or relevant.

It is highly recommended that students are given plenty of guidance in making sure that they recognise the command terms being used in the question stems and provide responses that are appropriate. A simple example of this was Question 5b., in which the stem indicates that a ‘name’ was required and then a justification of why this name was chosen. A significant number of students were not awarded marks here because they provided a chemical formula and did not include a written name. Likewise, in Question 3bii. students were asked to ‘compare’ the rates, and yet often no direct comparison was made. Subsequently it was not possible for those responses to be awarded full marks.

Redox-related questions were also an area of concern in both Section A, where in many of these questions the majority did not identify the correct responses, and in Section B, in which students often showed confusion in responses. Most commonly this confusion arose from the use of incorrect terminology or inaccurate identification of processes occurring at various sites. Responses to Question 2bi., where students claimed correctly that the electrons flowed from the anode to the cathode, but then contradicted themselves by claiming the anode was negatively charged and/or the cathode was positively charged, could not be awarded full marks.

Collision theory needs very specific language to ensure that full marks are obtained. It is vital that students recognise that they must always refer to the number of successful collisions **per unit time** or the **frequency** of successful collisions. Without this reference to time, no mark can be allocated for showing an understanding of how the **rate** of reaction is affected. In a similar fashion, when discussing the effect of a catalyst or temperature on the rate of reaction, the **proportion** of collisions that are successful must always be emphasised.

Students scored well on most parts of Question 5, the instrumentation question, and a large number of students were able to successfully deduce the correct structures of the molecule in question. A key point that was missed by a lot of students is that what spectra don’t show is often more powerful in justifying what a molecule cannot be than what they do show. For example, the clear lack of the very broad -O-H peak between 2500 cm-1 and 3500 cm-1 is the strongest argument why the molecule in question must be the ester and cannot be the carboxylic acid. Likewise, the lack of splitting in the 1H NMR clearly indicates that the two hydrogen environments are not adjacent to each other, and so the final structure cannot contain anything like a CH3-CH2 group.

Terminology being used by students also needs to be improved. Very general terms are often used when much more specific terminology is appropriate. For example, it was common to see ‘amount’ being used when a student was not specifically addressing the number of mol, and in fact more appropriately either ‘mass’ or ‘concentration’ are terms that would have shown a clearer understanding. In a similar fashion, when students are referring to the strength of intermolecular forces between molecules, they can mistakenly refer to the ‘weak’ dispersion forces causing a higher melting point, where they really need to be discussing the increased or decreased number of these weak forces causing the variation in melting points of different sized or shaped molecules.

Specific information

This report provides sample answers or an indication of what answers may have included. Unless otherwise stated, these are not intended to be exemplary or complete responses.

The statistics in this report may be subject to rounding, resulting in a total of more or less than 100 per cent.

Section A

The table below indicates the percentage of students who chose each option. The correct answer is indicated by shading.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Question | Correct answer | % A | % B | % C | % D | Comments |
| 1 | C | 5 | 1 | **93** | 1 | The purpose of an investigation is stated in the introduction. |
| 2 | A | **65** | 20 | 13 | 2 | Combustion is an exothermic reaction, indicated by ΔH < 0.The energy released during combustion of the fuel is absorbed by the water.While some energy would be released by the water as it cools down, after heating or due to poor insulation, that can only be after the energy released during combustion has been absorbed by the water. |
| 3 | C | 11 | 4 | **78** | 8 | The products of incomplete combustion of compounds containing C and H are carbon monoxide and water.C2H5OH + 3O2 → 2CO + 3H2O |
| 4 | A | **56** | 7 | 24 | 13 | In a fuel cell, the fuel is oxidised at the anode, and O2 is reduced at the cathode.Excess fuel can only be removed at the anode.Since a fuel cell converts chemical energy to electrical energy it provides electrical energy to the load (device) to which it is connected.Power sources are part of electrolytic cells and secondary cells but not fuel cells. |
| 5 | D | 1 | 11 | 20 | **67** | Bias in an experimental investigation would be related to situations where the method of investigation or interpretation of results is managed/influenced to produce preferred data.The validity of an experimental investigation is related to the experimental method and how appropriate it is in addressing the aim of the investigation.The accuracy of an experimental investigation refers to agreement between the outcome of an investigation and the true value.None of these attributes (bias, validity or accuracy) is improved by repeating the investigation multiple times.When an experiment is repeated multiple times using the same method and equipment each time with the same outcome, the investigation is shown to be reliable.An investigation can be reliable without providing an accurate outcome, for example, if the experimental method was not valid.  |
| 6 | B | 8 | **56** | 15 | 21 | Galvanic cells and fuel calls both convert chemical energy to electrical energy and heat energy.Fuel cells are not reversible.Students should be familiar with the energy transformations associated with the different types of electrochemical cells. |
| 7 | A | **78** | 10 | 8 | 4 | The primary structure is the only level of protein structure in which hydrogen bonding is not involved. |
| 8 | D | 14 | 11 | 10 | **65** | In fuel cells, like all electrochemical cells, the reactants must be kept apart to ensure the conversion of chemical energy to electrical energy. In combustion, where chemical energy is converted to thermal energy, the reactants are in direct contact. |
| 9 | B | 5 | **81** | 8 | 5 | Strong performance on this question indicates that students used the information in Table 9 of the Data Book very effectively.Linolenic acid is an omega-3 fatty acid because it has a C=C double bond starting at the third carbon from the end of the hydrocarbon chain; it also contains three C=C double bonds.Arachidonic acid and linoleic are both omega-6 fatty acids but these contain four C=C and two C=C double bonds respectively. |
| 10 | B | 18 | **46** | 18 | 17 | Glycerol is one of the products of the hydrolysis of triglycerides – the other product(s) are fatty acids.Hydrolysis of tripalmitin:C51H98O6 + 3H2O → 3C15H31COOH + C3H8O3n(C3H8O3) = 65.0 g / 92.0 g mol-1 = 0.707 moln(H2O) = 3 x 0.707 = 2.120 molm(H2O) = 2.120 mol x 18.0 g mol-1 = 38.2 g  |
| 11 | B | 13 | **63** | 7 | 17 | Since the forward reaction is exothermic, the products are at lower energy than the reactants – Graphs 3 and 4.It follows that the reverse reaction is endothermic, so the products are at higher energy than the reactants – Graphs 1 and 2.The presence of a catalyst lowers activation energy – Graphs 1 and 3.The profile for the reverse reaction without a catalyst is Graph 2. |
| 12 | A | **42** | 19 | 12 | 27 | In acidic conditions, basic groups (such as NH2) on side groups of the amino acids in enzymes are protonated and become positively charged.Zwitterions require the formation of both a positive and a negative ion on the same molecule – this will not happen in acidic environments.Acids do not esterify enzymes into smaller molecules. Acids do not react with carboxyl groups.There was a strong indication that the effect of pH on proteins was not well understood by the majority of students. |
| 13 | A | **29** | 39 | 10 | 21 | The product at the cathode is produced by the reduction of the strongest oxidising agent present. In this instance, the product of that reduction must be a gas.KI(aq) – oxidants present are K+(aq) and H2O(l).According to the electrochemical series, the stronger oxidant is H2O(l), which will be reduced according to:2H2O(l) + 2e- → H2(g) + 2OH-(aq).NaCl(l) – oxidant present is Na+(l), which would be reduced to Na(l).PbBr2(l) – oxidant present is Pb2+(l), which would be reduced to Pb(s).CuSO4(aq) – oxidants present are Cu2+(aq) and H2O(l).The stronger oxidant Cu2+(aq) would be reduced to Cu(s).Knowledge that oxidants are reduced at the cathode and the effective use of the electrochemical series are expected. |
| 14 | C | 10 | 14 | **53** | 23 | Recharging equation – reverse of discharging reaction – isV3+(aq) + VO2+(aq) + H2O(l) → VO2+(aq) + 2H+(aq) + V2+(aq)The only atom that changes oxidation number(s) in this reaction is V, which decreases during reduction and increases during oxidation.This eliminates options A and B.VO2+ is a product in the recharge, and so cannot be the oxidising agent, therefore option D is not viable.VO2+ is oxidised to VO2+ – oxidation number of V increases from +4 to +5, therefore VO2+ is the reducing agent. |
| 15 | D | 17 | 5 | 22 | **55** | The equation for respiration isC6H12O6(aq) + 6O2(g) → 6CO2(g) + 6H2O(l); ΔH = -2805 kJ mol-1.This an exothermic redox reaction, in which C6H12O6 is oxidised and so loses electrons. Oxidation number of carbon increases from an average of 0 to +4.The production of 2805 kJ of energy requires the consumption of 6 mol O2, so when 1 mol O2 is consumed 2805/6 = 467.5 kJ of energy is released. |
| 16 | B | 9 | **87** | 3 | 2 | 5 C atoms in longest chain, OH is attached to C-2, and Cl is attached to C-3. Hence, 3-chloro-2-pentanol. |
| 17 | B | 15 | **56** | 17 | 11 | Glucose and fructose molecules are structural isomers. Both compounds contain chiral carbons but are not mirror images of each other.Glucose undergoes condensation polymerisation to form glycogen.The disaccharide sucrose is made from the monosaccharides glucose and fructose, but the energy content of each is different due to structural differences. Once monosaccharides form a disaccharide energy is also altered.Since aspartame may be metabolised to the amino acids phenylalanine and aspartic acid as well as methanol, its energy density is slightly higher than sucrose. However, because aspartame is approximately 200 times as sweet as sucrose, very small amounts are needed to produce the required sweetness levels. |
| 18 | C | 22 | 13 | **44** | 20 | Using the relevant parts of the electrochemical series:Ag+(aq) + e- ⇋ Ag(s) +0.80 VSn4+(aq) + 2e- ⇋ Sn2+(aq) +0.15 VSn2+(aq) + e- ⇋ Sn(s) -0.14 VTo match the investigation stated in the stem of this question, one half-cell must contain Sn4+ and Sn2+, while the other half-cell must contain Ag+ and Ag.Hence, options A and B will not produce an electrochemical cell that directly explores the desired investigation. Sn will always be the reductant.Option D does not produce an operational galvanic cell.The half-equations for the Sn4+(aq)/Sn2+(aq) // Ag+(aq)/Ag(s) cell will be:(-) Sn2+(aq) → Sn4+(aq) + 2e-(+) Ag+(aq) + e- → Ag(s) |
| 19 | C | 13 | 8 | **72** | 7 | A chiral C centre is present when a C atom is bonded to four different atoms or groups of atoms.Glycine NH2CH2COOHGlycerol CH2OHCHOHCH2OHButan-2-ol CH3CHOHCH2CH31,1-dichloropropane CH3CH2CHCl2 |
| 20 | B | 34 | **34** | 15 | 17 | Referring to the electrochemical seriesCo2+(aq) + 2e- ⇋ Co(s) -0.28 VZn2+(aq) + 2e- ⇋ Zn(s) -0.76 V2H2O + 2e- ⇋ H2(g) + 2OH-(aq) -0.83 VThe strongest oxidising agent present is Co2+(aq) and the strongest reducing agent is Zn(s).Because these entities are in contact during the reaction, the chemical energy will be converted into heat energy, via the reaction Co2+(aq) + Zn(s) → Co(s) + Zn2+(aq)The equipment clearly did not represent an electrochemical cell as it would require separated half-cells, so options A and D are not feasible.   |
| 21 | D | 26 | 3 | 4 | **66** | I Incorrect – coenzymes may be changed during a catalytic reaction, but enzymes are not changed.II Incorrect – enzymes may require a coenzyme to be effective catalysts, but reactions catalysed by an inorganic catalyst do not.III Correct – coenzymes can act as electron carriers during reaction; they will gain electrons at one site and release those electrons elsewhere.IV Incorrect – coenzymes are organic molecules.V Correct – coenzymes bind to the surface of an enzyme and so allow the substrate access to the enzyme. |
| 22 | D | 9 | 22 | 3 | **65** | Reduction always occurs at the cathode.Electrodes are classified according to whether electrons are produced or consumed. Electrons are consumed, during reduction, at the cathode. |
| 23 | B | 20 | **63** | 5 | 11 | The recharge reaction for the Li ion battery is C6(s) + LiCoO2(s) → LiC6(s) + CoO2(s), so LiCoO2 is consumed, not formed, during recharge.Cations move towards the cathode, which, during discharge, is the (+) electrode, so Li+ ions move towards the positive electrode.The half-equations during the discharge of the lithium-ion battery are:(-) LiC6 → C6 + Li+ + e-(+) CoO2 + Li+ + e- → LiCoO2Raising battery temperature will generally decrease battery life.Discharge is a galvanic process and recharge is an electrolytic process. |
| 24 | D | 18 | 10 | 22 | **50** | The relative interactions between the side groups of the amino acids and the non-polar stationary and polar mobile phases are the key factors influencing retention times.Leu – CH2CH(CH3)2Ala – CH3Asn – CH2CONH2These side groups indicate that Leu – with its larger non-polar side group – will be most strongly attracted to the stationary phase and have the longest retention time.Asn – with its polar side group – will be most strongly attracted to the mobile phase and have the shortest retention time.The order of increasing retention times is Asn < Ala < Leu. |
| 25 | D | 25 | 31 | 12 | **33** | I Incorrect – biodiesel is more hydroscopic because of the polar ester groups in the molecules.II Correct – biodiesel molecules have stronger intermolecular attraction due to dipole-dipole forces and so biodiesel solidifies at a higher temperature than petrodiesel.III Correct – biodiesel is produced from vegetable oils and animal fats; petrodiesel is a fossil fuel extracted from oil produced from decomposing plant and animal material over millions of years.IV Correct – sulfur deposits from decomposing animal protein in crude oil mean that petrodiesel contains more sulfur than biodiesel. This means that more SO2 will be produced in the combustion of petrodiesel compared with biodiesel. |
| 26 | C | 27 | 10 | **57** | 5 | Since the same amount of energy was produced during the calibration of both calorimeters, the relative calibration factors depend on the relative temperature changes.Calorimeter 1, ΔT = 35 – 15 = 20⁰CCalorimeter 2. To determine ΔT the graph for the cooling phase should be extrapolated back to the start; the extrapolation goes back to 27.5⁰C so ΔT = 27.5 – 15 = 12.5 ⁰C.Since Calibration Factor = E / ΔT, it will be higher for Calorimeter 2. |
| 27 | C | 14 | 14 | **46** | 25 | Atom economy = [M(organic product) / M(reactants)] / 100A. Propyne combustion does not produce any organic molecules.B. C3H8 + I2 → C3H7I + HIAtom economy = [169.9 / (44.0 + 253.8)] x 100 = 57 %C. C3H6 + Br2 → C3H6Br2Atom economy = [201.8 / (42.0 + 159.8)] x 100 = 100 %D. 2C3H7NO2 → C6H12N2O3 + H2OAtom economy = [160.0 / (2 x 89.0)] x 100 = 90 % |
| 28 | D | 14 | 32 | 12 | **42** | The 13C spectrum shows two significant pieces of information.* The spectrum, having five signals, suggests that the molecules of the compound have five different carbon environments.
* The signal with a chemical shift close to 140 ppm indicates the presence of C=C according to Table 15 in the Book: R2C=CR2 110-140 ppm.

A. CH3CH2CH(CH3)CH2OH: 5 carbon environments, no C=CB. CH3CH2CH=CHCH2CH2OH: 6 carbon environments, C=C.C. CH$≡$CCH2CH2CH2OH: 5 carbon environments, no C=CD. CH2=CHCH2CH2CH2OH: 5 carbon environments and C=C |
| 29 | A | **54** | 11 | 15 | 19 | The reaction CH4(g) + X2(g) → CH3X(g) + HX(g) is exothermic, indicating that the energy released from the formation of C-X and H-X bonds is greater than the energy required to break C-H and X-X bonds.This suggests that ‘in combination’ C-X and H-X bonds are stronger than C-H and X-X bonds.The two factors that influence bond strength are atomic radius and the relative force of attraction of a nucleus for its outer shell electrons. Numerically this relative attraction of the nucleus of an atom in a molecule for its outer shell electrons, also called core charge or effective nuclear attraction, is the same as the number of outer shell electrons.Consider the alternatives.A. The core charge for C is +4 and the core charge for each of Br, Cl and F is +7. So the key factor is the atomic radius of the halogen atoms, which increases from F to Cl to Br. The greater the distance between the nuclei, the weaker the bond. So bond strength decreases from C-F to C-Cl to C-Br. The strength of bonds from weakest to strongest is C-Br < C-Cl < C-F.B/C. Hydrogen atoms have a much smaller radius than halogen atoms, and so despite the higher effective attraction for outer shell electrons (core charge) on the halogens the longer bond length from C-F to C-Cl to C-Br suggests the C-H bond is not the weakest bond nor weaker than the C-Br bond. Since C is involved in all the bonds, as the radius of the halogen atoms increases the bond strength decreases.The relative strength of bonds is reflected in average bond dissociation energies, shown here in kJ mol-1:C-H 410; C-F 450; C-Cl 330; C-Br 270D. Bond strength is not determined by the group in which atoms appear in the periodic table. |
| 30 | A | **34** | 24 | 23 | 18 | Based on the information supplied in terms of the standard electrode potentials, I2, a reducing agent, is below the oxidising agents BrO3- and HBrO but above HCrO4-, while Br-, a reducing agent, is below the oxidising agent HBrO but above IO3-.So the correct standard electrode potential order is HBrO(aq) + H+(aq) + e- ⇋ ½Br2(aq) + H2O(l)BrO3-(aq) + 6H+(aq) + 6e- ⇋ Br-(aq) + 3H2O(l)2IO3-(aq) + 12H+(aq) + 10e- ⇋ I2(aq) + 6 H2O(l)HCrO4-(aq) + 7H+(aq) + 3e- ⇋ Cr3+(aq) + 4 H2O(l)The cell producing the highest potential difference will be the cell containing the strongest oxidising agent, HBrO(aq), and the strongest reducing agent, Cr3+(aq).i.e., the half-cells HBrO(aq)/Br2(aq) and HCrO4-(aq)/Cr3+aq). |

Section B

Question 1a.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 36 | 64 | 0.6 |

Addition

Question 1b.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 52 | 48 | 0.5 |

CH3CHClCH2CH3

A clear attempt at providing the correct semi-structural representation of 2-chlorobutane was required.

A very common mistake occurred when students provided the structure of 1-chlorobutane, which cannot be formed from the specified reaction.

Question 1c.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 37 | 63 | 0.4 |

NaOH or KOH

Any soluble metal hydroxide was accepted. It should be noted that H2O is not a sufficiently powerful addition reagent for this reaction to proceed at an appreciable rate.

Question 1di.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 64 | 36 | 0.4 |

H2SO4 or H3PO4

Students must be aware that the concentrated or pure forms of these reagents are required, hence any reference to (aq) was not accepted.

Question 1dii.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 36 | 24 | 40 | 1.0 |

CH3CH2CH2OH + HCOOH → HCOOCH2CH2CH3 + H2O

One mark was awarded for the correct identification of the reactants. The second mark was awarded for the correct formation of products based on the reactants used.

Use of equilibrium arrows was accepted, and states were not assessed in this question.

Students sometimes chose the incorrect alcohol and therefore based their response on 2-butanol, which was formed in the previous part of Question 1. Careful reading of the question stem would have avoided this mistake.

Question 1diii.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 39 | 61 | 0.6 |

propyl methanoate

(Correct spelling of chemical names is required.)

Question 2a.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 19 | 34 | 47 | 1.3 |

One mark was awarded for the correct calculation of n(CO2).

P = nRT/V

T = 273 + 28 = 301 K, V = 2.0 x 104 L, R = 8.31 J K-1 mol-1

n(CO2) = 5.17 x 104 mol

The second mark was awarded for the correct calculation of pressure in kPa with three significant figures.

P = 5.17 x 104 x 8.31 x 301 / 20 x 103

 = 12931.7727 x 104 / 2 x 104

 = 6.47 x 103 (kPa)

The most common mistake in the approach being taken occurred when students attempted to calculate the mass of CO2.

Question 2bi.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 26 | 28 | 46 | 1.2 |

One mark was awarded for the clear representation of a downward arrow located in the box required.

The second mark was awarded for justifying their response based on one of:

* Electrons move / are pushed/forced towards the negative electrode/cathode.
* To produce the H2 from H+ electrons are gained, hence electrons must move toward the cathode / 2H+ + 2e- → H2 at the cathode.
* In all cells, the anode produces electrons and the cathode accepts electrons.
* In all cells, electrons flow from the anode to the cathode.

Inclusion of contradictory information such as (-) anode or (+) cathode resulted in failure to achieve this second mark.

Question 2bii.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 70 | 24 | 6 | 0.4 |

One mark was awarded for the clear indication that the membrane allowed H+ ions / protons to pass through in order to complete the circuit.

The second mark was awarded for either of:

* The membrane kept the O2 gas and H2 gas separated.
* The membrane prevented a spontaneous reaction between the products.

The most common incorrect response was that the membrane was being used to separate the reactants.

Question 2ci.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 49 | 51 | 0.5 |

2H2O(l) → 2H2(g) + O2(g)

(States were not assessed in this question.)

Question 2cii.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | 3 | Average |
| % | 19 | 12 | 23 | 46 | 1.9 |

The first mark was awarded for the correct calculation of Q

Q = It

 = 1625 x 75 x 60

 = 7.31x106 C (7,312,500 C)

The second mark was awarded for the correct calculation of n(e-)

n(e-) = Q/F

 = 7.31x106 / 96,500

 = 75.78 mol

The third mark was awarded for the correct calculation of n(H2)

n(H2) = n(e-)/2

 = 75.78/2

 = 37.9 mol

Consequential marks were awarded when students were able to show clear calculations.

Question 3ai.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 26 | 74 | 0.7 |

$$ K= \frac{\left[N\_{2}\right]^{2} \left[H\_{2}O\right]^{6}}{\left[NH\_{3}\right]^{4}\left[O\_{2}\right]^{3}}$$

Question 3aii

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 30 | 70 | 0.7 |

M or mol L-1

Question 3bi.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | 3 | 4 | Average |
| % | 24 | 11 | 14 | 35 | 16 | 2.1 |

The first mark was awarded for stating that the equilibrium constant decreases.

The second mark was awarded for recognising that the forward reaction is exothermic or the back reaction is endothermic.

The third mark was awarded for establishing that the increase in temperature causes the system to partially oppose this stress by causing a shift in the reverse direction, or by stating that the increase in temperature increases the rate of the back reaction more than the rate of the forward reaction.

The fourth mark was awarded for establishing that the [reactants] increases and the [products] decreases.

Many students failed to make a clear indication that both the reactants and products had changed in concentrations.

Question 3bii.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | 3 | Average |
| % | 17 | 21 | 36 | 26 | 1.7 |

The first mark was awarded for stating that the rate of the forward reaction will be greater at the new equilibrium after the temperature increase.

The second mark was awarded for either of

* recognising that the average energy/speed of all particles will increase, hence the frequency of collisions increases
* recognising reactant concentration increases due to the back reaction being favoured, which in turn means a greater number of collisions per unit time.

The third mark was awarded for establishing that there are more particles with energy above the activation energy (EA), and therefore increased probability/proportion/ratio of collisions that are successful.

When students approach any discussion of collision theory, they are always required to include reference to ‘time’ or ‘frequency’, and should also indicate the understanding of relative proportions of particles with specific energies.

Question 3c.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 54 | 46 | 0.5 |

The new line must show a decreased gradient and also show that it reaches the same concentration as the original, but at a time later than .

Question 4ai.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 30 | 70 | 0.7 |

Hydrolysis

Question 4aii.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | 3 | Average |
| % | 55 | 19 | 12 | 14 | 0.9 |

The first mark was awarded for indicating that gelatin contains essential amino acids and therefore these amino acids must be included as part of the diet in order for the synthesis of collagen to occur.

The second mark was awarded for indicating that once gelatin is consumed, it is then broken down via hydrolysis into its constituent amino acids.

The third mark was awarded for indicating that the body can then form the collagen it requires through the condensation of these amino acids to form the polypeptide.

A common mistake was students claiming that the gelatin could just undergo a condensation reaction to reform collagen.

This question also required that chemical processes needed to be mentioned, so only stating general terms like ‘metabolism’ or ‘digestion’ was not sufficient to be awarded marks.

Question 4bi.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 33 | 20 | 47 | 1.1 |

One mark was awarded for stating that vitamin C is sourced through diet or food.

The second mark was awarded for recognising that vitamin C is an essential vitamin and cannot be synthesised in the body.

Question 4bii.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 58 | 42 | 0.4 |

One mark was awarded if the student recognised that vitamin C is preferentially oxidised.

It was not enough for students to just state that vitamin C is an antioxidant, as this did not address the ‘how’ in the stem of the question.

Question 4ci.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 14 | 76 | 10 | 1.0 |

One mark was awarded for stating that the energy content of octane (47.9 kJ g-1) was higher than the energy content of 2-methylpropan-1-ol (36.1 kJ g-1).

The second mark was awarded for recognising that 2-methylpropan-1-ol contains oxygen and is therefore already partially oxidised.

A significant number of students incorrectly tried to claim that the longer carbon chain of octane delivered a greater energy per gram. This is contrary to what is shown in the Data Book, where longer carbon chains clearly show a decrease in the heat of combustion values.

Question 4cii.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | 3 | Average |
| % | 31 | 11 | 17 | 41 | 1.7 |

The first mark was awarded for the correct calculation of the energy released.

Energy released = 2.36 × 36.1 = 85.2 kJ

The second mark awarded for the correct calculation of ΔT.

E = mcΔT, therefore ΔT = E / mc

 = 85.2 x 103 / (500 × 4.18)

 = 40.8 °C

The third mark was awarded for the correct calculation of the final temperature.

Max. Temp = 25.0 + 40.8

 = 65.8 / 66 °C (339 K)

Consequential marks were awarded when students were able to show clear calculations.

Question 5a.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 11 | 89 | 0.9 |

Carboxylic acid (-COOH) or Ester (-COO-R)

Question 5b.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 39 | 41 | 20 | 0.8 |

Ester

The second mark was awarded for the recognition of the **absence** of a broad -O-H (acid) peak between 2500 cm-1 – 3500 cm-1 and therefore it could not be a carboxylic acid.

Question 5ci.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 85 | 15 | 0.1 |

The peak at m/z = 110 is due to the 37Cl isotope or is due to an isotope of chlorine.

Question 5cii.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 97 | 2 | 1 | 0.03 |

One mark was awarded for the recognition that the two peaks at m/z = 108 and m/z = 110 are both parent ions.

The second mark was awarded for the recognition that the relative molar mass is a weighted average of these two parent ions based on their relative abundances.

There were very few high-scoring responses to this question. Most students tried to discuss ‘base peak’ or ‘fragments’ and did not attempt to specifically address how the spectra allowed the determination of the relative molecular mass of the molecule.

Question 5d.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 17 | 38 | 45 | 1.3 |

One mark was awarded for the recognition that there are two different hydrogen environments.

The second mark was awarded for either one of the two following points:

* There are no neighbouring/adjacent hydrogen environments because the peaks are singlets.
* The ratio of the hydrogens in the two environments is 2:3.

Question 5e.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 55 | 10 | 35 | 0.8 |

One mark was awarded for any valid structural drawing with the chemical formulae C3H5O2Cl.

Because of the relative differences in chemical shifts of the two singlets, the second mark was awarded for specific drawing of either of the two compounds shown below.

Question 6a.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 11 | 27 | 61 | 1.5 |

One mark was awarded for the correct calculation of the energy released per 100 g.

Energy = 10.7 x 17 + 5.0 x 37 + 78.7 x 16

 = 181.9 + 185.0 + 1259.2

 = 1.63 x103 kJ

The second mark was awarded for the correct calculation of energy per gram.

Energy per gram = 1.63 x 103 / 100

 = 16.3 ( kJ g-1)

Question 6b.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 28 | 21 | 51 | 1.2 |

ΔT = 3.5⁰C

One mark was awarded for the correct calculation of energy present in a 1.50 g sample.

Energy = CF x ΔT

 = 6.54 x 3.5

 = 22.9 kJ

The second mark was awarded for the correct calculation of energy released per gram.

Energy per gram = 22.9 / 1.50

 = 15.3 (kJ g-1)

Question 6c.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 81 | 18 | 1 | 0.2 |

The two marks available for this question could have been obtained from any two of the following choices that clearly showed why the value for 6a. was higher than 6b.

* Nutrition label based on average quantities. Popcorn is not a homogeneous substance. Sample used in the bomb calorimeter could actually be less energy dense.
* The popcorn may contain water that reduces the amount of combustible material and therefore lowers the calculation of the energy released per g.
* Only one sample of popcorn was analysed using the bomb calorimeter. Need to analyse multiple samples to determine the reliability of the results. Possible that the average result of the multiple samples would be closer to the calculation in 6a.
* Mass lost during transfer from balance.
* If more water was present in the calorimeter than when it was calibrated, then a lower temperature change would occur and produce less of a temperature rise when popcorn is burnt.

Responses that were not accepted were ones in which students stated that ‘heat was lost from the calorimeter’ or ‘poor insulation’. Given that the question stem clearly indicated that the calorimeter was ‘accurately calibrated’, this means that students could not use these simplistic approaches to address this question.

Consequential marks were awarded when students were able to show clear reasoning if their calculated values in 6a. and 6b. showed the opposite trend.

Question 6d.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | 3 | Average |
| % | 24 | 22 | 20 | 33 | 1.6 |

The first mark was awarded for the correct ranking:

cellulose < amylose < amylopectin

(lowest GI) (highest GI)

The second mark was awarded for recognising the inability of the human body to digest cellulose due to a lack of the appropriate enzyme. No hydrolysis occurs (very limited), therefore no effect on glucose production and lowest GI value.

The third mark was awarded for either of:

* recognising that amylose is highly linear and coiled, and so decreases the ability for the enzyme to access sites for the hydrolysis, and hence amylose will have a low rate of glucose production, which results in a low GI value
* recognising that amylopectin is more branched and so increases the ability for the enzyme to access sites for the hydrolysis, hence amylopectin will have a high rate of glucose production, which results in a high GI value.

Question 6e.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 47 | 37 | 16 | 0.7 |

One mark was awarded for showing an understanding that boiling caused denaturation of the enzyme, thereby removing the catalyst and hence slowing the reaction.

The second mark was awarded for showing an understanding that freezing slows the rate of the reaction.

Question 6f.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | 3 | Average |
| % | 29 | 17 | 18 | 36 | 1.6 |

The first mark was awarded for showing an understanding that most of the listed fatty acids were unsaturated or contained C=C bonds.

The second mark was awarded for showing an understanding that these double bonds cause ‘kinks’ in the chains and prevent close packing.

The third mark was awarded for showing an understanding that there are weaker bonds between chains, which in turn will lower the melting point and produce a liquid rather than a solid.

Question 7a.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 23 | 45 | 32 | 1.1 |

C3H8(g) + 5O2(g) → 3CO2(g) + 4H2O(l) ΔH = -2220 kJ mol-1

One mark was awarded for a correctly balanced equation with correct states.

The second mark was awarded for showing correct ΔH (in kJ mol-1), including sign and units.

Question 7b.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 30 | 25 | 45 | 1.1 |

One mark was awarded for a correctly calculated mass of propane.

m(C3H8) = d x V

 = 0.510 x 33.7

 = 17.187 kg

Data Book: 1 g of C3H8 = 50.5 kJ, so 1 kg = 50.5 MJ

The second mark was awarded for the correct calculation of the energy released with units.

Energy released = 50.5 x 17.187 x 103 = 868 MJ / 8.68x105 kJ

Question 7c.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 35 | 65 | 0.7 |

Positive / (+)

Question 7d.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 40 | 22 | 38 | 1.0 |

C3H8 + 6H2O → 3CO2 + 20H+ + 20e-

One mark was awarded for correct reactants and products.

The second mark was awarded for a correctly balanced half equation.

(States were not assessed in this question.)

Question 7e.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 61 | 39 | 0.4 |

Any one of the following responses was awarded the mark.

* C3H8 and O2 / reactants continuously supplied to the C3H8-SOFC, whereas there is a fixed quantity of reactants at the start of the secondary cell life and the amount decreases during discharge.
* Products move out of the fuel cell, whereas in a secondary cell the products remain in contact with the electrodes.
* The SOFC produces greenhouse gases, whereas the secondary cell does not.

Both electrochemical cells were required to be mentioned in the response in order to receive the mark.

Question 8a.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 80 | 20 | 0.2 |

Step 11 in the method requires that the results be concordant, so the data that is obtained will be precise.

Students needed to clearly justify that by using correct experimental technique in a consistent fashion this would also produce a minimal spread in data collected, and lead to good precision.

Question 8b.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | 3 | Average |
| % | 67 | 7 | 7 | 19 | 0.8 |

The first mark was awarded for correctly determining the mass of ethanol in 245 g of wine:

Mass (ethanol in 245 g) = 245.00 × 0.0812 = 19.89 g

The second mark was awarded for correctly determining the total mass of ethanol in beaker 2:

Total mass of ethanol = 19.89 + 5.00 = 24.89 g

The third mark was awarded for correctly determining the initial ethanol concentration:

Initial % by mass = m(ethanol) / m(solution) x 100%

 = 24.89/250 ×100 %

 = 9.96 % m/m

Consequential marks were awarded when students were able to show clear calculations.

Question 8c.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 30 | 70 | 0.7 |

Either of the following responses was accepted.

* concentration of ethanol in beaker
* mass of ethanol added to the beaker

Question 8d.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 43 | 38 | 19 | 0.8 |

One mark was awarded for recognising that less NaOH would be required to neutralise the aliquot as the carboxylic acid formed would have been diluted by the water in the pipette.

The second mark was awarded for recognising that because the NaOH titre was smaller, then the calculated value for the acidity would be lower than the actual value.

Question 8e.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 78 | 22 | 0.2 |

One mark was awarded for the recognition that the oxidation of ethanol produces a carboxylic acid (ethanoic acid).

Question 8fi.

|  |  |  |  |
| --- | --- | --- | --- |
| Marks | 0 | 1 | Average |
| % | 81 | 19 | 0.2 |

One mark was awarded for the recognition that as the concentration of ethanol increases the rate of oxidation decreases.

Question 8fii.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | Average |
| % | 94 | 6 | 0 | 0.1 |

One mark was awarded for recognising any two of the following:

* The ethanol may not all be oxidised to ethanoic acid (i.e., the ethanol may only be oxidised to ethanal).
* It may have been better for the student to analyse the concentration of ethanol after two weeks, instead of performing an acid/base titration.
* The decrease could be the result of the higher ethanol concentration causing less oxygen to be present in the wine solution (altering the solubility), which means the oxidation will occur at a slower rate.
* The rate of oxidation should have increased as the concentration of ethanol increased, based on rate theory.
* The higher concentrations of ethanol may have inactivated the bacteria that was oxidising the ethanol / ethanol acts as a denaturant for enzymes.
* The different masses of wine used will contain different amounts of acid initially, hence will cause a decrease in titre.
* Radical changes (between beaker 2 and 3) to the observed titre compared to the regular/even increase in ethanol content.

Question 9a.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | 3 | 4 | Average |
| % | 27 | 19 | 27 | 20 | 7 | 1.6 |

The first mark was awarded for the correct definition of flashpoint:

* The flash point is the lowest temperature at which a substance (e.g. fuel oil) will give off a vapour that will flash or burn momentarily when ignited / exposed to a flame (IUPAC definition).

Reference to ‘lowest temperature’, ‘vapour’ and ‘source of ignition’ were all required for this mark.

The second mark was awarded for a clear link to the strength of intermolecular forces present:

* As the strength of intermolecular forces increases, the flashpoint increases.

The third mark was awarded for a clear link to the molecular structure:

* The flashpoint is affected by the presence of branching, length of chain, presence/absence of different functional groups / polarity.

The fourth mark was awarded for explaining how the variation between flashpoints was a direct result of the differences between molecules. Students could have addressed any of the following three differences, using specific examples, such as:

* Size – Alkanes are non-polar with weak dispersion forces between molecules. Since the strength of dispersion forces increases as the size of the molecule increases, then the flashpoint increases.
* Branching – Flash point of any methyl heptane (branched isomer) is lower than octane (linear isomer). Increasing the branching decreases the surface area of the molecule, therefore decreases the number/strength of dispersion forces, hence decreases the flashpoint.
* Bonding type – Hydrogen bonding between two carboxylic acids (e.g. propanoic acid) is stronger than the dipole-dipole bonding between two ester molecules (e.g. methyl ethanoate). The carboxylic acids would have the higher flashpoint.

This last mark was the discriminating mark, and high-scoring responses from students were easily shown when they discussed two similar but related molecules and the expected difference in flashpoint.

Question 9b.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Marks | 0 | 1 | 2 | 3 | 4 | Average |
| % | 38 | 18 | 18 | 16 | 10 | 1.4 |

The first mark was awarded when students showed or explained using either written communication or a diagram that the Boltzmann distribution shows the number of particles across the range of kinetic energies (in a gas mixture).

The second mark was awarded when students showed or explained using either written communication or a diagram that the proportion/fraction of particles that react / are involved in collisions that are successful is represented by the region under the curve where energy is equal to or greater than the activation energy (EA).

The third mark was awarded when students showed or explained, using either written communication or a diagram, either:

* that the total area under the curve represents the total number of particles
* a justification for the shape of the peak (i.e. there are a high number of particles with a common kinetic energy and – on either side of this peak – the numbers of particles decreases. These first three marks were often available with a very clearly annotated and well-labelled diagram.

The fourth mark was awarded when students clearly explained that the rate increases with the addition of a catalyst because the activation energy was lowered, via an alternative pathway, and so the proportion of molecules in collisions that are successful increases as indicated by the increased area under the curve.

To get this mark the student must specifically relate the proportion of the particles / successful collisions to the area under the curve. Possible responses include the following.

* In the absence of a catalyst, there is a smaller proportion of H2 and C2H4 particles that have sufficient energies to undergo successful collisions and a greater proportion of H2 and C2H4 particles that do not have sufficient kinetic energies to cause a reaction.
* The catalyst lowers the activation energy (EA) by adopting an alternative energy pathway. Since the activation energy is lowered, there is a greater proportion of H2 and C2H4 particles that have sufficient kinetic energies to have successful collisions. Reactant bonds are broken more frequently. This increases the likelihood of successful collisions and the reaction rate increases.

A significant number of students struggled in their approach to answering this question, which often resulted in them just writing everything they knew about Maxwell-Boltzmann distributions, therefore not specifically addressing the dot points specified in the stem.