



GENERAL COMMENTS

The 2012 Chemistry examination 2 was the last 90-minute examination covering the content of the VCE Unit 4 Chemistry course. From 2013 students will sit a two-and-a-half-hour examination that will cover the content of both Units 3 and 4. There have been some modifications to the study design, and in future years the dot point in Outcome 1 on the industrial production of a selected chemical (which was tested in Question 5 of Section B on this exam) will be assessed by school-assessed coursework rather than by examination. A sample end-of-year exam paper for the new exam is available on the VCAA website.

Students should be reminded that the examination assesses their ability to apply their knowledge and understanding in familiar and new contexts and, in most questions, this requires more than just recalling facts. Students are encouraged to engage in regular revision, particularly attempting practice questions, throughout the year. Skills in question interpretation should be consistently developed across diverse but relevant contexts. Students should aim to maintain familiarity with Unit 3 content by attempting practice questions while progressing through Unit 4; this should make final examination preparation more efficient and effective.

Students' overall performance on Section A of the examination was strong.

Responses for Questions 6, 8 and 9 indicated that there were aspects of equilibrium that were not well understood by many students. These included

- the self-ionisation of water and the nature of 'pure' water; that is, its neutrality (Question 6). Students should understand why the pH of 'pure' water decreases as temperature increases and how it remains neutral
- the effect of dilution on aqueous equilibria and the effects on associated concentration versus time graphs (Question 8)
- how to use numerical data to decide whether a reacting system is at equilibrium. By comparing the magnitude of concentration fraction (reaction quotient) with that of the equilibrium constant, it is possible to deduce which reaction direction will be favoured as a system and hence the relative rates of the forward and reverse reactions as the system moves to re-establish equilibrium (Question 9).

Questions 13, 14 and 15 required students to apply their understanding of energy transfer to and from water.

- In Question 13 many students missed the unit conversions required when dealing with molar enthalpy of combustion (kJ mol^{-1}) and specific heat capacity of water ($\text{J g}^{-1} \text{ } ^\circ\text{C}^{-1}$).
- Question 14 assessed student understanding of heat transfer from a high temperature environment to a lower temperature environment. Students needed to be aware that if water in a calorimeter absorbs energy, so do all the components of the calorimeter.
- Question 15 proved to be the most difficult question in this section of the examination. Students were required to calculate and add together 'the energy required to convert 100 g water to steam at its boiling temperature' and 'the energy required to raise 100 g of water from 20 $^\circ\text{C}$ to its boiling temperature'. Responses suggested that most students calculated one or other of these energies but did not add the two energies.

Section B was divided into questions relating to the 'Industrial Chemistry' Area of Study (Questions 1, 2, 3, 4 and 5) and the 'Supplying and Using Energy' Area of Study (Questions 6, 7, 8 and 9). Once again, the need to be able to 'apply understandings to both familiar and new contexts' was extensively tested.

It is important that students read each question carefully, and consider the information and data supplied. Sometimes a well-learned response is not enough or is not accurate in the context of the question. For example, in answering Question 6cii. most students displayed good understanding of the effect of a catalyst on reaction rate; however, most responses did not relate to the 'context' of the question – that is, why the catalyst was important in the cell 'used to power laptop computers and similar electrical devices'.

The importance of reading the questions carefully and considering the context of each question was also emphasised by the overall performance on Question 9a. Most students competently used their data books to identify the half-equation for the oxidation of Br^- ions to Br_2 at the anode during the electrolysis of molten XBr_2 . However, the correct state, (l) for Br^- , reflective of the molten state, was not used in most half-equations. Students should be reminded that accurate states are an important part of chemical equations.



Students were required to write balanced equation in six instances on this exam: for Questions 2a., 3bi., 6ci., 7ai., 7c. and 9a. Question 2a. was the only one where 50 per cent or more of the students were awarded the mark. However, it was only in Question 9a. that states proved to be a significant assessment factor.

Question 1a., which required students to describe how the rate of the reaction may be measured, proved challenging, mainly because few responses clearly indicated that measurements need to be recorded at different times. This question could be the basis of a useful practical exercise for future students. The rest of the question, dealing with factors that affect reaction rate in terms of collision theory, was generally well handled. Part c. required students to proceed beyond 'energy greater than the activation energy' to gain the second mark.

Question 2b. assessed effective interpretation of energy profiles. In part i., students were expected to refer in some way to the relative energy contents of the reactants and products as indicated on the profiles. Some time-based responses to part ii. suggested that energy profiles are best considered without reference to a horizontal axis. Students should be dissuaded from misconceptions linking the thermochemical nature of reactions to reaction rate. Also the relative magnitudes of the activation energy and ΔH do not distinguish an endothermic reaction from all exothermic reactions.

Question 3 was a 'new context' question for the majority of students. Responses such as 'does not ionise completely' were not fully adequate to answer part a.; 'does not ionise completely in water (aqueous solution)' was much better. Few responses to Question 3bi. linked the two K_a values to the presence of the two carboxyl groups. In Question 3bii. many students identified the removal of H^+ from the second carboxyl group but were unable to produce the 'appropriate' chemical equation. Performance on Question 3c. was surprising, as predicting and explaining the impact of an 'upset' on an equilibrium reaction has been regularly assessed. A number of responses incorrectly stated the direction of the equilibrium shift, suggesting that many considered the addition of the strong acid, $HCl(aq)$, would have the same impact as adding more sorbic acid. In terms of obtaining the correct final answer, Question 3d. was the most challenging question on the exam. The majority of students lost their way at the start of their solution by using the equilibrium law for the equation presented in part c., overlooking that the 'percentage dissociation' of weak acid is based on the ionisation of the weak acid in water. Of those who did use the correct equilibrium law (that for the ionisation of sorbic acid in water), the majority incorporated the assumption that the sorbic acid concentration at equilibrium was the same as its initial concentration. However, the initial concentration of sorbic acid was not supplied, although correct execution through this pathway could lead to two of the three available marks.

Questions 4a. clearly differentiated between students who had a good understanding of the significance of the value of an equilibrium constant and those who did not. Some students' performance on Question 4b. was affected by mathematical errors.

Question 5 assessed aspects of key knowledge associated with the 'chemical of local importance'. Overall performance on this question was strong. Future students should be aware that this is still part of Outcome 2 in the 'Industrial Chemistry' Area of Study from 2013 but will only be assessed as part of school-assessed coursework and will not be assessed as part of the examination.

Questions 6ai. and aii. were generally well done. Question 6b. required students to provide a reason for the difference between the ΔH value calculated from supplied data and the ΔH value determined from the Data Book molar enthalpies of combustion. Question 6cii. required students to provide a reason for using a catalyst that will significantly reduce the activation energy for the cell reaction. Responses to 6b. often lacked consistency with the information supplied in the question or were too general (for example, just stating 'different conditions'), while responses to Question 6c. were generally not consistent with the context of a laptop computer.

Question 7a., which required a balanced equation for the conversion of ethanoic acid to carbon dioxide, revealed an unexpected level of inconsistencies in half-equation balancing. Most responses to Question 7d. did not address the context of the question – the difference between an electrolysis cell and a fuel cell.

Questions 8ai. and 8aii. required accurate application of the data in the table provided and effective unit conversion. A common error in part ii. was incorrect use of, or lack of use of, the 40% to convert the mass of coal to mass of carbon. In Question 8b. students were expected to give two reasons, both of which were causes of the lower energy content. This proved challenging for some students.

Question 9 was well done, but it was important to relate answers to the context of the question when answering part a.



As part of their learning and examination preparation, students are encouraged to discuss the content and context of questions, particularly when reflecting on incorrect answers. There are often key words or expressions in questions (for example, 'laptop computer' in Question 6cii., 'electrolysis cell' in Question 7d. and 'molten' in Question 9a.) that can be missed. Question 7d. is particularly pertinent because most students would have seen a very similar question from a past exam when a 'galvanic cell' was the point of comparison. While students are encouraged to attempt relevant questions from previous exams, they should not let perceived similarities impact on their thorough reading of each question in the examination.

SPECIFIC INFORMATION

Section A – Multiple-choice questions

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

Question	%A	%B	%C	%D	Comments
1	1	1	3	96	
2	80	8	3	9	
3	16	9	8	67	<p>The graph indicates the average kinetic energy of the particles is greater at temperature 2 (T_2) than at temperature 1 (T_1). Hence, T_2 is greater than T_1. The area under the graphs for energy equal to or greater than the activation energy (required for reaction to occur) is larger on the T_2 graph than on the T_1 graph. Hence, at T_2 a greater number of particles have sufficient energy to react (option D).</p> <p>Students should be aware that an increase in reaction with temperature is due to an increase in the proportion of collisions with energy greater than the activation energy.</p> <p>Students who selected options A or C considered the relative 'heights' of the graphs to be indicative of relative temperatures.</p>
4	3	10	81	6	$\text{I}_2(\text{l}) \rightarrow \text{I}_2(\text{s}); \Delta H = -16 \text{ kJ mol}^{-1}$ $\text{I}_2(\text{s}) \rightarrow \text{I}_2(\text{g}); \Delta H = +62 \text{ kJ mol}^{-1}$ <p>Hence $\text{I}_2(\text{l}) \rightarrow \text{I}_2(\text{g}); \Delta H = -16 + 62$ $= +46 \text{ kJ mol}^{-1}$</p>
5	1	8	89	2	$2\text{NO}_2(\text{g}) \rightarrow \text{N}_2(\text{g}) + 2\text{O}_2(\text{g}); \Delta H = -66 \text{ kJ mol}^{-1}$ $\text{N}_2(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow 2\text{NO}_2(\text{g}); \Delta H = +66 \text{ kJ mol}^{-1}$ $\frac{1}{2}\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow \text{NO}_2(\text{g}); \Delta H = +33 \text{ kJ mol}^{-1}$
6	56	4	10	30	<p>At 25 °C the pH of pure water is 7. At 100 °C the pH of pure water is 6.14, implying a higher $[\text{H}_3\text{O}^+]$ than at 25 °C. This higher $[\text{H}_3\text{O}^+]$ at the higher temperature is consistent with the endothermic nature of the self-ionisation of water.</p> $2\text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{OH}^-(\text{aq})$ <p>Option D was surprisingly popular; students should be aware that the pH of water is temperature dependent, and 'pure' water is always neutral and hence the $[\text{H}_3\text{O}^+]$ is equal to the $[\text{OH}^-]$.</p>
7	95	2	2	1	

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Question	%A	%B	%C	%D	Comments
8	11	55	16	18	<p>On dilution, the concentrations of $\text{Fe}^{3+}(\text{aq})$, $\text{SCN}^{-}(\text{aq})$ and $\text{Fe}(\text{SCN})^{2+}(\text{aq})$ all decrease. The system responds to partially oppose this instantaneous decrease in 'total' concentration by moving to increase 'total' concentration; that is, favouring the reaction direction that produces more particles. The equilibrium $\text{Fe}^{3+}(\text{aq}) + \text{SCN}^{-}(\text{aq}) \rightleftharpoons \text{Fe}(\text{SCN})^{2+}(\text{aq})$ moves to the left, so the $[\text{Fe}(\text{SCN})^{2+}]$ continues to decrease as the $[\text{Fe}^{3+}]$ and $[\text{SCN}^{-}]$ both increase.</p> <p>Option A did not show the adjustment in concentrations as the system compensates for the initial decrease in concentrations. Option C suggested the equilibrium moves to the right rather than the left after the dilution. Option D was not consistent with the equilibrium position moving to produce more particles in the larger volume; the $[\text{Fe}(\text{SCN})^{2+}]$ must decrease.</p>
9	44	11	34	11	<p>At 30 seconds, $CF(Q) = \frac{[\text{CO}_2][\text{H}_2]}{[\text{CO}][\text{H}_2\text{O}]}$ $= 2.0 \times 2.0 \div \{0.1 \times 0.1\}$ $= 400$</p> <p>Since $CF(Q)$ is greater than K (210), the system is moving to decrease the concentration fraction and reach equilibrium. Hence, the amounts of products must be decreasing and the amounts of reactants increasing. This means the reverse reaction is favoured and this requires that the rate of the forward reaction is less than the rate of the reverse reaction.</p> <p>The popularity of option A may have been due to errors in calculating the value of the concentration fraction or not recognising the need to compare the concentration fraction with the K value.</p> <p>Students should note that a system can only get to equilibrium or change position of equilibrium if the rates of the forward and reverse reactions are different.</p>
10	12	77	4	6	<p>Since the forward reaction is exothermic, the yield of hydrogen would increase as the temperature decreases; that is, the system responds to the temperature decrease by moving in the direction of the energy-releasing reaction.</p> <p>An increase in pressure (option A) would have no effect on the equilibrium position, or yield of H_2, because the equilibrium has the same number of particles on both sides and cannot shift to oppose the pressure increase.</p>
11	2	3	86	9	<p>A catalyst increases the rate of reaction; hence the graph for the catalysed reaction is initially steeper. A catalyst has no effect on the yield/position of equilibrium, so both graphs level off at the same concentration of H_2.</p>
12	10	2	85	3	<p>$E_a = 200 - 25$ $= 175 \text{ kJ mol}^{-1}$</p> <p>$\Delta H = 125 - 25$ $= -100 \text{ kJ mol}^{-1}$</p>

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Question	%A	%B	%C	%D	Comments
13	26	16	50	8	$n(\text{glucose}) \text{ required} = 1.30 \text{ g} \div 180.0 \text{ g mol}^{-1}$ $= 7.33 \times 10^{-3} \text{ mol}$ Energy released = $n(\text{glucose}) \times \Delta H_c(\text{glucose})$ $= 7.33 \times 10^{-3} \text{ mol} \times 2816 \text{ kJ mol}^{-1}$ $= 20.3 \text{ kJ}$ Energy added to water = $4.18 \text{ J g}^{-1} \text{ K}^{-1} \times m(\text{H}_2\text{O}) \times \Delta T$ $20.3 \times 10^3 \text{ J} = 4.18 \times m(\text{H}_2\text{O}) \times 24.3$ $m(\text{H}_2\text{O}) = 20.3 \times 10^3 \div (4.18 \times 24.3)$ $= 200 \text{ g}$ $= 2.00 \times 10^2 \text{ g}$ Option A is consistent with not converting energy from kJ to J when using the relationship between energy and specific heat capacity of water.
14	12	15	15	57	Adding hot water (90 °C) to the lower-temperature calorimeter (water and components at 15 °C) results in thermal energy being transferred from the hot water to the cold water in the calorimeter and the calorimeter components until all the water and the calorimeter components are at the same temperature (45 °C). The temperature increase (30 °C) of the hot water is less than the temperature decrease (45 °C) of the hot water because of the energy absorbed by the components of the calorimeter. So the energy absorbed by the calorimeter is equal to the difference between the energy lost by the hot water and the energy gained by the cold water. Option A could apply if the calorimeter and the initial 50 g of water were treated as one entity, but there was a clear distinction made in the question, which is why option D best answers the question. Option B does not allow for the fact that, although the water in the calorimeter and the calorimeter components end up at the same temperature, they absorb different amounts of energy because of different heat capacities. Option C suggested that more energy was gained by the calorimeter than was lost by the hot water.
15	32	13	34	21	The energy required to heat 100 g of water from 20 °C to steam at 100 °C is the sum of the energy required to heat 100 g of water from 20 °C to 100 °C and the energy required to convert 100 g of water to steam at 100 °C. The energy required to heat 100 g of water from 20 °C to 100 °C is determined from the specific heat capacity of water. $E = 4.18 \times 100 \times 80$ $= 3.34 \times 10^4 \text{ J}$ $= 33.4 \text{ kJ}$ The energy required to convert 100 g water at 100 °C to steam is determined from the energy required to convert 1 mol – that is, 54.0 kJ mol ⁻¹ . $n(\text{H}_2\text{O}) = 100 \div 18.0$ $= 5.56 \text{ mol}$ $E = 5.56 \times 54.0$ $= 300 \text{ kJ}$ The total energy required to heat 100 g of water from 20 °C to steam at 100 °C $= 33.4 \text{ kJ} + 300 \text{ kJ}$ $= 333.4 \text{ kJ}$ $= 3.33 \times 10^2 \text{ kJ}$ Option A was only the energy required to convert 100 g of water to steam at 100 °C. Option C was only the energy required to heat 100 g of water from 20 °C to 100 °C. Option B reflected subtraction rather than addition of the energies.



Question	%A	%B	%C	%D	Comments
16	16	9	10	65	<p>According to the electrochemical series, $\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s}) \quad E^\circ = 0.80 \text{ V}$ $\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s}) \quad E^\circ = -0.76 \text{ V}$ The strongest oxidant, $\text{Ag}^+(\text{aq})$, will react with the strongest reductant, $\text{Zn}(\text{s})$. Anode (-): $\text{Zn}(\text{s}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2\text{e}^-$ Cathode (+): $\text{Ag}^+(\text{aq}) + \text{e}^- \rightarrow \text{Ag}(\text{s})$</p> <p>Electrons flow from the site of oxidation (anode) to the site of reduction (cathode) – that is, from the Zn electrode to the Ag electrode. Anions migrate towards the anode, Zn^{2+}/Zn half-cell. Cations migrate towards the cathode, Ag^+/Ag half-cell.</p> <p>This question assessed basic understanding of the fundamental principles of operation of galvanic cells.</p>
17	74	9	7	10	<p>The strongest oxidant, $\text{Ag}^+(\text{aq})$, is reduced at the cathode; the strongest reductant, $\text{Zn}(\text{s})$ is oxidised at the anode. Anode (-): $\text{Zn}(\text{s}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2\text{e}^-$ Cathode (+): $\text{Ag}^+(\text{aq}) + \text{e}^- \rightarrow \text{Ag}(\text{s})$</p>
18	4	80	4	11	<p>The predicted voltage, under standard conditions is $E = E^\circ(\text{half-cell containing the oxidant}) - E^\circ(\text{half-cell containing the reductant})$ $= 0.80 - (-0.76)$ $= 1.56 \text{ V}$</p>
19	6	84	9	2	Reduction always occurs at the cathode.
20	12	64	6	18	<p>At this stage, fuel cells are not a cheap source of electricity, therefore option B was correct.</p> <p>Fuel cells are quiet because they do not involve combustion but rather a quiet chemical to electrical energy conversion. Most fuel cells are hydrogen-oxygen fuel cells in which the only product is water. So the use of a hydrogen-oxygen fuel cell as an energy source instead of the combustion of a carbon based fuel will reduce emissions of carbon dioxide.</p>

Section B – Short-answer questions

Question 1a.

Marks	0	1	Average
%	80	20	0.2

Acceptable responses needed to refer to

- measuring the mass (loss of mass) of the beaker and contents over a time interval
- measuring the mass/volume of CO_2 produced over a time interval
- plotting the mass loss of beaker and contents, or mass/volume of CO_2 produced against time.

Students were expected to state the quantity being measured and indicate that it was measured at different times.

Responses such as ‘measure the rate of production of CO_2 ’ did not address the ‘how’ component of the question. ‘Measure the time taken for all the CaCO_3 to react’ was an inappropriate response since CaCO_3 was in excess in beaker B in experiment 2.

Question 1bi.

Marks	0	1	Average
%	22	78	0.8

Acceptable responses included

- surface area
- particle size of CaCO_3 .

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Question 1bii.

Marks	0	1	2	Average
%	9	12	79	1.7

Beaker A, because of the higher concentration of HCl. This will increase the frequency (number) of collisions between reactant particles/successful collisions/fruitful collisions/collisions with energy greater than activation energy.

One mark was awarded for recognising that the increased concentration of HCl was the reason why the rate was higher in Beaker A. The second mark was awarded for recognising the increase in frequency of collisions between reactants.

Students should be careful about using the term ‘proportion of successful collisions’. An increase in the ‘proportion’ of successful collisions occurs if there is an increase in temperature or a decrease in activation energy.

Question 1c.

Marks	0	1	2	Average
%	21	42	37	1.2

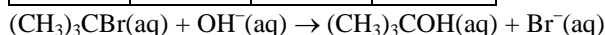
Only collisions with energy equal to or greater than the activation energy for the reaction can result in reaction. Chemical reaction requires breaking of bonds in the reactant particles; this requires collisions to have energy greater than or equal to the activation energy, or the reactant particles must collide with the correct orientation.

One mark was awarded for recognising that only collisions with energy $> E_A$ can lead to reaction. The second mark was awarded for linking the activation energy to the energy needed to to break the bonds in the reactants or stating that particles must also collide with correct orientation/equivalent explanation.

Most students were aware that only collisions with energy greater than the activation energy lead to reaction. Why that was the case (bond breaking) or other factors at play (orientation) were less well recognised.

Question 2a.

Marks	0	1	Average
%	28	72	0.7



Some students who did not receive the mark for this question simply wrote down all of the species shown on both sides of the step 1 and step 2 equations and did not provide a simplified equation.

Question 2bi.

Marks	0	1	Average
%	36	64	0.7

Step 1, because the energy (enthalpy) of the products, $[(\text{CH}_3)_3\text{C}^+, \text{Br}^-]$, is higher than that of the reactant $(\text{CH}_3)_3\text{CBr}$.

Students were expected to refer to the information provided on the profile rather than just the learned definition of endothermic reaction. The reason that ‘energy is absorbed’ in an endothermic reaction is because the enthalpy of the products is higher than the enthalpy of the reactants.

Some good responses linked the profile information to relative energies required for bond breaking and released in bond formation. However, although the argument that an endothermic reaction is one for which the activation energy is greater than the magnitude of the ΔH is an accurate description, it is not a distinguishing factor as it can also apply to some exothermic reactions.

Question 2bii.

Marks	0	1	2	Average
%	19	24	58	1.4

Step 1, because it has the higher activation energy or because a smaller proportion of the collisions between reactant particles will result in reaction.

Some students overlooked the clear difference in activation energy for the two reactions. Many students assumed that the horizontal axis was ‘time’ and endeavoured, incorrectly, to relate reaction rate to the horizontal distance between the



reactants and the products. The point of an energy profile is to show the relative energies (enthalpies) of reactants and product. A detailed energy profile will have a meaningful vertical scale but not a horizontal scale.

Some students mistakenly believed that because a reaction is endothermic it must occur at a slower rate. Students should be aware that the terms ‘exothermic’ and ‘endothermic’ do not provide an indication of reaction rate.

Question 3a.

Marks	0	1	Average
%	26	74	0.8

A weak acid (any one of)

- does not completely ionise in water
- only partially ionises (dissociates) in water
- does not easily donate protons in water.

Many students defined a weak acid as having a higher pH than a strong acid. This would only apply in aqueous solutions, of the same concentration, of both acids. A 0.0001 M solution of hydrochloric acid, a strong acid, has a higher pH (4.0) than a 1 M solution of ethanoic acid, a weak acid, (2.4).

Statements such as ‘a weak acid does not completely ionise’ without mentioning water (or an aqueous solution of the acid) were too vague, given that in the presence of a stoichiometric quantity of a strong base, a weak acid may be expected to fully ionise; for example, the determination of the ethanoic acid content of vinegar by titration with NaOH(aq). Students should also be aware that an aqueous solution of a weak acid is more ionised at lower concentration.

Weak acids have low K_a values because of the limited ionisation of the acids in aqueous solution.

Question 3bi.

Marks	0	1	Average
%	55	45	0.5

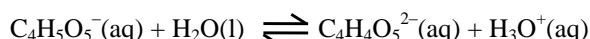
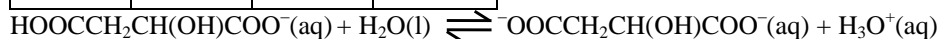
Because malic acid (any one of)

- is a diprotic acid
- is able to donate two protons (H^+)
- contains two carboxyl groups
- undergoes two-stage ionisation.

Most students did not relate the two K_a values to the ability to donate two protons – that is, that the acid is diprotic. Given that students should be aware that the carboxyl group in carboxylic acids is the source of their acidity, more responses were expected to refer to the presence of two carboxyl groups on malic acid molecules. Some students incorrectly related the ability to donate two protons to the presence of $-OH$ and $-COOH$ groups in the molecule rather than two $-COOH$ groups.

Question 3bii.

Marks	0	1	Average
%	73	27	0.3



Some students who recognised the intent of the question did not provide an ‘appropriate’ chemical equation. Many students recognised that the second K_a value referred to the ‘other’ carboxyl group but provided an equation for the ionisation of that group on the malic acid molecule rather than the ion formed in the equation for the first K_a value. Others wrote an equilibrium law equation, which was often accurate, for the second ionisation; however, the question clearly asked for a chemical equation.

When writing equations for equilibrium reactions, students must remember to include equilibrium arrows.

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Question 3c.

Marks	0	1	2	Average
%	41	28	31	0.9

The concentration of sorbic acid would increase because the added HCl reacts with $\text{OH}^-(\text{aq})$ /reduces the $[\text{OH}^-]$, thus causing the reaction (position of equilibrium) to shift to the right to partially oppose the change.

Although there were many excellent responses to this question, overall it was not handled as well as might have been expected. While the sorbate/sorbic acid equilibrium may be unfamiliar to students, it was a relatively fundamental application of Le Chatelier's principle.

Some students argued that the added acid reacted with $\text{OH}^-(\text{aq})$ to produce H_2O and the increased concentration of water was the reason the equilibrium shifted to the right. However, the concentration of water in an aqueous solution is effectively constant. Other students suggested the given equilibrium shifted to the right because the added acid reacted with the sorbate ion. This is not consistent with Le Chatelier's principle. There may be an argument for reaction of the sorbate ion with added acid, but only as a competing equilibrium to the one provided.

Arguments for a decrease in sorbic acid concentration were unexpectedly common, suggesting that many students considered that adding the strong acid, $\text{HCl}(\text{aq})$, would have the same effect as adding more sorbic acid.

Question 3d.

Marks	0	1	2	3	Average
%	72	8	19	1	0.5

There were a number of ways to calculate the percentage required, as can be seen below.

The long way

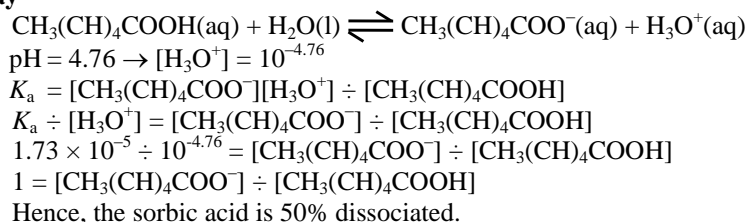
$$\begin{aligned} \text{CH}_3(\text{CH})_4\text{COOH}(\text{aq}) + \text{H}_2\text{O}(\text{l}) &\rightleftharpoons \text{CH}_3(\text{CH})_4\text{COO}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq}) \\ \text{pH} = 4.76 \rightarrow [\text{H}_3\text{O}^+] &= 10^{-4.76} = 1.738 \times 10^{-5} \text{ M} \\ &= [\text{CH}_3(\text{CH})_4\text{COO}^-]_{\text{eq}} \\ K_a &= \frac{[\text{CH}_3(\text{CH})_4\text{COO}^-]^2}{[\text{CH}_3(\text{CH})_4\text{COOH}(\text{aq})]} \\ 1.73 \times 10^{-5} &= (1.73 \times 10^{-5})^2 \div [\text{CH}_3(\text{CH})_4\text{COOH}] \text{ or } 1.73 \times 10^{-5} = (10^{-4.76})^2 \div [\text{CH}_3(\text{CH})_4\text{COOH}] \\ [\text{CH}_3(\text{CH})_4\text{COOH}]_{\text{eq}} &= (10^{-4.76})^2 \div 1.73 \times 10^{-5} \\ &= 1.746 \times 10^{-5} \text{ M} \\ \text{Initial } [\text{CH}_3(\text{CH})_4\text{COOH}] &= [\text{CH}_3(\text{CH})_4\text{COO}^-]_{\text{eq}} + [\text{CH}_3(\text{CH})_4\text{COOH}]_{\text{eq}} \\ &= 1.738 \times 10^{-5} + 1.746 \times 10^{-5} \\ &= 3.48 \times 10^{-5} \text{ M} \\ \% \text{ dissociation} &= \left\{ \frac{[\text{CH}_3(\text{CH})_4\text{COO}^-]_{\text{eq}}}{[\text{CH}_3(\text{CH})_4\text{COOH}]_{\text{initially}}} \right\} \times 100 \\ &= (1.738 \times 10^{-5} \div 3.48 \times 10^{-5}) \times 100 \\ &= 50\% \text{ (49.9\%)} \end{aligned}$$

The more intuitive way

$$\begin{aligned} \text{CH}_3(\text{CH})_4\text{COOH}(\text{aq}) + \text{H}_2\text{O}(\text{l}) &\rightleftharpoons \text{CH}_3(\text{CH})_4\text{COO}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq}) \\ \text{pH} = 4.76 \rightarrow [\text{H}_3\text{O}^+] &= 10^{-4.76} \\ K_a &= \frac{[\text{CH}_3(\text{CH})_4\text{COO}^-][\text{H}_3\text{O}^+]}{[\text{CH}_3(\text{CH})_4\text{COOH}(\text{aq})]} \\ 1.73 \times 10^{-5} &= [\text{CH}_3(\text{CH})_4\text{COO}^-] \times 10^{-4.76} \div [\text{CH}_3(\text{CH})_4\text{COOH}] \\ 1 &= \frac{[\text{CH}_3(\text{CH})_4\text{COO}^-]}{[\text{CH}_3(\text{CH})_4\text{COOH}]} \text{ or } \\ &[\text{CH}_3(\text{CH})_4\text{COO}^-] \text{ at equilibrium} = [\text{CH}_3(\text{CH})_4\text{COOH}] \text{ at equilibrium} \\ &[\text{CH}_3(\text{CH})_4\text{COOH}] \text{ at equilibrium} = [\text{CH}_3(\text{CH})_4\text{COOH}]_{\text{initially}} - [\text{CH}_3(\text{CH})_4\text{COO}^-] \text{ at equilibrium} \\ &[\text{CH}_3(\text{CH})_4\text{COOH}]_{\text{initially}} = [\text{CH}_3(\text{CH})_4\text{COOH}] \text{ at equilibrium} + [\text{CH}_3(\text{CH})_4\text{COO}^-] \text{ at equilibrium} \\ &= 2 \times [\text{CH}_3(\text{CH})_4\text{COOH}] \text{ at equilibrium} \\ \text{Hence 50\% of the sorbic acid is dissociated.} \end{aligned}$$



The quickest way



This question proved to be the most difficult on the exam. The most common answer was 99.6% dissociation. This response, which was based on the ‘correct’ equilibrium law (for the ionisation of sorbic acid), could gain a maximum of two marks. The response assumes that the concentration of the sorbic acid is the same at equilibrium as at its initial concentration – an assumption that was not valid in this case, particularly since the initial concentration was not supplied.

Most responses faltered at the start by using the equilibrium law for the formation of sorbic acid from sorbate ions (as per the equilibrium in part c.), instead of using the equilibrium law for the ionisation of sorbic acid. This led to invalid assumptions such as that the concentration of sorbic acid was the same as the concentration of hydroxide ions.

Question 4a.

Marks	0	1	2	Average
%	43	11	46	1.0

Both of

- the equilibrium constant is extremely small
- the amount of CO and Cl₂ produced/COCl₂ reacted in getting to equilibrium is so small that (to two significant figures) the n(COCl₂) at equilibrium will still be 1.0 mol.

One mark was awarded for recognising the very small K value/ratio of products to reactants, and the second mark for explaining what the low K value means in terms of extent of reaction.

Overall performance on this question showed that a large proportion of students did not see the significance of the size of the K value and the implication for extent of reaction. Many students referred to the somewhat arbitrary value of 10⁻⁴ as the deciding factor in what makes a K value ‘small’. Also, a number of students confused the K value with acidity constants and answered, inappropriately, in the context of weak acids. The ability to interpret what a K value implies about the extent of a reaction is an expected skill at this level.

Question 4bi.

Marks	0	1	2	3	Average
%	31	9	15	45	1.8

At equilibrium, [CO] = ‘y’ M = [Cl₂]

$$[\text{COCl}_2] = 1.0 \div 3.0$$

$$= 0.33 \text{ M}$$

$$K = \frac{[\text{CO}][\text{Cl}_2]}{[\text{COCl}_2]}$$

$$‘y’ \times ‘y’ \div 0.33 = 2.1 \times 10^{-8}$$

$$‘y’^2 = 2.1 \times 10^{-8} \times 0.33$$

$$‘y’ = \sqrt{(2.1 \times 10^{-8} \times 0.33)}$$

$$‘y’ = 8.3 \times 10^{-5}$$

$$[\text{CO}] = 8.3 \times 10^{-5} \text{ M} \quad (8.3 \times 10^{-5} - 8.4 \times 10^{-5})$$

One mark was awarded for recognising that [CO] = [Cl₂]. The second mark was awarded for using [COCl₂] – that is, one third or 0.33 in the correct equilibrium law. The third mark was awarded for accurately calculating [CO].

Common errors on this question included not calculating the [COCl₂], not recognising that [CO] = [Cl₂], dividing rather than multiplying by 0.33, not taking the square root and accuracy errors associated with rounding off one third to 0.3.

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Question 4bii.

Marks	0	1	Average
%	37	63	0.7

$8.3 \times 10^{-5} \text{ mol L}^{-1} \text{ (M)}$

The required answer was effectively the answer to part bi. with appropriate units. If no units are specified in the question, as in bii., they must be included as part of the answer.

Question 5

Most students handled Question 5 well.

Question 5a.

Marks	0	1	Average
%	23	77	0.8

The 'application' of the selected chemical required the identification of a 'use' of the chemical rather than just stating a chemical property of the chemical.

Students should think about their responses; for example, the application of sulfuric acid 'in fertilisers' is incorrect and is a significantly different response to 'in the production of fertilisers'.

Question 5b.

5bi.

Marks	0	1	Average
%	24	76	0.8

5bii.

Marks	0	1	Average
%	35	65	0.7

While the majority of students were able to identify an 'undesirable effect' on the environment in part i., some of those students did not effectively link their response to part ii. to this effect.

Question 6ai.

Marks	0	1	2	Average
%	11	22	67	1.6

$$E = VIt$$

$$= 5.25 \times 1.50 \times 3.00 \times 60$$

$$= 1.42 \times 10^3 \text{ J}$$

$$\begin{aligned} \text{Calorimeter constant} &= E \div \Delta T \\ &= 1.42 \times 10^3 \div 0.593 \\ &= 2.39 \times 10^3 \text{ J } ^\circ\text{C}^{-1} \\ &= 2.39 \text{ (kJ } ^\circ\text{C}^{-1}) \end{aligned}$$

One mark was awarded for accurately calculating the energy, and the second mark for accurately calculating the calorimeter constant (calibration factor), in $\text{kJ } ^\circ\text{C}^{-1}$, from the energy.

The most common error was not converting the energy from joules to kilojoules, or assuming that the unit of electrical energy in the VIt calculation was joules.

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Question 6a.ii.

Marks	0	1	2	3	4	5	Average
%	16	10	11	21	28	15	2.8

$$n(\text{CH}_3\text{OH}) \text{ reacting} = 0.934 \div 32.0 \\ = 0.0292 \text{ mol}$$

$$\text{Energy released by methanol} = CC \times \Delta T \\ = 2.39 \times 8.63 \\ = 20.6 \text{ kJ}$$

$$\text{Energy from 1 mol CH}_3\text{OH} = 20.6 \div 0.0292 \\ = 706 \text{ kJ}$$

$$\Delta H = -2 \times -706 \text{ kJ mol}^{-1} \\ = -1.41 \times 10^3 \text{ kJ mol}^{-1} \quad (-1.41 \times 10^6 \text{ J mol}^{-1})$$

One mark each was awarded for

- accurately calculating $n(\text{CH}_3\text{OH})$
- accurately calculating the energy released using the calorimeter constant from part ai.
- accurately calculating the energy for 2 mol of CH_3OH
- including the negative sign and giving the answer to three significant figures
- correct units on ΔH .

This question was generally well handled; however, some common errors included

- using the molar enthalpy of combustion from the Data Book, rather than the temperature change during combustion and the calibration constant, to calculate the energy released by the methanol
- not determining the energy for 2 mol CH_3OH
- inconsistent significant figures and/or units.

Question 6b.

Marks	0	1	Average
%	66	34	0.4

The calculated energy released in combustion is lower due to loss of heat/energy to the surroundings during combustion.

The better responses indicated that a lower temperature change during combustion due to loss of heat would lead to a lower calculated energy released.

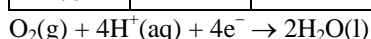
Students should avoid stating learned responses that are not relevant in this context; for example, as the question states that ‘methanol underwent complete combustion’, responses such as ‘incomplete combustion’ were not appropriate.

Statements such as ‘the Data Book gives the energy for one mole of methanol’ indicated that some students were comparing the ΔH for the reaction with the molar enthalpy of combustion from the Data Book rather than with ‘the value of ΔH , calculated using the enthalpy of combustion provided in the Data Book’.

Statements such as ‘the conditions of the experiment may not have been the same as those used to determine the values in the Data Book’ were not accepted because there was no indication of why or how this would **reduce** the calculated energy released.

Question 6ci.

Marks	0	1	Average
%	54	46	0.5



Given that students would have been well exposed to the half-equation for the reduction of oxygen in fuel cells, performance on this question was expected to be stronger. Students should know that reduction occurs at the cathode. The acidic electrolyte was implied in the given half-equation for oxidation.

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Question 6cii.

Marks	0	1	Average 0.2
%	83	17	

Either of

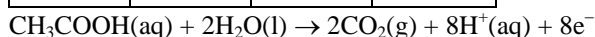
- a fast rate of reaction is necessary for efficient current flow/instantaneous current in the computer
- since the computer is being used at room temperature, the catalyst will increase the reaction rate to an acceptable level in the fuel cell.

Some logical indication of the ‘benefit/advantage’ of a faster reaction rate in the context of the laptop computer was required. Most students simply explained, often very well, why or how a catalyst reduces the activation reaction and increases reaction rate, but did not give any explanation of why it is important to have a catalyst in the context of laptop computers.

Some responses suggested that the presence of the catalyst would increase the voltage of the cell. Just as catalysts do not affect ΔH values or the values of equilibrium constants, they also do not affect the voltage generated in a fuel cell. Some students provided good responses in terms of power generated.

Question 7a.

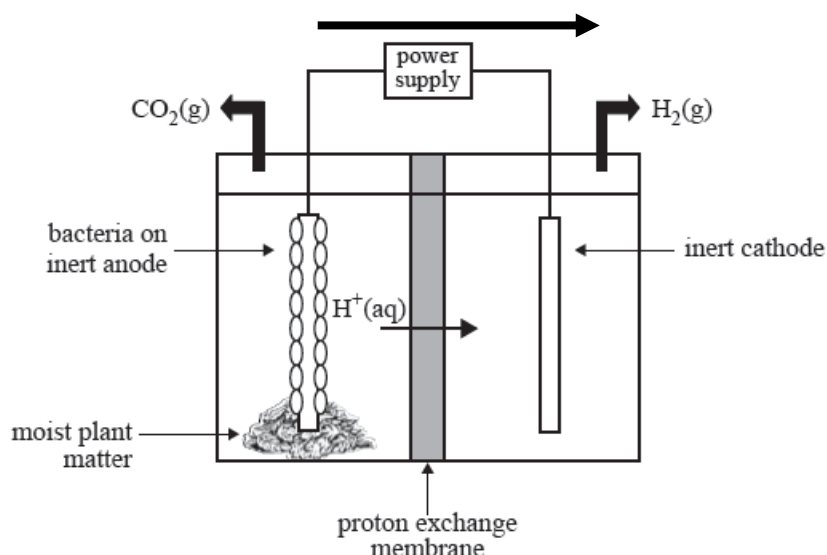
Marks	0	1	Average 0.3
%	67	33	



There was significant diversity in the responses to this question, mostly associated with balancing. The initial step in developing the half-equation, balancing the C atoms, was commonly missed.

Question 7b.

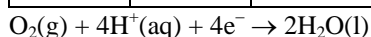
Marks	0	1	Average 0.7
%	37	63	



Students were expected to show that the electrons move from left to right (from the site of oxidation to the site of reduction) and in the external circuit. The most common errors showed electrons moving through the proton exchange membrane or in the wrong direction.

Question 7c.

Marks	0	1	Average 0.5
%	52	48	



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Question 7d.

Marks	0	1	Average
%	61	39	0.4

Acceptable responses included

- in a fuel cell, chemical energy is converted into electrical energy; in an electrolysis cell, electrical energy is converted to chemical energy
- in a fuel cell, the reaction produces electrical energy; in an electrolysis cell, electrical energy drives the reaction
- a fuel cell is not connected to an external power supply
- cathode/anode polarity is different in the two cells.

Most students clearly wanted to use the well-learned distinction between a fuel cell and a galvanic cell and referred to fuel cells having a continuous supply of reactants. This was not accepted as a distinction because some **electrolysis** cells, such as the production of NaOH by electrolysis of NaCl(aq), also have a continuous supply of reactants.

Question 8ai.

Marks	0	1	Average
%	50	50	0.5

$$\begin{aligned}
 m(\text{coal}) &= \text{energy released} \div \text{energy per gram} \\
 &= 3.6 \times 10^7 \text{ kJ} \div 5.0 \text{ kJ g}^{-1} \\
 &= 7.2 \times 10^6 \text{ g} \\
 &= 7.2 \text{ tonne}
 \end{aligned}$$

Most incorrect responses to this question were associated with unit conversion, particularly when expressing the mass in tonne, and/or calculating the mass of carbon rather than the mass of wet brown coal.

Question 8aii.

Marks	0	1	2	Average
%	45	33	22	0.8

$$\begin{aligned}
 m(\text{C}) &= 0.40 \times 7.2 \text{ (only 40\% of the sample is C)} \\
 &= 2.88 \text{ tonne} \\
 &= 2.88 \times 10^6 \text{ g} \\
 n(\text{CO}_2) &= n(\text{C}) \\
 &= 2.88 \times 10^6 \div 12.0 \\
 &= 2.4 \times 10^5 \text{ mol} \\
 m(\text{CO}_2) &= 2.4 \times 10^5 \times 44.0 \\
 &= 1.1 \times 10^7 \text{ g} \\
 &= 11 \text{ tonne}
 \end{aligned}$$

Many students who obtained the correct answer in part ai. did not use the fact that only 40 per cent of the wet brown coal content was carbon; others used the 40 per cent but did not proceed to accurately determine the mass of carbon dioxide from the mass of carbon.

Question 8b.

Marks	0	1	2	Average
%	46	49	5	0.6

Wet brown coal has a lower carbon content. Some of the energy released from the combustion of the carbon content is used to vaporise water in the coal – that is, not all of the energy available from the combustion of the carbon content is released during combustion of the coal.

One mark was awarded for referring to the lower carbon content of wet brown coal. The second mark was awarded for recognising that the energy content of wet brown coal is further reduced because some of the energy from the combustible component, C, will be expended in evaporating the water in the coal.

While the majority of students noted the lower carbon content of the coal, only a small proportion recognised the ‘impact’ of the water present on the overall energy content. Responses such as ‘wet brown coal contains water’ were

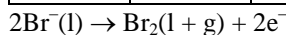
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not an appropriate alternative to 'lower carbon content', nor was 'water is not combustible' a suitable response to access the second mark.

Question 9a.

Marks	0	1	Average
%	91	9	0.1



The majority of students incorrectly included (aq) as the state for Br^- in their equations. The 'electrolysis of a molten salt' should have indicated that an aqueous solution was not present. Students should be aware that molten ionic compounds are liquids, and that oxidation occurs at the anode.

Equilibrium arrows in the half-equations on the electrochemical series reflect the fact that, in an electrochemical cell, whether a particular half-reaction proceeds to the left or the right depends on the other oxidant/reductant pair present in the cell. Once a decision has been made about the direction in which the half-reaction proceeds, equilibrium arrows are not included in the half-equation.

Question 9bi.

Marks	0	1	2	3	Average
%	19	5	22	54	2.1

$$Q = It$$

$$= 1.50 \times 30.0 \times 60$$

$$= 2.70 \times 10^3 \text{ C}$$

$$n(e^-) = Q \div F$$

$$= 2.7 \times 10^3 \div 96500$$

$$= 2.80 \times 10^{-2} \text{ mol}$$

Reduction of metal $\text{X}^{2+} + 2e^- \rightarrow \text{X}$

$$n(\text{X}) = n(e^-) \div 2$$

$$= 2.8 \times 10^{-2} \div 2$$

$$= 1.4 \times 10^{-2} \text{ mol}$$

The most common error on this part of the question was the omission or incorrect use of the relationship between the $n(\text{X})$ and the $n(e^-)$.

Question 9bii.

Marks	0	1	2	Average
%	31	5	64	1.3

$$M(\text{X}) = m \div n$$

$$= 2.90 \div 1.4 \times 10^{-2}$$

$$= 207.2 \text{ g mol}^{-1}$$

Lead (Pb)

Since the answer to this question was dependent on the answer to part i., it may seem strange that significantly more students obtained full marks for part ii. This shows how 'consequential' marks are applied. If the element identified in part ii. was consistent with the $n(\text{X})$ calculated in part i., and forms ions with a +2 charge, full marks were awarded for part ii. Therefore, if

- $n(\text{X}) = 0.0280 \text{ mol}$ in part i. due to not dividing $n(e^-)$, then $M(\text{X}) = 103.6 \text{ g mol}^{-1} \rightarrow$ Rhodium (Rh)
- $n(\text{X}) = 0.0560 \text{ mol}$ in part ii. due to multiplying $n(e^-)$ by 2, then $M(\text{X}) = 51.8 \text{ g mol}^{-1} \rightarrow$ Chromium (Cr).

This consequential mark was not awarded if a clearly monovalent metal such as K was given, since this was not consistent with the data provided as the metal ion had a charge of +2.