GENERAL COMMENTS

The performance on the 2010 November Chemistry examination was very similar to that on the 2010 June examination. It was evident that most students found the examination accessible, and the majority of students were able to complete the examination in the 90 minutes allowed.

While overall performance on Section A of the exam was strong, a number of questions revealed areas for improvement. In Questions 4 and 5, many students chose the graph shapes with which they may have been familiar. Responses to Question 8 showed that students may have benefited from further explanation of 'how' the [OH⁻] increases when an acidic solution is diluted. Question 10 indicated that students did not consider the chemical formula of barium hydroxide to be significant. Questions 16 and 18 indicated that many students struggled with key aspects of electrochemistry. Question 19 was the least well handled question in this section and students may have discounted the correct option because it seemed contradictory to their learned knowledge of fuel cells.

Section B was generally well handled, but aspects of some questions proved challenging for some students. In Question 1biii., many students did not access essential data from the Data Book after reading the question statement 'both hydrogen and methane can be burned to produce heat energy'. Responses to Question 2b. showed that while most students knew that the percentage ionisation of a weak acid increases on dilution, most were unable to explain how it occurs.

Students should be aware that accuracy is very important, particularly in answers to questions involving calculations. In Section B, Questions 1aiii., 1biii., 2ai., 4bii. and 7e., multi-step calculations were needed to get to the final answer. While it is acceptable to write down appropriately rounded amounts at each step of a calculation, the most accurate answer is obtained by using the unrounded data on the calculator. Significant figures are only considered in the final answer, which should be rounded off to the required number of significant figures. If severe rounding off or truncation has occurred, the final answer will generally be unacceptable.

In Section B, Questions 3aii., 3aiii. and 4bi., students were asked to explain the effect of excess reactant or temperature change on a system. Some students discussed the impact on the 'rate' of the reaction; however, this was not appropriate.

Questions 3aii. and 3biii. assessed students' ability to explain how particular reactions respond to specific situations. Most students seemed to ignore the type of arrows in the supplied equations and applied pre-prepared responses inappropriately. Student responses to Question 4 indicated that attention to calorimeter calibration by chemical reaction, as well as electrically, should be part of the learning process. Question 5 was generally answered well with many good common-sense responses. However, knowledge of key equations associated with the production of the chemical required improvement.

Many students ignored the information supplied in question stems, particularly in Section B, Questions 6 and 8. Students should ensure they make effective use of reading time and practise reading and interpreting information as part of their examination preparation.

Equation writing is a fundamental skill that should be well mastered. In Section B, students needed to write a balanced equation for Question 4a. – a combustion equation, Question 7c. – a redox equation for which the half-equations were on the electrochemical series, and Question 8b. – the overall equation for a hydrogen-oxygen fuel cell. It was evident that students found these questions challenging. However, Question 3ai., on which students had to balance a given equation, was very well handled.

Students' answers to Question 3b. in Section B suggested that most students did not take note of the nature of the 'arrow' in the equation before formulating a reason for the use of an excess of a reactant in 3bii.

Questions 6, 7 and 8 dealt with aspects of electrochemistry, with some question parts requiring students to make effective use of supplied data and information. Many students struggled to interpret and apply the information given in Questions 6, 7d. and 8. The ineffective, or lack of, use of the electrochemical series in Question 7c. was surprising.

Students are reminded that they must read questions carefully and ensure they answer them as asked. Students are encouraged to use past and sample exams as preparation tools, and should continue to develop the skill of reading and thinking through questions carefully, especially those requiring explanatory answers. Teachers are encouraged to use

the discussion throughout the rest of this report, as well as class and school statistical data for each question on the examination, in evaluating how their students performed and to use this in planning learning programs for the next cohort of students.

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	6	1	2	91	
2	2	1	91	6	
3	18	8	11	63	Decreasing the volume of a vessel in which a gas phase reaction is occurring will increase the rate of the reaction because the partial pressures and concentrations of the reactants increase, thus increasing the frequency of fruitful collisions. However, this has no effect on the activation energy (I), energy released when product bonds are formed (II) or the ΔH for the reaction.
4	62	23	9	7	Once the reaction has reached equilibrium, the forward reaction proceeds at a constant rate – the same rate as the reverse reaction. The addition of a compound that poisons the catalyst and stops it from working will increase the activation energy but does not push the system out of equilibrium. So the rate of the forward reaction (and reverse reaction) drops to a lower constant value. Option B implied that the rate of the forward reaction decreases then increases. This could only apply if there was an increase in reactant concentration or temperature, which is not consistent with the system being at equilibrium.
5	6	21	57	17	Because the system was at equilibrium when the catalyst stopped working, the concentrations of A, B and C were all constant. Although the rates of the forward and reverse reactions decrease, they remain equal and at the same value as they were immediately before the catalyst stopped working, because the system is not pushed out of equilibrium.

Question	% A	% B	% C	% D	Comments
6	67	15	11	7	$2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g)$ Initially 1.2 M - - Reacting 0.40 M $\rightarrow$ 0.40 M 0.20 M Equilibrium 0.80 M 0.40 M 0.20 M The 0.20 mol Cl_2 present in the 1.0 L flask at equilibrium was produced by the reaction of 0.40 mol NOCl, leaving 0.80 mol NOCl at equilibrium.

7	12	7	18	62	When volumes of the containers halve, all concentrations double.
					A. $N_2O_4(g) \rightleftharpoons 2NO_2(g)$
					     Concentration Fraction (CF) = $[NO_2]^2/[N_2O_4]$
					     Initially: $[NO_2] = x$, $[N_2O_4] = y$
					     After V change: $[NO_2] = 2x$, $[N_2O_4] = 2y$
					     CF changes from x^2/y to $(2x^2)/2y$, i.e. $2x^2/y$
					     CF increases by a factor of 2, i.e. by 100 %
					B. $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$
					     CF = $[HI]^2 / [H_2][I_2]$
					     Because there is the same number of particles on both sides of the reaction, the *CF* is not affected by changes in volume.
					C. $2CO_2(g) \rightleftharpoons 2CO(g) + O_2(g)$
					     CF = $[CO]^2[O_2] / [CO_2]^2$
					     Initially: $[CO_2] = x$, $[CO] = y$, $[O_2] = z$
					     After V change: $[CO_2] = 2x$, $[CO] = 2y$, $[O_2] = 2z$
					     CF changes from y^2z/x to $(2y)^2 x 2z/(2x^2)$, i.e. $2y^2z/x$
					     CF increases by a factor of 2 – that is, by 100 %
					D. $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$
					     CF = $[CH_3OH] / [CO][H_2]^2$
					     Initially: $[CO] = x$, $[H_2] = y$, $[CH_3OH] = z$
					     After V change: $[CO] = 2x$, $[H_2] = 2y$, $[CH_3OH] = 2z$
					     CF changes from z/xy^2 to $2z/2x(2y^2)$ – that is, $z/4xy^2$
					     CF decreases by a factor of 4 – that is, by 75 %
					
					All students received a mark for this question.

Question	% A	% B	% C	% D	Comments
8	25	49	16	9	HCl(aq) is a strong acid and it ionises completely so the concentration changes on dilution can be related to the equilibrium $2H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$ $K_w = [H_3O^+][OH^-] = 10^{-14}$ at 25°C. On dilution, the $[H_3O^+]$ and $[OH^-]$ both decrease, and since $[H_3O^+][OH^-] < K_w$, the forward reaction is favoured and both concentrations increase. The effect of this return to equilibrium impacts significantly more on the $[OH^-]$ than the $[H_3O^+]$. Consider 0.010 M HCl(aq) at 25°C $[H_3O^+] = 10^{-2}$ M and $[OH^-] = 10^{-12}$ M On dilution, by say a factor of 10, $[H_3O^+]$ immediately decreases to 10^{-3} M and $[OH^-]$ to 10^{-13} M and so $[H_3O^+][OH^-] = 10^{-16}$, i.e. $< 10^{-14}$. As the system moves to the right to return to equilibrium, the $[OH^-]$ increases from 10^{-13} M to 10^{-11} M, that is, by 9.9×10^{-12} M. The $[H_3O^+]$ also increases by 9.9×10^{-12} M, a negligible amount compared to its concentration, 10^{-3} M, on dilution. So while the $[H_3O^+]$ has decreased due to the dilution, the $[OH^-]$ has increased overall. More simply, HCl is a strong acid and so it is completely ionised in aqueous solution. On dilution, the $[H^+]$ decreases. Since the temperature is constant, $K_w - [H][OH^-]$ – does not change. Hence as $[H^+]$ decreases, $[OH^-]$ must increase. The choice of option A suggested that a significant number of students did not deal with the equilibrium issues involved. Students are expected to know that the value of $[H_3O^+][OH^-]$ at equilibrium will be the same before and after the dilution. This makes it impossible for both $[H_3O^+]$ and $[OH^-]$ to decrease overall as a result of the dilution.
9	16	58	20	6	All the acids listed were weak acids, so the solution with the lowest pH, due to the highest $[H_3O^+]$, is the one with the largest K_a value.
10	4	16	33	46	$Ba(OH)_2(aq) \rightarrow Ba^{2+}(aq) + 2OH^-(aq)$ $c(OH^-) = 2 \times 0.0050$ $\quad\quad\quad = 0.010$ M $c(H_3O^+) = 10^{-14} / 0.010$ $\quad\quad\quad = 1.0\times10^{-12}$ M pH = 12 The significance of the chemical formula of $Ba(OH)_2$ was overlooked by students who selected options B and C.
11	7	55	18	19	The graph indicated that the % yield: • increases as the pressure increases • increases as the temperature decreases. An equilibrium system responds to increased pressure by favouring the reaction that forms fewer particles. Since the % yield increases as the pressure increases, there will be fewer particles on the product side of the equilibrium/more particles on the reactant side of the equilibrium.
12	6	17	70	7	Since the % yield increases as the temperature decreases, the forward reaction is exothermic.

Question	% A	% B	% C	% D	Comments
13	2	4	68	26	n(Mg) = 7.29/24.3 Energy released = (7.29/24.3) x (1200/2) = 180 kJ Students who selected option D (360 kJ) may not have read that the equation indicated that 1200 kJ of energy is released when 2 mol Mg is burned.
14	4	74	17	6	
15	8	13	12	66	The energy profile showed that 58 kJ of energy was absorbed when 1 mol N_2O_4(g) is converted to 2 mol NO_2(g). i.e. $N_2O_4(g) \rightleftharpoons 2NO_2(g)$ $\Delta H = +58$ kJ mol^{-1} $2NO_2(g) \rightleftharpoons N_2O_4(g)$ $\Delta H = -58$ kJ mol^{-1} $NO_2(g) \rightleftharpoons \frac{1}{2}NO_2(g)$ $\Delta H = -29$ kJ mol^{-1}
16	8	19	54	19	Students should be aware that reduction involves the 'gain of electrons'. Option A was not balanced for charge and option D was not balanced for O atoms. It was concerning that 19 per cent of students chose option B (an oxidation reaction) as a reduction half-equation.
17	12	75	8	5	
18	21	54	15	9	Species present in the solution prior to electrolysis: K^+(aq), SO_4^{2-}(aq), H_2O(l) On the basis of the electrochemical series $S_2O_8^{2-}(aq) + 2e^- \rightleftharpoons 2SO_4^{2-}(aq)$ $O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l)$ $2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$ $K^+(aq) + e^- \rightleftharpoons K(s)$ The strongest reductant present in the solution – H_2O(l) – is oxidised at the anode according to $2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$. It was of concern that many students selected a reduction half-equation (options C and D) for the reaction occurring at the anode.
19	26	8	37	29	Students may have answered this question via the elimination of alternatives. Option A was incorrect because reactants are not stored in a fuel cell; option B was incorrect because products of discharge must remain at the electrodes for cells to be rechargeable; and option D was incorrect because fuel cells are not recharged. Students who did not choose option C may have been familiar with the 'electrons pass from the anode to cathode' principle of electron movement in an electrochemical cell, but may not have thought about the wording of the option. Before electrons can pass from the anode to the cathode through the external circuit of an electrochemical cell they must first be released onto the anode in an oxidation half-equation. Since the reductant is oxidised at the anode, the statement 'electrons pass from the reductant to the anode as electricity is produced' (option C) is accurate for electrochemical cells.

Question	% A	% B	% C	% D	Comments
20	7	9	14	70	For an object to be plated with Mg metal, Mg^{2+} ions must be reduced at the cathode. However, for $MgI_2(aq)$, the electrochemical series $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$ $Mg^{2+}(aq) + 2e^- \rightarrow Mg(s)$ indicates that an aqueous solution cannot be used because H_2O is a stronger oxidant than $Mg^{2+}(aq)$ and would be preferentially reduced at the cathode.

Section B – Short answer questions

Question 1ai.

Marks	0	1	Average
%	20	80	**0.8**

One of:

- $K = [CO][H_2]^3/[CH_4][H_2O]$
- $[CO][H_2]^3/[CH_4][H_2O]$.

As all the reactants and products are in the gaseous phase, water is not a solvent and must be included in the equilibrium expression. The most common errors made by students were leaving H_2O out of the equilibrium expression or having an incorrect power on the $[H_2]$.

Question 1aii.

Marks	0	1	Average
%	35	65	**0.5**

One of:

- the rate of reaction is too slow at low pressure
- to increase the rate of reaction
- to prevent air from entering the system
- to move reactants through faster.

Some students referred to the effect of pressure on equilibrium yield, effectively repeating the stem of the question.

Question 1aiii.

Marks	0	1	2	Average
%	11	21	68	**1.6**

$5.67 = [CO][H_2]^3 / [CH_4][H_2O]$
$\quad\quad = 0.300 \times [H_2]^3 / (0.400 \times 0.068)$
$5.67 \times (0.400 \times 0.068) = 0.300 \times [H_2]^3$
$[H_2]^3 = 5.67 \times (0.400 \times 0.068) / 0.300$
$\quad\quad = 0.514$
$[H_2] = \sqrt[3]{0.514}$ or $(0.514)^{1/3}$
$\quad\quad = 0.80 \ (0.801) \ (M)$

This question was well handled, with the most common errors associated with finding the cube root.

Question 1bi.

Marks	0	1	2	Average
%	21	21	58	**1.4**

Biochemical fuel (biomass) is more sustainable because natural gas is non-renewable (biomass is renewable).

Most students were well aware of the link between sustainabilty of energy sources and renewability. Those who were not aware of the link generally focused on methane as a 'natural' source or on relative CO_2 emissions. A number of students intepreted the word 'sustainable' as meaning 'abundant', focusing on the size of natural gas reserves.

Question 1bii.

Marks	0	1	Average
%	58	42	**0.4**

1.4×10^2 kJ g^{-1} (143)

This question was not well done by students. Although H_2 was given as the chemical formula of hydrogen in the molar enthalpy of combustion data (table 13 in the Data Book), many students did not recognise that 286 kJ mol^{-1} indicates 286 kJ of energy is released from 2.0 g H_2.

Question 1biii.

Marks	0	1	2	3	4	Average
%	29	8	12	11	40	**2.2**

$n(CH_4)$ = 2.0/24.5
= 0.0816 mol

Energy released by CH_4 = 0.0816 x 889
= 72.6 kJ

$n(H_2)$ = 72.6/286
= 0.254 mol

$V(H_2)$ = 0.254 x 24.5
= 6.2 (L)

Alternatively
Since $n(H_2) \times \Delta H_c(H_2) = n(CH_4) \times \Delta H_c(CH_4)$
and both gases are at the same temperature and pressure
$V(H_2) \times \Delta H_c(H_2) = V(CH_4) \times \Delta H_c(CH_4)$
$V(H_2)$ = $V(CH_4) \times \Delta H_c(CH_4)/\Delta H_c(H_2)$
= 2.0 x 889/286
= 6.2 (L)

Many students answered this question well; however, some made errors that indicated students had interpretation and calculation issues, including:
- using n = cV rather than n = V/V$_m$
- incorrect use of n = V/V$_m$
- using n = pV/RT but with unit errors that may not have occurred with n = V/V$_m$
- incorrect use of Energy = n x ΔH_c.

Many students ignored or misinterpreted the statement 'Both hydrogen and methane can be burned to produce heat energy' and did not make the connection to molar enthalpy of combustion data, using the ΔH value from the equation in 1a. Many of these students were still able to access two marks.

In a question with potentially multiple calculation steps such as this, students must be aware that severe rounding off in each step reduces the accuracy, and generally acceptability, of the final answer. While rounded answers may be shown in each step of the calculation, students should be encouraged to use the unrounded calculator value in subsequent steps. Significant figures are assessed on the final answer.

Question 2ai.

Marks	0	1	2	3	4	Average
%	19	18	3	8	52	**2.2**

n(lactic acid) = 4.50/90.0
= 0.0500 mol
c(lactic acid) = 0.0500/500.0x10^{-3}
= 0.100 M
$K_a = [A^-][H_3O^+] / [HA]$
$K_a = [H_3O^+]^2 / [CH_3CH(OH)COOH]$
$1.4x10^{-4} = [H_3O^+]^2/0.100$
$[H_3O^+] = \sqrt{(0.100 \times 1.4x10^{-4})}$
= 3.7 x 10^{-3} (M)

Generally, students either progressed smoothly to the correct answer or struggled to complete this question. Some worked out the c(lactic acid) and then stated that the $c(H_3O^+)$ was the same, even though the question stated that lactic acid is a weak acid.

Question 2aii.

Marks	0	1	Average
%	24	76	**0.8**

pH = -log$_{10}$ (3.74 x 10^{-3})
= 2.43

Students who accurately converted their answer to 2ai. to pH were awarded the mark.

Question 2aiii.

Marks	0	1	Average
%	48	52	**0.5**

% ionisation = (3.74x10^{-3}/0.100) x 100
= 3.74

Students should be aware that 'weak' acids do not fully ionise, and so 100 % was not a logical answer.

Question 2aiv.

Marks	0	1	Average
%	48	52	**0.5**

Acceptable reponses included:
- ionisation of lactic acid is negligible
- contribution to $[H_3O^+]$ from the self-ionisation of water is negligible
- $[CH_3CH(OH)COOH]$ at equilibrium is the same as its initial concentration
- $[H_3O^+] = [CH_3CH(OH)COO^-]$.

The statement 'ionisation of lactic acid produces equal amounts (in mol) of $CH_3CH(OH)COO^-$ and H_3O^+ ions' is a statement of fact, not an assumption. The assumption is that $[H_3O^+] = [CH_3CH(OH)COO^-]$ is linked to the negligible impact of the self-ionisation of water.

Question 2bi.

Marks	0	1	Average
%	34	66	**0.7**

Increase

Although the amount of H_3O^+ present increases following dilution as the equilibrium shifts right, the $[H_3O^+]$ is lower overall and so the pH increases.

Question 2bii.

Marks	0	1	Average
%	50	50	**0.5**

Increase

The amount of H_3O^+(aq) and A^-(aq) increases during the dilution of a weak acid, HA(aq), as the position of equilibrium shifts to the right. Hence, the percentage ionisation of a weak acid increases on dilution. Students should be aware that increased ionisation on dilution is a characteristic of weak acids.

Question 2biii.

Marks	0	1	Average
%	73	27	**0.3**

Acceptable responses included:
- adding water (dilution) decreases the overall concentration and the reaction shifts to produce more particles
- increasing the volume decreases the concentration fraction so forward reaction is favoured
- water is a reactant and so, according to Le Chatelier's principle, there is net forward reaction.

Many students who answered 2bii. correctly struggled to give a coherent reason why there is a net forward reaction on the addition of water.

Question 3ai.

Marks	0	1	Average
%	18	82	**0.8**

Acceptable responses included:
- $6NO(g) + 4NH_3(g) \rightarrow 5N_2(g) + 6H_2O(g)$
- $3NO(g) + 2NH_3(g) \rightarrow 2.5N_2(g) + 3H_2O(g)$.

Question 3aii.

Marks	0	1	2	Average
%	34	28	38	**1**

Too low – unreacted NO will also be released into the atmosphere (less N_2/H_2O is produced)
Too high – unreacted NH_3 will also be released into the atmosphere

Although equilibrium arrows were not part of the question, many students treated this question as if the reaction was an equilibrium reaction and applied Le Chatelier's principle to the low and high NH_3 level situations. Some students found describing the 'change in composition of the gases released into the atmosphere' a challenge.

Question 3bi.

Marks	0	1	Average
%	25	75	**0.8**

H_2O (water)

Urea has a larger molar mass than water, so for equal masses of both reactants, the mole amount of H_2O is higher and, since the reactants combine in a 1:1 mole ratio, it will be in excess.

Question 3bii.

Marks	0	1	Average
%	62	38	**0.4**

Acceptable responses included:
- to increase the amount of the other, more expensive, reactant consumed
- to increase the yield of NH_3
- to push the position of equilibrium further to the right.

A common incorrect response was 'to ensure all the urea reacts', suggesting that a large number of students did not note the significance of the equilibrium arrows in the equation. A number of students referred to rate of reaction; however, in the context of the question, this was not an appropriate response.

Question 3biii.

Marks	0	1	2	Average
%	19	18	63	**1.4**

The amount of NH_3 produced increases because the forward reaction is endothermic.

A number of students did not recognise that there were two components to the expected response – 'what happens to the amount of ammonia?' and 'why that happens'.

Question 3c.

Marks	0	1	Average
%	36	64	**0.6**

Onsite production eliminates the risks associated with the transport (handling) of NH_3 (due to it is being a gas/toxic/ chemically reactive).

It is much easier to store urea (solid) than ammonia (gas) or it is safer and easier to transport (handle) urea because it is a solid.

Students should be reminded that one-word responses, for example 'safety', are generally not sufficient in such a question. A better response would be reference to a property of NH_3 given in the table that indicates why the method is safer. A common answer was that it would reduce greenhouse gases due to the transport of ammonia, not appreciating that urea would also have to be transported.

Question 4a.

Marks	0	1	2	3	Average
%	15	26	37	22	**1.7**

Either of:
- $2C_6H_5COOH(s \ or \ l) + 15O_2(g) \rightarrow 14CO_2(g) + 6H_2O(g) \ \Delta H = -6454 \ (kJ \ mol^{-1})$
- $C_7H_6O_2(s \ or \ l) + 7.5O_2(g) \rightarrow 7CO_2(g) + 3H_2O(g); \ \Delta H = -3227 \ (kJ \ mol^{-1})$.

The three marks were awarded for all reactants and products correct, the equation correctly balanced, and the correct sign and magnitude of ΔH consistent with the equation.

Balancing for O_2 proved challenging for most students, with many not making allowance for the O atoms present in benzoic acid molecules.

Question 4bi.

Marks	0	1	Average
%	73	27	**0.3**

Acceptable responses included:
- to ensure there is sufficient O_2 for complete reaction of the benzoic acid
- to provide an excess of oxygen.

The most common incorrect response to this question was 'to increase the rate of the reaction'. Given that the purpose of the reaction was to calibrate the calorimeter, the key requirement is that all of the benzoic acid sealed in the reaction bomb must react. Students must consider the context of the question when framing their responses.

Question 4bii.

Marks	0	1	2	3	4	Average
%	23	13	13	24	27	**2.2**

$n(C_7H_6O_2)$ $= 1.025 / 122.0$
$= 8.402 \times 10^{-3} \ (mol)$
Energy released $= 8.402 \times 10^{-3} \times 3227$

$$= 27.11 \text{ (kJ)}$$

Calibration factor $= 27.11/2.17$

$= 12.5 \text{ kJ } °C^{-1} \ (1.25 \times 10^4 \text{ J } °C^{-1})$

Students needed to include the correct units and the answer calculated correct to three significant figures. Overall performance on this question indicated that many students were not comfortable with calorimeter calibration by chemical reaction and that further emphasis on this technique, as well as electrical calibration, might be appropriate. Many students attempted a pathway using the specific heat of water, misinterpreting the volume of the reaction bomb as the volume of water.

Question 4biii.

Marks	0	1	2	Average
%	38	14	48	**1.1**

Higher calibration factor and (either of):
- no insulation will cause a smaller temperature change during calibration
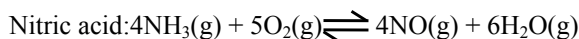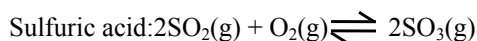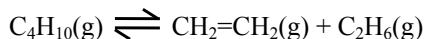- more energy is needed to raise the temperature (by 1°C) because of loss to the environment.

This question assessed students' understanding of the calibration process. The amount of energy released, as calculated, by the combustion of the benzoic acid is not affected; however, the temperature change of the water will be lower in the absence of insulation. Since CF = E/ΔT, a lower temperature change leads to a higher 'calculated' calibration factor.

Question 5ai.

Marks	0	1	Average
%	42	58	**0.6**

Ammonia: $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

Ethene: Any correctly balanced cracking equation in which C_2H_4 is a product was acceptable; for example,

$C_4H_{10}(g) \rightleftharpoons CH_2=CH_2(g) + C_2H_6(g)$

Sulfuric acid: $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

Nitric acid: $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$

This question assessed a fundamental aspect of the production of the particular chemicals and students were expected to be well aware of the key catalyst-linked equation in each process. Students who had studied ethene and explained that since thermal cracking does not involve the use of a catalyst an equation could not be written were awarded the mark.

Question 5aii.

Marks	0	1	Average
%	35	65	**0.7**

Ammonia: iron or iron oxides
Ethene: zeolites or 'no catalyst'
Sulfuric acid: vanadium pentoxide or vanadium(V) oxide
Nitric acid: platinum/rhodium

Naming the catalyst proved problematic for many students. Imprecise or incorrectly spelt answers such as 'vanadium oxide', 'vandium pentoxide' or 'vanadium oxide' were quite common.

Question 5aiii.

Marks	0	1	Average
%	22	78	**0.8**

A catalyst lowers the activation energy by providing an alternative reaction pathway.

Question 5bi.

Marks	0	1	Average
%	24	76	**0.8**

Acceptable responses for chemical hazards included:
- ammonia: toxic gas, corrosive
- ethene: explosive mixture with air, toxic gas
- sulfuric acid: corrosive, strong oxidant, strong acid, dehydrating agent, toxic vapours
- nitric acid: corrosive, strong oxidant, strong acid, toxic vapours.

Question 5bii.

Marks	0	1	Average
%	16	84	**0.8**

Acceptable responses, linked to a chemical hazard in 5bi., included:
- ammonia: severe respiratory irritant; liquid NH_3 may cause burns
- ethene: severe burns from explosion; asphyxiation
- sulfuric acid: severe burns; respiratory irritation
- nitric acid: severe burns; respiratory irritation.

Question 5biii.

Marks	0	1	Average
%	20	80	**0.8**

Acceptable responses included:
- appropriate protective clothing and equipment (where particular items relevant to the hazard are specified); for example, safety goggles/face shield, gloves, breathing apparatus
- spill-management strategies
- workers well practiced in emergency and first aid procedures
- fire prevention and firefighting strategies (ethene).

Students should be aware that simplistic responses such as 'wear a lab coat' are not sufficient for such a question. The question required students to link their answer to the hazard mentioned in 5bi.

Question 6a.

Marks	0	1	2	Average
%	47	8	45	**1**

Half-equation	E^0
$AgCl(s) + e \rightleftharpoons Ag(s) + Cl^-(aq)$	+0.22
$Cd^{2+}(aq) + 2e \rightleftharpoons Cd(s)$	
$PbSO_4(s) + 2e \rightleftharpoons Pb(s) + SO_4^{2-}(aq)$	

This question was challenging for most students. Many seemed to overlook the statement in the question 'although the numerical values of the E^0 values are correct, they have been incorrectly assigned to the three half-equations'. The fundamental point that electrons leave the standard hydrogen half-cell to an oxidant stronger than $H^+(aq)$ was the key to identifying the half-equation with the positive E^0 value from the experimental notes.
Only 'one' E^0 value was to be assigned, and students who had correctly identified the half-equation with the positive E^0 value, but incorrectly assigned values to the other two half-equations, lost a mark.

Question 6b.

Marks	0	1	Average
%	68	32	**0.3**

Acceptable responses included:
- both of the other half-equations have negative E^0 values, but to determine their locations, the potential difference of each when connected to the standard hydrogen electrode needed to be recorded

- both E^0 values are below the H^+/H_2 half-cell, but there is not enough information to identify their relative positions
- both undergo oxidation by $H^+(aq)$, but there is not enough data to determine which has the stronger reductant
- the data indicates that electrons flow from the two other half-cells to the SHE but does not give the potential differences.

Students needed to make a relevant comment about what the provided information indicated about the two E^0 values/half-cells and why more information was needed. The explanation of why the two E^0 values could not be correctly assigned required more than an isolated statement such as 'there is not enough information'.

Question 6c.

Marks	0	1	Average
%	55	45	**0.5**

Acceptable responses included:
- [$H^+(aq)$] decreases so pH increases
- reaction occurring is $2H^+(aq) + 2e^- \rightarrow H_2(g)$
- $H^+(aq)$ is the oxidant and is consumed.

Students should be aware that the only two possible reactions in the standard hydrogen half-cell involve either the consumption of $H^+(aq)$, resulting in higher pH or the production of $H^+(aq)$, resulting in lower pH.

Question 7a.

Marks	0	1	Average
%	11	89	**0.9**

Acceptable reponses included:
- a primary cell cannot be recharged
- a secondary cell can be recharged
- in a primary cell, the products of the discharge move away from the electrodes.

Question 7b.

Marks	0	1	Average
%	26	74	**0.7**

Acceptable reponses included:
- lithium is a strong reductant
- $Li^+(aq)/Li(s)$ has the lowest E^0
- lithium is more readily oxidised that other reductants
- lithium cells produce higher voltages
- lithium has a low molar mass.

Question 7c.

Marks	0	1	2	3	Average
%	38	17	26	20	**1.3**

Two marks were awarded for a correctly balanced equation (one of):
- $2Li(s) + 2H_2O(l) \rightarrow 2LiOH(aq) + H_2(g)$
- $2Li(s) + 2H_2O(l) \rightarrow 2Li^+(aq) + 2OH^-(aq) + H_2(g)$
- $Li(s) + H_2O(l) \rightarrow Li^+(aq) + OH^-(aq) + \frac{1}{2}H_2(g)$.

Acceptable responses for the third mark included:
- $H_2(g)$ is flammable and may be ignited by an electric spark, causing the battery to explode
- a build up of pressure in the battery due to the production of $H_2(g)$ causes it to explode.
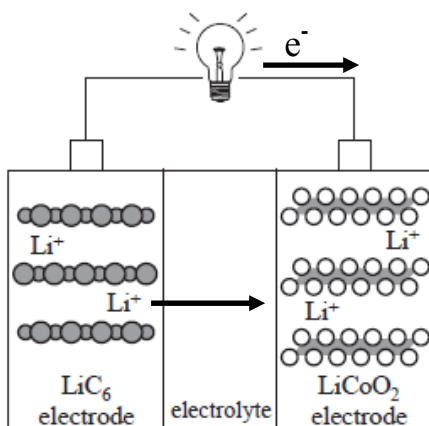
The relevant half-equations for the reaction between Li and H_2O were in the electrochemical series provided in the Data Book. Students are encouraged to consider the Data Book as a first option when writing equations for redox reactions.

A significant number of students produced the correct equation but did not explain why an explosion may occur. Students are reminded to read questions carefully and ensure that all parts of a question are answered.
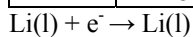
Question 7d.

Marks	0	1	2	Average
%	40	38	22	0.8

A significant number of students did not attempt this question. Others may have been confused by the lack of electrode signs on the diagram, although the preceding information indicated that LiC_6 was at the (-) electrode and $LiCoO_2$ was at the (+) electrode. During discharge both electrons and cations move towards the (+) electrode.

Question 7e.

Marks	0	1	2	3	Average
%	18	5	16	61	2.2

$Li(l) + e^- \rightarrow Li(l)$

$Q = It \quad = 6.50 \times 48.0 \times 60 \times 60$

$\quad\quad\quad = 1.1232 \times 10^6$ C

$n(e^-) = Q / F \quad = 1.1232 \times 10^6 / 96500$

$\quad\quad\quad\quad\quad = 11.64$ mol

$n(Li) = 11.64$ mol

$m(Li) \quad = 11.64 \times 6.9$

$\quad\quad\quad = 80$ g

While calculations associated with amounts of substance produced by electrolysis were handled well, incorrect conversion of hours to seconds was a common error.

Question 8a.

Marks	0	1	2	Average
%	46	38	16	0.7

Acceptable responses included:

- the phosphoric acid fuel cell is at 190 °C
- the electrolyte is pure phosphoric acid
- the electrolyte is not the 1 M H^+(aq) for which E^0 values are accurate
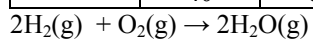- the 1.23 V predicted is based on conditions of 25 °C and 1 M solutions.

Most students seemed to ignore the information provided about the phosphoric acid fuel cell, and many resorted to 'non-standard conditions' or 'side reactions' responses. Given that the question asked for two specific reasons, these responses were not adequate. Since the temperature of the phosphoric acid fuel cell was clearly stated as 190 °C, statements such as 'the cell may not be at 25 °C' suggested that students may not have read the question carefully. A relevant 'technical' issue such as the impact of the resistances of cell components was accepted as long as either the 'temperature' or 'concentration' reason was also given.

Question 8b.

Marks	0	1	Average
%	40	60	**0.6**

$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$

Students needed to add the two half-equations given.