AQA A-LEVEL CHEMISTRY · 7405

CHEMISTRY



MARK SCHEME

3.1.11 ELECTRODE POTENTIALS AND ELECTROCHEMICAL CELLS

SCORE	PERCENTAGE
/463	%

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Q1.

(a) The ions in the ionic substance in the salt bridge move through the salt bridge

1

To maintain charge balance / complete the circuit

1

(b) F^-

1

(c) $E^{\ominus}$ SO_4^{2-} / SO_2 < $E^{\ominus}$ Br_2 / Br^-

Allow correct answer expressed in words, eg electrode potential for sulfate ions / sulfur dioxide is less than that for bromine / bromide

1

(d) 1.23 (V)

1

(e) A fuel cell converts more of the available energy from combustion of hydrogen into kinetic energy of the car / an internal combustion engine wastes more (heat) energy

1

[6]

Q2.

(a) (i) M1 Positive electrode $O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$

M2 Negative electrode $H_2 + 2OH^- \longrightarrow 2H_2O + 2e^-$

Allow multiples, ignore state symbols

If equations both correct but at the wrong electrodes allow 1 mark

1
1

$2H_2 + O_2 \longrightarrow 2H_2O$

Mark independently

Must be this way round

1

(ii) Increase (emf)

If decrease/no change then CE=0/2; if blank then mark on

1

$2H_2 + O_2 \longrightarrow 2H_2O$ will move to the right

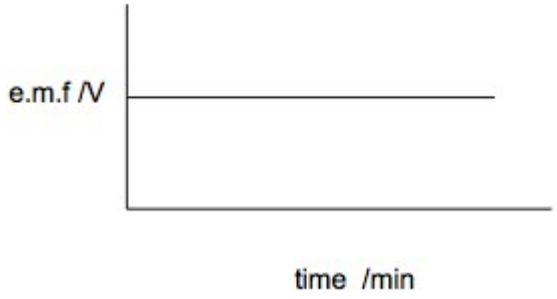
Or overall equation moves to the right

Allow $O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$ will move to the right / oxygen half equation moves to the RHS / $\boldsymbol{E^{\ominus}}$ $O_2|OH^-$ half cell

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moves to the right

1



(b)

Must start at y-axis

1

(c) (i) Unchanged

1

(ii) Water is the <u>only</u> product / fuel cell does not give out pollutants such as NO_x or CO_2 or SO_2 or C or CO or C_xH_y or unburnt hydrocarbons

Not fuel cell does not give out pollutants unless pollutant stated

1

(d) <u>CO_2 is released</u> because fossil fuels are burned to produce electricity <u>to generate hydrogen</u>
OR

<u>CO_2 is released</u> when methane reacts with steam <u>to produce hydrogen</u>

Allow CO_2 is released to produce the hydrogen

1

[9]

Q3.

(a) $Pt|H_2|H^+||Fe^{2+}|Fe$

Allow 1 for correct order of symbols but lose second mark for a wrong phase boundary(s) / Pt missing / extra Pt on RHS, additional phase boundary

Note, allow one mark only for correct symbol in reverse:

$Fe|Fe^{2+}||H^+|H_2|Pt$

Allow dashed lines for salt bridge

Ignore state symbols

Ignore 2 if used before H^+

2

(b) Electron donor

Allow (species that) loses electrons

Do not allow reference to electron pairs

1

(c) Cl_2 / chlorine

If M1 blank or incorrect cannot score M2

1

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(Species on RHS / electron donor) has most positive / largest $E^{\ominus}$ / has highest potential

Do not allow reference to e.m.f. or E(cell)

1

(d) (i) Cl / chlorine

1

(ii) Chlorine +1 to chlorine 0

CE if chlorine not identified in part (i)

Allow chlorine +1 to chlorine –1 (in Cl^-)

Allow oxidation state decreases by one OR two

Allow oxidation state changes by –1 OR –2

1

(e) $4HOCl + 4H^+ + 4OH^- \rightarrow 2Cl_2 + O_2 + 6H_2O$

OR

$4HOCl \rightarrow 2Cl_2 + O_2 + 2H_2O$

Allow one mark for any incorrect equation that shows $HOCl \rightarrow Cl_2 + O_2$

Allow multiples

Ignore state symbols

Penalise one mark for uncancelled or uncombined species (eg $H_2O + H_2O$ instead of $2H_2O$)

2

(f) (i) e.m.f. = 0.40 – (–1.25) = 1.65 (V) / +1.65 (V)

Allow –1.65 (V)

1

(ii) $2Zn + O_2 \rightarrow 2ZnO$

Allow multiples

Ignore state symbols

Do not allow uncancelled species

If more than one equation given, choose the best

1

(iii) **A** / stainless lid

If M1 incorrect or blank CE=0

1

O_2 (electrode) has a more positive $E^{\ominus}$ / oxygen (electrode) requires / gains electrons from external circuit

Or reference to the overall equation and a link to electrons going into A

Allow oxygen is reduced and reduction occurs at the positive electrode

OR Zinc (electrode) has more negative $E^{\ominus}$

Do not allow reference to e.m.f. or E(cell)

1

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(iv) (Cell) reaction(s) cannot be reversed / zinc oxide cannot be reduced to zinc by passing a current through it / zinc cannot be regenerated

Allow danger from production of gas / oxygen produced / hydrogen produced

1

[14]

Q4.

(a) (i) $H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$ / $H_2 \rightarrow 2H^+ + 2e^-$

Any order

1

$O_2 + 4e^- + 2H_2O \rightarrow 4OH^-$ / $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

1

(ii) Hydrogen (electrode) produces electrons

Ignore reference to salt bridge

Do not allow at negative / positive electrode – must identify hydrogen and oxygen

1

Oxygen (electrode) accepts electrons

Allow electrons flow to the oxygen electrode

1

(b) Hydrogen / the fuel / reactants supplied continuously / fed in

Do not accept oxygen supplied as the only statement

1

(c) In the fuel cell, a greater proportion of the energy available from the hydrogen–oxygen reaction is converted into useful energy

Allow less energy wasted / more efficient

Do not allow reference to safety

1

(d) Hydrogen is flammable / H^+ corrosive / OH^- corrosive / hydrogen explosive

1

[7]

Q5.

(a) Solar cells do not supply electrical energy all the time

1

Rechargeable cells can store electrical energy for use when the solar cells are not working

1

(b) Prevent pollution of the environment by toxic or dangerous substances / recycling of valuable components

Do not allow 'will not use up landfill sites'.

1

[3]

Q6.

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(a) It has mobile ions / ions can move through it / free ions

Do not allow movement of electrons.

Allow specific ions provided they are moving but do not react.

1

(b) Chloride ions react with copper ions / Cu^{2+} ***OR*** $[CuCl_4]^{2-}$ formed

If incorrect chemistry, mark = 0

1

(c) The Cu^{2+} ions / $CuSO_4$ in the left-hand electrode more concentrated

Allow converse.

1

So the reaction of Cu^{2+} with $2e^-$ will occur (in preference at) left-hand electrode / $Cu \rightarrow Cu^{2+}$ + electrons at right-hand electrode

Allow left-hand electrode positive / right-hand electrode negative.

Also reduction at left-hand electrode / oxidation at right-hand electrode.

Also left-hand electrode has oxidising agent / right-hand electrode has reducing agent.

Allow E left-hand side > E right-hand side

1

(d) (Eventually) the copper ions / $CuSO_4$ in each electrode will be at the same concentration

1

(e) (i) −3.05 (V)

Must have minus sign.

−3.05 only.

1

(ii) $LiMnO_2 \rightarrow Li + MnO_2$ correct equation

Allow 1 for reverse equation.

Allow multiples.

1

Correct direction

If Li^+ not cancelled but otherwise correct, max = 1

If electrons not cancelled, CE = 0

$LiMnO_2 \rightarrow Li + MnO_2$ scores 2

$Li^+ + LiMnO_2 \rightarrow Li^+ + Li + MnO_2$ scores 1

$Li + MnO_2 \rightarrow LiMnO_2$ scores 1

1

(iii) Electricity for recharging the cell may come from power stations burning (fossil) fuel

Allow any reference to burning (of carbon-containing) fuels.

Note combustion = burning.

1

[9]

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Q7.

(a) To remove the <u>oxide</u> layer on the aluminium

Do not allow 'cleaning' or 'removal of grease'.

Do not allow 'removal of impurities' without qualification.

1

(b) An appropriate method for delivering H_2 gas over a Pt electrode

Need H_2 gas and Pt electrode labelled (allow gas delivered directly below the electrode).

1

The Pt electrode must clearly be in contact with a solution of a named acid.

Ignore any concentration or pressure values.

Ignore absence of bubbles.

Allow if electrode is below outer acid level.

1

(c) The carbonate ion reacts with the acid (in the SHE) / reaction between carbonate and Al^{3+}

Lose this mark if aluminium carbonate formed but mark on.

1

Reaction given (either equation or products specified)

OR H^+ / Al^{3+} concentrations change / cell e.m.f. altered

1

[5]

Q8.

(a) Diagram of an Fe^{3+} / Fe^{2+} electrode that includes the following parts labelled:
Solution containing Fe^{2+} and Fe^{3+} ions

1

Platinum electrode connected to one terminal of a voltmeter

Must be in the solution of iron ions (one type will suffice)

1

Salt bridge

Do not allow incorrect material for salt bridge and salt bridge must be in the solution (ie it must be shown crossing a meniscus)

1

298 K and 100 kPa / 1 bar

1

<u>all solutions</u> unit / 1 mol dm^{-3} concentration

Allow zero current / high resistance voltmeter as alternative to M4 or M5

Ignore hydrogen electrode even if incorrect

1

(b) $Cu^{2+} + Fe \rightarrow Cu + Fe^{2+}$

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Ignore state symbols

1

Fe|Fe^{2+}||Cu^{2+}|Cu correct order

Allow Cu|Cu^{2+}||Fe^{2+}|Fe

1

Phase boundaries and salt bridge correct, no Pt

Allow single / double dashed line for salt bridge

Penalise phase boundary at either electrode end

Can only score M3 if M2 correct

1

Copper electrode

Allow any reference to copper

1

(c) $E^{\ominus}$ Au^{+}(/ Au) > $E^{\ominus}$ O_2 (/ H_2O)

Allow E cell / e.m.f. = 0.45 V

Allow 1.68 > 1.23

1

So Au^{+} ions will oxidise water / water reduces Au^{+}

QoL

1

$2Au^{+} + H_2O \rightarrow 2Au + \frac{1}{2}O_2 + 2H^{+}$

Allow multiples

1

(d) $E^{\ominus}$ Ag^{+}(/ Ag) > $E^{\ominus}$ Fe^{2+}(/ Fe)

Allow E cell / e.m.f. = 1.24

Allow 0.80 > −0.44

1

And $E^{\ominus}$ Ag^{+}(/ Ag) > $E^{\ominus}$ Fe^{3+}(/ Fe^{2+})

Allow E cell / e.m.f. = 0.03

Allow 0.80 > 0.77

1

So silver ions will oxidise iron (to iron(II) ions) and then oxidise Fe(II) ions (further to Fe(III) ions producing silver metal)

Allow Ag^{+} ions will oxidise iron to iron(III)

1

[15]

Q9.

(a) Electron acceptor / gains electrons / takes electrons away

Do not allow electron pair acceptor / gain of electrons / definition of redox (QWC)

1

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(b) $Cd(OH)_2$

Do not allow 'Cd(OH)$_2$/Cd'

1

Species (on LHS) with the least positive/most negative electrode potential / lowest *E* / smallest *E*

Only allow this mark if M1 answer given correctly or blank

Do not allow negative emf

1

(c) (i) 1.5 (V) / 1.50

1

(ii) $2MnO_2 + 2H_2O + Zn \rightarrow 2MnO(OH) + 2OH^- + Zn^{2+}$

Ignore state symbols

e^- must be cancelled

(take care that Zn^{2+} is on RHS)

1

(iii) Allows ions to pass (through it) or words to that effect

Penalise passage of electrons

Allow mention of particular ions

1

(iv) Allows electrons to flow / makes electrical contact / conductor

Allow acts as an (inert) electrode / anode / cathode

1

(v) Zn is 'used up' / has reacted / oxidised

Allow idea that zinc reacts

Do not allow just zinc corrodes

1

(d) (i) 3 / +3 / III

1

$2Ni(OH)_2 + Cd(OH)_2 \rightarrow 2NiO(OH) + Cd + 2H_2O$

For correct nickel and cadmium species in correct order (allow H_2O missing and OH^- not cancelled)

1

For balanced equation (also scores M2)

Allow max 1 for M2 and M3 if correct balanced equation but reversed.

Ignore state symbols

1

(ii) Metal / metal compounds are re-used / supplies are not depleted / It (the cell) can be re-used

Allow does not leak / no landfill problems / less mining / less energy to extract metals / less waste

Do not allow less CO_2 unless explained

1

(e) (i) $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$

Allow C_2H_6O

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1

(ii) $C_2H_5OH + 3H_2O \rightarrow 2CO_2 + 12H^+ + 12e^-$

Allow C_2H_6O

1

(iii) (+)0.23 (V)

1

(iv) $\underline{CO_2}$ released by combustion / fermentation / fuel cell / reaction with water

Can be answered with the aid of equations

1

(atmospheric) $\underline{CO_2}$ taken up in <u>photosynthesis</u>

1

[17]

Q10.

(a) loses electrons / donates electrons

penalise donates electron pair

1

(b) Zn

1

(most) negative E^o / lowest E^o / least positive

can only score M2 if M1 correct

do not allow e.m.f instead of E^o

1

(c) $\underline{E^o F_2}$ (/F^-) > $\underline{E^o O_2}$ (/H_2O)

or e.m.f is positive or e.m.f = 1.64 V

1

Fluorine reacts to form oxygen (can score from equation in M3 even if equation unbalanced provided no contradiction)
or fluorine oxidises water
or fluorine is a more powerful oxidising agent than oxygen

1

$2F_2 + 2H_2O \rightarrow 4F^- + 4H^+ + O_2$

allow 4HF in equation

balanced equation scores M2 and M3

1

(d) (i) order correct Zn Zn^{2+} Ag_2O Ag or reverse of this order

ignore ss , H^+ and H_2O, no. of moles

1

all phase boundaries correct

allow $Zn|Zn^{2+}||Ag_2O,Ag$

or $Zn|Zn^{2+}||Ag_2O|H^+|Ag$ for M1 & M2

e.g. $Zn|Zn^{2+}||Ag_2O|Ag$ or $Ag|Ag_2O||Zn^{2+}|Zn$ scores 2

M2 cannot be gained unless M1 scored

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allow H^+ either side of Ag_2O with comma or |

for M2 penalise

- *wrong phase boundary (allow dashed lines for salt bridge)*
- *Pt*
- *use of + (from half equation)*
- *water/H^+ outside Ag in Ag electrode*

1

(ii) 1.1 (V)

Allow no units, penalise wrong units

allow correct answer even if no answer to (d)(i) or answer to (d)(i) incorrect

allow –1.1 if silver electrode on Left in (d)(i) even if the species are in the wrong order.

1

(iii) Reaction(s) not reversible or H_2O electrolyses

do not allow hard to reverse

mention of primary cell is not enough to show that reaction(s) are irreversible

1

(e) (i) –0.46 (V)

Allow no units, penalise wrong units

1

(ii) $2PbSO_4 + 2H_2O \rightarrow Pb + PbO_2 + 2HSO_4^- + 2H^+$

lead species correct on correct sides of equation

1

equation balanced and includes H_2O,

HSO_4^- and H+ (or H_2SO_4)

allow ions / species must be fully cancelled out or combined

allow 1/2 for balanced reverse equation

1

(f) (i) reagents / PbO_2 / H_2SO_4 /acid / ions used up (or concentration decreases)

1

(ii) fuel cell

Ignore any other words

1

(iii) reagents / fuel supplied continuously

1

concentrations (of reagents) remain constant

1

[17]

Q11.

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(a) Hydrogen/H_2 gas/bubbles

1

1.0 mol dm^{-3} HCl/H^+

1

At 298K and 100kPa

Allow 1 bar instead of 100 kPa
Do not allow 1 atm

1

Pt (electrode)

1

(b) $Li^+ + MnO_2 + e^- \rightarrow LiMnO_2$

Ignore state symbols

1

–0.13(V)

1

(c) Fe^{3+} ions reduced to Fe^{2+}

Can score from equation/scheme

1

Because $E(Fe^{3+}/Fe^{2+}) > E(H^+/H_2)$/$E$(hydrogen)

Allow emf/E_{cell} +ve/0.77V
Allow Fe^{3+} better oxidising agent than H^+
Allow H_2 better reducing agent than Fe^{2+}
Only award this explanation mark if previous mark given

1

(d) Moles $Cr_2O_7^{2-}$ =$\underline{23.7 \times 0.01/1000}$ = 2.37×10^{-4}

1

1 mol $Cr_2O_7^{2-}$ reacts with 6 mol Fe^{2+} so moles Fe^{2+} in 25 cm^3 = $6 \times 2.37 \times 10^{-4} = 1.422 \times 10^{-3}$

1

M1 × 6

Moles Fe^{2+} in 250 cm^3 = 1.422×10^{-2}

M2 × 10 or M4/10

1

Original moles Fe^{2+} = $\underline{10.00/277.9}$ = 0.0360

Independent mark

1

Moles Fe^{2+} oxidised = 0.0360 – 0.0142 = 0.0218

M4 – M3

1

% oxidised = (0.0218 × 100)/0.0360 = 60.5%

(M5 × 100)/M4

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Allow 60 to 61
Note Max 3 if mol ratio for M2 wrong
eg 1:5 gives 67.1%
1:1 gives 93.4%
Note also, 39.5% (39-40) scores M1, M2, M3 and M4 (4 marks)

1

[14]

Q12.

(a) (i) Co/Cobalt

If Co or Cobalt not given CE = 0
ignore case in symbol for Co

1

(+) 4

1

(+) 3

Allow 4 and 3 in either order

1

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

Ignore state symbols
Allow e without -ve sign
Do not allow equilibrium sign

1

(iii) Platinum is a conductor

1

(Platinum is) unreactive/inert

Ignore mention of surface area or catalyst
Allow 2 marks if two properties given on one answer line
Apply list principle to contradictions/wrong answers
Do not allow platinum resists corrosion

1

(iv) Li reacts with water/forms lithium hydroxide

Allow water breaks down (or is electrolysed) on re-charge

1

(b) (i) $Pt \mid SO_3^{2-}(aq), SO_4^{2-}(aq) \mid\mid ClO_3^-(aq), Cl^-(aq) \mid Pt$

State symbols an ',' not necessary
Allow | in place of ',' NOT ',' in place of |
Ignore H^+ and H_2O
Deduct one mark for each mistake (e.g. Pt missed twice counts as two mistakes)
Allow reverse order for whole cell
Pt | Cl^-, ClO_3^- || SO_4^{2-}, SO_3^{2-} | Pt

2

(ii) $ClO_3^- + 3SO_3^{2-} \rightarrow Cl^- + 3SO_4^{2-}$

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1

Oxidising agent ClO_3^-

1

Reducing agent SO_3^{2-}

1

[12]

Q13.

(a) 1.4 V

Allow + or –

1

(b) $2NiO(OH) + 2H_2O + Cd \rightarrow 2Ni(OH)_2 + Cd(OH)_2$

Mark for species, Deduct a mark for additional species (eg OH^-) but allow balance mark

1

Balanced

If equation is reversed CE=0

1

(c) NiO(OH) or Ni(III) or nickel

1

+3

Allow conseq on wrong species

1

[5]

Q14.

(a) By definition

allow 'set to this value'

1

(b) 1.23 V

Allow + or –

1

(c) $Pt|H_2(g)|OH^-(aq),H_2O(l)||O_2(g)|H_2O(l),OH^-(aq)|Pt$

H_2O not essential, allow reverse order

Correct but with Pt missing

1

Includes Pt with correct representation

1

(d) Uses $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

And (2×) $2OH^- + H_2 \rightarrow 2H_2O + 2e^-$

1

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$2H_2 + O_2 \rightarrow 2H_2O$

1

(e) Increases the surface area (so reaction faster)

1

(f) Overall reaction is the same ($2H_2 + O_2 \rightarrow 2H_2O$)

Or shows e.m.f. is the same

1

(g) Hydrogen and oxygen supplied continuously

OR

Can be operated without stopping to recharge

Or can be refuelled quickly
Allow any one mark

1

(h) Hydrogen may need to be made using an energy source that is not 'carbon neutral'

1

[10]

Q15.

(a) (Standard) hydrogen (electrode) **(1)**

1

(b) (i) To allow transfer of electrons / provide a reaction surface **(1)**

(ii) 298 K **(1)**
Both F^{3+} (aq) and Fe^{2+} (aq) have a concentration of
1 mol dm^{-3} **(1)** (QoL)
OR $[H^+]$ = 1 mol dm^{-3}

NOT zero current or 100 kPa

3

(c) +1.34 V **(1)**
$2\ MnO_4^- + 5\ H_2SO_3 \rightarrow 2\ Mn^{2+} + 5\ SO_4^{2-} + 3\ H_2O + 4\ H^+$
Correct species / order **(1)**
Balanced and cancelled **(1)**

Allow one for $2\ MnO_4^- + 5\ H_2SO_3 \rightarrow 2\ Mn^{2+} + 5\ SO_4^{2-}$

3

(d) (i) Ce^{4+} (aq) **(1)**

(ii) VO_2^+ (aq) **(1)**; Cl_2 **(1)**

Penalise additional answers to zero

3

(e) Pt | Fe^{2+} (aq), Fe^{3+} (aq) || Ce^{4+}(aq), Ce^{3+} (aq) | Pt
Correct species **(1)**
Correct order **(1)**

Deduct one mark for each error

2

[12]

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Q2.

Only the more able students scored well in part (a)(i). Many students failed to give the correct equations at the electrodes and the overall equation was often not cancelled down to the simplest form. Most students scored the first mark in part (a)(ii) but only a very few students referred to an equation to score M2. Most students could draw the correct line on the graph in part (b) although several assorted incorrect curves were seen. The effect of changing the surface area was well known in part (c)(i). Some students failed to gain credit in part (d) because their answers were vague and did not identify pollutants. In part (e) a statement about carbon dioxide being released in the generation of hydrogen was required to score the mark; some students did not identify hydrogen as the fuel in the fuel cell and described general ways that carbon dioxide would be released when the fuel-cell was made e.g. transportation of hydrogen etc.

Q3.

Few correct answers were seen to part (a). Some students did not comply with the convention of placing the hydrogen electrode on the left when measuring the standard electrode potential. Some failed to include all the phase boundaries, putting a comma between H_2 and H^+ instead of a solidus, whilst other students included too many phase boundaries at the extremities or an incorrect, additional platinum connected to iron. Parts (b) and (c) were answered well. All the elements were chosen by students in part (d)(i) and where the correct answer of chlorine was selected, the oxidation states in part (d)(ii) and the equation in part (e) were usually correct. It was pleasing to find that answers to parts (f)(i) and (f)(ii) were usually correct. Most students identified the positive electrode correctly in part (f)(iii) but only the highest-scoring students used an appropriate electrode potential from the table to explain their answer.

Q4.

Answers to parts of this question were generally disappointing. In part (a)(i), the half-equation for the hydrogen electrode was usually correct but most students gave an incorrect equation for the reaction at the oxygen electrode involving the formation of oxide ions. Part (a)(ii) proved to be difficult and only the highest-scoring students were able to address the question properly by using the half equations to explain how a flow of electrons is generated in the external circuit.

Part (b) was answered well but answers to part (c) were mostly disappointing. Students appeared not to know that the major advantage of a fuel cell over a heat engine is its greater efficiency. It is difficult for examiners to understand why most students thought that the burning of hydrogen in an internal combustion engine would lead to formation of carbon dioxide and hence exacerbate global warming.

Q5.

In this part (a), there were many examples of full marks being awarded for vague, unclear or confusing answers. Unless the student makes it very clear which type of cell they are referring to in their answer they cannot gain full credit. Lenient marking was often seen here. The ideas in this part (b), however, were well understood.

Despite the long catalogue of points listed above, this was, overall, another very positive session in many schools and colleges. The new administrative arrangements were applied well and schools and colleges are thanked for this. Teachers in schools and

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colleges have, in the main, successfully and securely delivered the practical assessment and have impressed with the accurate and consistent standard of their marking. In my first report as Principal Moderator, I am grateful for the opportunity to salute their professionalism and thank them for their integrity.

Q6.

This was a testing question and in common with redox questions in previous years, performance by students was very mixed. In part (a), over 30% of students answered incorrectly that the salt bridge allowed electrons to flow through it. In part (b), students were expected to use their knowledge of copper chemistry to suggest that the chloride ions from the potassium chloride would react with the aqueous copper ions but only a very small percentage of students answered this correctly. Part (c) also proved to be a very demanding question. Only the best students gave a correct answer involving the higher concentration of copper ions in the left hand electrode. It was surprising that many students appeared to consider that the 0.2 mol dm^{-3} solution of $CuSO_4$ was more concentrated than the 1.0 mol dm^{-3} solution. Part (d) was very discriminating. The great majority of students answered incorrectly by stating that one of the reagents would be used up or had reacted completely. Answers to part (e) were much better. When students are asked to write an equation for an overall reaction, they should take care to cancel out identical species that appear on both sides of the final equation. In part (e)(ii), many students lost a mark because they failed to cancel out a lithium ion that appeared on both sides of the equation. In part (e)(iii), it was surprising to note that a considerable number of students thought that carbon dioxide would be produced by a reaction with an imaginary carbon electrode in the lithium cell.

Q7.

(a) This part was usually well answered. The usual mistakes were to make some reference to impurities without specifying aluminium oxide or contradicting an answer by giving an incorrect formula.

(b) Answers to this part were variable. Students familiar with the standard hydrogen electrode gave good answers, although many omitted to name the acid used.

(c) In this part, most students realised that a reaction would occur but gave impossible products and lost the mark. The consequences of reaction were not well understood. A number of students gave answers implying that a salt bridge would not be necessary or describing details of one specific use of a standard hydrogen electrode, which did not relate to the question being asked.

Q8.

This proved to be a difficult question. In part (a), answers were often very scrappy and disappointing. Diagrams showed a half cell that had no chance of working. The salt bridge, if present rarely dipped into a solution and the electrode material was often iron instead of the correct material, platinum. Only very good students showed a solution containing iron(II) and iron(III) ions and only the very highest-scoring students stated clearly that all aqueous species should have a concentration of 1 mol dm^{-3}. Answers to part (b) were more encouraging but only the better students realised that no platinum electrode are necessary with copper and iron electrodes. In parts (c) and (d), most students were unable to use data from the table correctly. For instance, it is correct to state that $E^{\ominus}$ $Au^{+}/Au > E^{\ominus}$ O_2/H_2O but not correct to state that $E^{\ominus}$ $Au^{+}/Au > E^{\ominus}$ H_2O/O_2 or that gold ions are better oxidising agents than water. In this reaction, water is the reducing agent. In part (d), only 6% of students recognised that silver ions would oxidise iron to iron(II) ions and then go on to oxidise iron(II) ions to iron(III) ions.

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Q9.

Part (a) was answered well. The most common error was to give the meaning of oxidation rather than an oxidising agent. Answers to part (b) were very often incorrect. All of the species from the table were seen in students' answers. The most common wrong answer was probably 'cadmium'. It still seems to be the case that many students do not understand that when redox half–equations are presented in their standard form with electrons on the left, the species on the left are oxidising agents and the species on the right are reducing agents. Parts (c)(i) and (ii) were answered correctly by most students. Part (c)(iii) proved to be more testing and only the best students recognised that the porous partition was acting in the same way as a salt bridge by permitting the transport of ions. Parts (c)(iv) and (v) were answered quite well although in part (c)(v) it was not always realised that the zinc container reacts to form zinc ions whilst the cell is in operation.

Part (d)(i) proved to be a discriminating question. An oxidation state of +2 for nickel in NiO(OH) was a common error and the equation was often unbalanced or not simplified by removing hydroxide ions. Part (d)(ii) was almost always answered correctly. In comparison, parts (e)(i) and (ii) were not answered well, usually because of a lack of attention to detail. Instead of using ethanol, a common mistake was to use CH_3OH. In part (e)(i), the equation for the combustion of ethanol was often unbalanced because students seemed to fail to take into account the oxygen in the ethanol. In part (e)(ii), despite being asked to write a half–equation, the electrons were often omitted or the numbers of hydrogen ions and electrons were wrong. Answers to part (e)(iii) were usually correct. In part (e)(iv), it seems that many students are still not clear about the meaning of the term carbon–neutral. The term is too often thought to refer just to carbon rather than to carbon dioxide in the atmosphere. Also, the majority of students did not make it clear that the carbon dioxide, released into the atmosphere by the processes that manufacture and use ethanol, can be balanced by the carbon dioxide taken out of the atmosphere by photosynthesis in plants.

Q10.

As usual, this question that tested candidates' understanding of redox and cells proved to be difficult but it was pleasing to note that even the weaker candidates were able to gain a significant number of marks. Parts (a) and (b) were answered well. Many candidates were able to score two out of three marks for part (c). The mark lost was usually due to incorrect use of data from the table. Many candidates stated that the electrode potential values showed that fluorine is a better oxidising agent than water. In this case, water is the reducing agent and candidates should have stated that the data shows that fluorine is a better oxidising agent than oxygen. In part (d)(i), a majority of candidates scored one mark out of the two available; only the best candidates showed metal species on the outside of the cell and all the phase boundaries, correctly indicated. Parts (d)(ii) and (e)(i) were answered well but only about a third of candidates gave a correct answer to part (d)(iii). In part (e)(ii) marks were lost because candidates did not simplify the overall equation after combining the half equations or the equation was for discharge rather than for recharging. As expected, part (f) proved to be challenging, particularly part (f)(iii). Fuel cells were included in the Specification as an example of 'How Science Works'. Their value is that they can produce efficiently a steady current to drive electric motors because the concentrations of the reactants remain constant when the fuel and the oxidant are supplied continuously.

Q11.

This was the most difficult question in the paper. In part (a) most candidates knew that a standard hydrogen electrode uses hydrogen gas and a platinum electrode but only a minority went on to state the correct and necessary conditions of concentration,

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temperature and pressure for operation of the electrode. In part (b) most candidates gave a correct value for the electrode potential of the positive electrode but very few candidates were able to use the cell representation to deduce a half-equation for the electrode reaction. Answers to part (c) were also disappointing. Despite the given electrode potentials and half-equations, most candidates could not predict and explain the redox reaction between hydrogen and iron(III) ions. Part (d) also proved to be a difficult question. Candidates were usually able to score three marks out of six for a correct calculation of the number of moles of dichromate(VI) ions, a calculation of the original number of moles of iron(II) sulfate and for recognising the involvement of a factor of ten. Only the very best candidates realised that the number of moles of iron ions was six times the number of moles of dichromate(VI) ions and that a subtraction was required to calculate the percentage of iron(II) ions that had been oxidised by air before the titration.

Q12.

Redox questions involving electrochemical cells are usually found to be very difficult. It was therefore very pleasing to find that this question was answered well in all parts except for parts (a)(iv) and (b)(i). In part (a)(iv) candidates were expected to recall from Unit 1 that lithium reacts with water but only about 20% were able to do this and these were not necessarily the best candidates. As expected, part (b)(i) proved to be discriminating. Although about one third of candidates scored both marks, others failed to include platinum or put the various ions in the wrong order.

Q13.

This question was answered well except for part (b) where only the best candidates were able to write a balanced equation with the oxidising and reducing agent in the correct position.

Q14.

This question covered a new area of the Specification although the principles of redox that were involved have been tested for many years. Candidates have always found difficulty with the understanding of these principles when applied to electrochemical cells. This question discriminated very effectively between candidates. In part (a) only about 20% of candidates knew that the zero electrode potential of the hydrogen electrode is an arbitrary definition. In part (c) candidates had great difficulty with the conventional representation of the alkaline fuel cell. The most common mistakes were to give the oxidised and reduced forms in the wrong order and to use the hydrogen half-equation in acidic rather than alkaline conditions. Similar mistakes were made in part (d) although 39% of candidates did score full marks. About half of all candidates scored full marks in parts (g) and (h) but only 23% of candidates gained the mark in part (f). Many candidates opted not to answer this part.

Q15.

There were many good answers to this question. Virtually all candidates were able to name the standard reference electrode in part (a). In part (b) only the best candidates stated the function of the platinum electrode correctly and many failed to state in section (ii) that, for standard conditions to apply, both Fe^{3+} (aq) and Fe^{2+} (aq) would need to be at a concentration of 1 mol dm^{-3} in the solution. Most deduced correctly the e.m.f. of the cell given in part (c).

Many scored one further mark in part (c) when they deduced the correct molar ratio of the reacting species in the equation but lost one mark when they failed to balance the equation correctly. In part (d) most candidates were able to deduce which of the species in the table of data was the strongest oxidising agent but many only gave one of the two

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correct answers in section (ii). A pleasing number of candidates gave a correct cell representation in part (e). Almost all were able to select the correct species for the cell but some then used the convention, as shown in part (c), incorrectly.

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Q1.

(a) It has mobile <u>ions</u> / <u>ions</u> can move through it / free <u>ions</u>

Do not allow movement of electrons.

1

(b) (+) 0.18 V

1

(c) The concentration is not <u>1</u>.(0) (mol dm^{-3})

1

(d) Cu (s)│ Cu^{2+}(aq) ‖ Cu^{2+}(aq) │ Cu(s)

1

(e) (Concentration) increases or ([Cu^{2+}] ions) increase

Mark independently

1

The [Cu^{2+}] ions in the two solutions become <u>equal/same</u>

Not, concentrations are constant

1

[6]

Q2.

(a) Fe^{2+}

Accept any Fe(II) compound – correct formula or name

1

$E^{\ominus}$ VO_2^+(/ VO^{2+}) > $E^{\ominus}$ Fe^{3+}(/Fe^{2+}) > $E^{\ominus}$ VO^{2+}(/V^{3+})

If calculations of EMF are provided producing EMFs = 0.23(V) and -0.43(V), with a comment, allow M2

allow <u>$E^{\ominus}$ Fe^{3+}</u> (/Fe^{2+}) value of +0.77 is between the $E^{\ominus}$ values for the electrode half-equations containing the V species or wtte

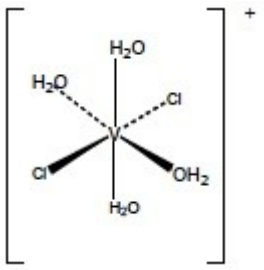
1

(b) (+) 4

IV or four

1

(c)



Ignore absence of charge

Wedges, dotted lines and [ ] not required

Do not penalise bond from H to V (in water ligands)

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1

Cis/trans

allow E/Z, geometric and stereo(isomerism)

1

(d) $2\ NH_4VO_3 \rightarrow V_2O_5 + H_2O + 2NH_3$

Accept multiples

Ignore state symbols

1

(e) $V_2O_5 + SO_2 \rightarrow V_2O_4 + SO_3$

$V_2O_4 + ½\ O2 \rightarrow V_2O_5$

Both equations needed for 1 mark in this order

Allow multiples

1

[7]

Q3.

B

[1]

Q4.

(a) (+) 5

1

(+) 2

1

Allow Roman numerals

(b) Cl^- / chloride (ions)

Allow $2Cl^-$

Do not allow chlorine / Cl / Cl_2

Ignore (aq)

1

(c) nitric acid / HNO_3

If not nitric acid then CE = 0

If NO_3^- ions identified, lose M1 and mark on

Allow 0.96V > 0.34V

1

the E^θ $\mathbf{NO_3^-}$ (/NO) > E^θ $\mathbf{Cu^{2+}}$(/Cu) or in words

Allow $\mathbf{NO_3^-}$ is a better oxidising agent than $\mathbf{Cu^{2+}}$

Allow $\mathbf{NO_3^-}$ has a more positive E^θ than $\mathbf{Cu^{2+}}$

1

$3Cu + 8H^+ + 2NO_3^- \longrightarrow 3Cu^{2+} + 2NO + 4H_2O$

Allow $3Cu + 8HNO_3 \longrightarrow 3Cu(NO_3)_2 + 2NO + 4\ H_2O$

1

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EMF for the reaction is 0.62(V)

1

[7]

Q5.

(a) Cl_2

1

(b) $Pt|H_2|H^+||Sn^{2+}|Sn$

Award 1 mark for species and 1 mark for correct order including Pt

Ignore state symbols

2

(c) 0.94 V

1

$Sn \longrightarrow Sn^{2+} + 2e^-$

1

(d) $Ag^+ + Fe^{2+} \rightarrow Ag + Fe^{3+}$

1

[6]

Q6.

(a) The ions in the ionic substance in the salt bridge move through the salt bridge

1

To maintain charge balance / complete the circuit

1

(b) F^-

1

(c) $E^\ominus$ SO_4^{2-} / SO_2 < $E^\ominus$ Br_2 / Br^-

Allow correct answer expressed in words, eg electrode potential for sulfate ions / sulfur dioxide is less than that for bromine / bromide

1

(d) 1.23 (V)

1

(e) A fuel cell converts more of the available energy from combustion of hydrogen into kinetic energy of the car / an internal combustion engine wastes more (heat) energy

1

[6]

Q7.

A

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[1]

Q8.

(a) Magnesium

If Mg^{2+} then CE = 0/2

1

It is the most powerful reducing agent / it has the most negative $E^{\ominus}$/ forms the cell with iron with the biggest emf

1

(b) $O_2 + 2H_2O + 4e^- \rightarrow 4OH-$

Allow fractions and multiples.

Ignore state symbols.

1

$4Al + 3O_2 + 6H_2O \rightarrow 4Al^{3+} + 12OH^-$

Allow fractions and multiples.

Ignore state symbols.

1

E = 0.40 – (–1.66) = <u>2.06</u> (V)

Lose this mark if answer is –2.06

1

(c) Non-standard conditions (T, p or concentration)

Current flow affects voltage

Al3+ ions may react in alkaline conditions / with OH−/form $Al(OH)_3$

Max 2 from 3

2

(d) The iron foil does not lose mass as it is protected by the operation of the sacrificial anode

1

(e) A coating developed on the aluminium preventing further reaction

1

[9]

Q9.

(a) (i) Zn^{2+}

$Zn^{2+}(aq)$

Apply List

1

(ii) 298 K /25°C

Ignore pressure

Ignore standard conditions

Ignore state symbols

1

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(Solutions at) unit concentration / 1 mol dm^{-3} (of Zn^{2+})

Ignore references to S.H.E

1

(b) Identifying it is the Zn/Zn^{2+} and Co^{2+}/Co half cells

1

$Zn \mid Zn^{2+} \mid \mid Co^{2+} \mid Co$

Correct order with phase boundaries and salt bridge correct, no Pt

If this is correct it scores M1 and M2

Allow double dashed line for salt bridge

Extra phase boundaries loses M2

Ignore state symbols

1

$Zn \longrightarrow Zn^{2+} + 2e^{(-)}$

M3 independent

Allow $-2e^-$ on LHS

1

(c) $\underline{Co^{3+}}$

Mark independently

1

$2Co^{3+}(aq) + H_2O(l)\ 2Co^{2+}(aq) + ½\ O_2(g) + 2H^+(aq)$

Ignore state symbols

Allow multiples

1

Oxygen /O_2

Allow ½ O_2

1

(d) $E^{\ominus}$ (O_2(|H_2O)) electrode $E^{\ominus}$ (O_2(|H_2O))
OR the $E^{\ominus}$ (Au^+|Au) electrode potential is more positive than the $E^{\ominus}$ (O_2|H_2O) electrode
OR The emf (for the reaction of Au and oxygen) is –0.45 V (and therefore not spontaneous)

Mark independently

1

So <u>oxygen</u> is unable to oxidise gold

Ignore references to water

Allow gold cannot reduce <u>oxygen</u>

1

[11]

Q10.

(a) Electron acceptor / gains electrons

do not allow electron pair acceptor

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1

(b) Fe^{2+} ions

1

Fe^{2+} / Fe or Fe^{2+} or it has smallest / most negative <u>electrode potential</u> / <u>*E*°</u>

Do not allow Fe / Fe^{2+}

Cannot score M2 if M1 incorrect

1

(c) $Pt|H_2|H^+||Ag^+|Ag$

M1 for H_2 H^+ Ag^+ Ag in correct order

1

allow dashed phase boundaries

$2H^+$ loses one mark (M2)

M2 for Pt correct and correct phase boundaries

Ignore state symbols. M1 must be correct to score M2

If answer correct but all in reverse order allow 1 mark out of two

1

Any **two** correct conditions

- 298 K / 25 °C
- 100 kPa
- both solutions of unit concentration
- zero current

Allow 1 bar

Do not apply list principle, mark correct answers.

2

(d) E Au^+(/ Au) > E O_2 (/ H_2O) OR e.m.f. / *E*cell = 0.45 V

If both species in electrode given, must be in correct order i.e. Au+ / Au

1

<u>Au^+ (ions) oxidise water</u> OR <u>water reduces Au^+</u> (ions)

Allow water donates electrons to Au+

1

<u>Gold</u> metal / solid / precipitate **OR** <u>bubbles</u> / effervescence of (oxygen gas) / gas produced

Penalise incorrect observations

1

$2Au^+ + H_2O \rightarrow 2Au + 2H^+ + \frac{1}{2} O_2$ OR $4Au^+ + 2H_2O \rightarrow 4Au + 4H^+ + O_2$

Allow multiples

1

(e) (i) 1.24 (V)

Do not allow −1.24

1

(ii) Chloride ions / Cl^- react with / form a precipitate with silver ions / Ag+ /

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form AgCl

Penalise reaction of chloride ions with iron ions or iron

1

(f) E O_2 (/ H_2O) > E Fe^{3+} (/ Fe^{2+}) (or e.m.f / *E*cell = 0.46 V)

Species in electrode if all given must be in correct order

1

Therefore the iron(II) ions are oxidised (or converted) into iron(III) ions (by oxygen)

If chloride ions oxidised to chlorine, lose M2

M2 can be obtained or lost from equation.

Ignore observations.

1

[15]

Q11.

(a) $Pt|H_2|H^+||Fe^{2+}|Fe$

Allow 1 for correct order of symbols but lose second mark for a wrong phase boundary(s) / Pt missing / extra Pt on RHS, additional phase boundary

Note, allow one mark only for correct symbol in reverse:

$Fe|Fe^{2+}||H^+|H_2|Pt$

Allow dashed lines for salt bridge

Ignore state symbols

Ignore 2 if used before H^+

2

(b) Electron donor

Allow (species that) loses electrons

Do not allow reference to electron pairs

1

(c) Cl_2 / chlorine

If M1 blank or incorrect cannot score M2

1

(Species on RHS / electron donor) has most positive / largest $E^{\ominus}$ / has highest potential

Do not allow reference to e.m.f. or E(cell)

1

(d) (i) Cl / chlorine

1

(ii) Chlorine +1 to chlorine 0

CE if chlorine not identified in part (i)

Allow chlorine +1 to chlorine –1 (in Cl^-)

Allow oxidation state decreases by one OR two

Allow oxidation state changes by –1 OR –2

1

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(e) $4HOCl + 4H^+ + 4OH^- \rightarrow 2Cl_2 + O_2 + 6H_2O$

OR

$4HOCl \rightarrow 2Cl_2 + O_2 + 2H_2O$

Allow one mark for any incorrect equation that shows $HOCl \rightarrow Cl_2 + O_2$

Allow multiples

Ignore state symbols

Penalise one mark for uncancelled or uncombined species (eg $H_2O + H_2O$ *instead of* $2H_2O$*)*

2

(f) (i) e.m.f. = 0.40 – (–1.25) = 1.65 (V) / +1.65 (V)

Allow –1.65 (V)

1

(ii) $2Zn + O_2 \rightarrow 2ZnO$

Allow multiples

Ignore state symbols

Do not allow uncancelled species

If more than one equation given, choose the best

1

(iii) **A** / stainless lid

If M1 incorrect or blank CE=0

1

O_2 (electrode) has a more positive $E^\ominus$ / oxygen (electrode) requires / gains electrons from external circuit

Or reference to the overall equation and a link to electrons going into A

Allow oxygen is reduced and reduction occurs at the positive electrode

OR Zinc (electrode) has more negative $E^\ominus$

Do not allow reference to e.m.f. or E(cell)

1

(iv) (Cell) reaction(s) cannot be reversed / zinc oxide cannot be reduced to zinc by passing a current through it / zinc cannot be regenerated

Allow danger from production of gas / oxygen produced / hydrogen produced

1

[14]

Q12.

(a) Platinum electrode

1

Solution in beaker is a mixture of named soluble iron(II) compound and named soluble iron(III) compound

Allow correct formulae for the iron compounds.

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1

Concentrations of Fe(II) and Fe(III) ions are both 1 mol dm^{-3}

Ignore any references to temperature.

If eg $Fe_2(SO_4)_3$ used then concentration must be 0.5

1

(b) Purpose: Allow movement of ions between electrodes

Allow to maintain an electric circuit.

Do not allow reference to movement of electrons in salt bridge.

1

Requirement: Must not react with the electrolyte / ions in solution

Do not allow 'must not react' without further qualification.

1

[5]

Q13.

(a) $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$

*If equations reversed, allow **M1** only.*

1

$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

Ignore state symbols.

1

(b) Moles of copper(II) reacted = (100 / 1000) × 0.5 = 0.05

1

Moles of zinc reacted = 0.05

1

Mass of zinc lost = 0.05 × 65.4 = 3.27 g

*Correct final answer without working scores **M3** only.*

1

(c) Allow cell to discharge until $[Cu^{2+}]$ is 0.5

Alternative: Allow cell to discharge completely.

1

Confirmed by colorimetric measurement or other suitable method

Solution colourless or use of chemical test to determine absence of copper(II)

1

Weigh the Zn electrode before and after the experiment

Weigh Zn electrodes before and after and halve the mass change.

1

[8]

Q14.

(a) It has mobile ions / ions can move through it / free ions

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Do not allow movement of electrons.

Allow specific ions provided they are moving but do not react.

1

(b) Chloride ions react with copper ions / Cu^{2+} ***OR*** $[CuCl_4]^{2-}$ formed

If incorrect chemistry, mark = 0

1

(c) The Cu^{2+} ions / $CuSO_4$ in the left-hand electrode more concentrated

Allow converse.

1

So the reaction of Cu^{2+} with $2e^-$ will occur (in preference at) left-hand electrode / $Cu \rightarrow Cu^{2+}$ + electrons at right-hand electrode

Allow left-hand electrode positive / right-hand electrode negative.

Also reduction at left-hand electrode / oxidation at right-hand electrode.

Also left-hand electrode has oxidising agent / right-hand electrode has reducing agent.

Allow E left-hand side > E right-hand side

1

(d) (Eventually) the copper ions / $CuSO_4$ in each electrode will be at the same concentration

1

(e) (i) −3.05 (V)

Must have minus sign.

−3.05 only.

1

(ii) $LiMnO_2 \rightarrow Li + MnO_2$ correct equation

Allow 1 for reverse equation.

Allow multiples.

1

Correct direction

If Li^+ not cancelled but otherwise correct, max = 1

If electrons not cancelled, CE = 0

$LiMnO_2 \rightarrow Li + MnO_2$ scores 2

$Li^+ + LiMnO_2 \rightarrow Li^+ + Li + MnO_2$ scores 1

$Li + MnO_2 \rightarrow LiMnO_2$ scores 1

1

(iii) Electricity for recharging the cell may come from power stations burning (fossil) fuel

Allow any reference to burning (of carbon-containing) fuels.

Note combustion = burning.

1

[9]

Q15.

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(a) To remove the <u>oxide</u> layer on the aluminium

Do not allow 'cleaning' or 'removal of grease'.

Do not allow 'removal of impurities' without qualification.

1

(b) An appropriate method for delivering H_2 gas over a Pt electrode

Need H_2 gas and Pt electrode labelled (allow gas delivered directly below the electrode).

1

The Pt electrode must clearly be in contact with a solution of a named acid.

Ignore any concentration or pressure values.

Ignore absence of bubbles.

Allow if electrode is below outer acid level.

1

(c) The carbonate ion reacts with the acid (in the SHE) / reaction between carbonate and Al^{3+}

Lose this mark if aluminium carbonate formed but mark on.

1

Reaction given (either equation or products specified)

OR H^+ / Al^{3+} concentrations change / cell e.m.f. altered

1

[5]

Q16.

(a) Diagram of an Fe^{3+} / Fe^{2+} electrode that includes the following parts labelled:
Solution containing Fe^{2+} and Fe^{3+} ions

1

Platinum electrode connected to one terminal of a voltmeter

Must be in the solution of iron ions (one type will suffice)

1

Salt bridge

Do not allow incorrect material for salt bridge and salt bridge must be in the solution (ie it must be shown crossing a meniscus)

1

298 K and 100 kPa / 1 bar

1

<u>all solutions</u> unit / 1 mol dm^{-3} concentration

Allow zero current / high resistance voltmeter as alternative to M4 or M5

Ignore hydrogen electrode even if incorrect

1

(b) $Cu^{2+} + Fe \rightarrow Cu + Fe^{2+}$

Ignore state symbols

1

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$Fe|Fe^{2+}||Cu^{2+}|Cu$ correct order

Allow $Cu|Cu^{2+}||Fe^{2+}|Fe$

1

Phase boundaries and salt bridge correct, no Pt

Allow single / double dashed line for salt bridge

Penalise phase boundary at either electrode end

Can only score M3 if M2 correct

1

Copper electrode

Allow any reference to copper

1

(c) $E^{\ominus}$ Au^{+}(/ Au) > $E^{\ominus}$ O_2 (/ H_2O)

Allow E cell / e.m.f. = 0.45 V

Allow 1.68 > 1.23

1

So Au^{+} ions will oxidise water / water reduces Au^{+}

QoL

1

$$2Au^{+} + H_2O \rightarrow 2Au + \frac{1}{2}O_2 + 2H^{+}$$

Allow multiples

1

(d) $E^{\ominus}$ Ag^{+}(/ Ag) > $E^{\ominus}$ Fe^{2+}(/ Fe)

Allow E cell / e.m.f. = 1.24

Allow 0.80 > −0.44

1

And $E^{\ominus}$ Ag^{+}(/ Ag) > $E^{\ominus}$ Fe^{3+}(/ Fe^{2+})

Allow E cell / e.m.f. = 0.03

Allow 0.80 > 0.77

1

So silver ions will oxidise iron (to iron(II) ions) and then oxidise Fe(II) ions (further to Fe(III) ions producing silver metal)

Allow Ag^{+} ions will oxidise iron to iron(III)

1

[15]

Q17.

(a) Electron acceptor / gains electrons / takes electrons away

Do not allow electron pair acceptor / gain of electrons / definition of redox (QWC)

1

(b) $Cd(OH)_2$

Do not allow 'Cd(OH)$_2$/Cd'

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1

Species (on LHS) with the least positive/most negative electrode potential / lowest *E* / smallest *E*

Only allow this mark if M1 answer given correctly or blank

Do not allow negative emf

1

(c) (i) 1.5 (V) / 1.50

1

(ii) $2MnO_2 + 2H_2O + Zn \rightarrow 2MnO(OH) + 2OH^- + Zn^{2+}$

Ignore state symbols

e^- must be cancelled

(take care that Zn^{2+} is on RHS)

1

(iii) Allows ions to pass (through it) or words to that effect

Penalise passage of electrons

Allow mention of particular ions

1

(iv) Allows electrons to flow / makes electrical contact / conductor

Allow acts as an (inert) electrode / anode / cathode

1

(v) Zn is 'used up' / has reacted / oxidised

Allow idea that zinc reacts

Do not allow just zinc corrodes

1

(d) (i) 3 / +3 / III

1

$2Ni(OH)_2 + Cd(OH)_2 \rightarrow 2NiO(OH) + Cd + 2H_2O$

For correct nickel and cadmium species in correct order (allow H_2O missing and OH^- not cancelled)

1

For balanced equation (also scores M2)

Allow max 1 for M2 and M3 if correct balanced equation but reversed.

Ignore state symbols

1

(ii) Metal / metal compounds are re-used / supplies are not depleted / It (the cell) can be re-used

Allow does not leak / no landfill problems / less mining / less energy to extract metals / less waste

Do not allow less CO_2 unless explained

1

(e) (i) $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$

Allow C_2H_6O

1

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(ii) $C_2H_5OH + 3H_2O \rightarrow 2CO_2 + 12H^+ + 12e^-$

Allow C_2H_6O

1

(iii) (+)0.23 (V)

1

(iv) $\underline{CO_2}$ released by combustion / fermentation / fuel cell / reaction with water

Can be answered with the aid of equations

1

(atmospheric) $\underline{CO_2}$ taken up in <u>photosynthesis</u>

1

[17]

Q18.

(a) Manganate would oxidise / react with $\underline{Cl^-}$

1

Because $E^\ominus$ for MnO_4^- is more positive than that for Cl^2 / 1.51 – 1.36 = +0.15 (V)

Must refer to data from the table for M2.

1

(b) Moles of $H^+ = 25 \times 0.0200 \times 8 / 1000 = 4.00 \times 10^{-3}$

1

Moles of $H_2SO_4 = 2.00 \times 10^{-3}$ ($4.00 \times 10^{-3} / 2$)

Allow consequential marking on incorrect moles of H^+

1

Volume $H_2SO_4 = 4.00$ (cm^3) ($2.00 \times 10^{-3} \times 1000 / 0.500$)

Allow consequential marking on incorrect moles of H_2SO_4

Accept 4 cm^3.

8 cm^3 scores 2 marks.

Do not penalise precision.

Correct answer without working scores M3 only.

1

(c) (i) $MnO_4^- + 4H^+ + 3e^- \rightarrow MnO_2 + 2H_2O$

Allow multiples, including fractions.

Ignore state symbols.

1

(ii) Can't see end point due to brown colour

1

<u>Larger</u> titre (than expected)

Allow the idea that with two reactions can't make use of titre in calculations.

Do not allow 'an inaccurate result' without qualification.

1

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(d) Solution (very) dilute / lots of water

1

[9]

Q19.

(a) HCl 1.0 mol dm^{-3}

Allow H_2SO_4 0.5 mol dm^{-3}

Allow HNO_3 1.0 mol dm^{-3}

Allow name or formula

Concentration can be given after "conditions"

1

(Hydrogen at) 100kPa / 1 bar

1

298 K

1

(b) Pt / Platinum

Mark on if no answer for M1

If wrong answer for M1, only mark on if electrode is Au, Ag, Pb or Ti

1

Inert / unreactive / does not create a potential difference

1

Conducts electricity / allows electron flow / conducts / conductor

1

(c) KCl

Allow NaCl, KNO_3, Na_2SO_4 etc NOT NH_4Cl

1

Does not react with either electrode / solution in electrode

Allow unreactive / inert

1

Ions can move

Allow conducts electricity / electrical connection / carries charge

Do not allow just connects / completes the circuit

Do not allow conducts / carries electrons

Mark these independently

1

(d) $Pt|H_2|H^+||Fe^{3+},Fe^{2+}|Pt$

Ignore state symbols

Order must be correct

| must be correct but allow | instead of , separating Fe^{3+} from Fe^{2+}

Allow , instead of | separating H_2 and H^+

1

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(e) (i) $2Fe^{3+} + H_2 \longrightarrow 2Fe^{2+} + 2H^+$

Allow multiples

1

(ii) The $\underline{Fe}^{3+}$ ions would be used up / reaction completed

Answer must relate to reactants in (e)(i) equation if given

Allow reactant / reactants used up

Do not allow concentration of Fe^{3+} decreases

Allow concentration of Fe^{3+} falls to zero

1

[12]

Q20.

(a) H_2O_2

Ignore state symbols

1

(b) $E^{\ominus}\ Cl_2/Cl^- > E^{\ominus}\ O_2/H_2O$

Allow potential for chlorine/Cl_2 greater than for oxygen/O_2

Allow 1.36 > 1.23 / E cell = 0.13

1

$Cl_2 + H_2O \longrightarrow 2Cl^- + 1/2O_2 + 2H^+$

Allow multiples

Allow + HCl

1

(c) Activation energy is high / light/UV provides the activation energy / light breaks chlorine molecule / Cl–Cl bond

If light used to break Cl–Cl bond award 1 mark and ignore product e.g. Cl^-

1

(d) $\underline{O}$ $\underline{(-1)}$ (in H_2O_2)

Must give oxidation state of O in H_2O_2= –1

1

Changes to $\underline{O(-2)}$ (in water)

Must give oxidation state of O in water = –2

CE = 0/2 if refers to oxidation state of H changing

1

(e) $E^{\ominus}\ H_2O_2/H_2O > E^{\ominus}\ O_2/H_2O_2$

Allow stated in words

Allow 1.77 > 0.68 / E cell = 1.09

1

$2H_2O_2 \longrightarrow O_2 + 2H_2O$

Allow multiples

H^+ and e^- must be cancelled

1

[8]

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Q21.

(a) loses electrons / donates electrons

penalise donates electron pair

1

(b) Zn

1

(most) negative E^{o} / lowest E^{o} / least positive

can only score M2 if M1 correct

do not allow e.m.f instead of E^{o}

1

(c) $\underline{E^{o}\ F_2}$ ($/F^-$) > $\underline{E^{o}\ O_2}$ ($/H_2O$)

or e.m.f is positive or e.m.f = 1.64 V

1

Fluorine reacts to form oxygen (can score from equation in M3 even if equation unbalanced provided no contradiction)
or fluorine oxidises water
or fluorine is a more powerful oxidising agent than oxygen

1

$2F_2 + 2H_2O \rightarrow 4F^- + 4H^+ + O_2$

allow 4HF in equation

balanced equation scores M2 and M3

1

(d) (i) order correct Zn Zn^{2+} Ag_2O Ag or reverse of this order

ignore ss , H^+ and H_2O, no. of moles

1

all phase boundaries correct

allow $Zn|Zn^{2+}||Ag_2O,Ag$

or $Zn|Zn^{2+}||Ag_2O|H^+|Ag$ for M1 & M2

e.g. $Zn|Zn^{2+}||Ag_2O|Ag$ or $Ag|Ag_2O||Zn^{2+}|Zn$ scores 2

M2 cannot be gained unless M1 scored

allow H^+ either side of Ag_2O with comma or |

for M2 penalise

- *wrong phase boundary (allow dashed lines for salt bridge)*
- *Pt*
- *use of + (from half equation)*
- *water/H^+ outside Ag in Ag electrode*

1

(ii) 1.1 (V)

Allow no units, penalise wrong units

allow correct answer even if no answer to (d)(i) or answer to (d)(i) incorrect

allow –1.1 if silver electrode on Left in (d)(i) even if the species are in the wrong order.

1

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(iii) Reaction(s) not reversible or H_2O electrolyses

do not allow hard to reverse

mention of primary cell is not enough to show that reaction(s) are irreversible

1

(e) (i) –0.46 (V)

Allow no units, penalise wrong units

1

(ii) $2PbSO_4 + 2H_2O \rightarrow Pb + PbO_2 + 2HSO_4^- + 2H^+$

lead species correct on correct sides of equation

1

equation balanced and includes H_2O,

HSO_4^- and H+ (or H_2SO_4)

allow ions / species must be fully cancelled out or combined

allow 1/2 for balanced reverse equation

1

(f) (i) reagents / PbO_2 / H_2SO_4 /acid / ions used up (or concentration decreases)

1

(ii) fuel cell

Ignore any other words

1

(iii) reagents / fuel supplied continuously

1

concentrations (of reagents) remain constant

1

[17]

Q22.

MnO_4^- will oxidise the chloride ion / reaction of MnO_4^- and Cl^- feasible

Accept converse argument with $Cr_2O_7^{2-}$

Accept calculations of overall E° values.

1

Larger volume needed

1

[2]

Q23.

(a) (i) Co/Cobalt

If Co or Cobalt not given CE = 0

ignore case in symbol for Co

1

(+) 4

1

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(+) 3

Allow 4 and 3 in either order

1

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

Ignore state symbols
Allow e without -ve sign
Do not allow equilibrium sign

1

(iii) Platinum is a conductor

1

(Platinum is) unreactive/inert

Ignore mention of surface area or catalyst
Allow 2 marks if two properties given on one answer line
Apply list principle to contradictions/wrong answers
Do not allow platinum resists corrosion

1

(iv) Li reacts with water/forms lithium hydroxide

Allow water breaks down (or is electrolysed) on re-charge

1

(b) (i) $Pt \mid SO_3^{2-}(aq), SO_4^{2-}(aq) \mid\mid ClO_3^-(aq), Cl^-(aq) \mid Pt$

State symbols an ',' not necessary
Allow | in place of ',' NOT ',' in place of |
Ignore H^+ and H_2O
Deduct one mark for each mistake (e.g. Pt missed twice counts as two mistakes)
Allow reverse order for whole cell
Pt | Cl^-, ClO_3^- || SO_4^{2-}, SO_3^{2-} | Pt

2

(ii) $ClO_3^- + 3SO_3^{2-} \rightarrow Cl^- + 3SO_4^{2-}$

1

Oxidising agent ClO_3^-

1

Reducing agent SO_3^{2-}

1

[12]

Q24.

(a) Hydrogen/H_2 gas/bubbles

1

1.0 mol dm^{-3} HCl/H^+

1

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At 298K and 100kPa

Allow 1 bar instead of 100 kPa
Do not allow 1 atm

1

Pt (electrode)

1

(b) $Li^+ + MnO_2 + e^- \rightarrow LiMnO_2$

Ignore state symbols

1

–0.13(V)

1

(c) Fe^{3+} ions reduced to Fe^{2+}

Can score from equation/scheme

1

Because $E(Fe^{3+}/Fe^{2+}) > E(H^+/H_2)$/*E*(hydrogen)

Allow emf/E_{cell} +ve/0.77V
Allow Fe^{3+} better oxidising agent than H^+
Allow H_2 better reducing agent than Fe^{2+}
Only award this explanation mark if previous mark given

1

(d) Moles $Cr_2O_7^{2-} = \underline{23.7 \times 0.01/1000} = 2.37 \times 10^{-4}$

1

1 mol $Cr_2O_7^{2-}$ reacts with 6 mol Fe^{2+} so moles Fe^{2+} in 25 $cm^3 = 6 \times 2.37 \times 10^{-4} = 1.422 \times 10^{-3}$

1

M1 × 6

Moles Fe^{2+} in 250 $cm^3 = 1.422 \times 10^{-2}$

M2 × 10 or M4/10

1

Original moles $Fe^{2+} = \underline{10.00/277.9} = 0.0360$

Independent mark

1

Moles Fe^{2+} oxidised = 0.0360 – 0.0142 = 0.0218

M4 – M3

1

% oxidised = (0.0218 × 100)/0.0360 = 60.5%

(M5 × 100)/M4
Allow 60 to 61
Note Max 3 if mol ratio for M2 wrong
eg 1:5 gives 67.1%
1:1 gives 93.4%
Note also, 39.5% (39-40) scores M1, M2, M3 and M4 (4 marks)

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1

[14]

Q25.

(a) 1.4 V

Allow + or –

1

(b) $2NiO(OH) + 2H_2O + Cd \rightarrow 2Ni(OH)_2 + Cd(OH)_2$

Mark for species, Deduct a mark for additional species (eg OH^-) but allow balance mark

1

Balanced

If equation is reversed CE=0

1

(c) NiO(OH) or Ni(III) or nickel

1

+3

Allow conseq on wrong species

1

[5]

Q26.

(a) (i) HgO

1

(ii) $Hg^{2+} + 2e^- \rightarrow Hg$

1

(iii) $2H_2O + SO_2 \rightarrow H_2SO_4 + 2e^-$ etc

1

(iv) $Cl_2 + 2e^- \rightarrow 2Cl^-$

1

(b) (i) Vanadium species: VO_2^+

1

Oxidation state: 5

1

Half-equation: $V^{2+} + 2H_2O \rightarrow VO_2^+ + 4H^+ + 3e^-$

1

(ii) Cell e.m.f 0.06 V

1

Change in e.m.f , Increases

1

More Fe^{3+} ions to accept electrons

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1

Fe^{3+}/Fe^{2+} electrode becomes more positive

1

(c) (i) $2H_2 \rightarrow 4H^+ + 4e^-$

1

$4e^- + O_2 + 2H_2O \rightarrow 4OH^-$

1

Overall equation $2H_2 + O_2 \rightarrow 2H_2O$

(ii) Unchanged

1

(d) Economic disadvantage; Use of CH_4 or cost of producing or high temp

1

Environmental disadvantage; Makes CO_2

1

(e) Cost of manufacture of solar cells

1

[17]

Q27.

(a) (i) Fe^{2+}

1

(ii) F_2O

1

(iii) Fe^{2+}

1

Cl^-

1

Use list principle if more than two answers

(b) (i) e.m.f. = *E*(rhs) – *E*(lhs)

1

= 1.52 – 0.77 = 0.75

(0.75 scores first mark also)

1

(ii) $Fe^{2+} \rightarrow Fe^{3+} + e^-$

1

(iii) Decrease

(Increase is CE, no further marks)

1

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Equilibrium (or reaction) shifts to R

(or L if refers to half equation in table)
(or in favour of more Fe^{3+})
(or more Fe^{3+} formed)
(or more electrons formed)

1

Electrode potential (for Fe^{3+}/Fe^{2+}) less positive (or decreases)

1

[10]

Q28.

(a) most powerful reducing agent: Zn;

1

(b) (i) reducing species: Fe^{2+}

1

(ii) oxidising species: Cl_2;

1

(c) (i) standard electrode potential 1.25 V;

1

(ii) equation: $Tl^{3+} + 2\ Fe^{2+} \rightarrow 2Fe^{3+} + Tl +$ balanced;

1

correct direction;

1

(d) (i) moles $KMnO_4 = 16.2 \times 0.0200 \times 10^{-3} = 3.24 \times 10^{-4}$;

1

moles H_2O_2 = Moles $KMnO_4 \times 5 / 2 = 8.10 \times {}^{-4}$;

1

8.10×10^{-4} moles H_2O_2 in 25 cm^3
$8.10 \times 10^{-4} \times 1000 / 25$ in 1000 $cm^3 = 0.0324$ mol dm^{-3};

1

hence g dm^{-3} = mol $dm^{-3} \times M_r = 0.0324 \times 34 = 1.10$;

(penalise use of an incorrect H_2O_2 to $KMnO_4$ ratio by two marks)

1

(ii) PV = nRT;

1

hence V = nRT / P
$= 8.10 \times 10^{-4} \times 8.31 \times 298/98000$;

1

$= 2.05 \times 10^{-5}$;

1

units m^3;

(mark consequentially to answers in (c)(i))

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(allow correct answers with other units)
(answers to (c)(i) and (ii) must be to 3 significant figures; penalise once only)

1

[14]

Q29.

(a) (i) 0.60 V

1

(ii) $H_2O + H_2SO_3 \rightarrow SO_4^{2-} + 4H^+ + 2e^-$

1

(b) (i) $2IO_3^- + 2H^+ 5H_2O_2 \rightarrow 5O_2 + I_2 + 6H_2O$ Species

1

Balanced

1

(ii) The concentration of the ions change or are no longer standard or the e.m.f is determined when no current flows

1

(iii) Unchanged

1

(iv) Increased

1

Equilibrium IO_3^-/I_2 displaced to the right

1

Electrons more readily accepted or more reduction occurs or electrode becomes more positive (Q o L)

1

(c) VO_2^+

1

5 or V

1

$V^{2+} + 2H_2O \rightarrow VO_2^+ + 4H^+ 3e^-$

1

[12]

Q30.

D

[1]

Q31.

C

[1]

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Q32.

B

[1]

Q33.

D

[1]

Q34.

(a) *Hydrogen ion concentration*: 1.00 mol dm^{-3} **(1)**

Hydrogen gas pressure: 100 kPa **(1)**

2

(b) *Explanation of change*: Equilibrium displaced to left **(1)**
to reduce constraint **(1)**

Change in electrode potential: Becomes negative or decreases **(1)**
allow more negative

3

(c) (i) 0.43V **(1)**

(ii) *Half-equation*: $2Br^- \rightarrow Br_2 + 2e^-$ **(1)**

Overall equation: $2BrO_3^- + 10Br^- + 12H^+ \rightarrow 6Br_2 + 6H_2O$ **(2)**
or $BrO_3^- + 5Br^- + 6H^+ \rightarrow 3Br_2 + 3H_2O$

*species **(1)***
*balanced **(1)***

4

[9]

Q35.

C

[1]

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Q1.

(a) Although 73.4% of students were able to answer correctly, some stated that the circuit was completed by the flow of electrons.

(b) Nearly two-thirds of the students (65.6%) could calculate the EMF of the cell.

(c) Students knew that the concentrations of copper sulfate were different but only just over 20% of them could state that the left-hand electrode's concentration needed to be 1 mol dm^{-3}.

(d) Many students did not give state symbols and a few gave extra phase boundaries and platinum electrodes.

(e) Only the best students (15.5%) scored both marks. Many students could state that the concentration of copper ions would increase but then thought that the reagents would run out.

Q2.

(a) Only 11.3% of students scored both marks here; sometimes Fe^{2+} was chosen but students could not explain their choice. The most common incorrect answer was Zn^{2+}.

(b) Just over three-quarters of students could give the oxidation state.

(c) The structure was often given, incorrectly, as a mirror image and the type of isomerism as optical; only 37.2% of students scored both marks.

(d) This was poorly answered, with only just over a third of students giving the correct equation.

(e) Over half of the students (55.6%) gave the correct equations; incorrect equations included charged vanadium species. Surprisingly, 12% of students were unable to make any attempt at this question.

Q3.

Just over two-thirds of students arrived at the correct answer. D (followed by A) was the commonest incorrect response.

Q4.

(a) The oxidation states were well known, with 92.2% of students gaining both marks; +7 was the commonest wrong answer for the nitrate ion.

(b) Just under half of students could identify the weakest reducing agent.

(c) "Nitrate ions" was a common insufficient answer, and sulfuric acid a common incorrect answer. Only the very best students scored mark point two; the common incorrect answer was that the E^{θ} for NO_3^- was more positive than the E^{θ} for copper. The equation was often unbalanced, but the cell emf was generally calculated correctly.

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Q8.

Part **(a)** posed a problem for some students because of the language they used – 'most negative' is more accurate than 'lowest'. Performance in **(b)** was good but in **(c)** credit was too often given for vague answers and for expanding on non-standard conditions for both marks. The sacrificial anode questions in **(d)** were done well by the abler students but resulted in some vagueness from others including a restatement of the information in the stem of the question.

Q9.

The correct answer was given by the majority of the students in part (a)(i). Part (a)(ii) was well done although a few students could not state the correct units of concentration. In part (b) the two half-cells were generally identified but the cell was often reversed as was the equation given. In part (c) the correct cobalt species was generally identified as the oxidising agent but the equation was often not balanced and the oxidation product given as Co^{2+} or H^+. Students found part (d) challenging. Very few gave $E^{\ominus}$ with the correct terminology; very often this was given the wrong way round e.g. $E^{\ominus}$ Au/Au^+. Most students thought, incorrectly, that the reaction was between gold and water. The $E^{\ominus}$ − values should have indicated to them that a redox reaction between gold and water is not feasible.

Q10.

Most students gave a correct answer to part (a) but some continued to confuse an oxidising agent with a Lewis acid and incorrectly stated that an oxidising agent is an electron pair acceptor. Inaccurate terminology continues to disadvantage students when they are asked to use electrode potential data to explain the action of oxidising and / or reducing agents. For example, in part (b), the iron (II) ion was the weakest oxidising agent in the Table because the E^{θ} value for the Fe^{2+} / Fe electrode is the least positive (or most negative). It is not precise enough to refer to the electrode potential of iron. In a similar way when gold (I) ions are added to water, the water is oxidised because the electrode potential of the Au^+ / Au electrode is more positive than that of the O_2 / H_2O electrode. It is correct in this context to say that Au^+ ions are a better oxidising agent than O_2 but it is not correct to say that Au^+ ions are a better oxidising agent than water. Parts (c) and (e)(i) were answered well by many students. Many answers to part (e)(ii) stated incorrectly that chloride ions would react with iron (II) ions. In part (f) similar imprecise use of the correct E^{θ} notation led to no marks being awarded for the use of data.

Q11.

Few correct answers were seen to part (a). Some students did not comply with the convention of placing the hydrogen electrode on the left when measuring the standard electrode potential. Some failed to include all the phase boundaries, putting a comma between H_2 and H^+ instead of a solidus, whilst other students included too many phase boundaries at the extremities or an incorrect, additional platinum connected to iron. Parts (b) and (c) were answered well. All the elements were chosen by students in part (d)(i) and where the correct answer of chlorine was selected, the oxidation states in part (d)(ii) and the equation in part (e) were usually correct. It was pleasing to find that answers to parts (f)(i) and (f)(ii) were usually correct. Most students identified the positive electrode correctly in part (f)(iii) but only the highest-scoring students used an appropriate electrode potential from the table to explain their answer.

Q12.

(a) The diagrams given for the half-cell in this part were occasionally poorly labelled and, too often, leniently marked. Full names or formulae of suitable iron(II) and iron(III) compounds must appear when the term 'reagent' is requested. In a few

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cases, students giving iron(III) sulfate as one reagent failed to realise that 1.0 mol dm–3 solutions of this would give double the ion concentration required. When only one reagent was given, this was penalised but the concentration mark could still be awarded and this was sometimes harshly treated by some teachers.

(b) This part was well understood by many but the use of 'movement of electrons' appeared occasionally and was not always penalised.

Q13.

Lots of correct answers were seen for in part (a) and (b) but part (c) caused many more problems with sketchy answers sometimes being credited with full marks. It was not clearly understood that a method for determining the point at which the copper(II) concentration was 0.5 mol dm^{-3} was needed. Calorimetry was a common error. A novel approach was to wait until the cell potential had fallen to half its original value but this is incorrect chemistry and so should not have been credited. This is a good example of where reference to the Assessment Adviser would be helpful.

Q14.

This was a testing question and in common with redox questions in previous years, performance by students was very mixed. In part (a), over 30% of students answered incorrectly that the salt bridge allowed electrons to flow through it. In part (b), students were expected to use their knowledge of copper chemistry to suggest that the chloride ions from the potassium chloride would react with the aqueous copper ions but only a very small percentage of students answered this correctly. Part (c) also proved to be a very demanding question. Only the best students gave a correct answer involving the higher concentration of copper ions in the left hand electrode. It was surprising that many students appeared to consider that the 0.2 mol dm^{-3} solution of $CuSO_4$ was more concentrated than the 1.0 mol dm^{-3} solution. Part (d) was very discriminating. The great majority of students answered incorrectly by stating that one of the reagents would be used up or had reacted completely. Answers to part (e) were much better. When students are asked to write an equation for an overall reaction, they should take care to cancel out identical species that appear on both sides of the final equation. In part (e)(ii), many students lost a mark because they failed to cancel out a lithium ion that appeared on both sides of the equation. In part (e)(iii), it was surprising to note that a considerable number of students thought that carbon dioxide would be produced by a reaction with an imaginary carbon electrode in the lithium cell.

Q15.

(a) This part was usually well answered. The usual mistakes were to make some reference to impurities without specifying aluminium oxide or contradicting an answer by giving an incorrect formula.

(b) Answers to this part were variable. Students familiar with the standard hydrogen electrode gave good answers, although many omitted to name the acid used.

(c) In this part, most students realised that a reaction would occur but gave impossible products and lost the mark. The consequences of reaction were not well understood. A number of students gave answers implying that a salt bridge would not be necessary or describing details of one specific use of a standard hydrogen electrode, which did not relate to the question being asked.

Q16.

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This proved to be a difficult question. In part (a), answers were often very scrappy and disappointing. Diagrams showed a half cell that had no chance of working. The salt bridge, if present rarely dipped into a solution and the electrode material was often iron instead of the correct material, platinum. Only very good students showed a solution containing iron(II) and iron(III) ions and only the very highest-scoring students stated clearly that all aqueous species should have a concentration of 1 mol dm^{-3}. Answers to part (b) were more encouraging but only the better students realised that no platinum electrode are necessary with copper and iron electrodes. In parts (c) and (d), most students were unable to use data from the table correctly. For instance, it is correct to state that $E^{\ominus}$ $Au^{+}/Au > E^{\ominus}$ O_2/H_2O but not correct to state that $E^{\ominus}$ $Au^{+}/Au > E^{\ominus}$ H_2O/O_2 or that gold ions are better oxidising agents than water. In this reaction, water is the reducing agent. In part (d), only 6% of students recognised that silver ions would oxidise iron to iron(II) ions and then go on to oxidise iron(II) ions to iron(III) ions.

Q17.

Part (a) was answered well. The most common error was to give the meaning of oxidation rather than an oxidising agent. Answers to part (b) were very often incorrect. All of the species from the table were seen in students' answers. The most common wrong answer was probably 'cadmium'. It still seems to be the case that many students do not understand that when redox half–equations are presented in their standard form with electrons on the left, the species on the left are oxidising agents and the species on the right are reducing agents. Parts (c)(i) and (ii) were answered correctly by most students. Part (c)(iii) proved to be more testing and only the best students recognised that the porous partition was acting in the same way as a salt bridge by permitting the transport of ions. Parts (c)(iv) and (v) were answered quite well although in part (c)(v) it was not always realised that the zinc container reacts to form zinc ions whilst the cell is in operation.

Part (d)(i) proved to be a discriminating question. An oxidation state of +2 for nickel in NiO(OH) was a common error and the equation was often unbalanced or not simplified by removing hydroxide ions. Part (d)(ii) was almost always answered correctly. In comparison, parts (e)(i) and (ii) were not answered well, usually because of a lack of attention to detail. Instead of using ethanol, a common mistake was to use CH_3OH. In part (e)(i), the equation for the combustion of ethanol was often unbalanced because students seemed to fail to take into account the oxygen in the ethanol. In part (e)(ii), despite being asked to write a half–equation, the electrons were often omitted or the numbers of hydrogen ions and electrons were wrong. Answers to part (e)(iii) were usually correct. In part (e)(iv), it seems that many students are still not clear about the meaning of the term carbon–neutral. The term is too often thought to refer just to carbon rather than to carbon dioxide in the atmosphere. Also, the majority of students did not make it clear that the carbon dioxide, released into the atmosphere by the processes that manufacture and use ethanol, can be balanced by the carbon dioxide taken out of the atmosphere by photosynthesis in plants.

Q18.

(a) Students usually struggle with questions where data from a table of E° values is used to explain a chemical reaction, and this part was no exception. Very few answers worth both marks were seen. Many students could not express themselves clearly while many others confused chlorine and the chloride ion. Statements such as 'manganate(VII) ions have a more positive electrode potential than chloride ions' and 'chlorine will oxidise manganese(II) ions' were very common and were often wrongly credited with a mark. In this question, students frequently ruined a promising answer by including some incorrect chemistry. Examples included 'manganate(VII) ions have a more positive electrode potential so will reduce chloride ions to chlorine' and 'hydrochloric acid was reduced by manganate(VII) ions'. It was

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difficult to see how an answer such as 'HCl is not electronegative enough to acidify $KMnO_4$' could have been given any marks but it was.

(b) The calculation in this part discriminated well. There were a lot of complete answers but many students, as expected, forgot that sulfuric acid is a dibasic acid.

(c) (i) The equation in this part must have been unfamiliar to most students but it proved straightforward.

(ii) In this part, most students appreciated that the presence of a brown precipitate would obscure the end-point, but the effect on the titre was not widely understood. Many students made a vague statement that the titre would be changed, but didn't explain the change itself.

(d) Most students appreciated the effect of a large volume of water in this part, but many added that manganate(VII) was a weak oxidising agent in solution so lost the mark because of the chemical contradiction.

Q19.

In part (a), only about 20% of students scored all three marks. In order to gain full marks it was necessary to identify solution **A** as, for example, hydrochloric acid not just as H^+ ions. Part (b) was answered well. Answers to part (c) very rarely scored all three marks. The most common error was to suggest that the salt bridge allowed transfer of electrons rather than movement of ions. Answers to parts (d), (e)(i) and (e)(ii) were pleasing and about half of all students gained the mark in each case.

Q20.

Part (a) was answered well. In part (b), answers were disappointing. Only about 20% of students used data from the table correctly. An effective way of using the data would have been to state that the electrode potential for the chlorine/chloride half equation is more positive than for the oxygen/water half equation. However, in many cases the species involved in the half equation were not mentioned or were in the wrong order. Answers to part (c) were often correct. Answers to part (d) were often disappointing and many students suggested that the oxidation state of hydrogen rather than oxygen was changing. Part (e) required similar understanding and use of electrode potentials as in part (b) and responses were similarly disappointing.

Q21.

As usual, this question that tested candidates' understanding of redox and cells proved to be difficult but it was pleasing to note that even the weaker candidates were able to gain a significant number of marks. Parts (a) and (b) were answered well. Many candidates were able to score two out of three marks for part (c). The mark lost was usually due to incorrect use of data from the table. Many candidates stated that the electrode potential values showed that fluorine is a better oxidising agent than water. In this case, water is the reducing agent and candidates should have stated that the data shows that fluorine is a better oxidising agent than oxygen. In part (d)(i), a majority of candidates scored one mark out of the two available; only the best candidates showed metal species on the outside of the cell and all the phase boundaries, correctly indicated. Parts (d)(ii) and (e)(i) were answered well but only about a third of candidates gave a correct answer to part (d)(iii). In part (e)(ii) marks were lost because candidates did not simplify the overall equation after combining the half equations or the equation was for discharge rather than for recharging. As expected, part (f) proved to be challenging, particularly part (f)(iii). Fuel cells were included in the Specification as an example of 'How Science Works'. Their value is that they can produce efficiently a steady current to drive electric motors because the

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concentrations of the reactants remain constant when the fuel and the oxidant are supplied continuously.

Q22.

This Question proved very demanding as expected. Many candidates provided some $E^{\ominus}$ calculations without any explanation of the significance of the results, and could not be given any marks. Confusion between chlorine and chloride ion was very common, often rendering the answer meaningless. A fair number of candidates thought that the oxidation of chloride ions took place instead of the oxidation of iron(II) ions. Full marks were quite rare.

Q23.

Redox questions involving electrochemical cells are usually found to be very difficult. It was therefore very pleasing to find that this question was answered well in all parts except for parts (a)(iv) and (b)(i). In part (a)(iv) candidates were expected to recall from Unit 1 that lithium reacts with water but only about 20% were able to do this and these were not necessarily the best candidates. As expected, part (b)(i) proved to be discriminating. Although about one third of candidates scored both marks, others failed to include platinum or put the various ions in the wrong order.

Q24.

This was the most difficult question in the paper. In part (a) most candidates knew that a standard hydrogen electrode uses hydrogen gas and a platinum electrode but only a minority went on to state the correct and necessary conditions of concentration, temperature and pressure for operation of the electrode. In part (b) most candidates gave a correct value for the electrode potential of the positive electrode but very few candidates were able to use the cell representation to deduce a half-equation for the electrode reaction. Answers to part (c) were also disappointing. Despite the given electrode potentials and half-equations, most candidates could not predict and explain the redox reaction between hydrogen and iron(III) ions. Part (d) also proved to be a difficult question. Candidates were usually able to score three marks out of six for a correct calculation of the number of moles of dichromate(VI) ions, a calculation of the original number of moles of iron(II) sulfate and for recognising the involvement of a factor of ten. Only the very best candidates realised that the number of moles of iron ions was six times the number of moles of dichromate(VI) ions and that a subtraction was required to calculate the percentage of iron(II) ions that had been oxidised by air before the titration.

Q25.

This question was answered well except for part (b) where only the best candidates were able to write a balanced equation with the oxidising and reducing agent in the correct position.

Q27.

This question discriminated very effectively between candidates. In part (a) weak candidates were confused about reducing and oxidising agents. These agents were confused with the species that could be reduced and oxidised. Thus for part (a)(i) Fe^{3+} was a very common wrong answer and for part (a)(ii) the F^- ion was often suggested. Similarly in part (a)(iii) species were often incorrectly chosen from the left-hand side of the redox half-equations. Parts (b)(i) and (b)(ii) were usually correct but candidates were less successful with part (b) (iii). About half of all candidates gave the incorrect answer, an increase in the concentration of Fe^{3+} ions. For those candidates who gave a correct

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change in concentration only the best gained two marks for the explanation. Most omitted to mention that the electrode potential of the Fe^{3+}/Fe^{2+} electrode would be reduced.

Q28.

Although parts (a), (b) and (c) were rather better answered than similar questions on earlier papers, a significant number of candidates still have problems using redox data. The calculation in (d)(i) was well done but many candidates lost one mark as, having calculated the concentration of the hydrogen peroxide solution in mol dm^{-3}, they failed to convert this to g dm^{-3} as required by the question. Part(d)(ii) was marked consequentially to answers determined in (d)(i). Almost all candidates stated the ideal gas equation and used it correctly but only the best candidates gave correct units for the volume of oxygen evolved.

Q29.

Almost every candidate calculated the cell e.m.f correctly and gave a correct half-equation in answer to part (a). Many also gave a correct equation in part (b) (i) but candidates who failed to cancel out the excess hydrogen ions lost one mark. By contrast, few stated in (b) (ii) either that when current flows the concentration of the species change or that the e.m.f. is measured when no current flows. Most answered (b) (iii) correctly. The effect on the cell e.m.f of changing the concentration of IO_3^- ions, required in (b) (iv), was deduced correctly by the better candidates many of whom also made the link to the position of the half-cell equilibrium process. Only the best then linked this change to the value of the electrode potential and stated that this becomes more positive. Sadly, in part (c), many candidates failed to read the question carefully and gave answers based on the formation of the intermediate species, V^{3+}, rather than VO_2^+, the species present at the end of the reaction with an excess of acidified potassium manganate(VII).

Q34.

Almost all candidates gave the correct hydrogen ion concentration and the correct hydrogen gas pressure in part (a). Most also explained correctly why the electrode potential of a hydrogen electrode changes when the hydrogen ion concentration is reduced. Using this information to deduce correctly that the electrode potential would become negative proved more difficult. Most candidates calculated the e.m.f of the cell in part (c)(i) and many also gave a correct half-equation and a correct overall equation in part (c)(ii).

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Q1.

D

[1]

Q2.

(a) (Standard) hydrogen (electrode) **(1)**

1

(b) (i) To allow transfer of electrons / provide a reaction surface **(1)**

(ii) 298 K **(1)**
Both F^{3+} (aq) and Fe^{2+} (aq) have a concentration of
1 mol dm^{-3} **(1)** (QoL)
OR $[H^+]$ = 1 mol dm^{-3}

NOT zero current or 100 kPa

3

(c) +1.34 V **(1)**
$2\ MnO_4^- + 5\ H_2SO_3 \rightarrow 2\ Mn^{2+} + 5\ SO_4^{2-} + 3\ H_2O + 4\ H^+$
Correct species / order **(1)**
Balanced and cancelled **(1)**

Allow one for $2\ MnO_4^- + 5\ H_2SO_3 \rightarrow 2\ Mn^{2+} + 5\ SO_4^{2-}$

3

(d) (i) Ce^{4+} (aq) **(1)**

(ii) VO_2^+ (aq) **(1)**; Cl_2 **(1)**

Penalise additional answers to zero

3

(e) Pt | Fe^{2+} (aq), Fe^{3+} (aq) || Ce^{4+}(aq), Ce^{3+} (aq) | Pt
Correct species **(1)**
Correct order **(1)**

Deduct one mark for each error

2

[12]

Q3.

(a) *Cell e.m.f.*: 1.93 (v) CE if negative value given **(1)**
Half equation: $Mg \rightarrow Mg^{2+} + 2\ e^-$ **(1)**

or ⇌

Ignore state symbols

Mark on after an AE

2

(b) *Change in e.m.f.*: increases **(1)**

Mark on even if incorrect

Explanation: Equilibrium displaced to Mg^{2+} or to the left **(1)**

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cell reaction or overall reaction goes to the right
Electrode is more negative or E decreases
or gives more electron
or forms more Mg^{2+} ions
Mark separately

3

(c) *Cell e.m.f.* : –0.84 (V) **(1)**

Explanation: Fe is giving electrons **or** forming Fe^{2+}
or reaction goes in the reverse direction **(1)**

Mark on after AE

N.B. In (a) and (c) mark on if no value given, but CE in both (a) and (c) if e.m.f. = 0

2

[7]

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Q2.

There were many good answers to this question. Virtually all candidates were able to name the standard reference electrode in part (a). In part (b) only the best candidates stated the function of the platinum electrode correctly and many failed to state in section (ii) that, for standard conditions to apply, both Fe^{3+} (aq) and Fe^{2+} (aq) would need to be at a concentration of 1 mol dm^{-3} in the solution. Most deduced correctly the e.m.f. of the cell given in part (c).

Many scored one further mark in part (c) when they deduced the correct molar ratio of the reacting species in the equation but lost one mark when they failed to balance the equation correctly. In part (d) most candidates were able to deduce which of the species in the table of data was the strongest oxidising agent but many only gave one of the two correct answers in section (ii). A pleasing number of candidates gave a correct cell representation in part (e). Almost all were able to select the correct species for the cell but some then used the convention, as shown in part (c), incorrectly.

Q3.

This proved to be the most challenging question on the paper and candidates appeared unfamiliar with the conventional representation of cells. In part (a) many candidates were able to calculate the e.m.f. of the given cell but rather less gave a correct half-equation for the reaction occurring at the negative electrode. Some gave the overall equation for the reaction whilst others gave incorrect half-equations. Good candidates were able to deduce how a change in the concentration of Mg2+ ions would affect the cell e.m.f. and gave correct explanations for this change. Credit was given to candidates who correctly explained the effect of changing the concentration of Mg2+ ions even though the were unable to link this to the change in the e.m.f of the cell. Part (c) was not well answered. Many candidates failed to use the conventional representation of cells to deduce that, in this case, the cell e.m.f. was negative and that the reaction would proceed spontaneously in the reverse direction with iron being oxidised to Fe^{2+} ions.

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