Q1.

This question is about fuel cells.

In a methanol–oxygen fuel cell, the overall reaction is

$$CH_3OH(l) + 1\frac{1}{2}\ O_2(g)\ \text{"}\ CO_2(g) + 2\ H_2O(l) \qquad \text{EMF} = +1.20\ \text{V}$$

(a) At the positive electrode, oxygen reacts with hydrogen ions to form water.

Give a half-equation for this reaction.

____

(1)

(b) At the negative electrode, methanol reacts with water to produce carbon dioxide and hydrogen ions.

Give a half-equation for this reaction.

____

(1)

(c) The standard electrode potential for the CO_2 / CH_3OH electrode is +0.03 V

Calculate the standard electrode potential for the O_2 / H_2O electrode.

____

(1)

(d) State why a fuel cell does **not** need to be electrically recharged.

____

____

(1)

(e) Suggest **one** advantage of using methanol, rather than hydrogen, in a fuel cell for use in cars.

____

____

____

(1)

(Total 5 marks)

Q2.

This question is about cells.

(a) The half-equations for two electrodes that combine to make a non-rechargeable cell are

$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$ $\qquad E^o = -0.76$ V

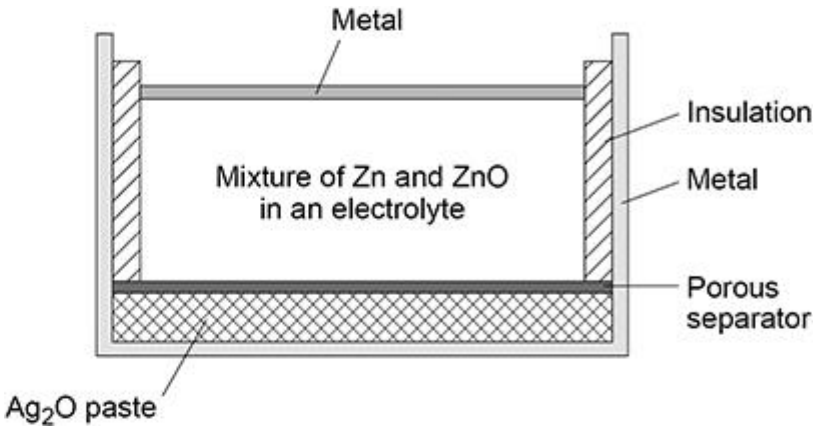
$2\ MnO_2(s) + 2\ NH_4^+(aq) + 2e^- \rightarrow Mn_2O_3\ (s) + 2\ NH_3(aq) + H_2O(l)$ $\qquad E^o = +0.52$ V

Identify the oxidising agent in this cell.

____

(1)

The diagram below shows a cross-section through a rechargeable silver–zinc cell.



(b) Suggest the function of the porous separator in above diagram.

____

(1)

(c) The standard electrode potentials for two half-equations for the silver–zinc cell are

$Ag_2O(s) + H_2O(l) + 2e^- \rightarrow 2\ Ag(s) + 2\ OH^-(aq)$ $\qquad E^o = +0.34$ V

$ZnO(s) + H_2O(l) + 2e^- \rightarrow Zn(s) + 2\ OH^-(aq)$ $\qquad E^o = –1.26$ V

Give an equation for the overall reaction that occurs when the cell is recharging.

____

(1)

The EMF of an alkaline hydrogen–oxygen fuel cell is +1.23 V
The standard electrode potential for one of the electrodes in the alkaline hydrogen–oxygen fuel cell is

$2\ H_2O(l) + 2e^- \rightarrow 2\ OH^-(aq) + H_2(g)$ $E^⦵ = –0.83$ V

(d) Give the half-equation for the other electrode and calculate its standard electrode potential.

Equation

____

E^θ ____

(2)

(e) Suggest why the EMF values of the acidic and alkaline hydrogen–oxygen fuel cells are the same.

____

____

(1)

(Total 6 marks)

Q3.

This question is about the development of lithium cells.
The value of $E^⦵$ for lithium suggests that a lithium cell could have a large EMF.

The table below shows some electrode potential data.

	$E^⦵$ / V
$Li^+(aq) + e^- \rightarrow Li(s)$	–3.04
$2\ H_2O(l) + 2\ e^- \rightarrow H_2(g) + 2\ OH^-(aq)$	–0.83
$\frac{1}{2}\ I_2(s) + e^- \rightarrow I^-(aq)$	+0.54

(a) Use data in the table above to explain why an aqueous electrolyte is **not** used for a lithium cell.

____

____

____

(2)

(b) In the 1970s lithium-iodine cells became a common power source for heart pacemakers. Lithium iodide is the final product of the cell reaction.

Use the data in the table above to calculate the cell EMF of a standard lithium-iodine cell.

___

(1)

(c) An EMF value for a commercial lithium-iodine cell is 2.80 V

Suggest why this value is different from the value calculated in part (b).

___

___

(1)

(d) In some lithium cells, lithium perchlorate ($LiClO_4$) is used as the electrolyte.

Deduce the oxidation state of chlorine in $LiClO_4$

___

(1)

In other lithium cells, lithium cobalt oxide electrodes **and** lithium electrodes are used.

(e) Give an equation for the reaction that occurs at the positive lithium cobalt oxide electrode.

___

(1)

(f) Give an equation for the reaction that occurs at the negative lithium electrode.

___

(1)

(Total 7 marks)

Q4.

This question is about a glucose–oxygen fuel cell.

When the cell operates, the glucose ($C_6H_{12}O_6$) molecules react with water at the negative electrode to form carbon dioxide and hydrogen ions.

Oxygen gas reacts with hydrogen ions to form water at the positive electrode.

(a) Deduce the half-equation for the reaction at the negative electrode.

___

(1)

(b) Deduce the half-equation for the reaction at the positive electrode.

___

(1)

(c) Give the equation for the overall reaction that occurs in the Glucose–oxygen fuel cell.

____

(1)

(d) The negative electrode is made of carbon and the positive electrode is made of platinum.

Give the conventional representation for the glucose–oxygen fuel cell.

____

____

(2)

(e) State what must be done to maintain the EMF of this fuel cell when in use.

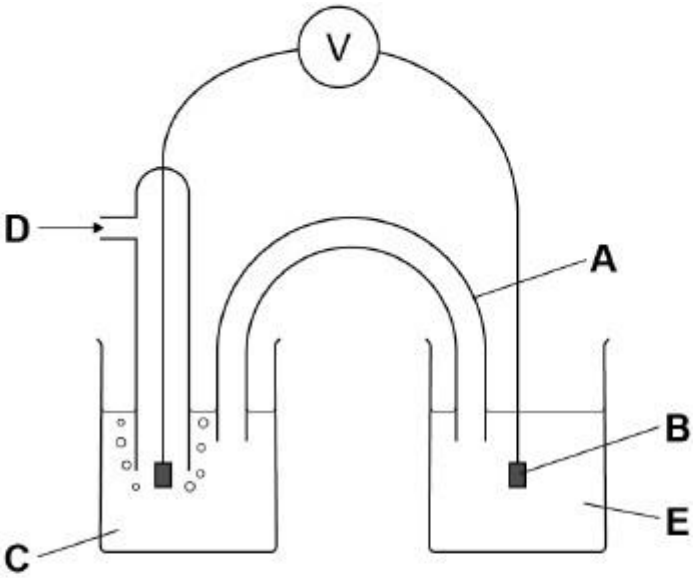
____

(1)

(Total 6 marks)

Q5.

The diagram represents the cell used to measure the standard electrode potential for the Fe^{3+}/Fe^{2+} electrode.



(a) Name the piece of apparatus labelled **A**.

____

(1)

(b) State the purpose of **A**.

____

____

(1)

(c) Name the substance used as electrode **B** in the diagram above.

____

(1)

(d) Complete **Table 1** to identify **C**, **D** and **E** from the diagram above.
Include the essential conditions for each.

Table 1

	Identity	Conditions
C		
D		
E		

(4)

(e) The standard electrode potential, $E^{\ominus}$, for the Fe^{3+}/Fe^{2+} electrode is +0.77 V

Give the ionic equation for the overall reaction in the cell in the diagram above.

State the change that needs to be made to the apparatus in the diagram to allow the cell reaction to go to completion.

Ionic equation ____

Change ____

____

(2)

(f) A student sets up a cell as shown in the cell representation.

$$Zn(s)|Zn^{2+}(aq)||Cu^{2+}(aq)|Cu(s)$$

The student measures the cell EMF, E_{cell}, with several different concentrations of Cu^{2+} ions and Zn^{2+} ions.

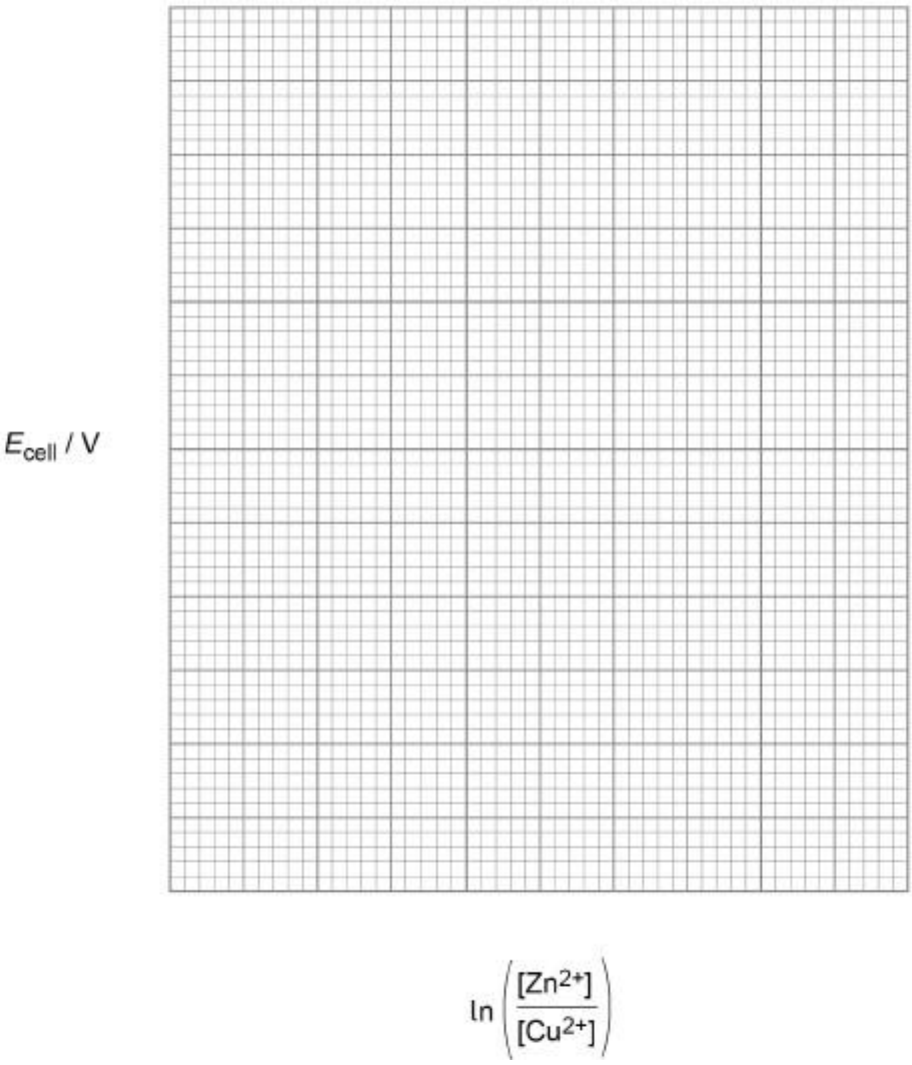
The results are shown in **Table 2** on the next page.

Table 2

Experiment	$[Zn^{2+}]$ / mol dm^{-3}	$[Cu^{2+}]$ / mol dm^{-3}	$\ln\left(\frac{[Zn^{2+}]}{[Cu^{2+}]}\right)$	E_{cell} / V
1	0.010	1.0	−4.61	1.16
2	0.10	1.0	−2.30	1.13
3	1.0	1.0	0.00	1.10
4	1.0	0.10		1.07
5	1.0	0.010	4.61	1.04

Complete **Table 2** to show the value missing from experiment **4**.

Plot a graph of E_{cell} against ln ($[Zn^{2+}]/[Cu^{2+}]$) on the grid.



(3)

(g) This equation shows how E_{cell} varies with concentration for this reaction.

$$E_{cell} = (-4.3 \times 10^{-5} \times T)\ \ln\left(\frac{[Zn^{2+}]}{[Cu^{2+}]}\right) + E^{\ominus}_{cell}$$

This equation is in the form of the equation for a straight line, y = mx + c

Calculate the gradient of your plotted line on the graph in part **(f)**.

You must show your working.

Use your gradient to calculate the temperature, *T*, at which the measurements of E_{cell} were taken.
(If you were unable to calculate a gradient you should use the value -0.016 V
This is **not** the correct value.)

Gradient ______________________________ V

T ______________________________ K

(3)

(h) In experiment **2** in **Table 2** the electrode potential of the Cu^{2+}/Cu electrode is +0.33 V

Use data from **Table 2** in part **(f)** to calculate the electrode potential for the Zn^{2+}/Zn electrode in experiment **2**.

Give one reason why your calculated value is different from the standard electrode potential for Zn^{2+}/Zn electrode.

Electrode potential ______________________________ V

Reason ____

____

____

(2)

(Total 17 marks)

Q6.

Fuel cells are an increasingly important energy source for vehicles. Standard electrode potentials are used in understanding some familiar chemical reactions including those in fuel cells.

The following table contains some standard electrode potential data.

Electrode half-equation	***E***$^{\ominus}$ **/ V**
$F_2 + 2e^- \longrightarrow 2F^-$	+2.87
$Cl_2 + 2e^- \longrightarrow 2Cl^-$	+1.36
$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$	+1.23
$Br_2 + 2e^- \longrightarrow 2Br^-$	+1.07
$I_2 + 2e^- \longrightarrow 2I^-$	+0.54
$O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$	+0.40
$SO_4^{2-} + 4H^+ + 2e^- \longrightarrow SO_2 + 2H_2O$	+0.17
$2H^+ + 2e^- \longrightarrow H_2$	0.00
$4H_2O + 4e^- \longrightarrow 4OH^- + 2H_2$	−0.83

(a) A salt bridge was used in a cell to measure electrode potential.

Explain the function of the salt bridge.

____

____

____

(2)

(b) Use data from the table above to deduce the halide ion that is the weakest reducing agent.

____

(1)

(c) Use data from the table to justify why sulfate ions should **not** be capable of oxidising bromide ions.

____

____

____

(1)

(d) Use data from the table to calculate a value for the EMF of a hydrogen–oxygen fuel cell operating under alkaline conditions.

EMF = ________________ V

(1)

(e) There are two ways to use hydrogen as a fuel for cars. One way is in a fuel cell to power an electric motor, the other is as a fuel in an internal combustion engine.

Suggest the major advantage of using the fuel cell.

____

____

____

(1)

(Total 6 marks)

Q7.

A representation of a hydrogen–oxygen fuel cell that operates in alkaline conditions is

$$Pt|H_2|H_2O||O_2|OH^-|Pt$$

(a) (i) Write a half-equation for the reaction that occurs at each electrode. Use the half-equations to deduce an overall equation for the cell.

Half-equation at positive electrode ________________________________

Half-equation at negative electrode ________________________________

Overall equation ____

(3)

(ii) State and explain the effect, if any, of increasing the pressure of oxygen on the e.m.f of this cell.

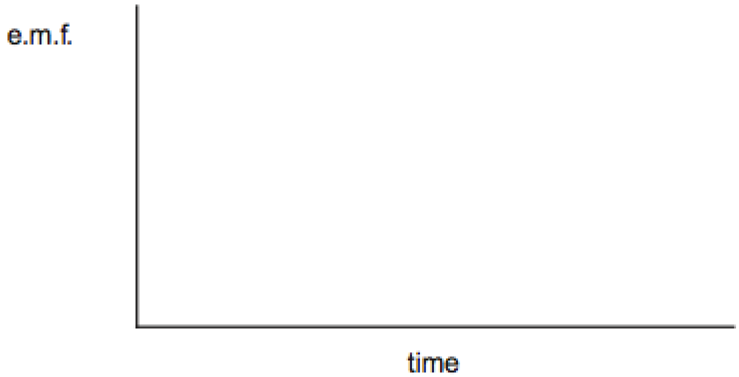
Effect on e.m.f. ____

Explanation ____

____

(2)

(b) Complete the diagram to show how the e.m.f. of a hydrogen–oxygen fuel cell changes with time.



(1)

(c) (i) Suggest the effect, if any, on the e.m.f. of this cell if the surface area of each platinum electrode is increased.

____

(1)

(ii) State the main environmental advantage of using a hydrogen–oxygen fuel cell to power a car.

____

____

(1)

(d) Suggest why the use of a hydrogen–oxygen fuel cell might not be carbon-neutral.

____

____

____

____

(1)

(Total 9 marks)

Q8.

The table below shows some standard electrode potential data.

	$E^{\ominus}$ / V
$ZnO(s) + H_2O(l) + 2e^- \longrightarrow Zn(s) + 2OH^-(aq)$	–1.25
$Fe^{2+}(aq) + 2e^- \longrightarrow Fe(s)$	–0.44
$O_2(g) + 2H_2O(l) + 4e^- \longrightarrow 4OH^-(aq)$	+0.40
$2HOCl(aq) + 2H^+(aq) + 2e^- \longrightarrow Cl_2(g) + 2H_2O(l)$	+1.64

(a) Give the conventional representation of the cell that is used to measure the standard electrode potential of iron as shown in the table.

____

(2)

(b) With reference to electrons, give the meaning of the term **reducing agent**.

____

____

(1)

(c) Identify the weakest reducing agent from the species in the table.

Explain how you deduced your answer.

Species ____

Explanation ____

____

(2)

(d) When HOCl acts as an oxidising agent, one of the atoms in the molecule is reduced.

(i) Place a tick (✓) next to the atom that is reduced.

Atom that is reduced	**Tick (✓)**
H	
O	
Cl	

(1)

(ii) Explain your answer to part (i) in terms of the change in the oxidation state of this atom.

____

____

(1)

(e) Using the information given in the table, deduce an equation for the redox reaction that would occur when hydroxide ions are added to HOCl

____

____

____

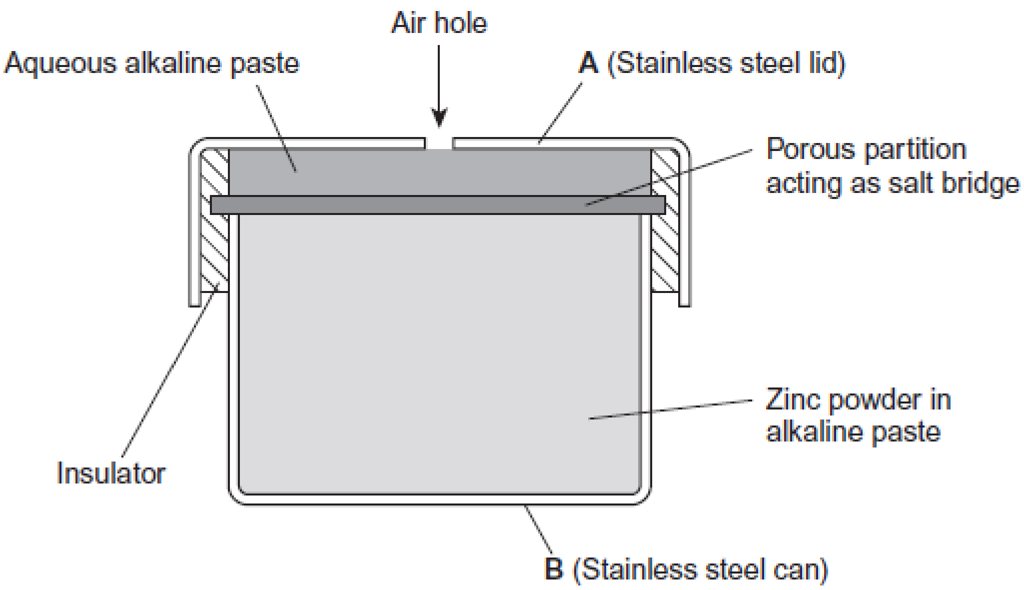
(2)

(f) The table is repeated to help you answer this question.

	$E^\ominus$ / V
$ZnO(s) + H_2O(l) + 2e^- \longrightarrow Zn(s) + 2OH^-(aq)$	–1.25
$Fe^{2+}(aq) + 2e^- \longrightarrow Fe(s)$	–0.44
$O_2(g) + 2H_2O(l) + 4e^- \longrightarrow 4OH^-(aq)$	+0.40
$2HOCl(aq) + 2H^+(aq) + 2e^- \longrightarrow Cl_2(g) + 2H_2O(l)$	+1.64

The half-equations from the table that involve zinc and oxygen are simplified versions of those that occur in hearing aid cells.

A simplified diagram of a hearing aid cell is shown in the following figure.



(i) Use data from the table to calculate the e.m.f. of this cell.

___

___

Answer = ___

(1)

(ii) Use half-equations from the table to construct an overall equation for the cell reaction.

___

___

___

(1)

(iii) Identify which of **A** or **B**, in the figure, is the positive electrode. Give a reason for your answer.

Positive electrode ___

Reason ___

___

___

(2)

(iv) Suggest **one** reason, other than cost, why this type of cell is **not** recharged.

___

___

(1)

(Total 14 marks)

Mark Scheme

Q1.

(a) $O_2 + 4\ H^+ + 4\ e^- \rightarrow 2\ H_2O$

1

(b) $CH_3OH + H_2O \rightarrow CO_2 + 6\ H^+ + 6\ e^-$

1

(c) 1.23 (V)

1

(d) Reactants supplied continuously

Allow fuel continuously supplied

Allow continuous supply of chemicals

1

(e) Methanol (is liquid so) can be stored easily or transported easily

More energy can be produced from 1 cm^3 of methanol (liquid) than from 1 cm^3 of hydrogen (gas)

Ignore references to safety and cost

Do not accept no greenhouse gas emissions

1

[5]

Q2.

(a) MnO_2

1

(b) allows ions to move/flow/transfer

ignore to allow current/charge to flow

*do **not** accept electrons to flow*

or
to complete the circuit
or
acts as a salt bridge

1

(c) $2\ Ag + ZnO \longrightarrow Zn + Ag_2O$

ignore state symbols

1

(d) $O_2(g) + 2\ H_2O(l) + 4\ e^- \rightarrow 4\ OH^-(aq)$

ignore state symbols

allow multiples

1

E⦵ = (+) 0.4(0) (V)

1

(e) same <u>overall</u> reaction
or
$2\ H_2 + O_2 \rightarrow 2\ H_2O$

1

[6]

Q3.

(a) Lithium would react with the electrolyte/water

Allow water will oxidise Li to Li^+ or Li will reduce water to hydrogen

1

$E^{\ominus}$ for Li^+(/Li) more negative than for water or EMF= 2.21(V)
or $E^{\ominus}$ Li^+ (/Li) < H_2O(/H_2 ,OH^-)

Ignore EMF is negative

1

(b) 0.54 – (–3.04) = <u>3.58</u> (V)

1

(c) Non-standard conditions

Allow non-aqueous conditions or different conditions

1

(d) (+) 7

Accept VII

1

(e) $Li^+ + CoO_2 + e^- \rightarrow Li^+CoO_2^-$ or
$Li^+ + CoO_2 + e^- \rightarrow LiCoO_2$

1

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

1

[7]

Q4.

(a) $C_6H_{12}O_6 + 6\ H_2O \rightarrow 6\ CO_2 + 24\ H^+ + 24\ e^-$

Accept multiples

1

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

Accept multiples

1

(c) $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$

Accept multiples

1

(d) C(s) | $C_6H_{12}O_6$(aq), H^+(aq) | CO_2(g) || O_2(g) | H^+(aq),H_2O(l) | Pt(s)

OR

C|$C_6H_{12}O_6$, H^+| CO_2 || O_2 | H^+,H_2O | Pt

__M1__ Must see following in correct order:

C | $C_6H_{12}O_6$ CO_2 || O_2 H_2O | Pt

__M2__ Cell completely correct

Ignore H_2O on LHS
Ignore state symbols
Allow $H^+(aq)$|$H_2O(l)$ on RHS
0 marks if electrons included.

2

(e) (Constantly) add reactants/glucose (and oxygen) OR keep concentration of reactants constant

1

[6]

Q5.

(a) salt bridge

Allow description of salt bridge, e.g. filter paper / string / wick soaked in suitable solution

U tube (NOT YouTube) filled with suitable solution / gel

NOT U tube alone

1

(b) complete the circuit

Allow ions to flow / move / transfer

Allow to balance charge / to maintain electrical neutrality

Ignore current / charge to flow

NOT electrons to flow

1

(c) **B** = platinum

Allow Pt / platinum black

1

(d)

		Identity	Conditions
M1	**C**	HCl	1 mol dm^{-3}
M2	**D**	H_2 / hydrogen	100 kPa
M3	**E**	$FeCl_2$ and $FeCl_3$	1 mol dm^{-3}

NOT incorrect state symbols

Allow M or molar or mol/dm^3 for mol dm^{-3}

__M1__ Allow 1 mol dm^{-3} H^+

Allow 0.5 mol dm^{-3} H_2SO_4

Allow 1 mol dm^{-3} HNO_3

Ignore 100 kPa

1

__M2__ Allow 1 bar

NOT 1 atm / 101 kPa

NOT H for hydrogen

NOT 1 mol dm^{-3}

1

***M3** Allow 1 mol dm^{-3} Fe^{2+} and Fe^{3+}*

Allow other identified Fe(II) and Fe(III) compounds with appropriate concentrations, e.g. 1 mol dm^{-3} $FeSO_4$ and 0.5 mol dm^{-3} $Fe_2(SO_4)_3$

Ignore 100 kPa

1

M4 298 K (any mention)

1

(e) **M1** $H_2 + 2\ Fe^{3+} \rightarrow 2\ H^+ + 2\ Fe^{2+}$

***M1** Ignore state symbols*

Allow multiples / fractions

Allow equation with equilibrium sign if forward reaction shown is in this direction

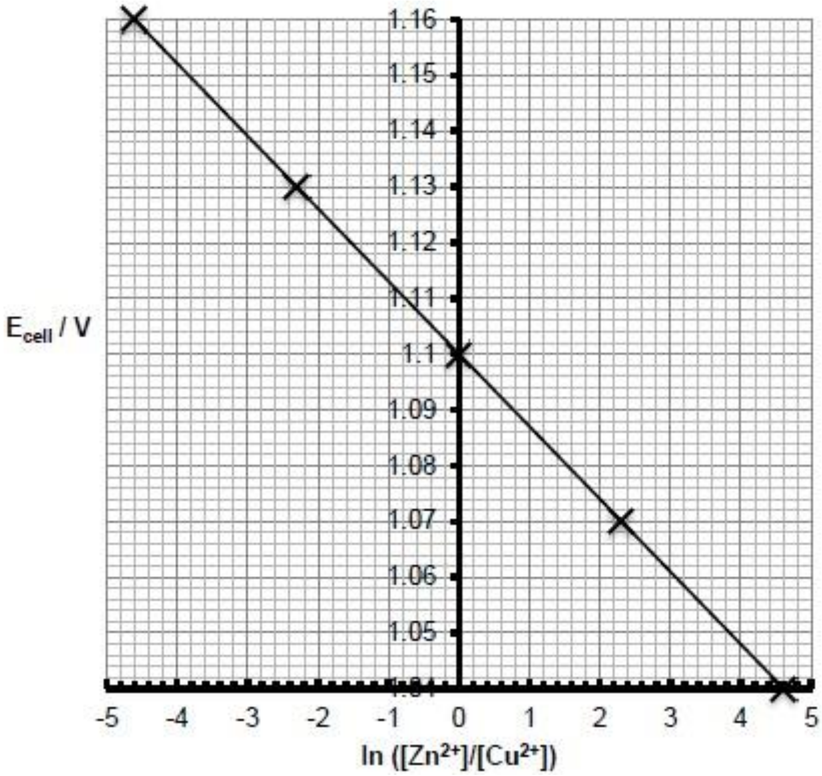
1

M2 replace voltmeter with lamp/wire/ammeter owtte

***M2** Allow remove voltmeter*

1

(f) **M1** missing value (+) 2.3(0)



1

M2 suitable scales (plotted points use at least half of grid)

***M2** Allow scales which use half the grid for plotted points*

1

M3 points plotted correctly (± ½ small square per point) and best fit line drawn (within one small square of each point)

***M3** If **M1** incorrect, should be plotted accordingly and best fit line Ignore if anomalous*

1

(g) **M1** gradient = –0.013 (must be negative)

__M1__ Allow –0.0125 to –0.0136

Allow ECF from graph if outside this range

1

M2 M1 = (–) 4.3 × 10^{-5} T or $T = \frac{M1}{(-)4.3 \times 10^{-5}}$

1

M3 T = 302 or 303 (K)

***M3** temperature must match gradient unless –0.016 used (Allow positive temperature if positive gradient used)*

at least 2sf

*Correct **M3** also scores **M2***

NOT negative temperature

***M3** (Alternate gradient = –0.016 gives) T = 372 (K)*

1

(h) **M1** E = –0.8(0) V

1

M2 non standard conditions or

concentration (of Zn^{2+}) not 1 (mol dm^{-3}) or

concentration (of Zn^{2+}) less than 1 (mol dm^{-3})

***M2** Allow temperature is not 298K*

NOT concentration (of Zn^{2+}) greater than 1 (mol dm^{-3})

NOT concentration (of Zn^{2+}) is different

1

[17]

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) (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

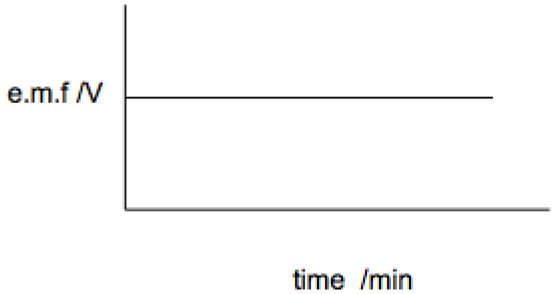
1

$2H_2 + O_2 \longrightarrow 2H_2O$ 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 / **E**$^\ominus$ $O_2|OH^-$ half cell 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]

Q8.

(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

(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]