Q11.

The $E^{\ominus}$ values for two electrodes are shown.

$$Fe^{2+}(aq) + 2\ e^- \rightarrow Fe(s)\ E^{\ominus} = -0.44\ V$$

$$Cu^{2+}(aq) + 2\ e^- \rightarrow Cu(s)\ E^{\ominus} = +0.34\ V$$

What is the EMF of the cell $Fe(s)|Fe^{2+}(aq)||Cu^{2+}(aq)|Cu(s)$?

A +0.78 V ⬭

B +0.10 V ⬭

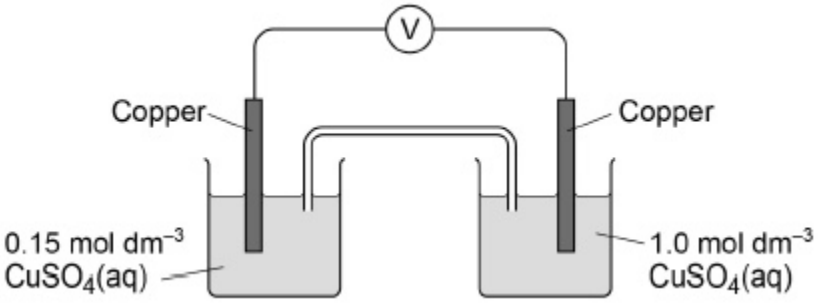
C −0.10 V ⬭

D −0.78 V ⬭

(Total 1 mark)

Q12.

A student set up the cell shown in the diagram.



The student recorded an initial voltage of +0.16 V at 25 °C

(a) Explain how the salt bridge provides an electrical connection between the two solutions.

_____

_____

_____

(1)

(b) The standard electrode potential for the Cu^{2+}/Cu electrode is

$$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s) \qquad E^{o} = +0.34\ V$$

Calculate the electrode potential of the left-hand electrode in the diagram.

Electrode potential _____ V

(1)

(c) Both electrodes contain a strip of copper metal in a solution of aqueous Cu^{2+} ions.

State why the left-hand electrode does **not** have an electrode potential of +0.34 V

_____

_____

(1)

(d) Give the conventional representation for the cell in the diagram.
Include all state symbols.

_____

(1)

(e) When the voltmeter is replaced by a bulb, the EMF of the cell in the diagram decreases over time to 0 V

Suggest how the concentration of copper(II) ions in the left-hand electrode changes when the bulb is alight.
Give **one** reason why the EMF of the cell decreases to 0 V

Change in concentration of copper(II) ions in the left-hand electrode

_____

_____

Reason why the EMF decreases to 0 V _____

_____

_____

_____

(2)

(Total 6 marks)

Q13.

This question is about vanadium compounds and ions.

(a) Use data from Table 4 to identify the species that can be used to reduce VO_2^+ ions to VO^{2+} in aqueous solution and no further.

Explain your answer.

Electrode half-equation	$E^\ominus$ / V
$VO_2^+(aq) + 2H^+(aq) + e^- \rightarrow VO^{2+}(aq) + H_2O(l)$	+1.00
$VO^{2+}(aq) + 2H^+(aq) + e^- \rightarrow V^{3+}(aq) + H_2O(l)$	+0.34
$Cl_2(aq) + 2e^- \rightarrow 2Cl^-(aq)$	+1.36
$Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$	+0.77
$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$	–0.76

Reagent _____

Justification _____

_____

_____

(2)

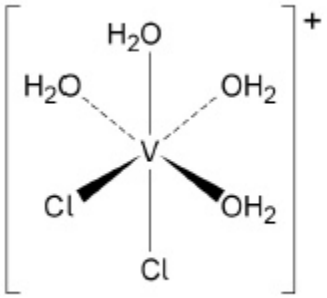
(b) Give the oxidation state of vanadium in $[VO(H_2O)_5]^{2+}$

_____

(1)

(c) The $[V(H_2O)_4Cl_2]^+$ ion exists as two isomers. One isomer is shown.

Draw the structure of the other isomer and state the type of isomerism.



Type of isomerism _____

(2)

(d) Heating NH_4VO_3 produces vanadium(V) oxide, water and one other product.

Give an equation for the reaction.

_____

(1)

(e) Vanadium(V) oxide is the catalyst used in the manufacture of sulfur trioxide.

Give **two** equations to show how the catalyst is used and regenerated.

_____

_____

(1)

(Total 7 marks)

Q14.

Which ion **cannot** catalyse the reaction between iodide (I^-) and peroxodisulfate ($S_2O_8^{2-}$)?

Use the data below to help you answer this question.

Half-equation	E^o / V
$S_2O_8^{2-} + 2e^- \rightarrow 2SO_4^{2-}$	+2.01
$Co^{3+} + e^- \rightarrow Co^{2+}$	+1.82
$Fe^{3+} + e^- \rightarrow Fe^{2+}$	+0.77
$I_2 + 2e^- \rightarrow 2I^-$	+0.54
$Cr^{3+} + e^- \rightarrow Cr^{2+}$	–0.41

A Co^{2+} ⬭

B Cr^{2+} ⬭

C Fe^{2+} ⬭

D Fe^{3+} ⬭

(Total 1 mark)

Q15.

The table shows some electrode half-equations and their standard electrode potentials.

Electrode half-equation	$E^{\ominus}$ / V
$Cl_2(g) + 2e^- \longrightarrow 2Cl^-(aq)$	+1.36
$NO_3^-(aq) + 4H^+(aq) + 3e^- \longrightarrow NO(aq) + 2H_2O(aq)$	+0.96
$Fe^{3+}(aq) + e^- \longrightarrow Fe^{3+}(aq)$	+0.77
$Cu^{2}+(aq) + 2e^- \longrightarrow Cu(s)$	+0.34
$SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \longrightarrow SO2(g) + 2H_2O(aq)$	+0.17
$2H^+(aq) + 2e^- \longrightarrow H_2(g)$	0.00
$Fe^{2+}(aq) + 2e^- \longrightarrow Fe(s)$	−0.44

(a) Deduce the oxidation state of nitrogen in NO_3^- and in NO

Nitrogen in NO_3^- _____

Nitrogen in NO _____

(2)

(b) State the weakest reducing agent in the table.

_____

(1)

(c) Use data from the table to identify an acid that will oxidise copper.

Explain your choice of acid.

Use these data to suggest a possible equation for the reaction.

Calculate the EMF of the cell that has the same overall reaction.

_____

_____

_____

_____

_____

_____

_____

_____

(4)

(Total 7 marks)

Q16.

The table shows some standard electrode potential data.

Electrode half-equation	$E^{\ominus}$ / V
$Cl_2(g) + 2e^- \longrightarrow 2Cl^-(aq)$	+1.36
$Ag^+(aq) + e^- \longrightarrow Ag(s)$	+0.80
$Fe^{3+}(aq) + e^- \longrightarrow Fe^{2+}(aq)$	+0.77
$Sn^{2+}(aq) + 2e^- \longrightarrow Sn(s)$	−0.14
$Fe^{2+}(aq) + 2e^- \longrightarrow Fe(s)$	−0.44

(a) Use data from the table to deduce the species that is the best oxidising agent.

_____

(1)

(b) Write the conventional representation for the cell used to measure the standard electrode potential for the conversion of tin(II) ions to tin.

_____

(2)

(c) A cell was made by connecting two half-cells with a salt bridge. One half-cell consisted of silver in a solution of silver nitrate solution and the other consisted of tin in a solution of tin(II) nitrate solution.

Calculate the EMF of this cell and write a half-equation for the reaction that occurs at the negative electrode.

EMF _____

Half-equation

_____

(2)

(d) Use data from the table above to write an equation for the reaction of silver(I) ions with iron(II) ions.

_____

(1)

(Total 6 marks)

Q17.

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)

Q18.

The following cell has an EMF of +0.46 V.

$$Cu \mid Cu^{2+} \mid\mid Ag^{+} \mid Ag$$

Which statement is correct about the operation of the cell?

A Metallic copper is oxidised by Ag^{+} ions. ⬭

B The silver electrode has a negative polarity. ⬭

C The silver electrode gradually dissolves to form Ag^{+} ions. ⬭

D Electrons flow from the silver electrode to the copper electrode via an external circuit. ⬭

(Total 1 mark)

Q19.

Iron used in the construction of pipes, bridges and ships, can be protected by attaching a sacrificial anode (electrode) to the structure. This sacrificial anode is another metal that corrodes in preference to iron, keeping the iron structure unaffected. This metal must be a stronger reducing agent than iron.

The table shows the standard electrode potentials for some common metal electrodes in alphabetical order.

	Electrode equation	Standard electrode potential / V
aluminium	$Al^{3+}(aq) + 3e^- \longrightarrow Al(s)$	–1.66
copper	$Cu^{2+}(aq) + 2e^- \longrightarrow Cu(s)$	+0.34
iron	$Fe^{2+}(aq) + 2e^- \longrightarrow Fe(s)$	–0.44
lead	$Pb^{2+}(aq) + 2e^- \longrightarrow Pb(s)$	–0.13
magnesium	$Mg^{2+}(aq) + 2e^- \longrightarrow Mg(s)$	–2.37
tin	$Sn^{2+}(aq) + 2e^- \longrightarrow Sn(s)$	–0.14
zinc	$Zn^{2+}(aq) + 2e^- \longrightarrow Zn(s)$	–0.76

(a) Use the standard electrode potentials in the table to identify the most effective metal for use as a sacrificial anode for iron and explain your answer.

_____

_____

_____

(2)

(b) The pH of seawater varies between 7.5 and 8.4. An aluminium sacrificial anode slowly corrodes during its use. When attached to a ship it comes into contact with seawater. The aluminium sets up a cell between itself and the iron structure. In this cell, oxygen dissolved in water is reduced to hydroxide ions on the iron surface. This oxygen/hydroxide electrode has a standard electrode potential of +0.40 V.

Write a half-equation for the oxygen/hydroxide electrode reaction.
Construct an equation to show the overall cell reaction involving the aluminium anode.
Use the table and the information above to calculate the e.m.f. of the cell.

Half-equation _____

Overall cell reaction _____

Cell e.m.f. _____

(3)

(c) Give **two** reasons why the value of the cell e.m.f that you calculated in part **(b)** would not normally be achieved when the cell operates in seawater.

_____

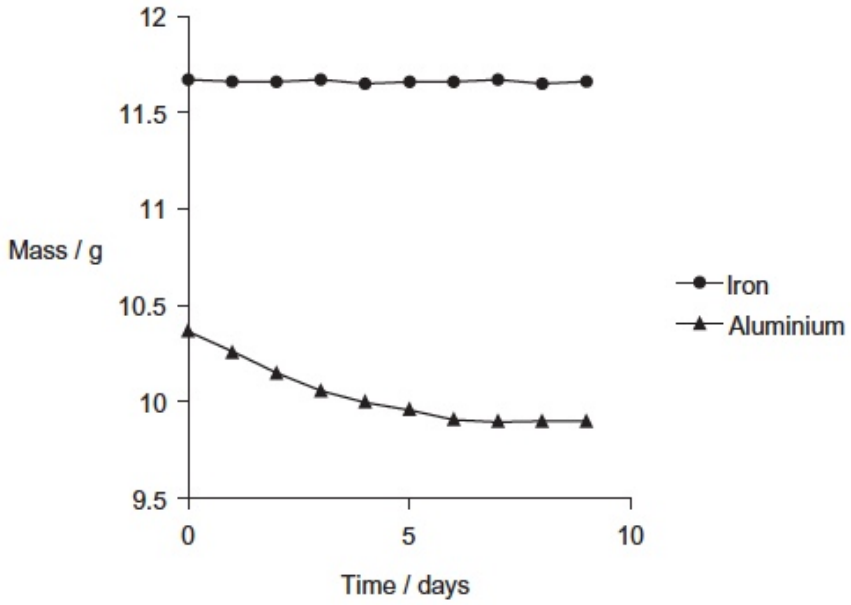
_____

_____

_____

(2)

To examine the effect of a sacrificial anode, a student carefully cleaned a piece of iron foil and a piece of aluminium foil. These were joined and placed in a beaker containing a buffer solution at pH 8.0. Air was bubbled steadily into the solution. At intervals the foils were removed, separated, dried and weighed before being placed back in the buffer solution. The results obtained were plotted on the graph.



(d) Explain briefly the results obtained for the iron foil.

_____

_____

_____

(1)

(e) Suggest briefly why the aluminium foil stopped decreasing in mass after a time.

_____

_____

_____

(1)

(Total 9 marks)

Q20.

The table shows some standard electrode potential data.

Electrode half-reaction	***E*°/V**
$Zn^{2+}(aq) + 2e^- \longrightarrow Zn(s)$	–0.76
$Co^{2+}(aq) + 2e^- \longrightarrow Co(s)$	–0.28
$\frac{1}{2}O_2(g) + 2H^+(aq) + 2e^- \longrightarrow H_2O(l)$	+1.23
$Au^+(aq) + e^- \longrightarrow Au(s)$	+1.68
$Co^{3+}(aq) + e^- \longrightarrow Co^{2+}(aq)/p>$	+1.82

(a) (i) Identify the weakest oxidising agent in the table.

_____

(1)

(ii) Give the conditions under which the electrode potential of the Zn^{2+}/Zn electrode is –0.76 V.

_____

_____

_____

(2)

(b) Two half-cells, involving species in the table, are connected together to give a cell with an e.m.f. = +0.48 V.

Use data from the table to deduce the conventional representation of this cell. Write the half-equation for the reaction that occurs at the negative electrode.

Conventional representation _____

_____

Half-equation _____

(3)

(c) Use data from the table to identify a cobalt species that can react with water.

Write an equation for the redox reaction that occurs and identify the oxidation product in the reaction.

Cobalt species _____

Equation _____

_____

_____

Oxidation product _____

(3)

(d) Use data from the table to explain why gold jewellery is unreactive in moist air.

_____

_____

_____

_____

_____

_____

(2)

(Total 11 marks)

Q21.

The table contains some standard electrode potential data.

Electrode half-equation	***E*⊖ / V**
$F_2 + 2e^- \longrightarrow 2F^-$	+2.87
$Au^+ + e^- \longrightarrow Au$	+1.68
$2HOCl + 2H^+ + 2e^- \longrightarrow Cl_2 + 2H_2O$	+1.64
$Cl_2 + 2e^- \longrightarrow 2Cl^-$	+1.36
$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$	+1.23
$Ag^+ + e^- \longrightarrow Ag$	+0.80
$Fe^{3+} + e^- \longrightarrow Fe^{2+}$	+0.77
$2H^+ + 2e^- \longrightarrow H_2$	0.00
$Fe^{2+} + 2e^- \longrightarrow Fe$	−0.44

(a) In terms of electrons, explain the meaning of the term **oxidising agent**.

_____

_____

(1)

(b) Identify the weakest oxidising agent in the table.
Explain your choice.

Weakest oxidising agent _____

Explanation _____

_____

_____

(2)

(c) Write the conventional representation of the cell used to measure the standard electrode potential for the Ag^+ / Ag electrode.

State the conditions necessary when measuring this value.

Conventional representation _____

_____

Conditions _____

_____

_____

_____

(4)

(d) Use data from the table to explain, in terms of redox, what happens when a soluble gold(I) compound containing Au^+ ions is added to water.

State what you would observe.

Write an equation for the reaction that occurs.

Explanation _____

_____

_____

_____

Observation _____

_____

Equation _____

(4)

The table is repeated below to help you answer these questions.

Electrode half-equation	$E^{\ominus}$ / V
$F_2 + 2e^- \longrightarrow 2F^-$	+2.87
$Au^+ + e^- \longrightarrow Au$	+1.68
$2HOCl + 2H^+ + 2e^- \longrightarrow Cl_2 + 2H_2O$	+1.64
$Cl_2 + 2e^- \longrightarrow 2Cl^-$	+1.36
$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$	+1.23
$Ag^+ + e^- \longrightarrow Ag$	+0.80
$Fe^{3+} + e^- \longrightarrow Fe^{2+}$	+0.77
$2H^+ + 2e^- \longrightarrow H_2$	0.00
$Fe^{2+} + 2e^- \longrightarrow Fe$	−0.44

(e) A cell is made by connecting Fe^{2+} / Fe and Ag^+ / Ag electrodes with a salt bridge.

(i) Calculate the e.m.f. of this cell.

_____

_____

Answer _____

(1)

(ii) Suggest why potassium chloride would **not** be suitable for use in the salt bridge of this cell.

_____

_____

(1)

(f) Use data from the table to explain what happens when a solution of iron(II) chloride is exposed to the air.

_____

_____

_____

_____

(2)

(Total 15 marks)

Mark Scheme

Q11.

A

[1]

Q12.

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

Do not allow movement of electrons.

1

(b) (+) 0.18 V

1

(c) The concentration is not 1.(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 equal/same

Not, concentrations are constant

1

[6]

Q13.

(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

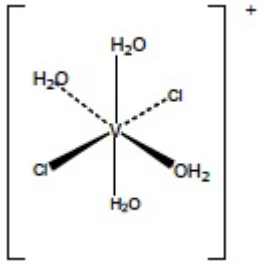
allow $E^{\ominus}$ Fe^{3+} (/Fe^{2+}) value of +0.77 is between the $E^{\ominus}$ values for the electrode half-equations containing the V species or wtte

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)

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]

Q14.

B

[1]

Q15.

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

Allow ***NO_3^-*** *is a better oxidising agent than* ***Cu^{2+}***

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

1

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

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

1

EMF for the reaction is <u>0.62(V)</u>

1

[7]

Q16.

(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]

Q17.

(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]

Q18.

A

[1]

Q19.

(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]

Q20.

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

$Zn^{2+}(aq)$

Apply List

1

(ii) 298 K /25°C

Ignore pressure

Ignore standard conditions

Ignore state symbols

1

(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

$2Co^{3+}(aq) + H_2O(l)\ 2Co^{2+}(aq) + \frac{1}{2}\ O_2(g) + 2H^+(aq)$

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]

Q21.

(a) Electron acceptor / gains electrons

do not allow electron pair acceptor

1

(b) Fe^{2+} ions

1

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

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

Au^+ (ions) oxidise water OR water reduces Au^+ (ions)

Allow water donates electrons to Au+

1

Gold metal / solid / precipitate **OR** bubbles / 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+ / 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]