A-Level Chemistry

Electrode Potentials

Question Paper

Time available: 64 minutes
Marks available: 51 marks

1. This question is about electrode potentials and electrochemical cells.

(a) State the meaning of the term electrochemical series.

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_____

(1)

The table below shows some electrode potentials.

	E^o / V
$[Fe(H_2O)_6]^{2+}(aq) + 2\ e^- \rightarrow Fe(s) + 6\ H_2O(l)$	–0.44
$H^+(aq) + e^- \rightarrow \frac{1}{2} H_2(g)$	0.00
$[Co(NH_3)_6]^{3+}(aq) + e^- \rightarrow [Co(NH_3)_6]^{2+}(aq)$	+0.11
$[Fe(H_2O)_6]^{3+}(aq) + e^- \rightarrow [Fe(H_2O)_6]^{2+}(aq)$	+0.77
$VO_2^+(aq) + 2\ H^+(aq) + e^- \rightarrow VO^{2+}(aq) + H_2O(l)$	+1.00
$[Co(H_2O)_6]^{3+}(aq) + e^- \rightarrow [Co(H_2O)_6]^{2+}(aq)$	+1.81

(b) State **two** conditions needed for the following half-cell to have E^o = 0.00 V

$$H^+(aq) + e^- \rightarrow \frac{1}{2}H_2(g)$$

_____

_____

(1)

(c) Identify the weakest reducing agent in the table above.

_____

(1)

(d) Use half-equations from the table above to deduce an equation for the reduction of VO_2^+ to form VO^{2+} in aqueous solution by iron.

_____

(2)

(e) Use data from the table above to explain why $[Co(H_2O)_6]^{3+}(aq)$ will undergo a redox reaction with $[Fe(H_2O)_6]^{2+}(aq)$

Give an equation for this reaction.

Explanation _____

_____

_____

Equation

_____

(2)

(f) Suggest why the **two** cobalt(III) complex ions in the table above have different electrode potentials.

_____

_____

_____

(1)

(Total 8 marks)

2. Standard electrode potentials are measured by comparison with the standard hydrogen electrode.

(a) State the substances and conditions needed in a standard hydrogen electrode.

_____

_____

_____

_____

(3)

It is difficult to ensure consistency with the setup of a standard hydrogen electrode. A $Cu^{2+}(aq)$ / Cu(s) electrode (E^{o} = +0.34 V) can be used as a secondary standard.

A student does an experiment to measure the standard electrode potential for the $TiO^{2+}(aq)$ / Ti(s) electrode using the $Cu^{2+}(aq)$ / Cu(s) electrode as a secondary standard.

A suitable solution containing the acidified $TiO^{2+}(aq)$ ion is formed when titanium(IV) oxysulfate ($TiOSO_4$) is dissolved in 0.50 mol dm^{-3} sulfuric acid to make 50 cm^3 of solution.

(b) Describe an experiment the student does to show that the standard electrode potential for the $TiO^{2+}(aq)$ / Ti(s) electrode is −0.88 V

The student is provided with:

- the $Cu^{2+}(aq)$ / Cu(s) electrode set up ready to use
- solid titanium(IV) oxysulfate (M_r = 159.9)
- 0.50 mol dm^{-3} sulfuric acid
- a strip of titanium
- laboratory apparatus and chemicals.

Your answer should include details of:

- how to prepare the solution of acidified $TiO^{2+}(aq)$
- how to connect the electrodes
- measurements taken
- how the measurements should be used to calculate the standard electrode potential for the $TiO^{2+}(aq)$ / Ti(s) electrode.

(6)

(c) Give the half-equation for the electrode reaction in the $TiO^{2+}(aq)$ / Ti(s) electrode in acidic conditions.

_____

(1)

(d) The table shows some electrode potential data.

Electrode reaction	***E*⊖ / V**
$2\ H^+(aq) + 2\ e^- \rightarrow H_2(g)$	0.00
$Cu^{2+}(aq) + 2\ e^- \rightarrow Cu(s)$	+0.34
$NO_3^-(aq) + 4\ H^+(aq) + 3\ e^- \rightarrow NO(g) + 2\ H_2O(l)$	+0.96

Use the data in the table to explain why copper does **not** react with most acids but does react with nitric acid.

Give an equation for the reaction between copper and nitric acid.

Explanation _____

_____

_____

_____

_____

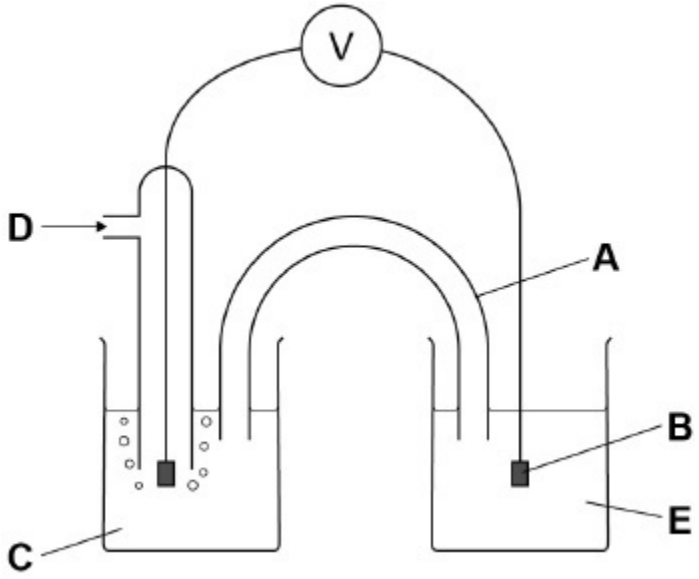
Equation _____

_____

(3)

(Total 13 marks)

3. 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**.

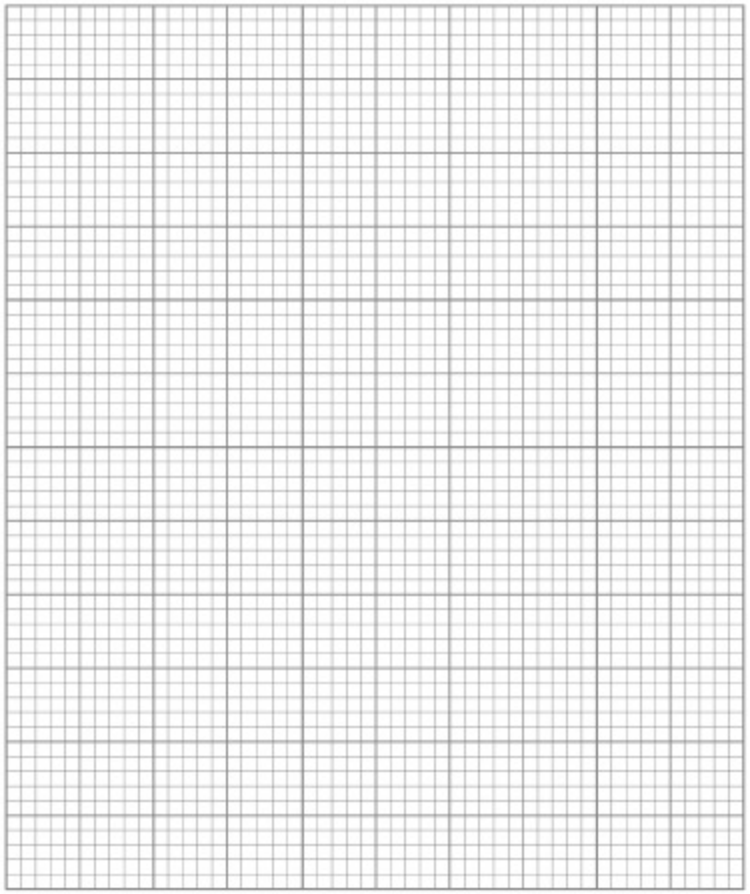
Table 2

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.

E_{cell} / V



$$\ln\left(\frac{[Zn^{2+}]}{[Cu^{2+}]}\right)$$

(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)

4. 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)

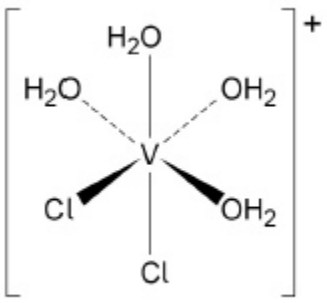
(b) Give the oxidation state of vanadium in $[VO(H_2O)_5]^{2+}$

_____

(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.

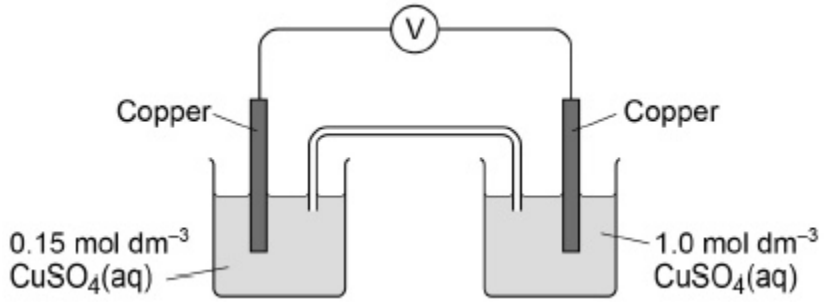
_____

_____

(1)

(Total 7 marks)

5. 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

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

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)