24. Electrochemistry

24.1 Electrolysis

Paper 4

Question Paper

1 **(d)** A fuel cell is an electrochemical cell that can be used to generate electrical energy by using oxygen to oxidise a fuel.

Methanoic acid, HCOOH, is being investigated as a fuel in fuel cells.

When the cell operates, HCOOH is oxidised to carbon dioxide.

The half-equation for the reaction at the cathode is: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$.

In this fuel cell, the overall cell reaction is the same as that for the complete combustion of HCOOH.

(i) Deduce the half-equation for the reaction at the anode.

..... [1]

(ii) Calculate the volume, in cm^3, of oxygen used when a current of 3.75A is delivered by the cell for 40.0 minutes. Assume the cell operates at room conditions.

volume of oxygen = ... cm^3 [2]

2 Some electrode potentials are shown in Table 3.1.

Table 3.1

electrode reaction	$E^{\ominus}$/V
$V^{2+} + 2e^- \rightleftharpoons V$	–1.20
$V^{3+} + e^- \rightleftharpoons V^{2+}$	–0.26
$VO^{2+} + 2H^+ + e^- \rightleftharpoons V^{3+} + H_2O$	+0.34
$VO_2^+ + 2H^+ + e^- \rightleftharpoons VO^{2+} + H_2O$	+1.00
$Fe^{2+} + 2e^- \rightleftharpoons Fe$	–0.44
$Fe^{3+} + 3e^- \rightleftharpoons Fe$	–0.04
$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	+0.77
$2H^+ + 2e^- \rightleftharpoons H_2$	0.00
$ClO^- + H_2O + 2e^- \rightleftharpoons Cl^- + 2OH^-$	+0.89

(e) A solution of iron(II) sulfate, $FeSO_4(aq)$ is electrolysed with iron electrodes. Under the conditions used, no gas is evolved at the cathode.

A current of 0.640 A is passed for 17.0 minutes. The mass of the cathode increases by 0.185 g.

Use these results to calculate an experimental value for the Avogadro constant, *L*.

Show your working.

L = ... mol^{-1} [3]

3 **(a)** Complete Table 5.1 to predict the substance liberated at each electrode during electrolysis of the indicated electrolyte with inert electrodes.

Table 5.1

electrolyte	substance liberated at the anode	substance liberated at the cathode
$PbBr_2(l)$		
concentrated $NaCl(aq)$		
$Cu(NO_3)_2(aq)$		

[3]

(b) An electrolytic cell is set up to determine a value for the Avogadro constant, *L*. The electrolyte is dilute sulfuric acid and both electrodes are copper.

When a current of 0.600 A is passed through the acid for 30.0 minutes, the anode decreases in mass by 0.350 g.

(i) State the relationship between the Faraday constant, *F*, and the Avogadro constant, *L*.

..... [1]

(ii) Use the experimental information in **(b)** and data from the table on page 23 to calculate a value for the Avogadro constant, *L*.

Show all working.

Avogadro constant, *L* = ... [4]

4 Data should be selected from Table 3.1 in order to answer some parts of this question.

Table 3.1

electrode reaction	$E^{\ominus}$ / V
$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$	+1.36
$2HOCl + 2H^+ + 2e^- \rightleftharpoons Cl_2 + 2H_2O$	+1.64
$ClO^- + H_2O + 2e^- \rightleftharpoons Cl^- + 2OH^-$	+0.89
$Sn^{4+} + 2e^- \rightleftharpoons Sn^{2+}$	+0.15
$Sn^{2+} + 2e^- \rightleftharpoons Sn$	–0.14
$V^{2+} + 2e^- \rightleftharpoons V$	–1.20
$V^{3+} + e^- \rightleftharpoons V^{2+}$	–0.26
$VO^{2+} + 2H^+ + e^- \rightleftharpoons V^{3+} + H_2O$	+0.34
$VO_2^+ + 2H^+ + e^- \rightleftharpoons VO^{2+} + H_2O$	+1.00

(b) A solution of $SnCl_2$(aq) is electrolysed for a measured time using a steady current.

A mass of 2.95 g of tin metal is produced at the cathode.

Al_2O_3(l) is electrolysed for the same time by the same current.

Calculate the mass of aluminium metal produced at the cathode. Give your answer to **three** significant figures. Show your working.

mass of aluminium metal = ... g [2]

5 Data should be selected from Table 3.1 in order to answer some parts of this question.

Table 3.1

electrode reaction	$E^{\ominus}$/V
$Mg^{2+} + 2e^- \rightleftharpoons Mg$	–2.38
$Mn^{2+} + 2e^- \rightleftharpoons Mn$	–1.18
$Mn^{3+} + e^- \rightleftharpoons Mn^{2+}$	+1.49
$MnO_2 + 4H^+ + 2e^- \rightleftharpoons Mn^{2+} + 2H_2O$	+1.23
$MnO_4^- + e^- \rightleftharpoons MnO_4^{2-}$	+0.56
$MnO_4^- + 4H^+ + 3e^- \rightleftharpoons MnO_2 + 2H_2O$	+1.67
$MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O$	+1.52

(b) A molten magnesium salt is electrolysed for 15.0 minutes by a constant current.

4.75×10^{22} magnesium atoms are produced at the cathode.

Calculate the value of the current used.

current = ... A [2]

6 **(b)** **(i)** Identify the substances formed at the anode and at the cathode during the electrolysis of saturated $CaCl_2$(aq).

at the anode .....

at the cathode .....

[1]

(ii) Calcium can be produced by the electrolysis of molten calcium chloride, $CaCl_2$(l).

Calculate the mass, in g, of Ca formed when a current of 0.75A passes through $CaCl_2$(l) for 60 minutes.
[A_r: Ca, 40.1]

mass of Ca = ... g [2]

7 When dilute sulfuric acid is electrolysed, water is split into hydrogen and oxygen.

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

A current of **x** A is passed through the solution for 14.0 minutes. 462 cm^3 of hydrogen are produced at the cathode, measured under room conditions.

(a) Calculate the number of hydrogen molecules produced during the electrolysis.

number of hydrogen molecules = ... [2]

(b) Calculate the total number of electrons transferred to produce this number of hydrogen molecules.

total number of electrons = ... [1]

(c) Calculate the quantity of charge, in coulombs, of the total number of electrons calculated in **(b)**.

quantity of charge = ... C [1]

(d) Calculate the current, **x**, passed during this experiment.

x = ... A [1]

8 Pure water is a very poor conductor of electricity. However, when hydrogen chloride gas is dissolved in water, ions are formed and a current flows during electrolysis.

$$HCl(g) + aq \rightarrow H^+(aq) + Cl^-(aq)$$

The overall change after electrolysis is that hydrogen chloride gas is converted into hydrogen and chlorine.

$$2HCl(g) \rightarrow H_2(g) + Cl_2(g)$$

When a current of 3.10 A is passed through the solution for *Y* minutes, 351 cm^3 of chlorine are produced at the anode, measured under room conditions.

(a) Calculate the number of chlorine molecules produced during the electrolysis.

number of chlorine molecules = ... [2]

(b) Calculate the total number of electrons transferred to produce this number of chlorine molecules.

total number of electrons = ... [1]

(c) Calculate the quantity of charge, in coulombs, of the total number of electrons calculated in **(b)**.

quantity of charge = ... C [1]

(d) Calculate the time, *Y*, in minutes, for which the current flows.

Y = ... minutes [1]

9 **(a)** Identify the substances liberated at the anode and at the cathode during the electrolysis of aqueous sodium sulfate, $Na_2SO_4(aq)$.

anode .....

cathode .....
[1]

(b) When molten sodium chloride is electrolysed, chlorine is liberated at the anode and sodium is liberated at the cathode.

A sample of molten sodium chloride is electrolysed for 1.50 hours using a current of 4.50 A.

Calculate the volume of chlorine and the mass of sodium that are liberated under room conditions.

volume of chlorine = ... dm^3

mass of sodium = ... g
[4]

10 **(a)** Identify the substances liberated at the anode and at the cathode during the electrolysis of saturated KCl(aq).

at the anode .....

at the cathode .....

[1]

(b) When dilute sulfuric acid is electrolysed, oxygen is liberated at the anode.

Dilute sulfuric acid is electrolysed for 15.0 minutes using a current of 0.750A.

Calculate the volume of oxygen that is liberated under room conditions.

volume of oxygen = ... cm^3 [3]

11 An electrochemical cell is constructed using two half-cells.

- an Sn^{4+}/Sn^{2+} half-cell
- an Al^{3+}/Al half-cell

(c) Aluminium is produced industrially by electrolysis of a melt containing large amounts of Al^{3+} ions.

Calculate the mass of aluminium that is obtained when a current of 300000A is passed for 24 hours. Give your answer to **three** significant figures.

mass = ... units = ...

[4]

12 An electrochemical cell is constructed using two half-cells.

- a Br_2/Br^- half-cell
- an Mn^{3+}/Mn^{2+} half-cell

(c) An aqueous solution of copper(II) sulfate is electrolysed using copper electrodes. A current of 1.50 A is passed for 3.00 hours. 5.09 g of copper is deposited on the cathode.

The charge on one electron is -1.60×10^{-19} C.

The relative atomic mass of copper is 63.5.

Use these data to calculate an experimentally determined value for the Avogadro constant, *L*. Give your answer to **three** significant figures.

L = ... mol^{-1} [5]

(d) Explain why magnesium metal cannot be obtained by the electrolysis of dilute aqueous magnesium sulfate. Your answer should include data from the *Data Booklet*.

.....

.....

.....

..... [2]

13 **(a)** Complete the table, identifying the substance liberated at each electrode during electrolysis with inert electrodes.

electrolyte	substance liberated at the anode	substance liberated at the cathode
$AgNO_3(aq)$		
concentrated $NaCl(aq)$		
$CuSO_4(aq)$		

[3]

(b) Molten calcium iodide, CaI_2, is electrolysed in an inert atmosphere with inert electrodes.

(i) Write ionic equations for the reactions occurring at the electrodes.

- .....
- .....

[2]

(ii) The electrolysis of molten CaI_2 is a redox process.

Identify the ion that is oxidised and the ion that is reduced, explaining your answer by reference to oxidation numbers.

.....

.....

..... [2]

(iii) Describe **two** visual observations that would be made during this electrolysis.

1 .....

2 .....

[1]

(c) An oxide of iron dissolved in an inert solvent is electrolysed for 2.00 hours using a current of 0.800A. The electrolysis products are iron and oxygen. The mass of iron produced is 1.11 g.

Calculate the oxidation number of Fe in the oxide of iron. Show **all** your working.

oxidation number of Fe = ... [3]