Electrolysis, Electrode Potentials & Cells

Question Paper 4

Level	International A Level
Subject	Chemistry
Exam Board	CIE
Topic	Electrochemistry
Sub-Topic	Electrolysis, Electrode Potentials & Cells
Paper Type	Theory
Booklet	Question Paper 4

Time Allowed: **72 minutes**

Score: **/60**

Percentage: **/100**

Grade Boundaries:

A*	A	B	C	D	E	U
>85%	777.5%	70%	62.5%	57.5%	45%	<45%

1 Chlorine is manufactured by the electrolysis of brine, NaC*l*(aq). At the cathode, H_2(g) and OH^-(aq) are produced, but the product at the anode depends on the [NaC*l*(aq)] in the solution. Either O_2(g) or Cl_2(g) is produced.

(a) The equation for the cathode reaction is $2H_2O(l) + 2e^- \longrightarrow H_2(g) + 2OH^-(aq)$.

Starting from **neutral** NaC*l*(aq), write equations for the production at the anode of

(i) O_2(g), ...

(ii) Cl_2(g). ....

[2]

(b) For electrolysis to occur, the voltage applied to the cell must be at least as large as the $E^{\ominus}_{cell}$, as calculated from standard electrode potentials.
Use the *Data Booklet* to calculate $E^{\ominus}_{cell}$ for the production at the anode of

(i) O_2(g), ...

(ii) Cl_2(g). ....

[2]

(c) **(i)** By using **one** of the phrases *more positive*, *less positive* or *no change*, use the equations you wrote in **(a)** to deduce the effect of increasing [Cl^-(aq)] on

- the E_{anode} for the production of O_2(g), ...
- the E_{anode} for the production of Cl_2(g). ....

(ii) Hence explain why the Cl_2(g) : O_2(g) atio increases as [NaC*l*(aq)] increases.

....

....[3]

(d) Sodium chlorate(V) is prepared commercially by electrolysing NaC*l*(aq) in a cell which allows the cathode and anode electrolytes to mix.
The cathode reaction is the same as that described in **(a)**.
The equation for the anode reaction is

$$Cl^-(aq) + 6OH^-(aq) - 6e^- \longrightarrow ClO_3^-(aq) + 3H_2O(l)$$

(i) Construct an ionic equation for the overall reaction.

....

(ii) Calculate the mass of $NaClO_3$ that is produced when a current of 250 A is passed through the cell for 60 minutes.

mass of $NaClO_3$ = ... g [4]

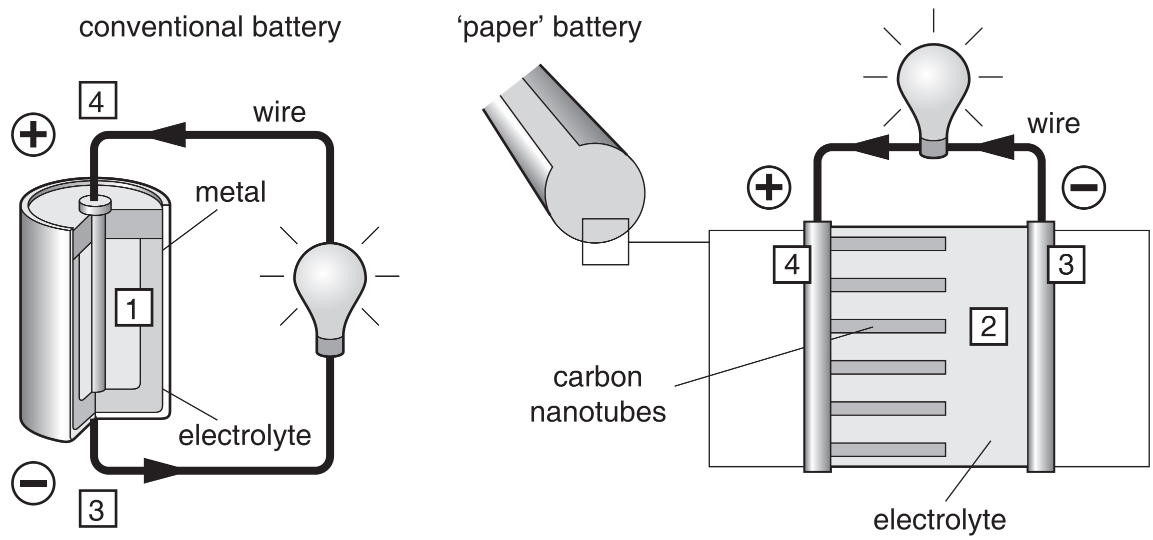
[Total: 11]

2 A new method of making very light, flexible batteries using nanotechnology was announced in August 2007. Read the passage and answer the questions related to it.

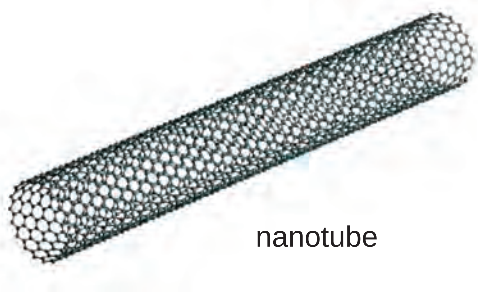
Researchers have developed a new energy-storage device that could easily be mistaken for a simple sheet of black paper. The nano-engineered battery is lightweight, ultra-thin and completely flexible. It is geared towards meeting the difficult design and energy requirements of tomorrow's gadgets, such as implantable medical devices and even vehicles.

Researchers soaked 'paper' in an ionic liquid electrolyte which carries the charge. They then treated it with aligned carbon nanotubes, which give the device its black colour.

The nanotubes act as electrodes and allow the storage devices to conduct electricity. The device, engineered to function as both a battery and a supercapacitor, can provide the long, steady power output comparable to a conventional battery, as well as a supercapacitor's quick burst of high energy. The device can be rolled, twisted, folded, or cut into shapes with no loss of strength or efficiency. The 'paper' batteries can also be stacked, like a pile of printer paper, to boost the total power output.



1. *Conventional batteries produce electrons through a chemical reaction between electrolyte and metal.*
2. *Chemical reaction in the 'paper' battery is between electrolyte and carbon nanotubes.*
3. *Electrons collect on the negative terminal of a battery.*
4. *Electrons must flow from the negative terminal, through the external circuit to the positive terminal for the chemical reaction to continue.*



nanotube

(a) From your knowledge of the different structures of carbon, suggest which of these is used to make nanotubes.

.... [1]

(b) Suggest a property of this structure that makes it suitable for making nanotubes.

....

.... [1]

(c) Carbon in its bulk form is brittle like most non-metallic solids. Suggest why the energy storage device described can be rolled into a cylinder.

....

.... [1]

(d) Name an example of an 'ionic *liquid* electrolyte' (not a solution).

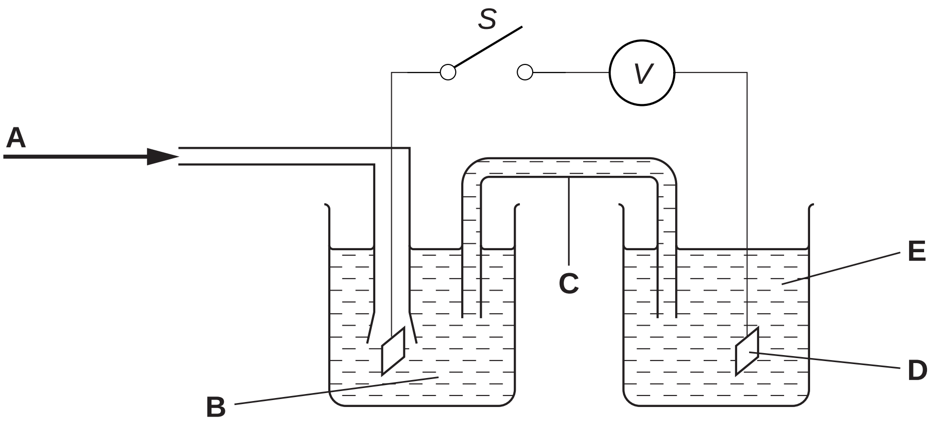
.... [1]

[Total: 4]

3 Chlorine gas and iron(II) ions react together in aqueous solution as follows.

$$Cl_2 + 2Fe^{2+} \rightarrow 2Cl^- + 2Fe^{3+}$$

(a) The following diagram shows the apparatus needed to measure the $E^{\ominus}_{cell}$ for the above reaction.



(i) In the spaces below, identify what the five letters **A** – **E** in the above diagram represent.

A ....

B ....

C ....

D ....

E ....

(ii) Use the *Data Booklet* to calculate the $E^{\ominus}_{cell}$ for this reaction, and hence decide which direction (left to right, or right to left) electrons would flow through the voltmeter *V* when switch *S* is closed.

$E^{\ominus}_{cell}$ = ... V

direction of electron flow ....

[7]

(b) Iron(III) chloride readily dissolves in water.

$$FeCl_3(s) \longrightarrow Fe^{3+}(aq) + 3Cl^-(aq)$$

(i) Use the following data to calculate the standard enthalpy change for this process.

species	$\Delta H_f^{\ominus}$ / kJ mol^{-1}
$FeCl_3(s)$	–399.5
$Fe^{3+}(aq)$	–48.5
$Cl^-(aq)$	–167.2

$\Delta H^{\ominus}$ = ...kJ mol^{-1}

(ii) A solution of iron(III) chloride is used to dissolve unwanted copper from printed circuit boards.

When a copper-coated printed circuit board is immersed in $FeCl_3(aq)$, the solution turns pale blue.

Suggest an equation for the reaction between copper and iron(III) chloride and use the Data Booklet to calculate the $E^{\ominus}$ for the reaction.

equation ....

$E^{\ominus}$ = ... V
[4]

[Total: 11]

4 Chlorine gas is manufactured by the electrolysis of brine using a diaphragm cell.

(a) Write half-equations, including state symbols, for the reactions occurring at each of the electrodes of a diaphragm cell.

anode ....

cathode .... [2]

(b) In the diaphragm cell, the anode is made of titanium and the cathode is made of steel.

Suggest why steel is never used for the anode.

....

.... [1]

(c) One important product made in the diaphragm cell is formed in aqueous solution.

(i) What substance is produced in aqueous solution in the diaphragm cell?

....

(ii) Explain, with the aid of appropriate half-equation(s), how this compound is formed by electrolysis.

....

....

.... [3]

(d) Chlorine is very reactive and will form compounds by direct combination with many elements.

Describe what you would see when chlorine is passed over separate heated samples of sodium and phosphorus. In **each** case write an equation for the reaction.

sodium ....

....

....

phosphorus ....

....

.... [4]

(e) Magnesium chloride, $MgCl_2$, and silicon tetrachloride, $SiCl_4$, each dissolve in or react with water.

Suggest the approximate pH of the solution formed in **each** case.

$MgCl_2$ ………………………………… $SiCl_4$ …………………………………

Explain, with the aid of an equation, the difference between the two values.

....

....

....

.... [5]

[Total: 15]

5 Zinc chloride is one of the most important compounds of zinc. It is used in dry cell batteries, as a flux for soldering and tinning, as a corrosion inhibitor in cooling towers and in the manufacture of rayon.

(a) Draw a **fully labelled** diagram to show how you could use a standard hydrogen electrode to measure the standard electrode potential, $E^{\ominus}$, of zinc.

[6]

(b) The electrolysis of zinc chloride can give different electrode products, depending on the conditions used.
Suggest the products formed at each electrode in the following cases. One space has been filled in for you.

conditions	product at anode	product at cathode
$ZnCl_2$(l)	***chlorine***	
$ZnCl_2$(concentrated aqueous)		
$ZnCl_2$(dilute aqueous)		

[3]

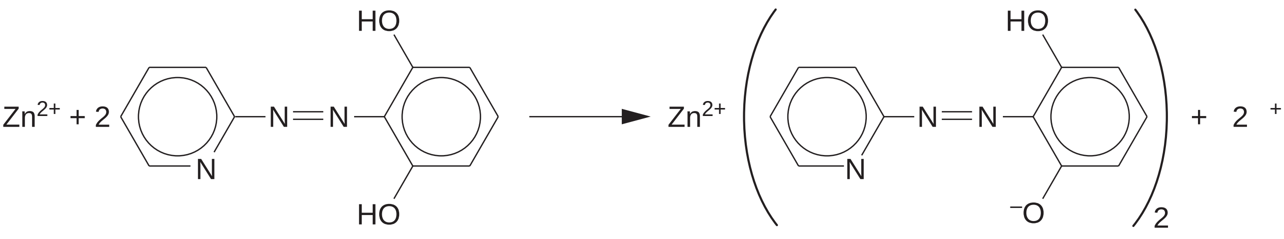
(c) Use the following data, together with relevant data from the *Data Booklet*, to construct a Born-Haber cycle and calculate a value for the lattice energy of zinc chloride.

standard enthalpy change of formation of $ZnCl_2$	–415 kJ mol^{-1}
standard enthalpy change of atomisation of Zn(s)	+131 kJ mol^{-1}
electron affinity per mole of chlorine atoms	–349 kJ mol^{-1}

lattice energy = ... kJ mol^{-1} [3]

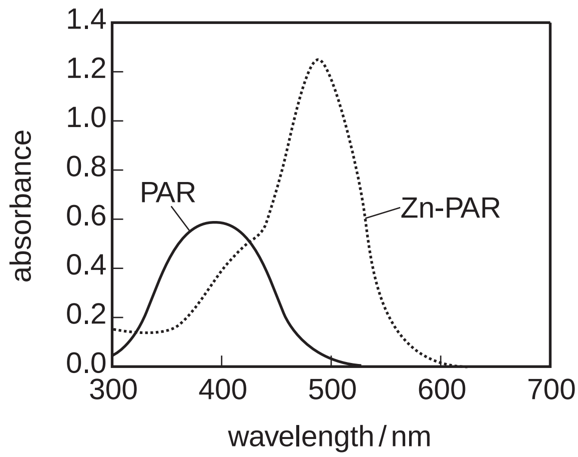
(d) Zinc is an essential element for plant and animal life. It is often administered in the form of a chelate, which is a complex between a metal ion and a polydentate ligand.

The rate of the reaction between zinc ions and the ligand 4-(2-pyridylazo)resorcinol, PAR, has been studied.



PAR Zn-PAR

Both PAR and its zinc complex absorb radiation in the UV-visible region. The figure below shows their absorption spectra.



(i) Devise a suitable experimental technique for studying how the rate of this reaction varies with $[Zn^{2+}(aq)]$.

....

....

....

....

....

....

....

(ii) Describe a reaction you could carry out to show that PAR is a phenol.

....

....

[7]

[Total: 19]