ACTIVITY BRIEF

Extracting and purifying metals

The science at work

In an electrolytic cell, electricity (a flow of electrons) is used to bring about a chemical reaction. These cells are of huge commercial importance. They are used for the production and purification of many metals.

Though not covered in this unit, other commercially important applications include:

- manufacturing chlorine and sodium hydroxide in the alkali industry
- electroplating.

Your brief

The unit specification says you must make a presentation outlining the applications of electrochemical changes. You will have already done work on electrochemical cells for producing electrical energy. Now you need to find out about electrolytic cells. Putting this work together will enable you to produce the required presentation.

You also need to carry out a practical investigation into factors that affect the efficiency of a simple laboratory experiment in which an object is copper plated.

Task 1 Industrial extraction and purification of metals

Complete *Study Sheet: Industrial extraction and purification of metals*. Find out about the processes and describe them in terms of redox reactions.

Task 2 Refining copper

Complete *Practical Sheet: Refining copper*. You will probably work in a team to complete this task. Your teacher will advise you.

STUDY SHEET

Industrial extraction and purification of metals

By completing this study sheet you will learn about electrolysis, and its use in the extraction of sodium and aluminium, and in the purification of copper.

Electrolysis

Ionic solids consist of negatively charged ions and positively charged ions arranged in a giant three-dimensional lattice.

Complete this sentence:

Anions have a ______________ charge; cations have a ______________ charge.

Ionic solids do not conduct electricity. However, they do when the compounds are molten (sometimes called fused) or dissolved in water. What's more, they also decompose. A substance that conducts electricity and is decomposed in the process is called an electrolyte.

The assembly of reaction vessel, electrodes and electrolyte is called an electrolytic cell.

Before going further, make sure you know the meaning of:

electrolytic cell electrolyte anode cathode

You should also know (and you may find the mnemonic OILRIG a good way to remember this):

Oxidation **I**s **L**oss of electrons and **R**eduction **I**s **G**ain of electrons

OILRIG

Electrolysis of molten metal salts

Zinc chloride is a metal salt. It has a giant lattice structure. When molten this structure breaks down and zinc ions and chloride ions move around. Its electrolysis is typical of molten salts.

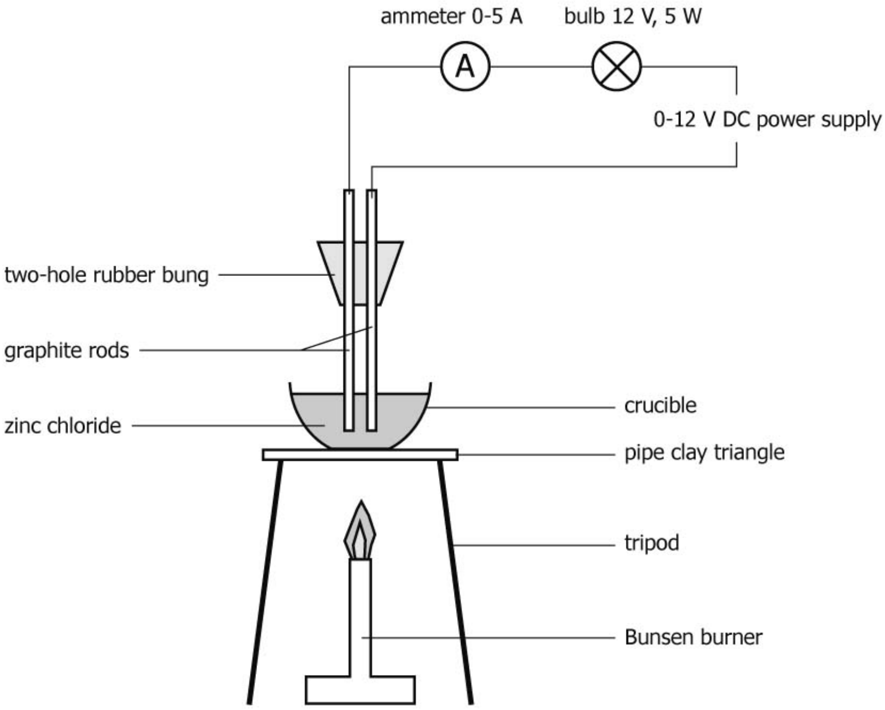
How to do it and what you see

See diagram on next page.

Powdered zinc chloride is put into a crucible and heated with a low to medium Bunsen burner flame. As the zinc chloride melts (in three or four minutes) the bulb lights up and the ammeter gives a reading. The power supply is adjusted to a current of 0.5 A.

During electrolysis:

- bubbles of chlorine gas form at the positive electrode
- zinc crystals form at the negative electrode (they are also seen in the melt).



Questions

1 Which ions move towards the cathode? ______________________________

2 Which ions move towards the anode? ______________________________

3 Complete these equations, using e^- to represent one mole of electrons:

a The reaction at the ________ is Zn^{2+} + ___ → ___

b Zinc ions have been ____________

c The reaction at the ________ is $2Cl^-$ → ___ + ___

d Chloride ions have been ____________

4 Write an overall equation for the electrolysis of molten zinc chloride:

____

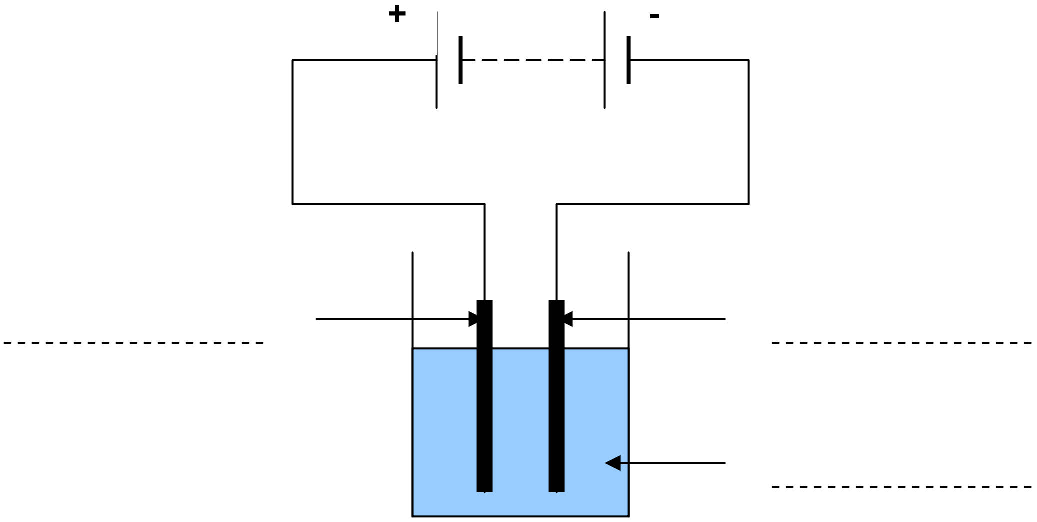
Note

Your teacher may demonstrate this experiment. If not, you can watch a short video of it produced by the Royal Society of Chemistry. Go to this website: http://www.chemsoc.org/networks/learnnet/videoclips.htm. Scroll down to *Demonstrations* and select *Electrolysis of molten zinc chloride*.

Electrolysis of aqueous metal salts

The electrolysis of aqueous solutions of metal salts can be more complex than for the molten salts. Label the diagram on the next page using the terms:

metal salt solution (electrolyte) anode cathode



Although water is molecular, there are small amounts of hydroxonium ions, H_3O^+, and hydroxide ions, OH^-, due to the ionisations of some water molecules:

$2H_2O \rightleftharpoons H_3O^+ + OH^-$

At the negative electrode metal or hydrogen forms:

- $2H_3O^+ + 2e^- \rightarrow 2H_2O + H_2$
- $M^{x+} + xe^- \rightarrow M$

At the positive electrode oxygen forms, and is given off, unless halide ions are in solution. In this case, a mixture of oxygen and halogen forms. The relative proportions depend on the concentration of the metal halide.

- $4OH^- \rightarrow 2H_2O + O_2 + 4e^-$
- $2X^- \rightarrow X_2 + 2e^-$ where X = Cl, Br, I

The material the electrode is made of may also have an effect. Most metal anodes get dissolved by the electrochemical reaction, instead of oxygen or a halogen being released.

Aqueous copper(II) chloride. Copper(II) chloride dissolves in water. Hydrated copper(II) ions and hydrated chloride ions form and move around freely. When two carbon electrodes are dipped into the solution and connected to a power supply an electric current passes.

In the electrolysis of a concentrated solution of copper(II) chloride, copper forms at the negative electrode and chlorine gas forms at the positive electrode.

1 Write an ionic equation for the reaction at the cathode.

____

2 Write ionic equations for the reactions at the anode.

____

3 From the information above, work out how the electrolysis of dilute copper(II) chloride solution differs from the electrolysis of a concentrated solution.

____

____

4 Write ionic equations for the reactions at the anode and cathode when copper(II) sulfate solution is electrolysed using carbon electrodes.

Aqueous sodium chloride. Sodium chloride solution contains hydrated sodium ions and hydrated chloride ions. Different products are obtained when 0.1 mol dm^{-3} and 2 mol dm^{-3} solutions are electrolysed.

For both solutions:

5 Name the product(s) formed at the cathode and write an appropriate ionic equation(s).

6 Name the product(s) formed at the anode and write an appropriate ionic equation(s).

Aqueous solution of zinc sulfate and copper sulfate. An electric current passes through an aqueous solution of zinc sulfate and copper sulfate. The concentrations of the two salts are similar. Hint: Think about the electrochemical series.

7 Name the product(s) formed at the cathode and write an appropriate ionic equation(s).

8 Name the product(s) formed at the anode and write an appropriate ionic equation(s).

Quantities and costs of electricity

Quantities

Electric charge = current x time

$$Q = It$$

Units: electric charge, coulomb (C); current, amp (A); time, second (s)

Before the coulomb, the faraday (F) was used. One faraday (equivalent to 96 500 C) is the electric charge equal to that of one mole of electrons. It's still quite useful when looking at chemical equations. The electrolysis of molten lead chloride will illustrate:

At the negative electrode (the cathode): $Pb^{2+} + 2e^- \rightarrow Pb$

We can read this equation as:

'one mole of lead ions combine with 2 moles of electrons to produce one mole of lead atoms'

The relative atomic mass of lead = 207.2. Therefore …

- 2 moles of electrons produce 1 mole of lead, which a has a mass 207.2 g
- 2 F of electric charge are needed = 2 x 96 500 = 193 000 C

This electric charge is carried when a current of 1 ampere passes for 193 000 seconds, or 53.6 hours. As the current increases, the time required decreases.

Complete these …

1 A current of 10 A through molten lead chloride for _______ seconds produces 2.072 g of lead.

2 A current of 100 kA through molten lead bromide for _______ seconds produces 514.4 g of lead.

3 A current of 100 A through molten lead chloride for _______ seconds produces 207.2 g of lead.

4 A current of ___ A through molten lead chloride for 1 hour produces 10.36 g of lead.

and try these …

5 A current of 3 A is passed through molten magnesium chloride, $MgCl_2$, for 10 hours. What mass of magnesium is produced at the cathode? (Relative atomic mass Mg = 24.3)

____

6 A current of 1 A is passed through molten lithium chloride, LiCl, for 96 500 seconds. What mass of lithium is produced at the cathode? (Relative atomic mass Li = 6.94)

____

Costs

There are many providers of electricity and each has its own pricing policy. There are several tariffs available from each provider. However, below are some average figures given in March 2006. You may be able to find more recent prices.

Year	2000	2001	2002	2003	2004	2005
Domestic (p/kWh)	7.1	7.0	7.0	7.1	7.5	8.2
Industrial (p/kWh)	3.7	3.6	3.5	3.4	3.7	4.6

Prices are given in pence per kilowatt hour (p/kWh).

To calculate the number of kilowatt hours you need to use some simple relationships:

Power = current x voltage

$$P = IV$$

Units: current, amps (A); voltage, volts (V); power, watts (W)

Remember 1000 W = 1 kW

To calculate the kWh used by a device, multiply the power (make sure it is in kilowatts) by the hours of use.

Try these …

Using a price of 5p/kWh, calculate the cost of the following:

1 using a 1.5 kW electrical heater for eight hours

____

2 lighting a laboratory with twenty 30 W low energy electric bulbs for eight hours

____

3 using a 450 W freezer for 16 hours

---

4 using a 1200 W electric hotplate in the laboratory for 1.5 hours

---

5 electrolysing molten lead chloride using a current of 5 A and a voltage of 6 V for one hour

---

6 electrolysing molten lithium chloride using a current of 5 A and a voltage of 12 V for six hours

---

7 electrolysing molten calcium chloride using a current of 5000 A and a voltage of 4.5 V for 24 hours

---

Extracting sodium

World production: 60,000 – 80,000 tonnes per year

UK production: none

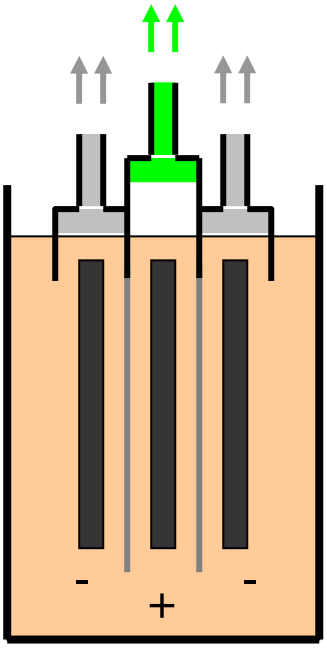
Sodium is extracted by electrolysis of molten sodium chloride (purified rock salt). This is carried out in a Downs electrolytic cell. Sodium was produced in Cheshire, but nowadays there is no UK production.

You can find out more and watch a video about sodium production at: http://www.chemsoc.org/networks/learnnet/alchemy/index2.htm. Select Sodium from the menu on the left-hand side of the screen.

A Downs cell consists of graphite (carbon) anode inside a tubular steel cathode, with a diaphragm between them to prevent the sodium and chlorine from mixing. A typical continuous flow reactor consists of four Downs cells.

Label the diagram of a Downs electrolytic cell on the next page using these terms:

graphite carbon anode
chlorine gas
molten sodium
steel gauze diaphragm
steel cathode
molten electrolyte



Questions

1 Why is rock salt purified before it is used as the raw material for sodium production?

2 The cells are made of steel lined with heat resistant bricks and each cell is rebuilt every three years or so. Why do you think the cells are lined with heat resistant bricks?

3 Why do think the anode is made of carbon rather than steel, like the cathode?

4 Calcium chloride, $CaCl_2$, and barium chloride, $BaCl_2$ are added to lower the melting point of the molten electrolyte from 804 ^{o}C (the melting point of sodium chloride) to about 600 ^{o}C. Why do you think this important?

5 Why is it important to prevent the sodium from coming in contacting with air?

6 How is the sodium stored?

7 A typical factory might have 25 reactors, each made up of four cells. The current in each cell is 30 000 A.

Calculate the quantity of electricity, in faradays, used for all the cells in the factory in 24 hours.

Calculate the mass of sodium produced in the factory 24 hours. (Relative atomic mass: Na = 23.0, 1 tonne = 1000 kg).

8 What other product is obtained from the electrolysis of molten sodium chloride and how is it stored?

Give some of its uses.

9 What precautions are taken in the process to ensure safety and minimise any environmental impact?

Extracting aluminium

World production: 19.5 million tonnes per year

UK production: 250 000 tonnes per year

Aluminium is obtained by the electrolysis of aluminium oxide. The oxide is obtained by purifying bauxite. The Hall-Héroult electrolytic process used is a 24 hour, 365 days a year continuous process.

You can find out more and watch a video about aluminium production at: http://www.chemsoc.org/networks/learnnet/alchemy/index2.htm. Select *Aluminium* from the menu on the left-hand side of the screen.

1 Why is bauxite used to obtain aluminium oxide for the process?

2 Write down the formula of aluminium oxide. ____________________

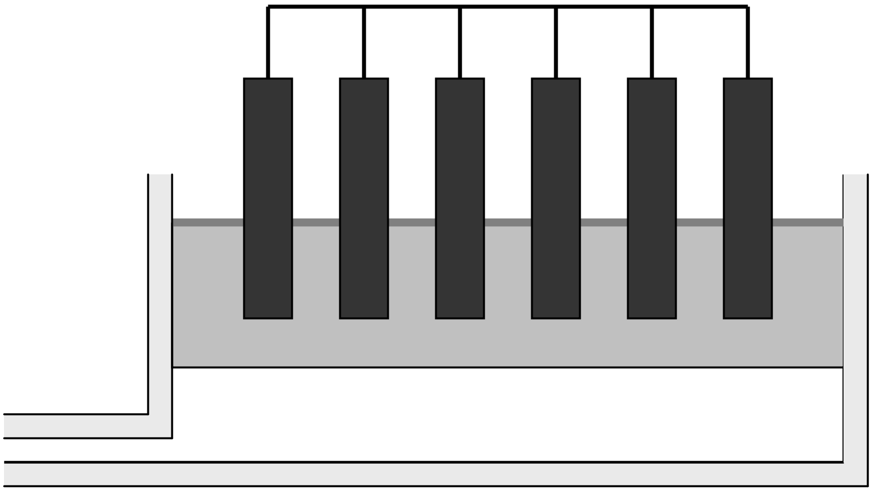
3 Write equations for the reactions at the electrodes when molten aluminium oxide is electrolysed

Cathode ________________________________

Anode ________________________________

4 The cell is a rectangular steel trough, lined with brick and then carbon. Label the diagram below using these terms:

graphite carbon anode	molten electrolyte	steel casing
graphite carbon cathode	molten aluminium	solid crust of electrolyte



5 Why are both electrodes made of carbon?

____

____

6 Why do you think the steel shell of the cell is lined with brick and then carbon rather than just carbon?

____

____

7 How is the aluminium stored?

____

____

8 The melting point of aluminium oxide is 2072 ^{o}C. It is dissolved in cryolite (Na_3AlF_6) to give an electrolyte mixture that is molten at 955 ^{o}C. Why do you think aluminium oxide is not simply melted and electrolysed?

____

____

9 In a typical plant there may be 300 cells running 24 hours a day, 365 days a year and operating at 157 000 A and 4.5 V.

What mass of aluminium can be produced in the plant per annum? (Relative atomic mass: Al = 27)

Estimate the cost of electricity (for electrolysis alone – not for heating as well), assuming an industrial price of 5p per kilowatt hour (p/kWh).

10 What precautions are taken in the process to ensure safety and minimise any environmental impact?

Purifying copper

World production: 15 million tonnes per year (13 million tonnes primary copper, 2 million tonnes from recycling)

UK production: none

Electrolysis is used to purify 'blister copper' (impure copper extracted from copper ore) or copper-containing scrap.

You can find out more and watch a video about copper refining at: http://www.chemsoc.org/networks/learnnet/alchemy/index2.htm. Select Copper from the menu on the left-hand side of the screen.

1 Why is copper in such high demand?

Impure copper is melted, then cast into anodes. The cathodes are stainless steel. Typically, a plant has around 300 cells operating at 24 000 A. The electrolyte is a solution of copper(II) sulfate in hot dilute sulfuric acid.

2 Sketch a labelled diagram of a cell used for purifying copper:

3 Complete the ionic equations for the reactions at the electrodes during the purification process.

Anode $Cu \rightarrow \_\_\_ + 2e^-$

Cathode $\_\_\_ + 2e^- \rightarrow \_\_\_$

4 A cell in the copper purification process has a current of 24 000 A passing through it.

Calculate the quantity of electricity, in faradays, passed through the cell in 24 hours.

Calculate the mass of copper formed in the cell in 24 hours. (Relative atomic mass: Cu = 63.5)

5 Impure copper contains other metals. Some of these may be above copper in the electrochemical series. Others are below.

Explain what happens to metals above copper in the electrochemical series.

Explain what happens to metals below copper in the electrochemical series.

PRACTICAL SHEET

Refining copper

In this unit you need to set up a simple electrolytic cell to obtain pure copper. You also need to calculate and measure the amount of product deposited at an electrode during electrolysis under different conditions. This practical sheet will guide you through a suitable investigation.

The outcome should be a report on your investigation into the factors which affect the efficiency of a simple laboratory experiment in which an object is copper plated.

The purification process

Impure copper is purified (refined) by electrolysis. The cathode is made of pure copper upon which further pure copper is deposited. The anode is impure copper. During electrolysis, these reactions take place:

At the cathode (the negative electrode), copper(II) ions gain electrons to form copper atoms

$$Cu^{2+}(aq) + 2e^- \rightarrow Cu$$

At the anode (the positive electrode), copper atoms loses electrons to form copper(II) ions

$$Cu \rightarrow Cu^{2+}(aq) + 2e^-$$

An earlier researcher’s investigation

A chemist working for a company that purifies metals by electrolysis wanted to explore the idea that in the electrolysis of aqueous copper(II) sulfate the number of moles of copper deposited at a cathode increases in direct proportion to time.

The chemist kept these factors constant:

- volume (600 cm^3) and concentration (0.20 mol dm^{-3}) of aqueous copper(II) sulfate
- current (5.35 A)
- temperature (17 °C)
- surface area and distance between copper electrodes (though the values were not recorded).

Here are her results:

Time / minutes	0	1	2	3	4	5	6	7
Copper deposited / g	0	0.110	0.210	0.320	0.430	0.595	0.645	0.750

1 Plot a graph of copper deposited (g) against time (minutes). You could use an Excel spreadsheet and the Chart Wizard (Chart Type: XY Scatter) to do this.

2 Do the chemist’s results support the hypothesis that ‘the number of moles of copper deposited at a cathode increases in direct proportion to time’? Explain your answer.

3 Calculate (a) the quantity of electricity, in coulombs, that passed through the cell in 5 minutes, (b) the theoretical yield of copper in 5 minutes.

(1 mole Cu requires 2 faradays (2 x 96 500 coulombs); relative atomic mass Cu = 63.5)

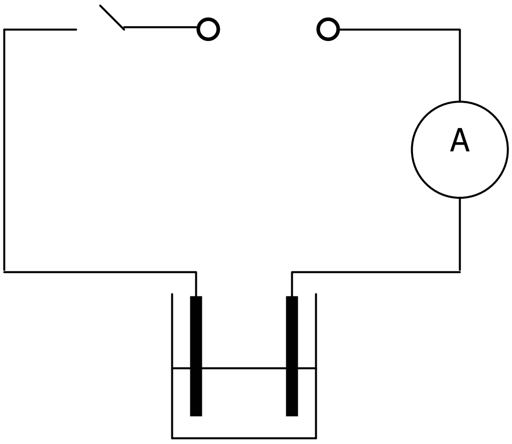
4 Calculate the maximum quantity of copper that can be obtained from 600 cm^3 of 0.20 mol dm^{-3} aqueous copper(II) sulfate.

Your investigation

Now imagine you have been asked to extend the chemist's investigation. Start by listing factors you would investigate and the effect they might have on the deposition of copper over a period of time.

Submit a plan to your supervisor (your teacher) to say what you intend doing including health and safety precautions. Your teacher will comment on your plan and, between you, the actual investigation to carry out should be agreed.

You will be provided with:



- ammeter (0-1 A), DC
- low voltage power supply (0-12 V)
- two copper strips
- leads and crocodile clips (to hold copper strips)
- copper(II) sulfate solution (solutions below 1 mol dm^{-3} are considered a LOW HAZARD, but above this concentration they are HARMFUL)
- 100 cm^3 beaker
- electronic balance with a sensitivity of 0.01 g or better
- propanone [HIGHLY FLAMMABLE] [IRRITANT]

Your plan must include a detailed risk assessment. Keep the risk assessment, together with any annotations made by your teachers, in your notebook or file. It is part of the report of your investigation.

Your report

Write a report on your investigation. Make sure you include:

- your detailed risk assessment
- relevant observations and measurements, recorded to the appropriate precision
- all calculations correctly done, and to an appropriate degree of precision
- conclusions drawn from your results
- an evaluation of your procedures, with justified suggestions for practical techniques that will improve results.

Teacher notes

This activity links to **OCR A2 Unit 12 Electrons in action.**

Study Sheet: Industrial extraction and purification of metals

As part of the unit specification, students must:

> *produce evidence of their investigation into the principles and applications of electrochemical changes. This evidence needs to include:*
>
> ***AO1:** a presentation outlining the applications of stated electrochemical changes*

By completing *Study Sheet: Industrial extraction and purification of metals* students can collect material for the required presentation. In addition they will need to include information about electrochemical cells in the presentation.

To achieve the highest marks for this part of the unit, students should

> - *investigate redox equilibria and demonstrate a thorough knowledge and understanding of the principles underlying the full range of applications of electrochemical changes identified in this unit; give clear explanations and use appropriate scientific terms and conventions accurately throughout*
> - *demonstrate research into the production of electricity and metals, using the full range of examples given, selecting and interpreting information and presenting it clearly*
> - *carry out complex calculations of quantities of charge and mass of products.*

Note: The sodium, aluminium and copper videoclips mentioned in the Study Sheet are also available on the Royal Society of Chemistry *Alchemy?* CD-ROM distributed to schools in 2002.

If you decide to demonstrate the electrolysis please note that it must be carried out in a fume cupboard wearing goggles or a face shield. Chlorine gas is toxic and zinc chloride is corrosive.

Electrolysis

Anions have a **negative** charge; cations have a **positive** charge.

Electrolysis of molten metal salts

Answers

1 Which ions move towards the cathode? **Zn^{2+}**

2 Which ions move towards the anode? **Cl^-**

3 Complete these equations, using e^- to represent one mole of electrons:

   a The reaction at the **cathode** is Zn^{2+} + **$2e^-$ → Zn**

   b Zinc ions have been **reduced**

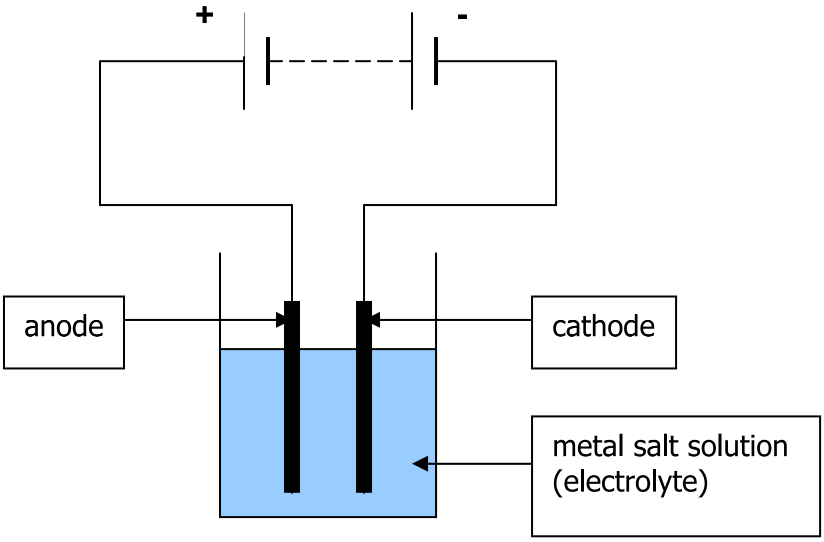
   c The reaction at the **anode** is $2Cl^-$ → **Cl_2 + $2e^-$**

   d Chloride ions have been **oxidised**

5 Write an overall equation for the electrolysis of molten zinc chloride:

$ZnCl_2 \rightarrow Zn + Cl_2$

Electrolysis of aqueous metal salts



Aqueous copper(II) chloride

1 $Cu^{2+} + 2e^- \rightarrow Cu$

2 $2Cl^- \rightarrow Cl_2 + 2e^-$ and $4OH^- \rightarrow 2H_2O + O_2 + 4e^-$

3 Both chlorine and oxygen are produced at the anode. The ratio of chlorine to oxygen is higher the more concentrated the solution.

4 cathode: $Cu^{2+} + 2e^- \rightarrow Cu$ and anode: $4OH^- \rightarrow 2H_2O + O_2 + 4e^-$

Aqueous sodium chloride

Note: The electrolysis of aqueous sodium chloride is complex (products include NaOH, NaOCl and $NaClO_3$). However, the following answers are sufficient at this stage of understanding.

5 In both cases, hydrogen is produced: $2H^+ + 2e^- \rightarrow H_2$

6 In both cases a mixture of chlorine and oxygen is produced: $2Cl^- \rightarrow Cl_2 + 2e^-$ and $4OH^- \rightarrow 2H_2O + O_2 + 4e^-$; ratio of chlorine to oxygen is higher the more concentrated the solution.

Aqueous solution of zinc sulfate and copper sulfate

7 Initially copper forms ($Cu^{2+} + 2e^- \rightarrow Cu$). As the concentration of copper ions decreases, zinc is also formed ($Zn^{2+} + 2e^- \rightarrow Zn$).

8 In both cases, oxygen is produced ($4OH^- \rightarrow 2H_2O + O_2 + 4e^-$)

Quantities and costs of electricity

Quantities

1 193 seconds
2 3.86 seconds
3 1930 seconds
4 2.68 A
5 13.6 g
6 6.94 g

Costs

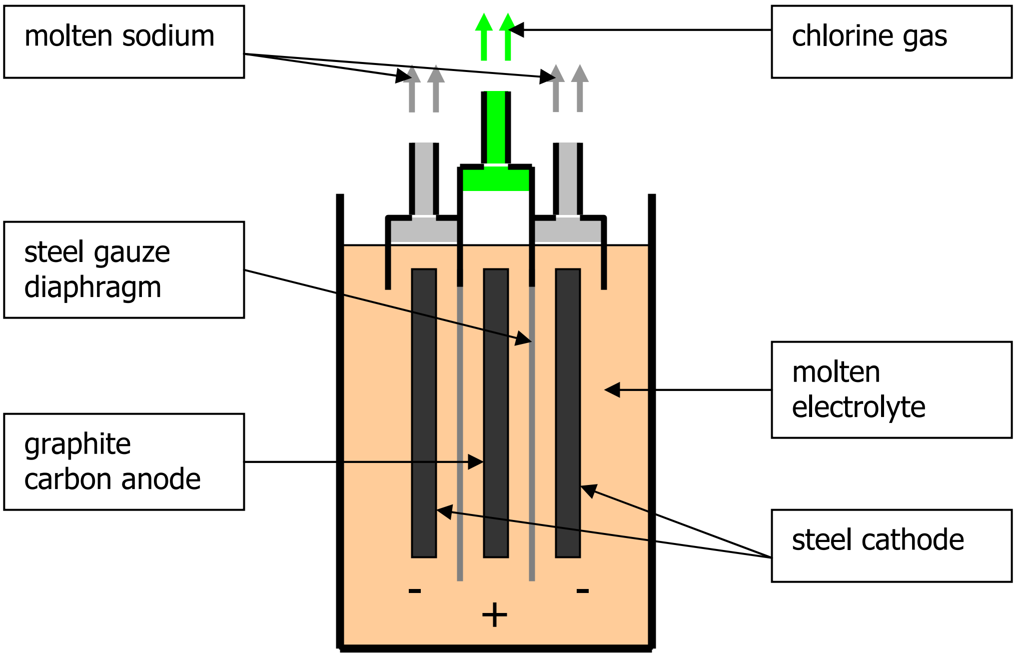
Using a price of 5p/kWh, calculate the cost of the following:

1 60 p 2 24 p 3 36 p

4 9 p 5 0.15 p 6 1.8 p 7 2700 p (£27)

(Q6 5 x 12 x 6 Wh = 0.36 kWh x 5p)

Extracting sodium



Answers

1 To reduce the production of impurities during the electrolysis

2 For insulation; if the cell cooled the sodium would solidify

3 Chlorine reacts with steel but not with graphite

4 A lower melting point means less energy is needed to melt the mixture, making the electrolysis cheaper. Also, at this lower temperature sodium and chlorine do not attack the electrodes. Also, at 800 °C sodium is approaching its boiling point, producing vapour which would ignite on contact with air.

5 Sodium oxidises readily in air, and would probably catch fire.

6 As a liquid in storage tanks with a small gas flame beneath them to keep the sodium molten. Some sodium is cooled and stored as solid blocks packed in air-tight drums.

7 Quantity of electricity used for all the cells in the factory in 24 hours = about 2 700 000 F

Mass of sodium produced in the factory 24 hours = 61.8 tonnes

8 Chlorine, liquefied and stored under pressure in tanks. Uses of chlorine include: sterilisation (not purification) of water; production of paper products, dyestuffs, textiles, petroleum products, medicines, antiseptics, insecticides, foodstuffs, solvents, paints, plastics, and many other consumer products (e.g. bleach and disinfectants); manufacture of chlorates, trichloromethane and tetrachloromethane (organic solvents).

9 Precautions taken in the process to ensure safety and minimise any environmental impact include: choice of materials for electrolysis cells (cells rebuilt every 36 months),

salt thoroughly dried before electrolysis, calcium chloride added to reduce melting point (which reduces the amount of electricity used), avoiding escape of chlorine into the air.

Extracting aluminium

1 Bauxite is the most common ore of aluminium

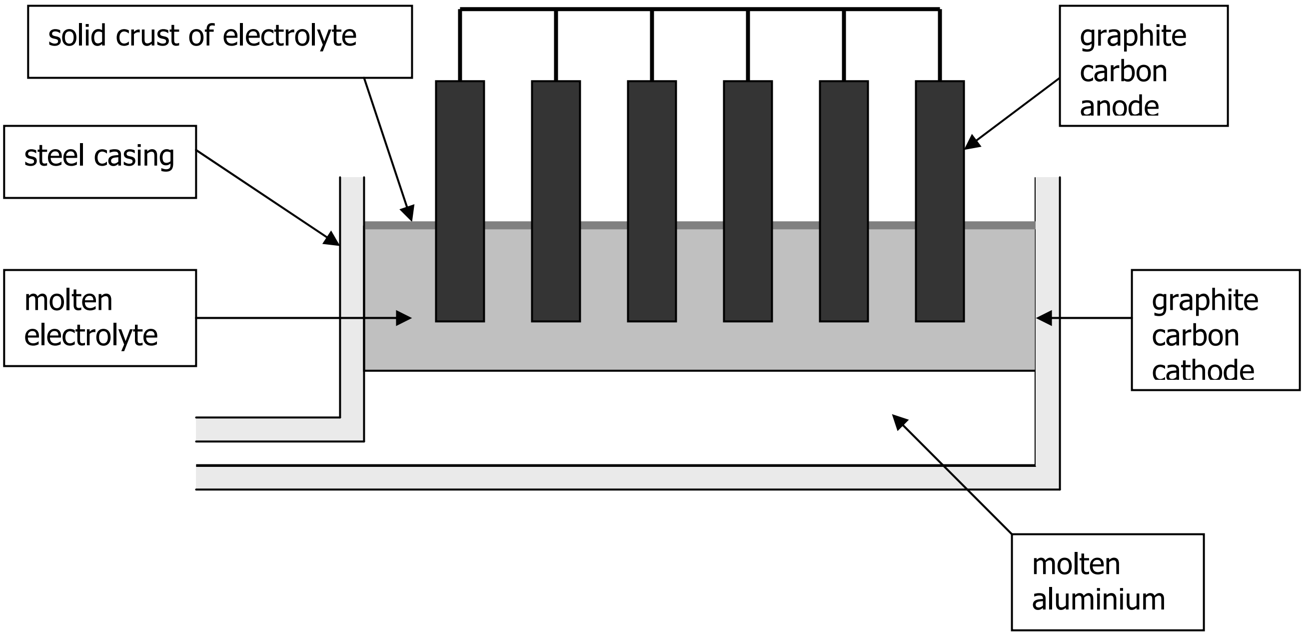
2 Al_2O_3

3 Cathode: $Al^{3+} + 3\,e^- \rightarrow Al$

Anode: $2O^{2-} \rightarrow O_2 + 4e^-$

Note: these are extreme simplifications of the reactions taking place at the electrodes. See, for example, http://www.chemguide.co.uk/inorganic/extraction/aluminium.html.

4 Electrolysis cell



1 Carbon is a good conductor of electricity and will not melt at the temperature of the cell. Note, however, that the carbon anodes get burnt away by oxygen produced by the electrolysis. They must be replaced regularly.

2 The bricks protect the steel casing, and also provide both thermal and electrical insulation.

3 Molten aluminium is stored in brick-lined steel crucibles. It is poured into moulds where it cools to give blocks of the solid metal. Some of the aluminium is alloyed with other metals (e.g. magnesium) while still in its molten state.

4 It takes far less energy to melt the alumina/cryolite mixture. Less electricity is used, meaning less carbon emissions at fossil fuel power plants and making the process cheaper (students need to realise that it is current that causes melting).

5 Mass of aluminium produced in the plant per annum = about 139 000 tonne

The power needed to run each cell is 706.5 kW and each cell operates for 8760 hours per year.

Therefore: one cell uses 706.5 x 8760 kW h and 300 cells use 300 x 706.5 x 8760 kW h

Therefore, cost = £300 x 706.5 x 8760 x 0.05 = £92 834 100

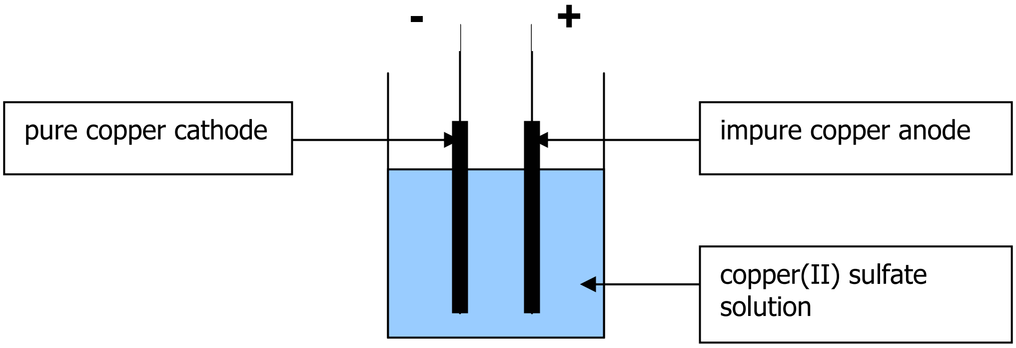
That is approximately £93 million per year

6 See http://www.chemguide.co.uk/inorganic/extraction/aluminium.html for a good summary.

Purifying copper

1 It is used extensively in electrical wiring, plumbing (copper pipes), heat exchangers and coinage (£1 and £2; since 1993, 1p and 2p coins have been only copper-plated steel.)

2 Diagram such as.



3 Complete the ionic equations for the reactions at the electrodes during the purification process.

Anode $Cu \rightarrow \mathbf{Cu^{2+}} + 2e^-$

Cathode $\mathbf{Cu^{2+}} + 2e^- \rightarrow \mathbf{Cu}$

4 Quantity of electricity passed through the cell in 24 hours = 21 488 F = about 21 500 F

Mass of copper formed in the cell in 24 hours = 682 244 g = about 682 kg

5 Metals above copper in the electrochemical series will be oxidised and go in to solution as ions. However, since their concentration is low compared to copper ions, these metal ions will not be reduced at the cathode to form the metal.

Metals below copper in the electrochemical series do not go in to solution as ions. They remain in the 'sludge' that falls from the bottom of the anode. This sludge may contain valuable metals such as gold and silver.

Practical Sheet: Refining copper

As part of the unit specification, students must:

> *produce evidence of their investigation into the principles and applications of electrochemical changes. This evidence needs to include:*
>
> ***AO3:** practical investigations into the factors which affect the efficiency of a simple laboratory experiment in which an object is copper plated*

By completing *Practical Sheet: Refining copper* students investigate the purification of copper using electrolysis.

To achieve the highest marks for this part of the unit, students should

- *carry out complex calculations of quantities of charge and mass of products*
- *produce their own detailed risk assessments, consistent with COSHH guidelines; carry out a wide range of measurements of mass of copper plate; consider and change a range of conditions to obtain corresponding sets of results for measurement of EMF and for the measurement of copper plate – at least* ***one*** *set of results show no effect; explain any practical techniques that will improve results; work with an appropriate degree of accuracy*
- *make and record relevant observations and measurements from the above experiments, using precision in your measurements; display the data obtained accurately in a range of ways*
- *interpret the results in detail and draw conclusions; evaluate your procedures and* suggest alternatives.

It is assumed that students will have completed *Study Sheet: Industrial extraction and purification of metals* before starting this practical sheet.

Health and safety

Please note that when writing risk assessments students should refer to the *Management of Health and Safety at work Regulations* as well as COSHH guidelines.

General guidance statements are provided on these websites:

Practical Chemistry: http://www.practicalchemistry.org/health-and-safety/ (Royal Society of Chemistry, Nuffield Curriculum Centre and CLEAPSS)

Practical Physics: http://www.practicalphysics.org/go/Guidance_22.html;jsessionid=aA-ymIW-eSBb (Institute of Physics and Nuffield Curriculum Centre)

Getting started

The task starts by asking student to look at the results obtained by a hypothetical industrial chemist. Its purpose is to get students thinking about their own investigation to come.

After looking at the researcher’s data, students plan their investigation. You need to make sure that it enables them to meet the assessment requirement:

- *carry out a wide range of measurements – at least one set of results show no effect*

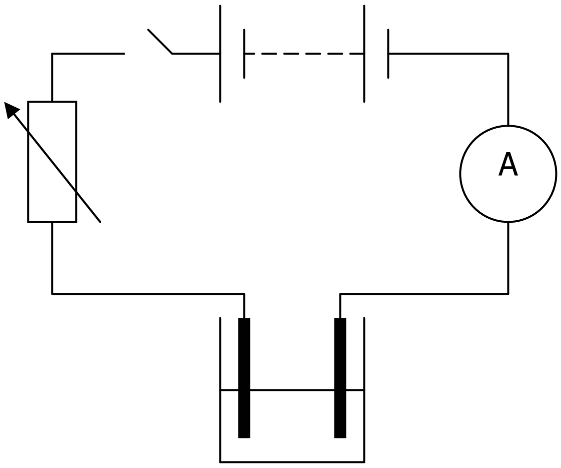
There are no marks for planning in the grading criteria, so there is no reason why you should not give students appropriate guidance.

Risk assessment

Students must produce their own *detailed risk assessments, consistent with COSHH guidelines*. However, they should check this with their teacher before proceeding. It is suggested that the teacher corrects the risk assessment if necessary by annotating a student’s version. The student should keep this annotated copy in their file or notebook as assessment evidence.

Students are provided with a list of equipment and materials available, together with an outline of how to carry out the electrolysis.

If low voltage power supplies are not available, students could use this alternative circuit



- ammeter (0-1 A), DC
- rheostat (10-15 ohms), rated to carry at least 1A
- battery, 12 V

Suitable range of investigations

Students must *carry out a wide range of measurements of mass of copper plate*. This will be time-consuming. They are also expected to *consider and change a range of conditions to obtain corresponding sets of results for the measurement of copper plate – at least one set of results show no effect*.

To set up a circuit and measure the mass of copper deposited may take 20-40 minutes depending on the conditions used. It is important not to deposit copper too quickly as the copper will not stick to the cathode very well. At an average of 30 minutes this means that it takes 3 hours to do the necessary practical work to generate just six results. This is tedious and an ineffective use of time.

Better that students begin by writing down the conditions they think might be investigated. For example: time, current, concentration of copper(II) sulfate solution, size of electrodes, distance between electrodes and temperature.

The faraday is a unit of electrical charge equal to the charge of one mole (6.02×10^{23}) electrons. However, the SI unit is the coulomb.

Reaction at the cathode: $Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s)$

- to deposit 63.5 g Cu (1 mol) requires 2 x 96485 coulombs (2 faradays)
- to deposit 0.2 g (a reasonable mass to weigh accurately) requires 608 coulombs

1 coulomb = 1 amp x 1 second

608 coulombs = 1 amp for 608 seconds, 0.5 amps for 1216 seconds etc

Therefore, suggested currents and times:

Current / amps	0.50	0.25	0.10
Time / minutes	20	40	100

Note: higher currents for shorter times may not result in successful plating of the copper.

A minimum investigation might involve different combinations of concentration, current and time. For example:

- three concentrations of $Cu^{2+}(aq)$: 0.5 mol dm^{-3}; 0.25 mol dm^{-3}; 0.1 mol dm^{-3}
- at each concentration:
  - 0.5 amp for 10 minute, (300 coulombs)
  - 0.5 amps for 20 minutes, (600 coulombs)

  - 0.25 amp for 20 minutes, (300 coulombs)
  - 0.25 amps for 40 minutes, (600 coulombs)
  - 0.1 amp for 50 minutes, (300 coulombs)
  - 0.1 amps for 100 minutes, (600 coulombs)

This gives a total of 18 experiments - all carried out at room temperature, and in each case, the same area of submerged copper electrodes and the same distance between them.

If time permits, student can investigate the effect of varying the area of the electrode and the distance between them.

The class might come together to share these ideas and come up with a plan for the class as a whole. Then students might work in pairs, each pair assigned three sets of conditions to investigate. The class shares the data obtained. Students work individually to meet the remaining assessment criteria:

- *explain any practical techniques that will improve results*
- *work with an appropriate degree of accuracy*
- *make and record relevant observations and measurements from the above experiments, using precision in their measurements*
- *display the data obtained accurately in a range of ways*
- *interpret the results in detail and draw conclusions*
- *evaluate their procedures and suggest alternatives.*