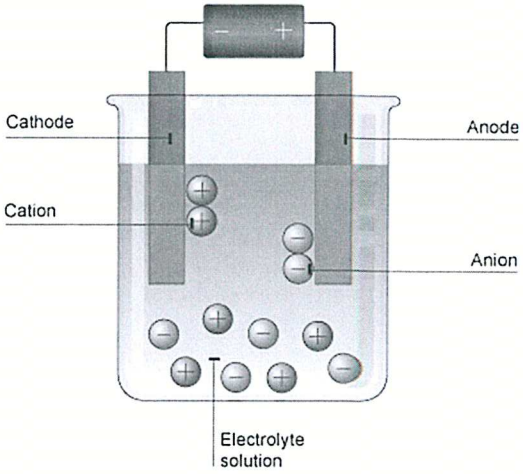
Electrolysis

The process of electrolysis



When an ionic compound is melted or dissolved in water, the ions are free to move about within the liquid or solution.
These liquids and solutions are able to conduct electricity and are called electrolytes.
Passing an electric current through electrolytes causes the ions to move to the electrodes.
Positively charged ions move to the negative electrode (the cathode), and negatively charged ions move the positive electrode (the anode).
Ions are discharged at the electrodes producing elements. This process of splitting ionic substances with electricity is called electrolysis.

PANIC – positive anode, negative is cathode.

Electrolysis of molten ionic compounds

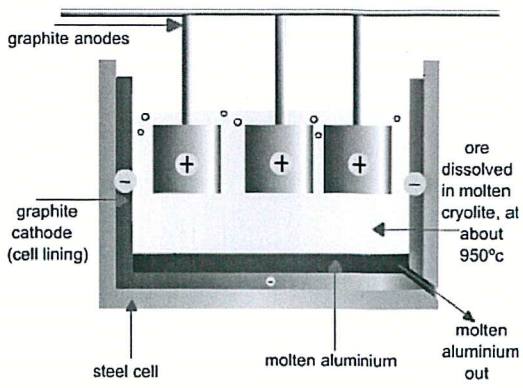
When a simple ionic compound (e.g. lead bromide) is electrolysed in the molten state (a liquid) using inert electrodes (made from graphite), the metal (lead) is produced at the cathode because metal ions are positive so are attracted to negative and the non-metal (bromine) is produced at the anode because non-metal ions are negative so they are attracted to positive.

	Oxidation is loss	**Reduction is gain**
	OIL	RIG
Molten (PbBr)	$2Br^- \rightarrow Br_2 + 2e^-$	$Pb^{2+} + 2e^- \rightarrow Pb$
Solution (KBr)	$2Br^- \rightarrow Br_2 + 2e^-$	$2H^+ + 2e^- \rightarrow H_2$

HT Only

Reactions at electrodes can be represented by half equations, for example:
$2Cl^- \rightarrow Cl_2 + 2e^-$

Using electrolysis to extract metals



Metals can be extracted from molten compounds using electrolysis.
Electrolysis is used if the metal is too reactive to be extracted by reduction with carbon or if the metal reacts with carbon.
Large amounts of energy are used in the extraction process to melt the compounds and to produce the electrical current.
Aluminium is manufactured by the electrolysis of a molten mixture of aluminium oxide and cryolite using carbon as the positive electrode (anode).

Aluminium forms at the negative electrode and oxygen at the positive electrode. The positive electrode is made of carbon, which reacts with the oxygen to produce carbon dioxide.

Overall equation: aluminium oxide → aluminium + oxygen

$2Al_2O_3 \rightarrow 4Al + 3O_2$

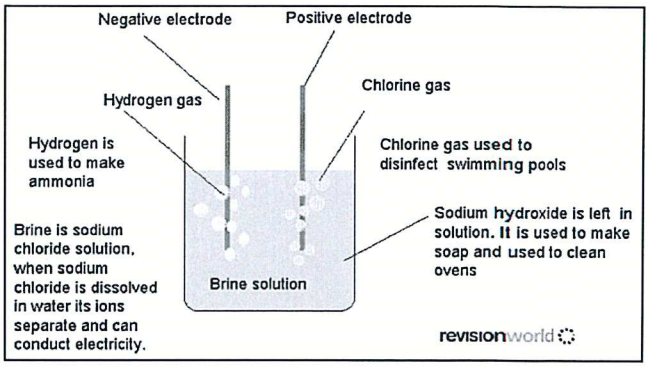
At anode: $6O^{2-} \rightarrow 3O_2\ (g) + 12e^-$

At cathode: $4Al^{3+}\ (aq) + 12e^- \rightarrow 4Al$

Electrolysis of aqueous solutions

The ions discharged when an aqueous solution is electrolysed using inert electrodes depend on the reactivity of the elements involved.

At the negative electrode (cathode), hydrogen is produced if the metal is more reactive than hydrogen.
At the positive electrode (anode), oxygen is produced unless the solution contains halide ions when the halogen is produced.



This happens because in the aqueous solution water molecules break down producing hydrogen ions and hydroxide ions that are discharged. *REQUIRED PRACTICAL*

At anode

$2Cl^-_{(aq)} \rightarrow Cl_{2\,(g)} + 2e^-$

At cathode

$2H^+_{(aq)} + 2e^- \rightarrow H_{2\,(g)}$

In solution

Na^+ and OH^-

Representation of reactions at electrodes as half equations (HT only)

During electrolysis, at the cathode (negative electrode), positively charged ions gain electrons and so the reactions are reductions. At the anode (positive electrode), negatively charged ions lose electrons and so the reactions are oxidations.

Reactions at electrodes can be represented by half equations, for example:

$2H+ + 2e- \rightarrow H_2$ and $4OH^- \rightarrow O_2 + 2H_2O + 4e^-$

b Which letter is pointing to the **electrolyte**?

Tick **one** box.

A ☐ B ☐ C ☐ D ☐ [1 mark]

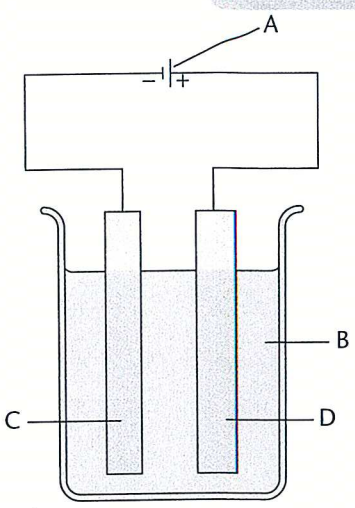


Figure 7

c Why does the electrolyte need to be molten or in solution?

Tick **one** box.

☐ So the ions are free to move ☐ So it is inert

☐ To decrease its melting point ☐ To provide a current

[1 mark]

2. Look at **Figure 8.**

Draw **two** arrows on **Figure 8** to show the direction of movement of the ions. [2 marks]

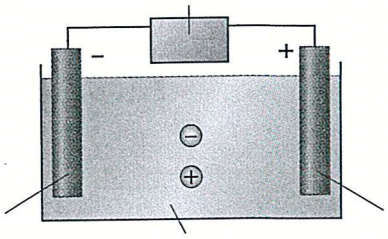


Figure 8

3. Use the words in the box to complete the sentences.

anode	cathode	compounds	electrodes	elements	power supply

During electrolysis ions move to the _____.

Positively charged ions move to the _____.

Negatively charged ions move to the _____.

The ions are discharged as _____. [4 marks]

Electrolysis of molten ionic compounds

1. Which compounds will conduct electricity **when melted?**

Tick **two** boxes.

☐ Sodium chloride (NaCl) ☐ Silicon dioxide (SiO_2)

☐ Calcium oxide (CaO) ☐ Glucose ($C_6H_{12}O_6$)

[2 marks]

Remember

Only ionic compounds will conduct electricity when molten.

Ionic compounds are made up of metals atoms bonded to non-metal atoms.

2. Name the products produced at each electrode when electrolysis is carried out on molten KF.

Anode _____

Cathode _____ [2 marks]

Analyse the question

The question asks you to name the elements. Do not just write the symbols.

3. Look at **Figure 9**.

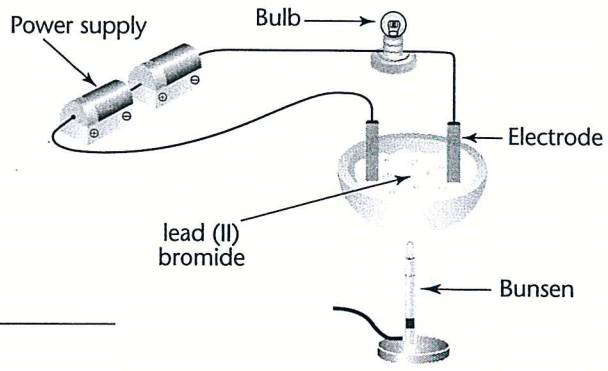


Figure 9

a As the lead(II) bromide is heated it starts to melt.

Explain why the bulb lights.

_____

_____

_____ [3 marks]

b Bubbles of a brown gas are seen at the positive electrode.

Explain why.

_____

_____ [2 marks]

Using electrolysis to extract metals

1. Why are some metals extracted using electrolysis?

Tick **one** box.

- ☐ They are less reactive than carbon.
- ☐ They are more reactive than carbon.
- ☐ They are very unreactive.
- ☐ They are found pure in the Earth's crust. [1 mark]

2. **Figure 10** shows how aluminium is extracted using electrolysis.

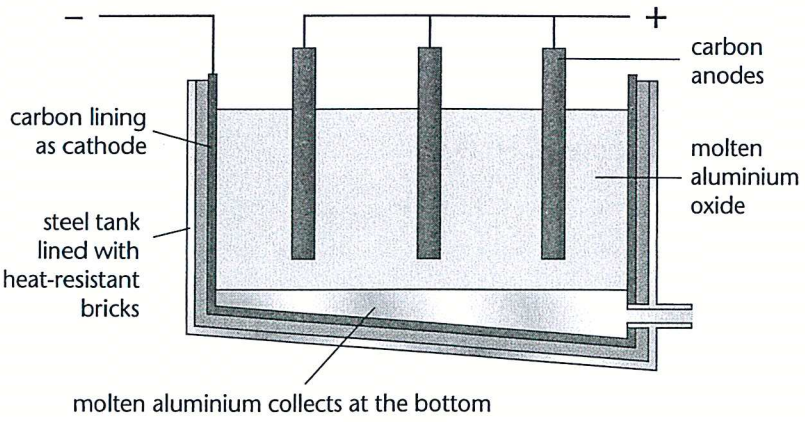


Figure 10

b Which letter is pointing to the **electrolyte**?

Tick **one** box.

A ☐ B ☐ C ☐ D ☐ [1 mark]

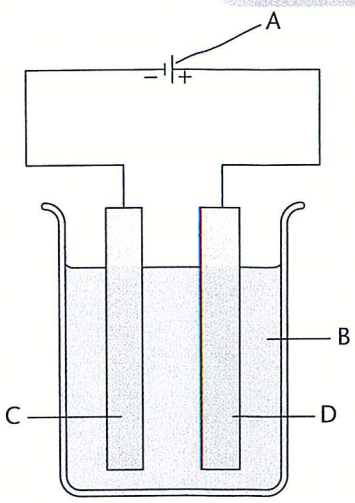


Figure 7

c Why does the electrolyte need to be molten or in solution?

Tick **one** box.

☐ So the ions are free to move ☐ So it is inert

☐ To decrease its melting point ☐ To provide a current

[1 mark]

2. Look at **Figure 8.**

Draw **two** arrows on **Figure 8** to show the direction of movement of the ions. [2 marks]

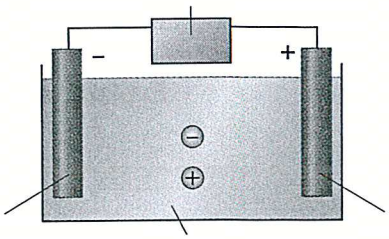


Figure 8

3. Use the words in the box to complete the sentences.

anode	cathode	compounds	electrodes	elements	power supply

During electrolysis ions move to the _____.

Positively charged ions move to the _____.

Negatively charged ions move to the _____.

The ions are discharged as _____. [4 marks]

Electrolysis of molten ionic compounds

1. Which compounds will conduct electricity **when melted?**

Tick **two** boxes.

☐ Sodium chloride (NaCl) ☐ Silicon dioxide (SiO_2)

☐ Calcium oxide (CaO) ☐ Glucose ($C_6H_{12}O_6$)

[2 marks]

Remember

Only ionic compounds will conduct electricity when molten.

Ionic compounds are made up of metals atoms bonded to non-metal atoms.

2. Name the products produced at each electrode when electrolysis is carried out on molten KF.

Anode _____

Cathode _____ [2 marks]

Analyse the question

The question asks you to name the elements. Do not just write the symbols.

a Explain why aluminium collects at the bottom of the tank.

_____

_____ [2 marks]

b The carbon anodes need to constantly be replaced.

Explain why.

_____

_____ [3 marks]

3. This information was printed in a magazine.

Literacy

> When you throw away aluminium, you are wasting energy.
>
> The processes used to extract aluminium from compounds found in the Earth's crust require a lot of energy.
>
> When aluminium is recycled it is heated to melt it. The molten metal is then used to make new aluminium objects. This process can be repeated again and again.
>
> It requires up to 95% less energy to recycle aluminium than to produce new metal.

Use the information from the magazine and your knowledge and understanding to explain the difference in energy costs between recycling aluminium and extracting new aluminium.

_____

_____

_____

_____

_____

_____

_____ [6 marks]

Electrolysis of aqueous solutions

1. Electrolysis is carried out on copper sulfate ($CuSO_4$) solution.

Practical

a Which ions are attracted to the **anode**?

Tick **one** box.

- ☐ Copper and hydrogen
- ☐ Oxygen and sulfate
- ☐ Hydrogen and hydroxide
- ☐ Sulfate and hydroxide

Remember
Solutions contain water.
Water can split into the ions: hydrogen (H^+) and hydroxide (OH^-)

[1 mark]

b Predict what will be seen at the electrode.

Give a reason for your answer.

Prediction _____

Reason _____ [2 marks]

2. A student is asked to investigate the electrolysis of sodium chloride solution.

Their hypothesis is: hydrogen ions will be discharged at the cathode.

a Describe a method to test the hypothesis. For the method you should include:

- a diagram to show the equipment to use set up correctly
- a way of testing if the hypothesis is correct

_____

_____ [6 marks]

Half equations at electrodes

1. Electrolysis is carried out on melted sodium chloride (NaCl).

Higher Tier only

a Name the two products.

1 _____

2 _____ [2 marks]

2. A, B and C show three different half equations

Higher Tier only

A: $2Br^- - 2e^- \rightarrow Br_2$ B: $2H^+ + 2e^- \rightarrow H_2$ C: $Zn^{2+} + 2e^- \rightarrow Zn$

a Which half equation happens at the anode?

A ☐ B ☐ C ☐ [1 mark]

b Which half equation shows the reduction of a non-metal ion?

A ☐ B ☐ C ☐ [1 mark]

Synoptic

c Which half equation takes place when electrolysis is carried out on acids?

A ☐ B ☐ C ☐ [1 mark]

3. Use the words in the box to complete the sentences.

Higher Tier only

anode	atoms	cathode	electrons	oxidation	reduction

Positively charged ions are attracted to the _____.

They gain _____.

The reactions are _____. [3 marks]

4. Complete the half equations for the electrolysis of copper sulfate ($CuSO_4$) solution.

Higher Tier only

a At the cathode: Cu^{2+} + _____ $\rightarrow Cu$ [1 mark]

b At the anode: _____ $-4e^- \rightarrow O_2 + 2H_2O$ [1 mark]

Section 4: Chemical changes

Metal oxides

1. magnesium + oxygen → magnesium oxide [1 mark]

   zinc + oxygen → zinc(II) oxide [1 mark]
2. Answers in order: oxides, oxidation [2 marks]
3. **a** copper oxide [1 mark]

   b $2Cu + O_2 \rightarrow 2CuO$ [2 marks]

   c The inside did not come into contact with oxygen [1 mark], so no copper oxide/CuO was formed. [1 mark]

Reactivity series

1. potassium hydroxide [1 mark], hydrogen [1 mark]
2. magnesium [1 mark], hydrogen [1 mark]
3. **a** A, C, D, B [2 marks]

   b B [1 mark] because it does not react with acid or water [1 mark]

   c Worked example – full answer given in workbook.

Reactivity series – displacement

1. Magnesium [1 mark]
2. **a** Worked example – full answer given in workbook.

   b iron [1 mark], copper [1 mark]
3. chromium, cobalt, nickel [1 mark]

   Cobalt can displace nickel from its solution (so must be more reactive than nickel). [1 mark]

   Chromium can displace cobalt from its solution (so must be more reactive than cobalt). [1 mark]

Extraction of metals

1. In a compound, with other elements [1 mark]
2. iron – reduction with carbon [1 mark], aluminium – electrolysis [1 mark], sodium – electrolysis [1 mark], lead – reduction with carbon [1 mark]
3. **a** zinc oxide [1 mark]

   b carbon [1 mark]

   c For 2 marks, any one from:

   Quarrying of zinc oxide [1 mark] can destroy habitats/ reduce biodiversity. [1 mark]

   Carbon dioxide is produced which is a greenhouse gas [1 mark] and contributes to climate change. [1 mark]

   Carbon/zinc oxide are limited resources [1 mark] so supplies will run out in the future. [1 mark]

Oxidation and reduction in terms of electrons

1. A metal loses electrons to form ions. [1 mark]
2. $Na^+ + e^- \rightarrow Na$ – Reduction [1 mark], $2Cl^- \rightarrow 2e^- + Cl_2$ – Oxidation [1 mark], $Zn - 2e^- \rightarrow Zn^{2+}$ – Oxidation [1 mark], $2F^- - 2e^- \rightarrow F_2$ – Oxidation [1 mark]
3. 4 [1 mark]
4. **a** $2CuO$ [1 mark] + C [1 mark] $\rightarrow 2Cu + CO_2$ [1 mark]
   b $2Cu^{2+} + 2e^- \rightarrow Cu$ [1 mark]

Reactions of acids with metals

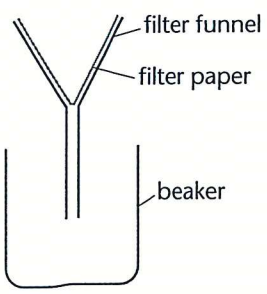
1. Metal: Zinc [1 mark], Acid: Sulfuric acid [1 mark]
2. **a** magnesium chloride [1 mark]
   b Worked example – full answer given in workbook.
   c Collect the gas. [1 mark] Add a lighted splint. [1 mark] There will be a squeaky pop noise. [1 mark]
   d $Mg + 2HCl \rightarrow MgCl_2 + H_2$ (one mark for each correct reactant/product) for 4 marks in total

Neutralisation of acids and making salts

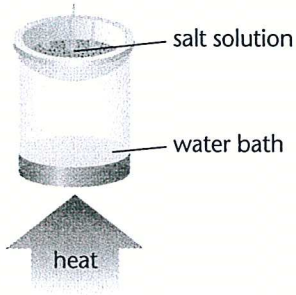
1. They are insoluble. [1 mark]
   They neutralise acids. [1 mark]
2. potassium chloride [1 mark]
3. Calcium oxide + sulfuric acid – Calcium sulfate + water [1 mark], Calcium carbonate + sulfuric acid – calcium sulfate + water + carbon dioxide [1 mark], Calcium oxide + nitric acid – Calcium nitrate + water [1 mark], Worked example answer given in workbook for the 4th mark.
4. Nitric acid [1 mark]
   Potassium hydroxide [1 mark]

Making soluble salts

1. **a** Hazard:
   Any one from: Acid in eyes
   Burns from Bunsen burner/glassware [1 mark]
   Way of reducing the risk of harm:
   Answer should be a sensible way of reducing the risk from the hazard mentioned: e.g. Wear eye protection/ let equipment cool before touching it [1 mark]
   b There will be unreacted copper oxide in the beaker. [1 mark]
   c Copper sulfate [1 mark]
   d



   Filter funnel [1 mark], Filter paper [1 mark]
   e Filtration/filtering [1 mark]
2. **a**



   [2 marks]
   b The water will evaporate from the solution. [1 mark]
   The salt will remain in the dish. [1 mark]
   Award 1 mark for 'the water will be removed'.

pH and neutralisation

1. H^+ [1 mark]
2. Universal indicator [1 mark], pH probe [1 mark]
3. 1–6 – Acidic [1 mark], 7 – Neutral [1 mark], 8–14 – Alkaline [1 mark]
4. $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$ [2 marks]
5. **a** Add universal indicator to the sodium hydroxide. [1 mark] Add small amounts of acid, mixing [1 mark] until the indicator just turns green. [1 mark]
   b Any one from: It is difficult to tell when the solution is just neutral/no precise colour change. It dyes the salt solution/needs to be removed. [1 mark]

Titrations

*separate sciences.

1. **a** Neutralisation [1 mark]
   b Burette [1 mark]
   c To clearly see colour change of indicator [1 mark] To get an accurate volume of acid (needed to neutralise the alkali) [1 mark]
   d Instrument: Pipette [1 mark] Reason: It gives an accurate measurement of volume. [1 mark]
2. **a** Ring drawn around 29.5 [1 mark]
   b (25.8 + 26.4 + 26.2)/3 [1 mark] = 26.1 cm^3 [1 mark]

Strong and weak acids

1. fully ionises [1 mark], H^+ ions [1 mark], nitric [1 mark]
2. Numbering boxes on the left from the top:
   1 – Strong and dilute [1 mark], 2 – Weak and dilute [1 mark], 3 – Weak and concentrated [1 mark], 4 – Strong and concentrated [1 mark]
3. It decreases/goes down [1 mark] because the number of hydrogen ions increases. [1 mark]

The process of electrolysis

1. **a** C [1 mark] **b** B [1 mark]
   c So the ions are free to move [1 mark]

2. Arrow drawn from negative ion to the positive electrode [1 mark] Arrow drawn from positive ion to the negative electrode [1 mark]
3. Answers in order: electrodes, cathode, anode, elements [4 marks]

Electrolysis of molten ionic compounds

1. Sodium chloride (NaCl) [1 mark], Calcium oxide (CaO) [1 mark]
2. Anode: fluorine [1 mark], Cathode: potassium [1 mark]
3. **a** The ions (in the lead(II) bromide) are free to move [1 mark] to conduct electricity [1 mark] and complete the circuit [1 mark]
   b Bromide ions are attracted to the positive electrode. [1 mark] Bromine gas is being formed. [1 mark]

Using electrolysis to extract metals

1. They are more reactive than carbon. [1 mark]
2. **a** Aluminium ions have a positive charge. [1 mark] They are attracted to the (negative) cathode. [1 mark]
   b Negative oxygen ions/O^{2-} ions [1 mark] are attracted to the anodes [1 mark] and react to form carbon dioxide. [1 mark]
3. Level 3: Student compares associated energy costs of recycling and extracting aluminium with examples of where energy is used. [5–6 marks]

   Level 2: Student compares some associated energy costs of recycling and extracting aluminium. [3–4 marks]

   Level 1: Student states some energy costs of recycling and extracting aluminium [1–2 marks]

Indicative content

Recycling:

Uses less energy than extracting aluminium.

Energy is used to transport the collected aluminium from homes/businesses to the recycling plant.

Energy is used to sort the aluminium from other metals.

Energy is used to melt the metal.

Extracting aluminium:

Energy is used to mine the aluminium oxide, transport and process it.

Energy is used to melt the aluminium oxide.

Cryolite is added to the aluminium oxide to reduce the melting point and reduce energy costs.

A lot of electricity is used to carry out electrolysis.

Generating electricity also has energy costs.

Electrolysis of aqueous solutions

1. **a** Sulfate and hydroxide [1 mark]
   b Prediction: The electrode will be covered in copper/copper will be formed. [1 mark]

   Reason: Copper is less reactive than hydrogen [1 mark]
2. Diagram [4 marks]:

   Two inert/graphite electrodes

   In beaker of sodium chloride solution

   In electrical circuit containing power supply

   One electrode connected to the negative terminal and one connected to the positive

   Add lighted splint to gas produced at the cathode. [1 mark]

   If hydrogen is present then there will be a squeaky pop noise. [1 mark]

Half equations at electrodes

1. 1: Sodium [1 mark], 2: Chlorine (do not accept 'chloride') [1 mark]
2. **a** A [1 mark] **b** B [1 mark] **c** B [1 mark]
3. Answers in order: cathode [1 mark], electrons [1 mark], reduction [1 mark]
4. **a** $2e^-$ [1 mark] **b** $4OH^-$ [1 mark]

Topic 4 – Chemical Changes Glossary

Key Word	Definition
Acid	A substance the releases H^+ ions when dissolved in water.
Alkali	A substance the releases OH^- ions when dissolved in water.
Anion	An atom that has gained electrons to form a negative ion.
Anode	The positive electrode in an electrolysis cell.
Aqueous solution	A solution containing water as the solvent.
Base	A substance with a pH greater than 7, often in the form of metal carbonates, metal oxides and metal hydrogen carbonates.
Bauxite	The name of the ore containing aluminium oxide.
Cathode	The negative electrode in an electrolysis cell.
Cation	An atom that has lost electrons to form a positive ion
Cryolite	A substance added to aluminium oxide to lower its melting point.
Displacement reaction	A reaction where a more reactive substance takes the place of a less reactive substance in a compound.
Dissolve	To spread out into a solvent.
Electrolysis	The splitting of ionic substances using electricity.
Electrolyte	The substance being electrolysed.
Half equations	One of two equations that describe a redox reaction
Halogen	An element in group 7 of the Periodic Table.
Indicator	A substance that changes colour in the presence of acids or alkalis.
Inert	Unreactive.
Insoluble	Does not dissolve in a particular solvent.
Ionic compound	A substance made up of oppositely charged ions (metals and non-metals) held together by electrostatic forces of attraction.
Ionised	Converted from an atom into an ion.
Metal	An element found on the left hand side/middle of the periodic table.
Metal ore	A rock that contains enough of a metal compound to extract the metal for profit.
Metal salt	The general name for a compound containing a metal that has been formed when a metal, wholly or partially, replaces the hydrogen in an acid

Molten	Melted into a liquid.
Native metal	A metal found in its pure element form, unreacted.
Neutralisation	A chemical reaction that occurs between an acid and an alkali. The products are a neutral metal salt and water.
Oxidation	A reaction where a substance gains oxygen **or** loses electrons.
pH number	A measure of acidity or alkalinity of water soluble substances.
pH scale	A scale from 1 – 14 which identifies, with 7 as the middle (neutral) point. Values below 7 indicate acidity which increases as the number decreases, 1 being the most acidic and 14 being the most alkaline.
Reactivity	The tendency of a substance to take part in chemical reactions, either by itself or with other materials, to release energy.
Reactivity series	A series of metals, arranged by their "reactivity" from highest to lowest.
Redox reaction	A reaction where reduction and oxidation happen at the same time.
Reduction	A reaction where a substance loses oxygen **or** gains electrons.
Universal indicator	A wide range indicator that turns a range of colours to identify the strength of an acid or alkali.