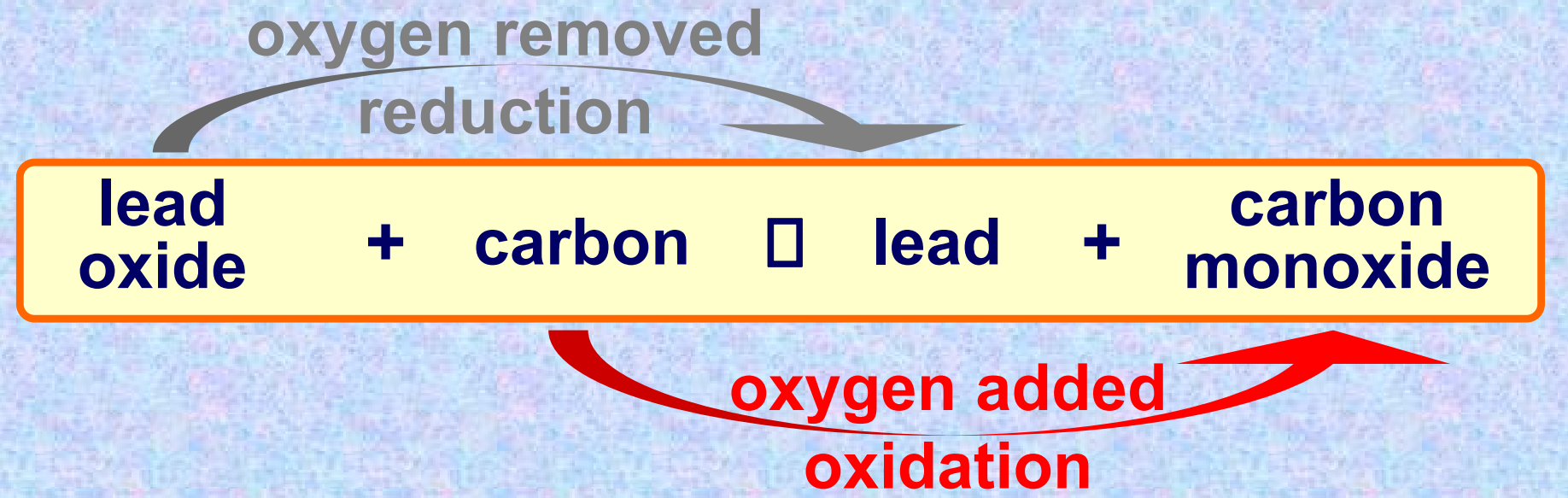
ELECTROLYSIS

What is a redox reaction?

Oxidation is the **addition of oxygen** to a substance and **reduction** is the **removal of oxygen** from a substance.

Which substances are oxidized and reduced in this reaction?



Reduction and oxidation always take place together.
Why is this type of reaction called a **redox** reaction?

redox = reduction and oxidation

Redox and electrons

Magnesium burns in oxygen to form magnesium oxide.

It is obvious that the magnesium has been oxidized, but what has happened to the oxygen?

A redox reaction can also be explained in terms of the gain or loss of **electrons.**

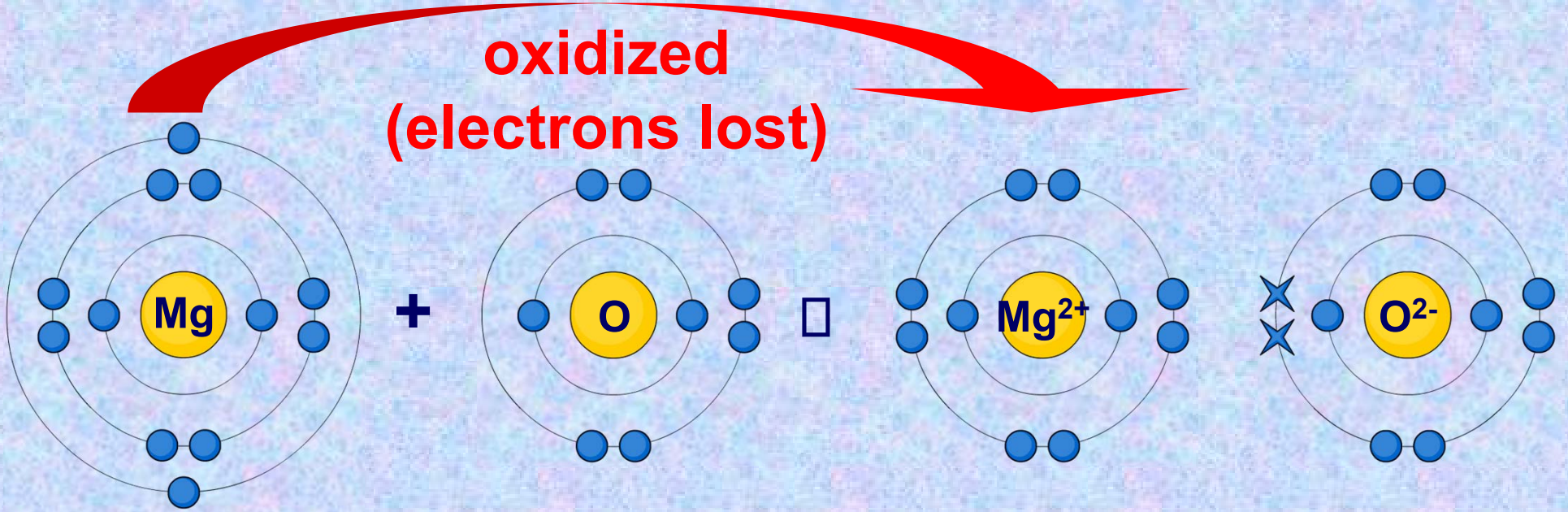
What happens to the atoms and electrons in this reaction?

magnesium + oxygen □ magnesium oxide

$2Mg(s) + O_2(g) \square 2MgO(s)$

Oxidation and electron loss

When magnesium burns in oxygen to form magnesium oxide, what happens to magnesium and its electrons?

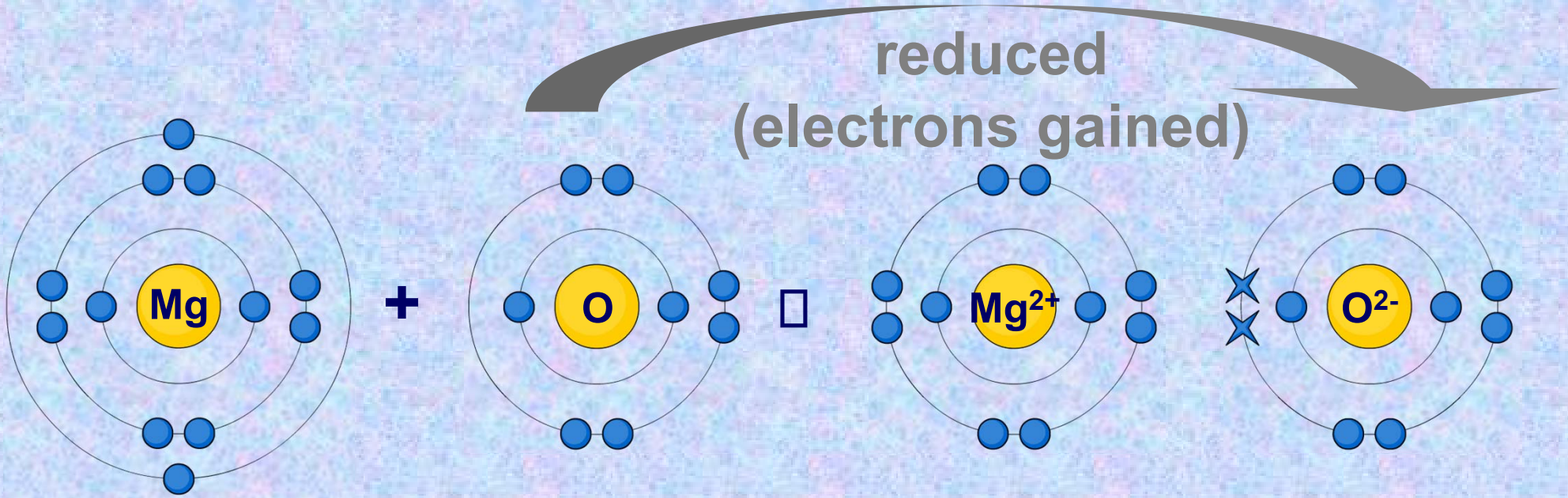


- The magnesium has been oxidized.
- The Mg atom has lost 2 electrons to form a Mg^{2+} ion.

Oxidation is the **loss** of electrons.

Oxidation and electron gain

When magnesium burns in oxygen to form magnesium oxide, what happens to oxygen and its electrons?

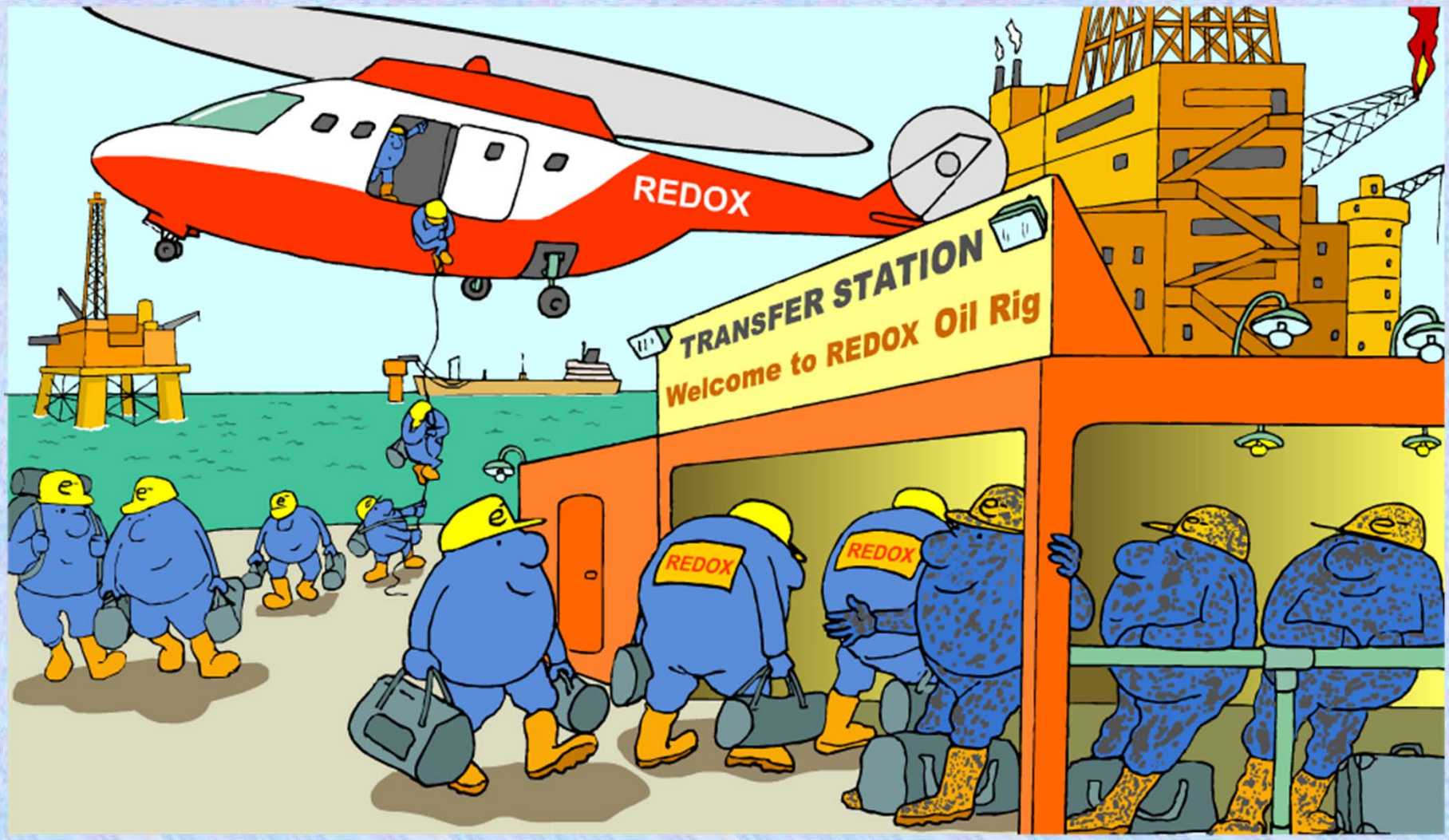


- The oxygen has been reduced.
- The O atom has gained 2 electrons to form a O^{2-} ion.

Reduction is the **loss** of electrons.

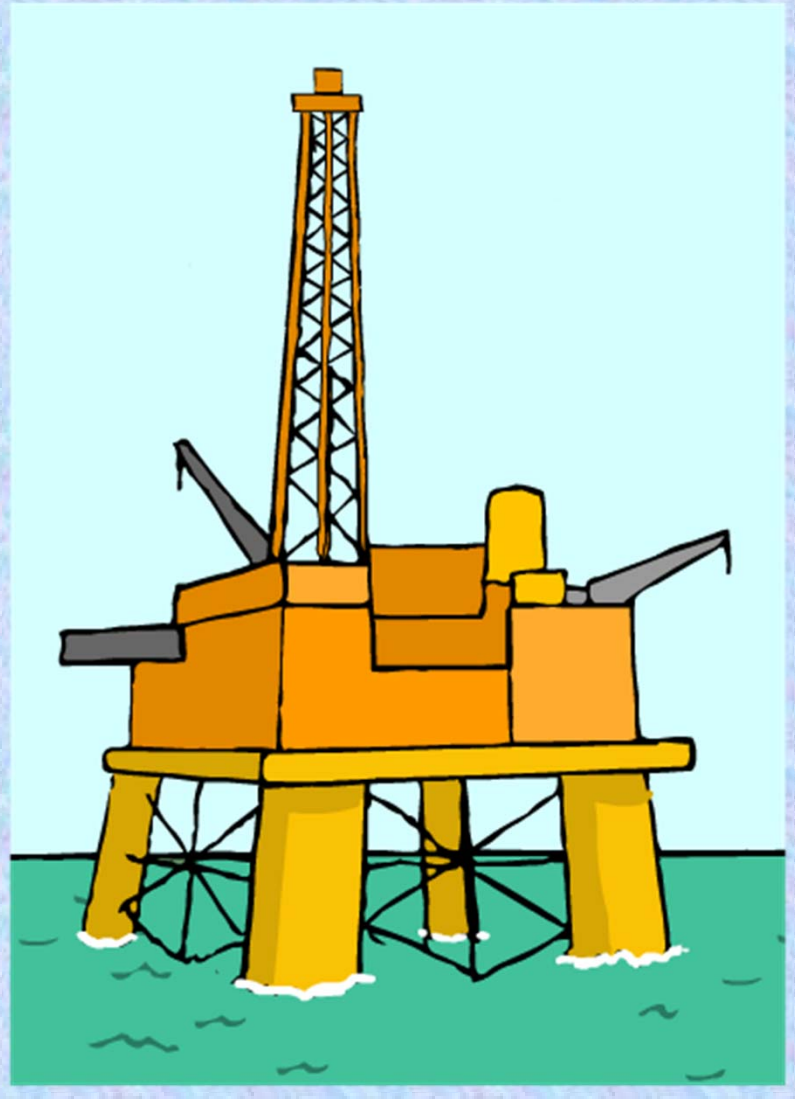
Redox and OILRIG

An easy way to remember what happens to the electrons during oxidation and reduction is to think… **OILRIG**!



Using OILRIG

What does **OILRIG** stand for in terms of redox reactions?



Oxidation

Is

Loss of electrons

Reduction

Is

Gain of electrons

What is a half-equation?

Redox reactions involve the transfer of electrons.

Equations written to show what happens to the electrons during oxidation and reduction are called **half-equations**.

What are the half-equations for the oxidation and reduction processes in this reaction?

magnesium + oxygen → magnesium oxide

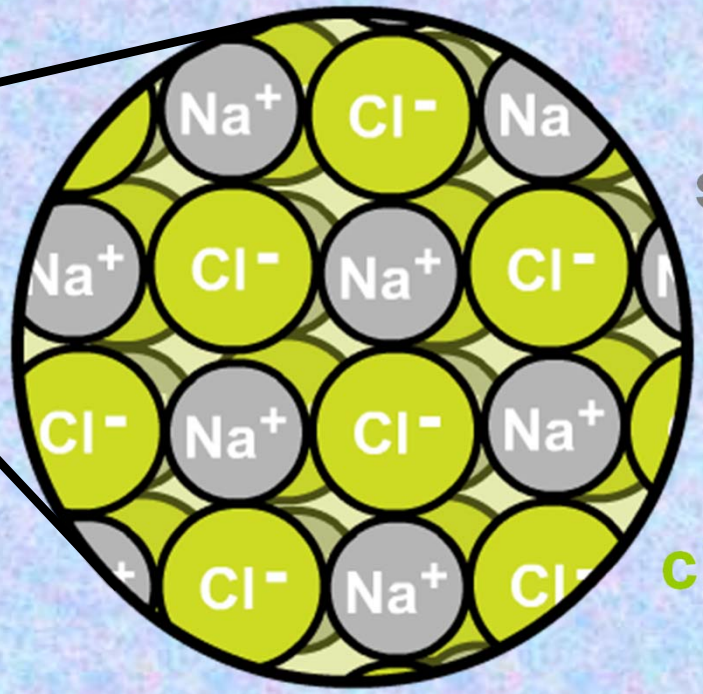
$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$

oxidation: $Mg \rightarrow Mg^{2+} + 2e^-$

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

What are ionic compounds?

Ionic compounds are made up of **positive metal ions** and **negative non-metal ions**. What ions are in sodium chloride?



positive sodium ions

negative chloride ions

The positive and negative ions in an ionic compound attract each other strongly. It takes a lot of energy to separate them.

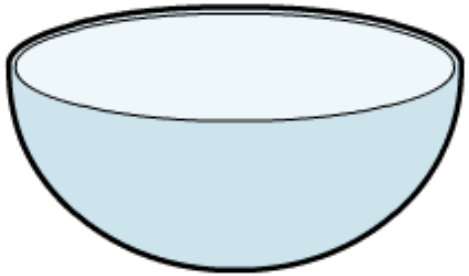
How does structure affect the properties of ionic compounds?

Do molten ionic compounds conduct?

Does a molten ionic compound conduct electricity?

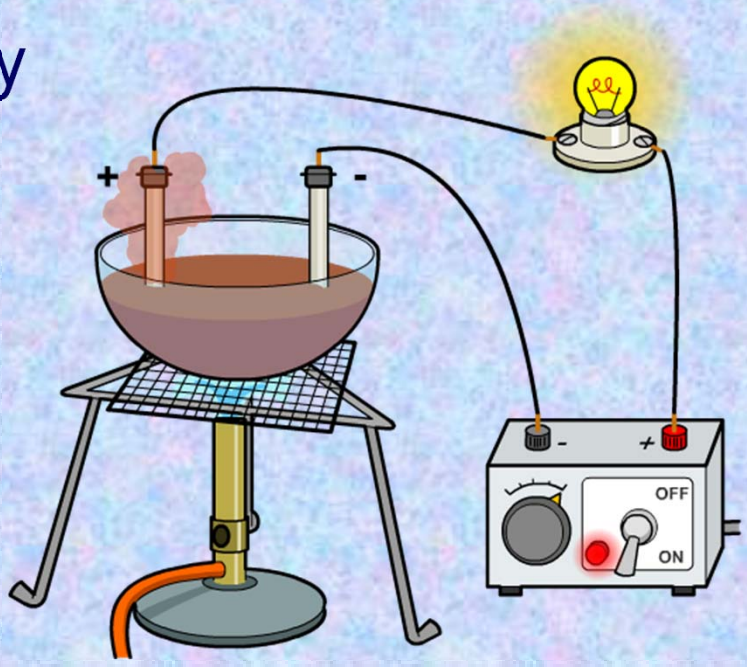
Will an ionic compound conduct electricity when it is **molten**?

Click "**play**" to find out what happens when a current is passed through **solid** and **molten lead bromide**.



What is electrolysis?

An ionic compound conducts electricity when it is molten or in solution. The current causes the ionic compound to **split up** and form new substances.



This process is called **electrolysis**, a word which comes from Greek and means "**splitting by electricity**".

Electrolysis has many uses, including:

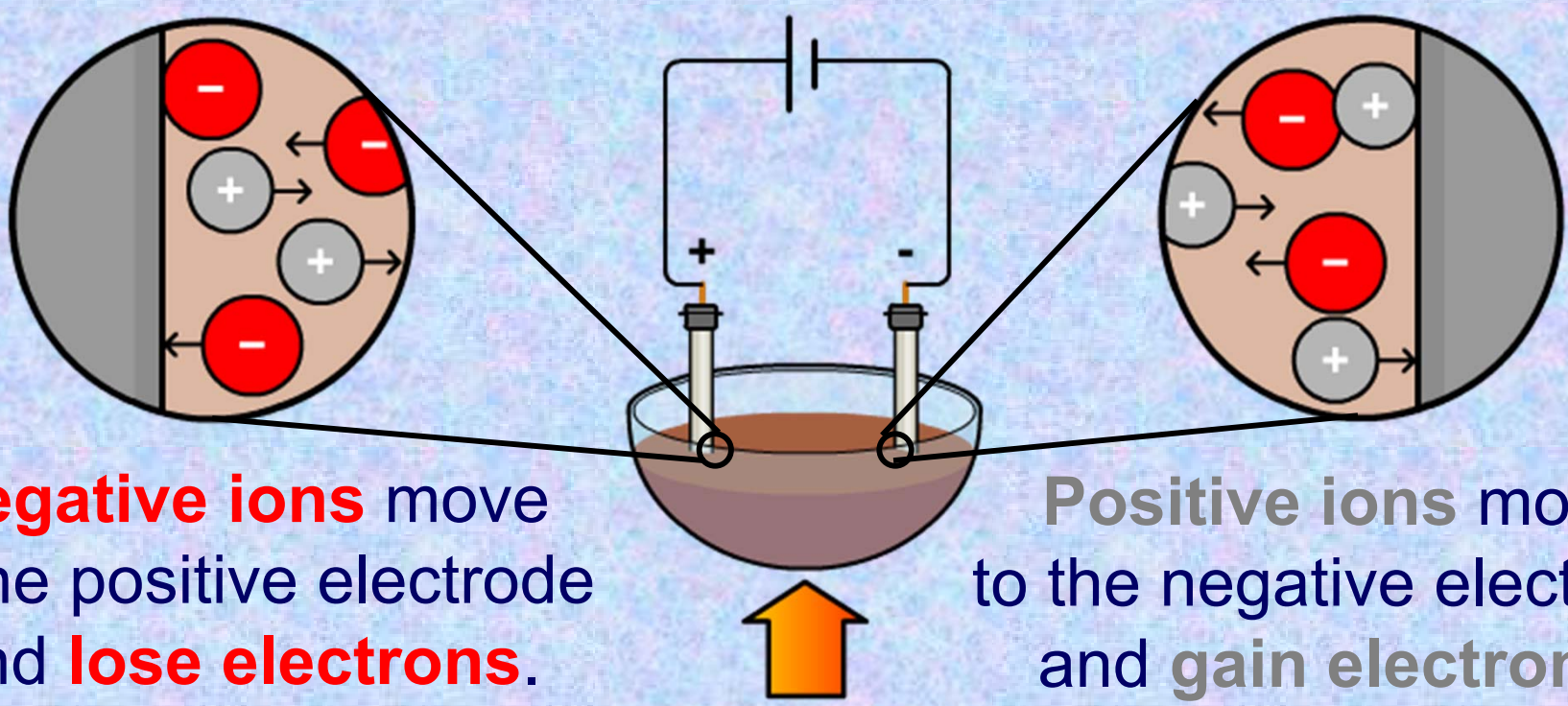
- purifying copper
- plating metals with silver and gold
- extracting reactive metals, such as aluminium
- making chlorine, hydrogen and sodium hydroxide.

What happens during electrolysis?

In electrolysis, the substance that the current passes through and splits up is called the **electrolyte**.

The electrolyte contains positive and negative **ions**.

What happens to these ions during electrolysis?



Negative ions move to the positive electrode and **lose electrons**.

This is **oxidation**.

Positive ions move to the negative electrode and **gain electrons**.

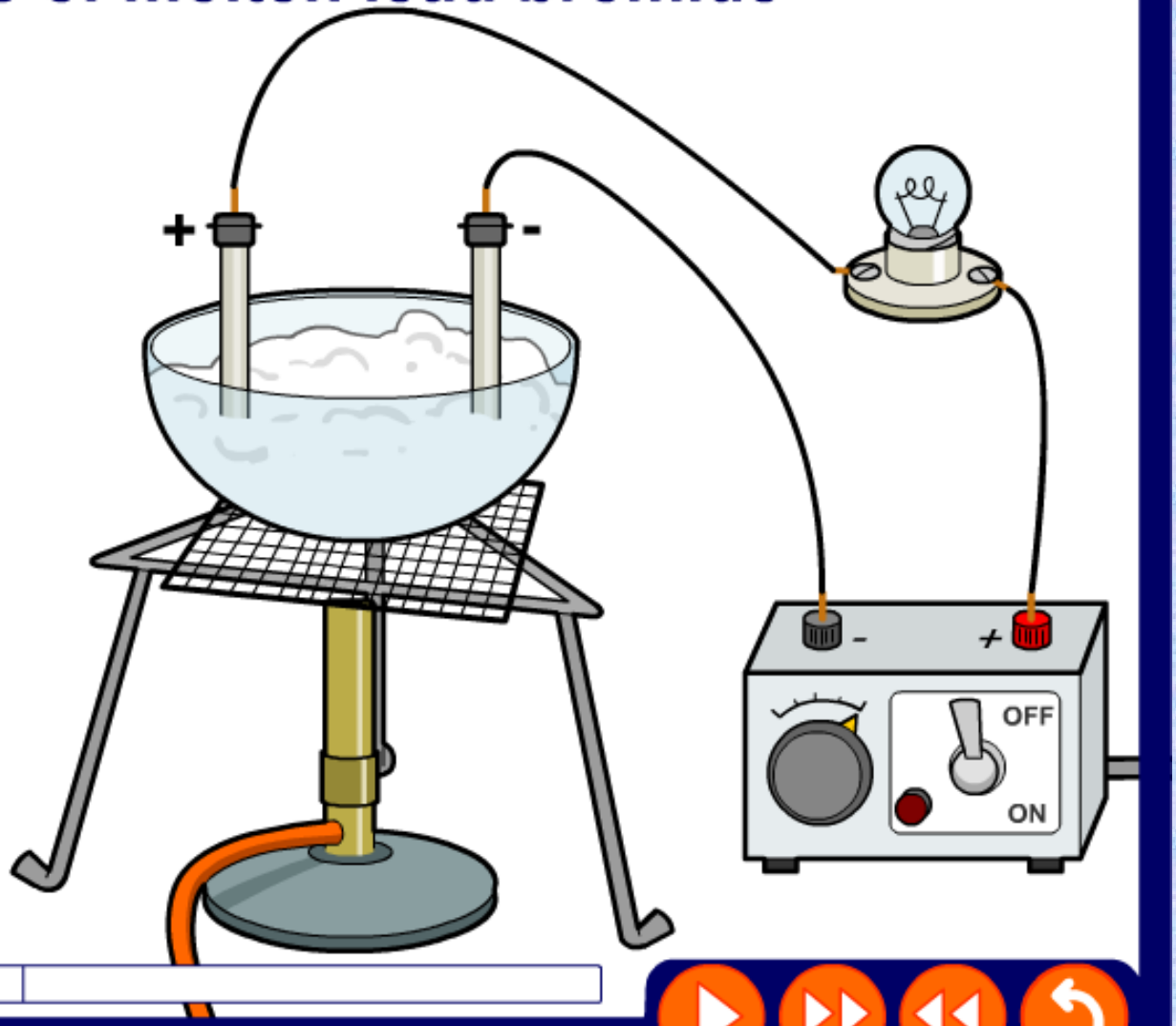
This is **reduction**.

Electrolysis of molten lead bromide

Electrolysis of molten lead bromide

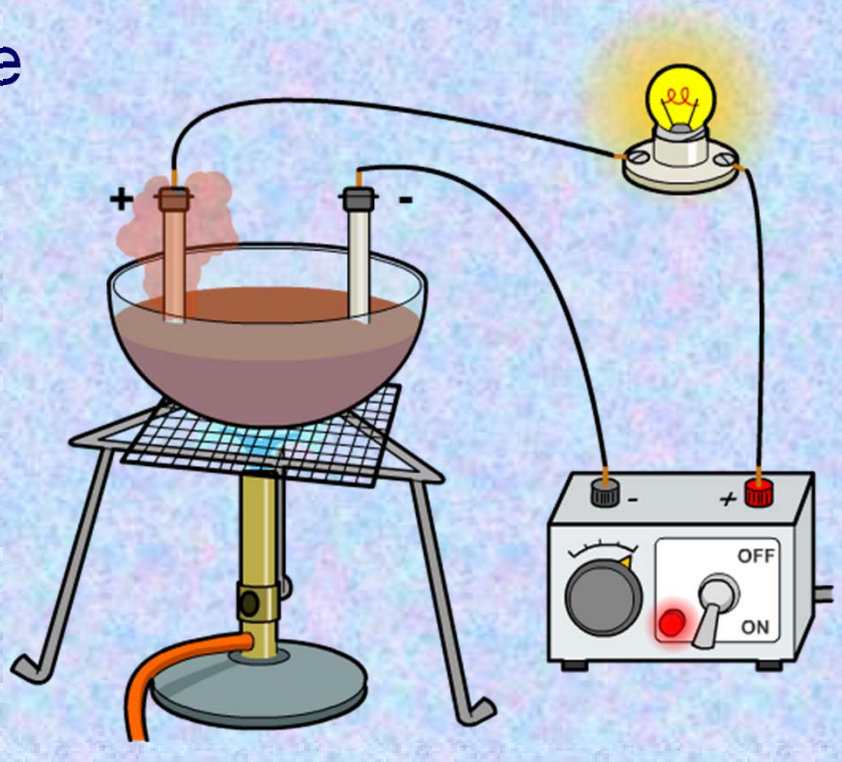
A molten ionic compound can be split into its elements by passing an electric current through it. This is called **electrolysis**.

Click "**play**" to find out what happens during the electrolysis of molten lead bromide.



Electrolysis of molten $PbBr_2$ – redox equations

What redox processes occur at the electrodes during the electrolysis of molten lead bromide ($PbBr_2$)?



At the negative electrode:

$Pb^{2+} + 2e^- \rightarrow Pb$ (reduction)

At the positive electrode:

$2Br^- \rightarrow Br_2 + 2e^-$ (oxidation)

What is the overall equation for the electrolysis of molten lead bromide ?

lead **bromide** → lead **+ bromine**

$PbBr_2$ (l) → Pb (l) + Br_2 (g)

Why and how is aluminium extracted?

Aluminium is one of the most useful metals in the world.

Electrolysis is used to extract aluminium from its ore. Why is it not possible to extract aluminium by heating its ore with carbon?


Dr John Mileham

Aluminium ore (bauxite) has a very high melting point (2050 °C).

For electrolysis, the ore is dissolved in a compound called **cryolite** (Na_3AlF_6), which lowers the melting point to 700 °C. Why is this important economically?

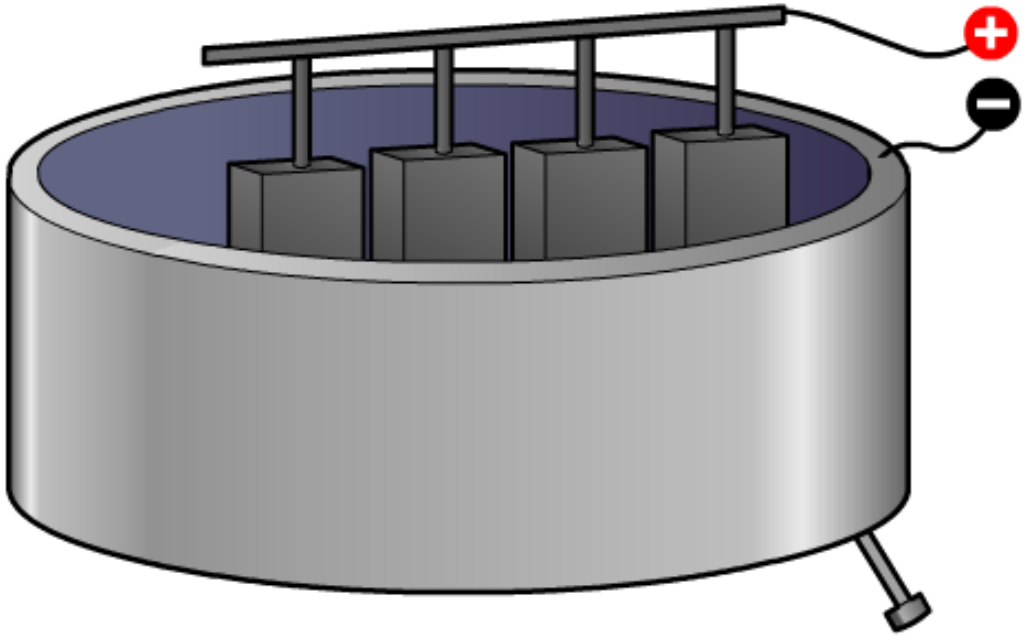
Extracting aluminium

How is aluminium extracted by electrolysis?

Bauxite is the main ore of aluminium.

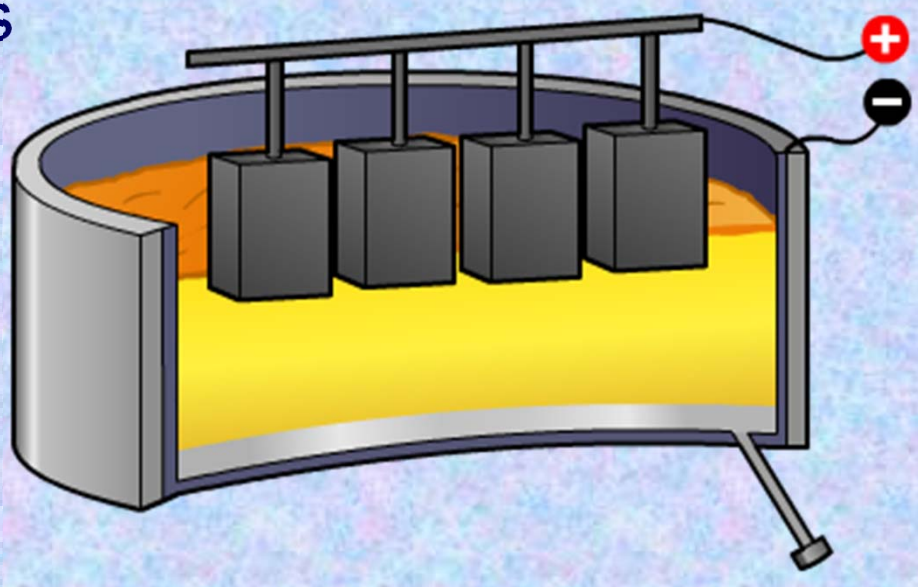
This ore consists mainly of aluminium oxide (Al_2O_3).

Click "**play**" to find out how electrolysis is used to extract aluminium from its ore.



Extracting aluminium – redox equations

What redox processes occur at the electrodes during the electrolysis of aluminium oxide (Al_2O_3)?



At the negative electrode:

$Al^{3+} + 3e^- \rightarrow Al$ (reduction)

At the positive electrode:

$2O^{2-} \rightarrow O_2 + 4e^-$ (oxidation)

What is the overall equation for the extraction of aluminium by electrolysis?

aluminium **oxide** → aluminium **+ oxygen**

$$2\,Al_2O_3\,(l) \rightarrow 4\,Al\,(l) + 3\,O_2\,(g)$$

What are the products of electrolysis?

Complete the table for each molten ionic compound.

Molten ionic compound	Product at the negative electrode	Product at the positive electrode
lead bromide	lead	?
lead chloride	?	chlorine
aluminium chloride	?	?
?	aluminium	oxygen
copper chloride	?	chlorine

chlorine

?

C

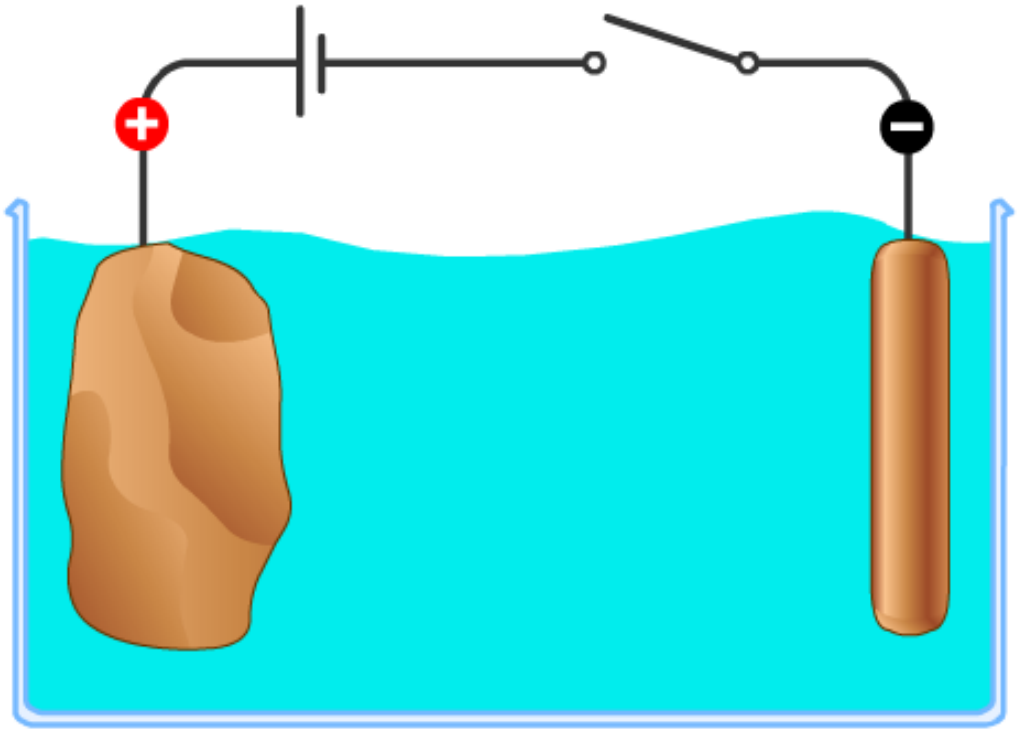
solve

Purifying copper using electrolysis

How is copper purified by electrolysis?

Electrolysis is used to remove any impurities from copper so that it is pure enough for making electrical wires.

Click "**play**" to find out what happens during the purification of copper by electrolysis.



Purifying copper – redox equations

What happens at the electrodes during the purification of copper by electrolysis ?

At the negative electrode:

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

At the positive electrode:

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

This process is carried out on a huge scale in industry and the copper formed on the negative electrodes is 99.99% pure.

The precious metals recovered from the impurities are also sold off and help to make this industrial process profitable.

Purifying copper – true or false?

Are these statements about purifying copper true or false?

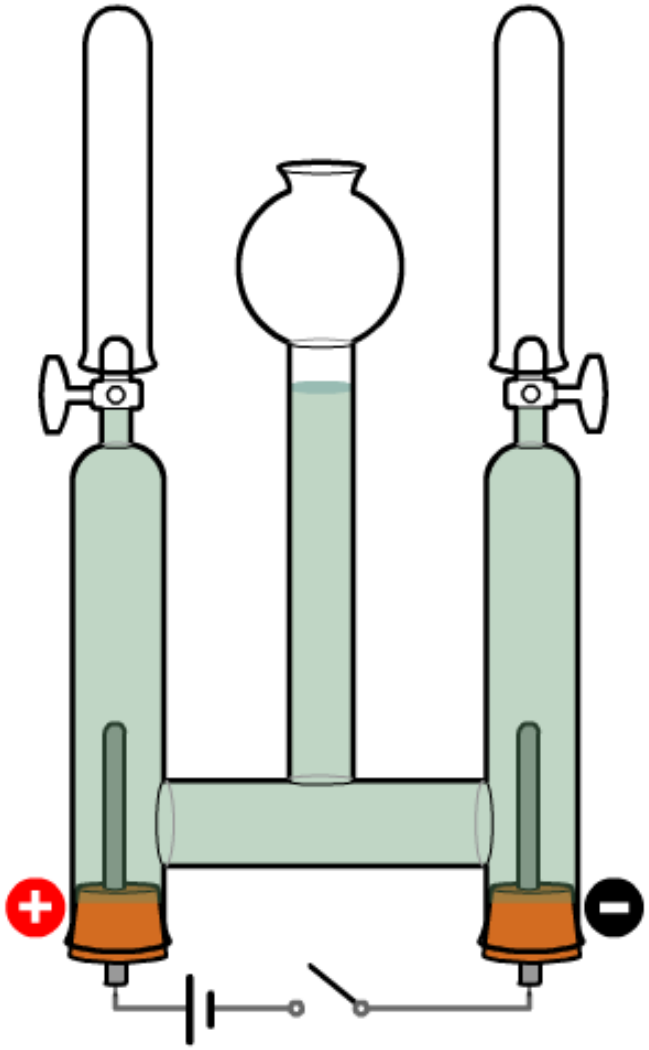
1.	The positive electrode is made of impure copper.	
2.	Gold is formed at the negative electrode.	
3.	The positive electrode dissolves during the process.	
4.	The sludge is valuable because it contains silver and gold.	
5.	Three electrons are needed to turn a Cu^{2+} ion into a Cu atom.	
6.	Reduction takes place at the positive electrode.	

true false

? solve

Electrolysis of NaCl solution

Electrolysis of sodium chloride solution



Electrolysis can be used to split a dissolved ionic compound and form new substances.

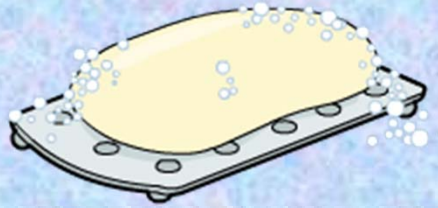
Click "**play**" to find out about the products of the electrolysis of **sodium chloride solution**.

Products of electrolysis of NaCl solution

The electrolysis of sodium chloride solution produces **three** very useful products:

- **Chlorine** used for killing bacteria in water, for bleach and making plastics like PVC.

- **Hydrogen** used for making margarine and fertilizers, and for rocket fuel.



- **Sodium hydroxide** used in many chemical reactions, such as making soap, neutralizing acids and making paper.

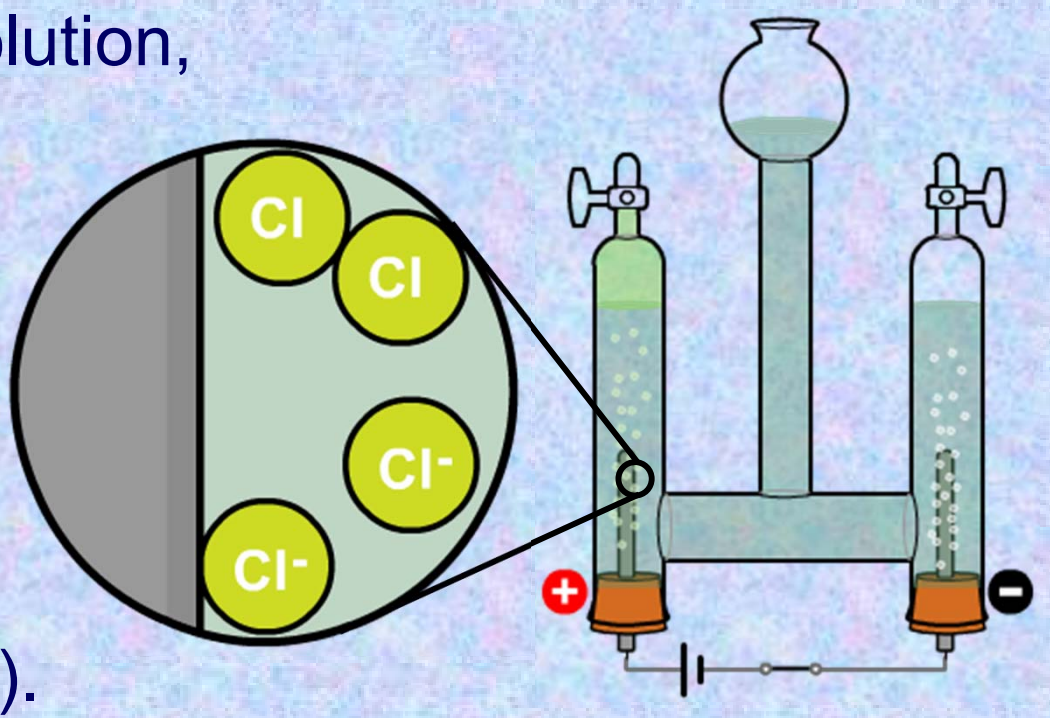
Chlorine is expected as a product of this process but hydrogen and sodium hydroxide are surprising products.

What happens at the electrodes to form these products?

How does the chlorine form?

In the electrolysis of NaCl solution, the **negative chloride ions (Cl^-)** are attracted to the positive electrode.

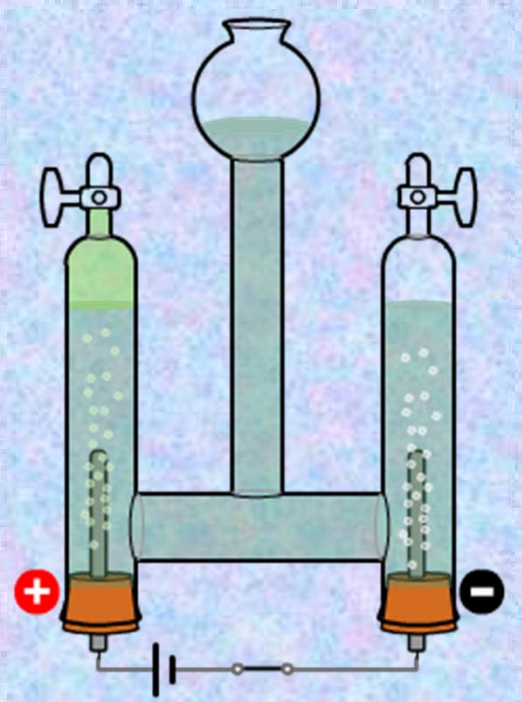
Here, the **Cl^- ions lose electrons** to make chlorine atoms, which then form chlorine molecules (**Cl_2**).



- Are the **Cl^-** ions oxidized or reduced? **oxidized**
- How many electrons are lost by each **Cl^-** ion? **one**
- How many **Cl^-** ions join to make a **Cl_2** molecule? **two**
- What is the half-equation for this redox process?

$2Cl^- \rightarrow Cl_2 + 2e^-$ (oxidation)

Why is sodium not formed?



In the electrolysis of sodium chloride solution, the **Na^+** ions might be expected to form **sodium** at the **negative electrode**.

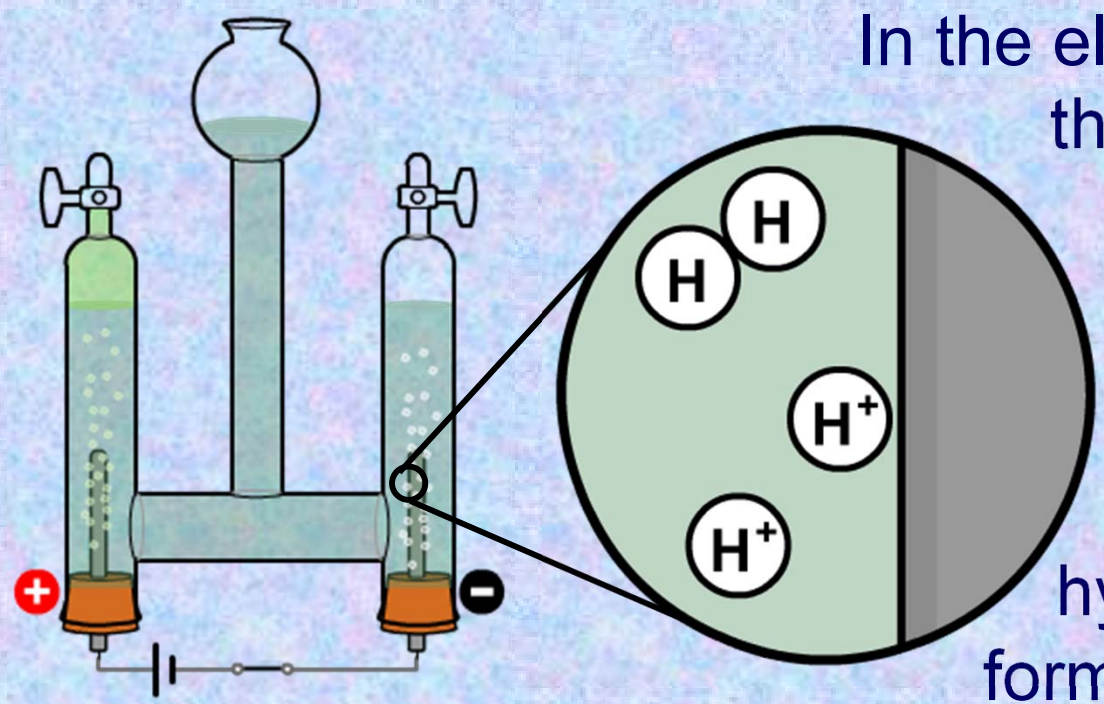
Instead, **hydrogen gas** is produced here.

This is because sodium chloride solution also contains **H^+ ions** from some of the water: **$H_2O\ (l) \rightarrow H^+\ (aq) + OH^-\ (aq)$**.

At the negative electrode, the **H^+** ions compete with the **Na^+** ions. The **H^+** ions gain electrons; the **Na^+** ions stay in solution.

For all ionic compounds containing a **metal that is more reactive than hydrogen**, electrolysis of a solution of the compound will produce hydrogen rather than the metal.

How does the hydrogen form?



In the electrolysis of NaCl solution, the **positive hydrogen ions (H^+)** are attracted to the negative electrode.

Here, the **H^+ ions gain electrons** to make hydrogen atoms, which then form hydrogen molecules (**H_2**).

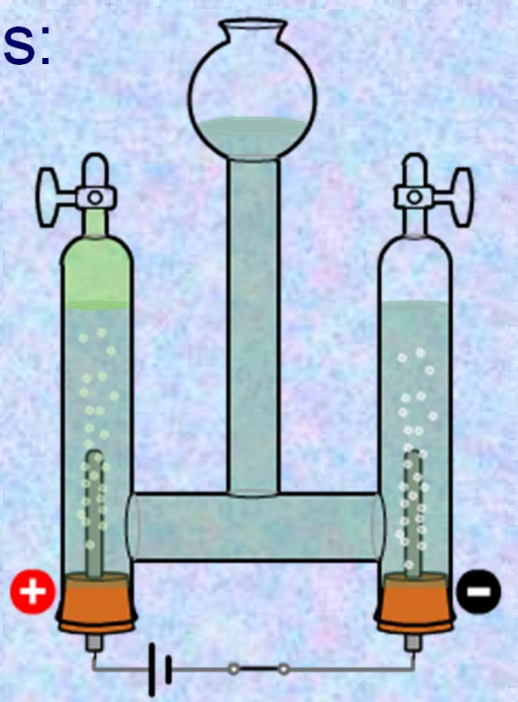
- Are the **H^+** ions oxidized or reduced? **reduced**
- How many electrons are gained by each **H+** ion? **one**
- How many **H^+** ions join to make a **H_2** molecule? **two**
- What is the half-equation for this redox process?

$$2H^+ + 2e^- \rightarrow H_2 \text{ (reduction)}$$

How does the sodium hydroxide form?

Sodium chloride solution has four types of ions:

- **Na^+** and **Cl^-** ions from the sodium chloride
- **H^+** and **OH^-** ions from the water.



The **Cl^-** ions form chlorine at the positive electrode and the **H^+** ions form hydrogen at the negative electrode. So, what's left?

Na^+ and **OH^-** ions are left behind and so a solution of **sodium hydroxide** (**NaOH**) is formed.

What is the overall equation for the electrolysis of a sodium chloride solution?

$2NaCl\ (aq) + 2H_2O\ (l) \rightarrow H_2\ (g) + Cl_2\ (g) + 2NaOH\ (aq)$

Hydrogen or metal?

potassium
sodium
calcium
magnesium
aluminium
(carbon)
zinc
iron
lead
(hydrogen)
copper
silver
gold
platinum

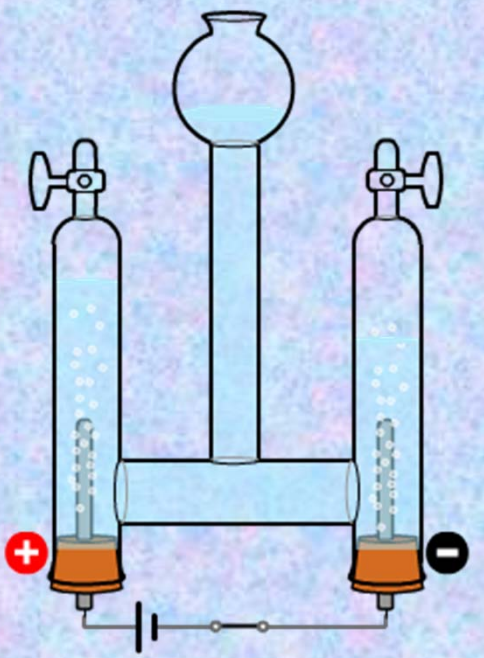
If an ionic compound contains **a metal that is more reactive than hydrogen**, electrolysis of a solution of the compound will produce hydrogen, not the metal.

Complete the table for these compounds.

Ionic compound	Product at the negative electrode
potassium chloride	hydrogen
copper sulphate	copper
sodium bromide	hydrogen
silver nitrate	silver
zinc chloride	hydrogen

Electrolysis of dilute sulfuric acid

Electrolysis can be used to split **water** (H_2O) into its elements, **hydrogen** and **oxygen**.



This is how hydrogen for fuel cells can be made and how oxygen can be produced from water on spacecraft.

Water is a covalent compound and so is a poor conductor of electricity. However, it does contain a few free H^+ and OH^- ions:

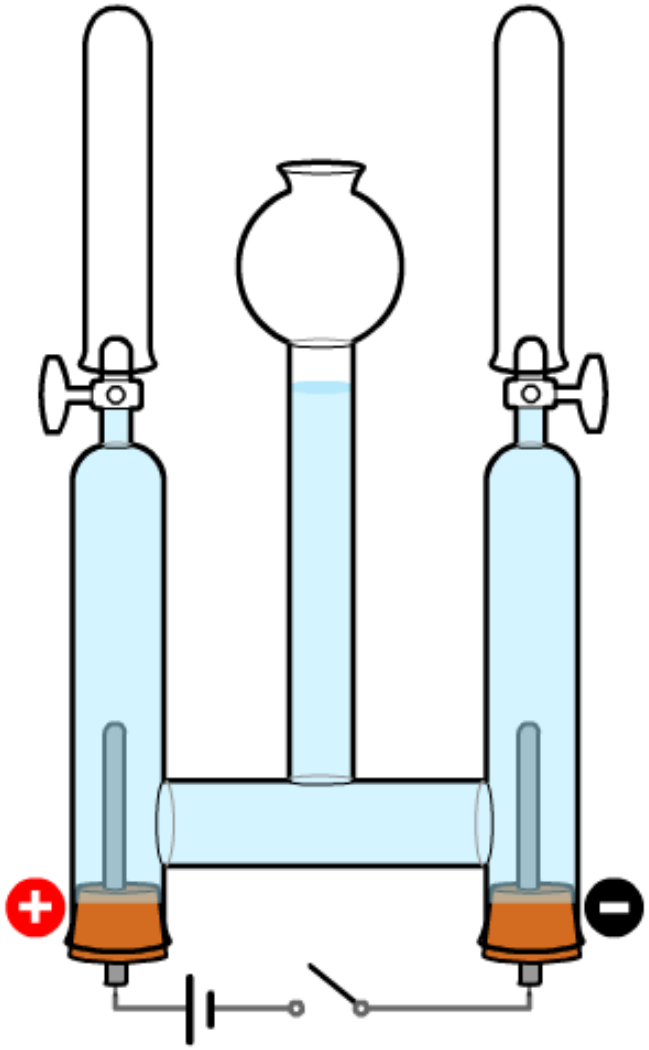
$$H_2O\ (l) \rightarrow H^+\ (aq) + OH^-\ (aq).$$

The conductivity of water can be improved by adding **dilute sulfuric acid**. This releases more ions so that more current flows during electrolysis, which creates hydrogen and oxygen.

Which product will form at each electrode?

Electrolysis of dilute sulfuric acid

Electrolysis of dilute sulfuric acid

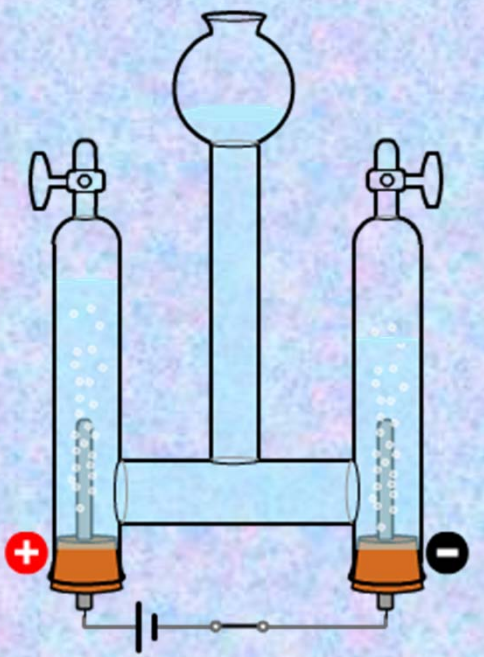


The electrolysis of dilute sulfuric acid is used to split water into its elements.

Click "**play**" to find out more about the products of the electrolysis of **dilute sulfuric acid**.

Electrolysis of dilute H_2SO_4 – redox equations

What happens at the electrodes during the electrolysis of dilute sulfuric acid?



At the negative electrode:

$2H^+ + 2e^- \rightarrow H_2$ (reduction)

At the positive electrode:

$4OH^- \rightarrow 2H_2O + O_2 + 4e^-$ (oxidation)

What is the overall equation for the electrolysis of dilute sulfuric acid?

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

Twice as much hydrogen forms as oxygen. Why is this?

In water, there are 2 hydrogen atoms for every oxygen atom, so the ratio by volume, of **H_2** to **O_2**, is **2:1**.

Glossary

- **electrode –** A solid conductor of electricity, which is used to make electrical contact with an electrolyte.
- **electrolysis –** The process which uses electricity to split up compounds.
- **electrolyte –** A substance which conducts electricity and can be split up by a current when molten or in solution.
- **ions –** Charged particles formed when atoms lose or gain electrons.
- **oxidation –** A type of reaction involving the gain of oxygen or the loss of electrons.
- **redox –** A type of reaction in which oxidation and reduction take place at the same time.
- **reduction –** A type of reaction involving the loss of oxygen or the gain of electrons.

What is involved in electrolysis?

Complete the table for the electrolysis of each electrolyte.

Electrolyte	Product at the negative electrode	Product at the negative electrode
?	lead	bromine
copper sulphate solution	?	oxygen
?	aluminium	oxygen
sodium chloride solution	?	?
dilute sulfuric acid	hydrogen	?

copper

?

C solve