# FACTFILE: GCSE CHEMISTRY: UNIT 2.1

Rewarding Learning

## Metals and the Reactivity Series

### Learning outcomes

Student should be able to:

2.1.1 recall the reactivity series of metals, including K, Na, Ca, Mg, Al, Zn, Fe, and Cu;

2.1.2 describe the reactions, if any, of the above metals with the following and describe how to collect the gas produced where appropriate:

- with air
- with water
- with steam.

2.1.3 explain how the reactivity of metals is related to the tendency of a metal to form its positive ion.

2.1.4 explain and describe the displacement reactions of metals with other metal ions in solution.

2.1.5 collect and/or analyse experimental data to predict where an unfamiliar element should be placed in the reactivity series or to make predictions about how it will react.

2.1.6 examine the relationship between the extraction of a metal from its ore and its position in the reactivity series, for example:

- aluminium, a reactive metal, is extracted by electrolysis; and
- iron, a less reactive metal, by chemical reduction.

**2.1.7 recall that the Earth's resources of metal ores are limited and that alternative methods, such as phytomining, are used;**

**2.1.8 recall the following aspects of phytomining:**

- **plants are used to absorb metal compounds such as copper(II) compounds;**
- **the plants are harvested, then burned to produce ash, which contains the metal compounds;**
- **an acid is added to the ash to produce a solution containing dissolved metal compounds (leachate);**
- **copper can be obtained from the solution by displacement using scrap iron; and**
- **this technique avoids traditional mining methods of digging, moving and disposing of large amounts of rock.**

Some metals are very unreactive, this means they do not easily take part in chemical reactions. Precious metals such as gold, silver and platinum are unreactive. However, some metals are very reactive. They easily take part in chemical reactions to make new substances. If we put the metals in order of their reactivity, from most reactive down to least reactive, we get a list called the reactivity series.

## The Reactivity Series

| | | |
|---|---|---|
| Potassium | K | MOST REACTIVE |
| Sodium | Na | ↓ |
| Calcium | Ca | |
| Magnesium | Mg | |
| Aluminium | Al | |
| Zinc | Zn | |
| Iron | Fe | |
| Copper | Cu | LEAST REACTIVE |

To make this series easier to learn a mnemonic may be constructed using the first letter of each metal in the series. For example:

'**P**enny **S**avage **C**aught **M**ammoths **A**nd **Z**ebras **I**n **C**apetown'

## Reactions of Metals

### 1. With air

The metals react when heated in air.

- Potassium burns with a lilac flame producing a white solid (potassium oxide)

  $4K + O_2 \rightarrow 2K_2O$

- Sodium burns with a yellow/orange flame producing a white solid (sodium oxide)

  $4Na + O_2 \rightarrow 2Na_2O$

- Calcium burns with a brick red flame producing a white solid (calcium oxide)

  $2Ca + O_2 \rightarrow 2CaO$

- Magnesium burns with a bright white light forming a white solid (magnesium oxide)

  $2Mg + O_2 \rightarrow 2MgO$

- Aluminium powder burns with a bright white light forming a white solid (aluminium oxide)

  $4Al + 3O_2 \rightarrow 2Al_2O_3$

- Zinc glows orange and produces a yellow solid which changes to white on cooling (zinc oxide)

  $2Zn + O_2 \rightarrow 2ZnO$

- Iron filings burn with orange sparks producing a black solid ($Fe_3O_4$)

  $3Fe + 2O_2 \rightarrow Fe_3O_4$

- Copper glows orange and produces a black solid (copper(II) oxide)

  $2Cu + O_2 \rightarrow 2CuO$

### 2. with cold water

Potassium, sodium and calcium all react with cold water.

| Potassium | Sodium | Calcium |
|---|---|---|
| Floats<br>Moves very rapidly across the surface<br>Bubbles of gas released<br>Heat is released<br>Ignites with a lilac flame<br>Crackles at the end/explosion<br>Colourless solution forms | Floats<br>Moves rapidly across the surface<br>Bubbles of gas released<br>Heat is released<br>Melts to form a sphere of molten metal<br>Colourless solution forms | Granules sink and rise continuously<br>Bubbles of gas released<br>Heat is released<br>Grey powdered solid forms in the water |

When these metals react with cold water they produce a METAL HYDROXIDE and HYDROGEN GAS.

potassium + water → potassium hydroxide + hydrogen

$$2K + 2H_2O \rightarrow 2KOH + H_2$$

sodium + water → sodium hydroxide + hydrogen

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

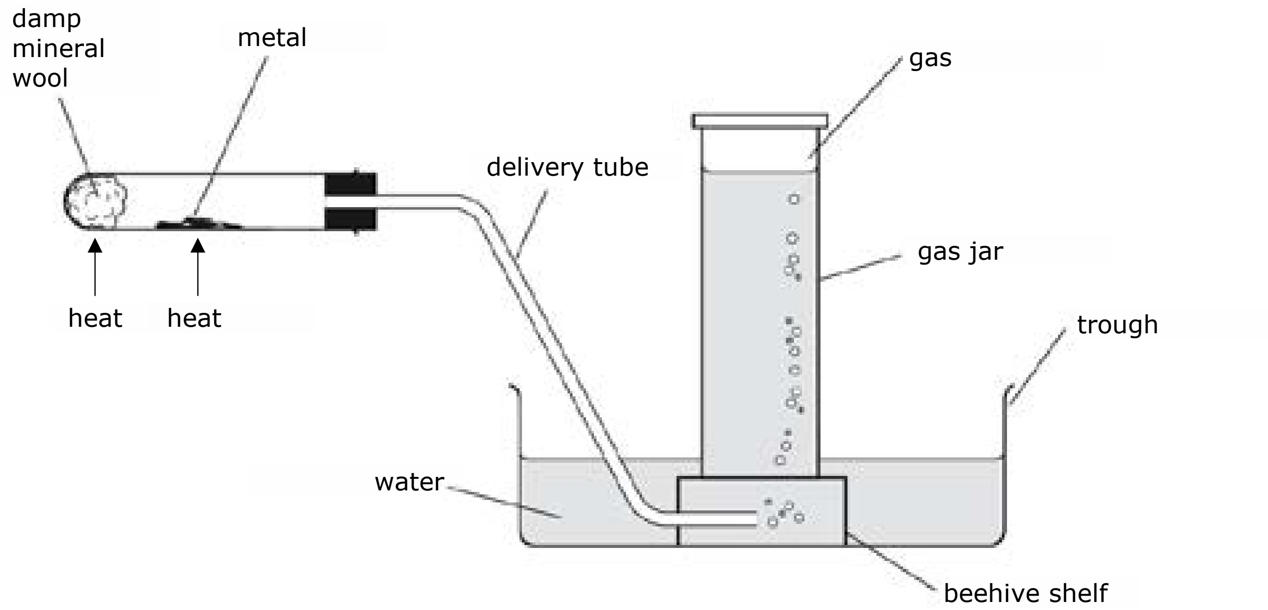
calcium + water → calcium hydroxide + hydrogen

$$Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$$

The metal hydroxides produced will turn universal indicator solution/pH paper **blue** indicating they are alkaline solutions. Hydrogen gas can be confirmed by placing a burning splint into contact with the gas and a squeaky pop will be produced. Magnesium only produces and few bubbles of gas even when left for several days with cold water. Zinc, iron and copper show no reaction with cold water.

### 3. with steam

Magnesium, zinc, aluminium and iron all react with steam using the following apparatus:




| Magnesium | Zinc | Aluminium | Iron |
|---|---|---|---|
| Bright white light produced<br><br>White powder remains | Glows and produces a yellow powder<br><br>Yellow powder turns white when cooled | Glows and produces a white powder<br><br>White powder remains | Iron is heated until it glows red<br><br>Black solid forms |

In these reactions a metal oxide and hydrogen gas are produced.

magnesium + steam ⟶ magnesium oxide + hydrogen

$$Mg + H_2O \longrightarrow MgO + H_2$$

zinc + steam ⟶ zinc oxide + hydrogen

$$Zn + H_2O \longrightarrow ZnO + H_2$$

iron + steam ⟶ iron(III) oxide + hydrogen

$$2Fe + 3H_2O \longrightarrow Fe_2O_3 + 3H_2$$

Copper is too unreactive to show any reaction with steam.

The reactivity of a metal can be linked to the ability of the metal to form its positive ion. The more reactive the metal, the greater tendency it has to form a positive ion (cation) in the context of a chemical reaction. For example:

- $K \rightarrow K^+ + e^-$
- $Na \rightarrow Na^+ + e^-$
- $Ca \rightarrow Ca^{2+} + 2e^-$

**4. Displacement Reactions**

A metal will displace (take the place of) a **less reactive** metal in a metal salt solution.

A sample set of results is shown below:

| | Cu | Fe | Mg | Zn |
|---|---|---|---|---|
| $CuSO_4$ | no reaction | red-brown layer of copper on the iron filings, blue colour fades | red-brown layer of copper on the magnesium strip, blue colour fades | red-brown layer of copper on the zinc granules, blue colour fades |
| $FeSO_4$ | no reaction | no reaction | grey solid on the magnesium ribbon | grey solid on the zinc granules |
| $MgSO_4$ | no reaction | no reaction | no reaction | no reaction |
| $ZnSO_4$ | no reaction | no reaction | grey solid on the magnesium ribbon | no reaction |

Using the information in the table it is possible to make the following conclusions:

- Magnesium is the most reactive metal. It DISPLACES **ALL** other metals from their metal salt solutions. The magnesium is never displaced from the magnesium sulfate solution.
- Copper is the least reactive metal. It does **NOT** DISPLACE any metals from their metal salt solutions. Copper is **ALWAYS** displaced from the solution of copper(II) sulfate.
- The order of reactivity of the metals can be confirmed (most reactive first):

**Mg, Zn, Fe and then Cu.**

It is possible to write equations for all of the reactions that took place. For example:

magnesium + copper(II) sulfate $\rightarrow$ magnesium sulfate + copper

$$Mg + CuSO_4 \rightarrow MgSO_4 + Cu$$

**By using experimental data it is possible to place metals in a reactivity series. A tick ✓ represents a reaction and an ✗ represents no reaction.**

| | Metal X | Metal Y | Metal Z |
|---|---|---|---|
| X sulfate | | ✗ | ✗ |
| Y sulfate | ✓ | | ✓ |
| Z sulfate | ✓ | ✗ | |

**Metal X** displaces both Y and Z – so it must be the **most reactive** and be at the top of this reactivity series.

**Metal Y** cannot displace either X or Z – so it must be the **least reactive** and be at the bottom of this reactivity series.

**Metal Z** displaces Y but cannot displace X – so it must be more reactive than Y but less reactive than X, and be in between them in this reactivity series.
Therefore, the order of decreasing reactivity is:

METAL X
METAL Z
METAL Y

## Extraction of metals

The method used to extract metals from the ore in which they are found depends on their reactivity. For example, reactive metals such as aluminium are extracted by *electrolysis* while a less-reactive metal such as iron may be extracted by *reduction* with carbon or carbon monoxide.

| Metals – in decreasing order of reactivity | Reactivity |
|---|---|
| potassium<br>sodium<br>calcium<br>magnesium<br>aluminium | extract by *electrolysis* |
| zinc<br>iron | extract by *reduction* reaction using *carbon* or *carbon monoxide* |

Metal ores are a finite resource and are therefore in limited supply. Phytomining is a new method which can be used to extract metals from low grade ores providing an alternative method to the traditional mining previously used. Copper is one such metal where phytomining has been used in its extraction.
In the process of phytomining plants are grown on top of the low grade ores. The plants absorb the copper(II) ions through their roots. The plants are then harvested and burnt to produce ashes which contain the copper(II) ions, these are then reacted with sulfuric acid producing copper(II) sulfate. These ashes containing copper(II) sulfate are then reacted with scrap iron and through a **displacement reaction** copper metal is produced.

iron + copper(II) sulfate $\longrightarrow$ iron(II) sulfate + copper

There are both advantages and disadvantages to the phytomining extraction process.

Advantages

- Energy can be produced when plants are burned;
- Environmentally friendly process compared to mining – plants can remove $CO_2$;
- No waste rock requiring disposal.

Disadvantages

- Currently more costly than mining;
- Dependent on growing conditions – weather, altitude and soil quality.

## REVISION QUESTIONS

1 The reactivity of metals can be studied using displacement reactions. If a displacement reaction occurs there is a temperature rise.

In an experiment the following method was used:

- Pour some copper(II) sulfate solution into a polystyrene cup and record the temperature of the solution.
- Add a known mass of metal and stir.
- Record the maximum temperature of the mixture.
- Repeat the experiment.

The results of this experiment are shown in the table below.

| Metal | Temperature increase (°C) | | Average temperature rise (°C) |
|---|---|---|---|
| | Experiment 1 | Experiment 2 | |
| magnesium | 11.5 | 16.5 | 14.0 |
| silver | 0.0 | 0.0 | 0.0 |
| iron | 3.0 | 4.0 | 3.5 |
| gold | 0.0 | 0.0 | 0.0 |
| zinc | 7.0 | 8.0 | 7.5 |

(a) State two factors which should be kept the same in this experiment to make it a fair test.

___________________________________________________________________________

___________________________________________________________________________ [2]

(b) State and explain which of the metals gave the least reliable temperature rise.

___________________________________________________________________________ [1]

(c) State and explain which of the metals used in the experiment is the most reactive.

___________________________________________________________________________

___________________________________________________________________________ [2]

(d) Explain why there is no temperature rise when silver is added to copper(II) sulfate solution.

___________________________________________________________________________

___________________________________________________________________________ [1]

(e) Why do the results make it impossible to decide which of the metals is the least reactive?

_______________________________________________________________________________

_____________________________________________________________________________ [1]

(f) Write a balanced symbol equation for the displacement reaction between zinc and copper(II) sulfate solution.

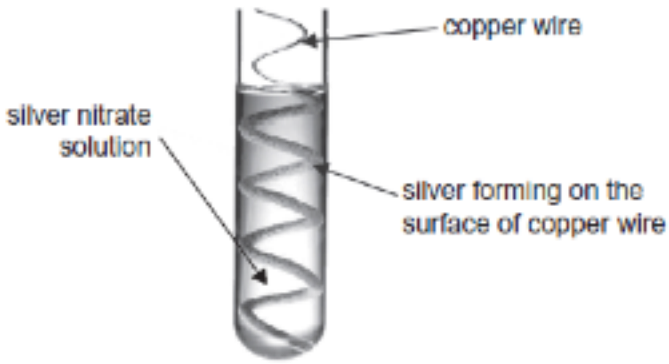
_____________________________________________________________________________ [1]

2.

A reactivity series of some metals is shown below:

potassium
sodium
calcium
magnesium
aluminium
iron
copper


**(a)** Silver metal does not appear on the above reactivity series. Copper metal will react with silver nitrate solution to form silver as shown below.

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**(i)** Write a balanced symbol equation for the reaction of copper with silver nitrate forming silver and copper(II) nitrate.

_______________________________________________ [3]

**(ii)** Indicate the position of silver on the reactivity series shown above. [1]

(iii) Silver nitrate solution is colourless. What is the colour of the solution at the end of this reaction?

_______________________________________________ [1]

(iv) Explain why copper displaces silver from a solution of silver nitrate.

_______________________________________________

_______________________________________________ [2]