Cambridge (CIE) IGCSE Chemistry

Your notes

Reactivity Series & Corrosion of Metals

Contents

Reactivity series

What is the reactivity series of metals?

- The chemistry of the metals is studied by analysing their reactions with water and acids
- Based on these reactions a reactivity series of metals can be produced
- The series can be used to place a group of metals in **order of reactivity** based on the observations of their reactions with water and acids
- The non-metals hydrogen and carbon are also included in the reactivity series as they are used to extract metals from their oxides

Reactivity Series of Metals

Metal	Reaction with cold water	Reaction with acid	Reaction with oxygen
Most reactive			
Potassium	Reacts violently	Reacts violently	Reacts quickly in air
Sodium	Reacts quickly	Reacts quickly	Reacts quickly in air
Calcium	Reacts less strongly	Reacts vigorously	Reacts readily
Magnesium	Slow reaction (reacts with steam)	Reacts vigorously	Reacts readily
Aluminium	Slow reaction (reacts with steam)	Reacts readily	Reacts readily
Carbon			
Zinc	Very slow reaction (reacts slowly with steam)	Reacts less strongly	Reacts
Iron	Very slow reaction (reacts slowly with steam)	Reacts less strongly	Reacts
Hydrogen			

Copper	No reaction with steam or water	No reaction	Reacts
Silver	No reaction with steam or water	No reaction	Reacts
Gold	No reaction with steam or water	No reaction	No reaction
Least reactive			

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How to remember the reactivity series

- Observations from the table above allow the following reactivity series to be deduced
- The order of this reactivity series can be memorised using the following mnemonic
  - “Please send cats, monkeys and cute zebras into hot countries signed Gordon"

Reactivity Series Mnemonic

Metal	Abbreviation
Most reactive	
Potassium	P - Please
Sodium	S - send
Calcium	C - cats,
Magnesium	M - monkeys,
Aluminium	A - and
Carbon	C - cute
Zinc	Z - zebras
Iron	I - into
Hydrogen	H - hot
Copper	C - countries
Silver	S - signed

Gold	G - Gordan
Least reactive	

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Reaction of metals with cold water

- The more reactive metals will react with cold water to form a metal hydroxide and hydrogen gas
- Potassium, sodium and calcium all undergo reactions with cold water as they are the most reactive metals:

$$\text{metal + water} \rightarrow \text{metal hydroxide + hydrogen}$$

- For example, calcium and potassium:

$$Ca\ (s) + 2H_2O\ (l) \rightarrow Ca(OH)_2\ (aq) + H_2\ (g)$$

$$2K\ (s) + 2H_2O\ (l) \rightarrow 2KOH\ (aq) + H_2\ (g)$$

Reactions of metals with steam

- Metals just below calcium in the reactivity series do not react with cold water but will react with steam to form a metal oxide and hydrogen gas, for example, magnesium:

$$Mg\ (s) + H_2O\ (g) \rightarrow MgO\ (s) + H_2\ (g)$$

Reaction with dilute acids

- Only metals **above hydrogen** in the reactivity series will react with dilute acids
- Unreactive metals below hydrogen, such as gold, silver and copper, do not react with acids
- The more reactive the metal then the more vigorous the reaction will be
- Metals that are placed high on the reactivity series such as potassium and sodium are very dangerous and react **explosively** with acids
- When acids react with metals they form a **salt** and **hydrogen gas:**
- The general equation is:

$$\textbf{metal + acid} \rightarrow \textbf{salt + hydrogen}$$

- Some examples of metal-acid reactions and their equations are given below:

Acid–Metal Reactions Table

Metal	Sulfuric acid	Hydrochloric acid
Magnesium	$Mg + H_2SO_4 \rightarrow MgSO_4 + H_2$	$Mg + 2HCl \rightarrow MgCl_2 + H_2$

Zinc	$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$	$Zn + 2HCl \rightarrow ZnCl_2 + H_2$
Iron	$Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$	$Fe + 2HCl \rightarrow FeCl_2 + H_2$

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Reaction with oxygen

- Some reactive metals, such as the alkali metals, react easily with oxygen
- Silver, copper and iron can also react with oxygen although much more slowly
- When metals react with oxygen a metal oxide is formed, for example, copper:

$$\text{metal} + \text{oxygen} \rightarrow \text{metal oxide}$$

$$2Cu\,(s) + O_2\,(g) \rightarrow 2CuO\,(s)$$

- Gold does not react with oxygen

Deducing the order of reactivity

- The order of reactivity of metals can be deduced by making experimental observations of reactions between metals and water, acids and oxygen
- The more vigorous the reaction of the metal, the higher up the reactivity series the metal is
- A combination of reactions may be needed, for example, the order of reactivity of the more reactive metals can be determined by their reactions with water
- The less reactive metals react slowly or not at all with water, so the order of reactivity would need to be determined by observing their reactions with dilute acid
- Temperature change in a reaction can also be used to determine the order of reactivity
- The greater the temperature change in a reaction involving a metal, the more reactive the metal is

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Explaining reactivity

Extended tier only

- Metal atoms form **positive ions** by loss of electrons when they react with other substances
- The **tendency** of a metal to lose electrons is a measure of how reactive the metal is
- A metal that is high up on the series loses electrons easily and is thus **more reactive** than one which is lower down on the series

Displacement reactions between metals and aqueous solutions of metal salts

- Any metal will displace another metal that is **below** it in the reactivity series from a solution of one of its salts
- This is because more reactive metals lose electrons and form ions more readily than less reactive metals, making them better **reducing agents**
- The less reactive metal is a better electron acceptor than the more reactive metal, thus the less reactive metal is reduced
    - OILRIG: reduction is gain of electrons

Magnesium + copper sulfate

- Magnesium is a reactive metal and can displace copper from a copper sulfate solution
- Magnesium loses its electrons more easily and the ion of the less reactive metal, copper, will gain these electrons to form elemental copper
- This is easily seen as the more reactive metal slowly **disappears** from the solution, **displacing** the less reactive metal

magnesium + copper sulfate → magnesium sulfate + copper

$$Mg\,(s) + CuSO_4\,(aq) \rightarrow MgSO_4\,(aq) + Cu\,(s)$$

- The blue colour of the $CuSO_4$ solution **fades** as colourless magnesium sulfate solution is formed
- Copper coats the surface of the magnesium and also forms solid metal which falls to the bottom of the beaker

The reaction between magnesium and copper sulfate

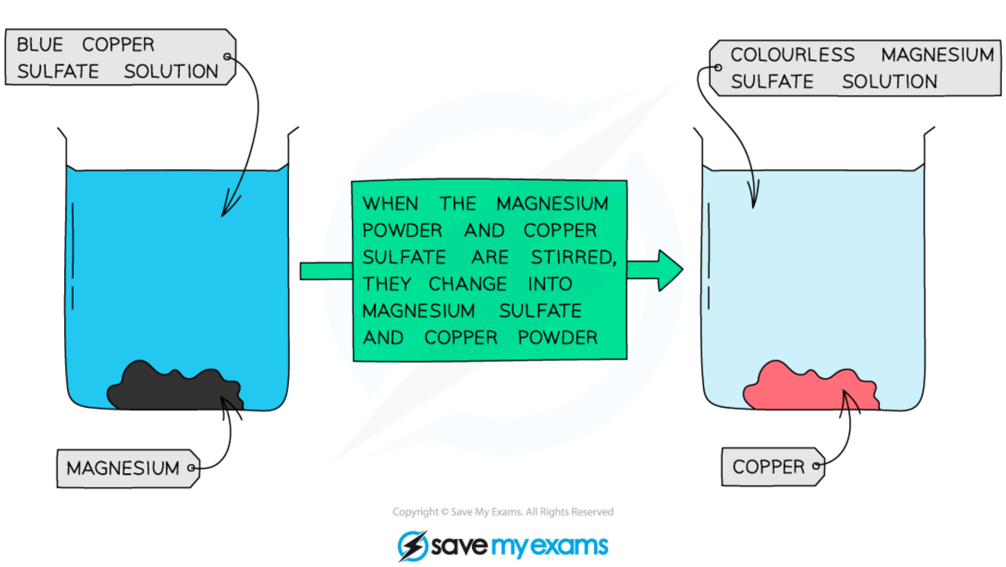

Diagram showing the colour change when magnesium displaces copper from copper sulfate

- By combining different metals and metal salts solutions it is possible to come up with a relative reactivity order

Metal Solutions Displacement Table

Mixture	Products	Equation for Reaction
Magnesium and iron(II) sulfate	Magnesium sulfate and iron	$Mg + FeSO_4 \rightarrow MgSO_4 + Fe$
Zinc and iron chloride	Zinc chloride and iron	$Zn + FeCl_2 \rightarrow ZnCl_2 + Fe$
Iron and silver nitrate	Iron(II) nitrate and silver	$Fe + AgNO_3 \rightarrow Fe(NO_3)_2 + 2Ag$
Copper and iron(II) chloride	No reaction	------
Silver and copper(II) sulfate	No reaction	------
Zinc and magnesium chloride	No reaction	------

- From this table we can deduce the order of reactivity:
  - Magnesium and zinc are both more reactive than iron but magnesium is more reactive than zinc

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- Copper and silver are both less reactive than iron but silver is less reactive than copper
- The order of reactivity of the metals tested can be therefore be deduced as:
  - Mg > Zn > Fe > Cu > Ag

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Reactivity of aluminium

- Aluminium is high in the reactivity series, but in reality, it does not react with water and the reaction with dilute acids can be quite slow
- This is because it reacts readily with oxygen, forming a protective layer of aluminium oxide which is very thin
- This layer prevents reaction with water and dilute acids, so aluminium can behave as if it is unreactive

Rusting of iron

What is rusting?

- Rusting is a chemical reaction between iron, water and oxygen
  - Rust is the reddish-brown compound product called hydrated iron(III) oxide
- Both oxygen and water must be present for rusting to occur
  - Steel, which contains iron, also rusts under the same conditions
- During rusting, iron is oxidised

iron + water + oxygen → hydrated iron(III) oxide

Investigating rusting

- To investigate the conditions required for rusting, prepare three test tubes as shown in the diagram
- The oil layer in the 2nd tube keeps out air and the water has been boiled so that no air is left in it
- The calcium chloride in the 3rd tube is used to remove any moisture in the air
- After a few days, the iron nail in the 1st tube will be the only nail to show signs of rust

Requirements for rusting

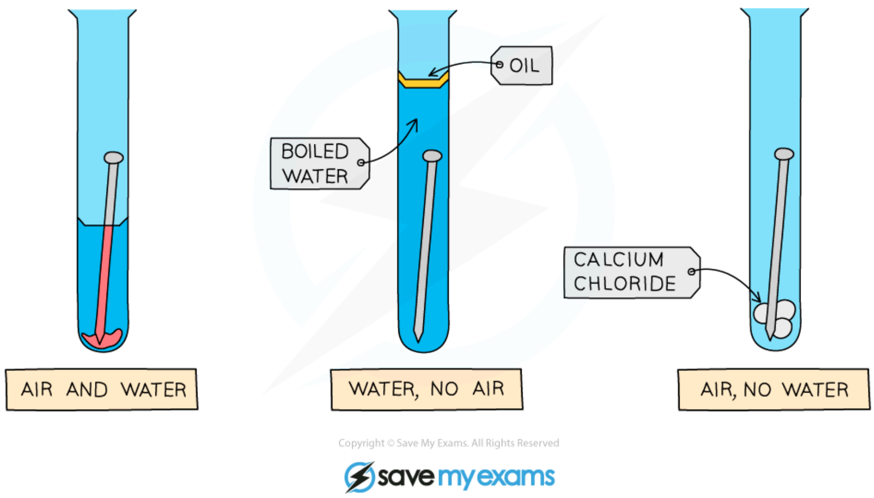

Diagram showing the requirements of oxygen and water for rust to occur: only the nail exposed to both air and water rusts

Rust prevention methods

- Rust can be prevented by coating iron or steel with barriers that prevent the iron from coming into contact with water and oxygen
- However, if the coatings are removed or scratched, the iron or steel is once again exposed to water and oxygen and will rust

Table to show common barrier methods

Common barrier methods	
Grease	Oil
Paint	Plastic

Examiner Tips and Tricks

Only iron or steel (an alloy made from iron) can **rust**. If any other metal oxidises in air causing the metal to break down, you should say that the metal has **corroded**.

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Galvanising & sacrificial protection

Extended tier only

Sacrificial Protection

- Iron can be prevented from rusting using the **reactivity series**
- A **more** reactive metal can be attached to a **less** reactive metal
- The more reactive metal will oxidise and therefore corrode first, protecting the less reactive metal from corrosion

Zinc bars on the side of steel ships

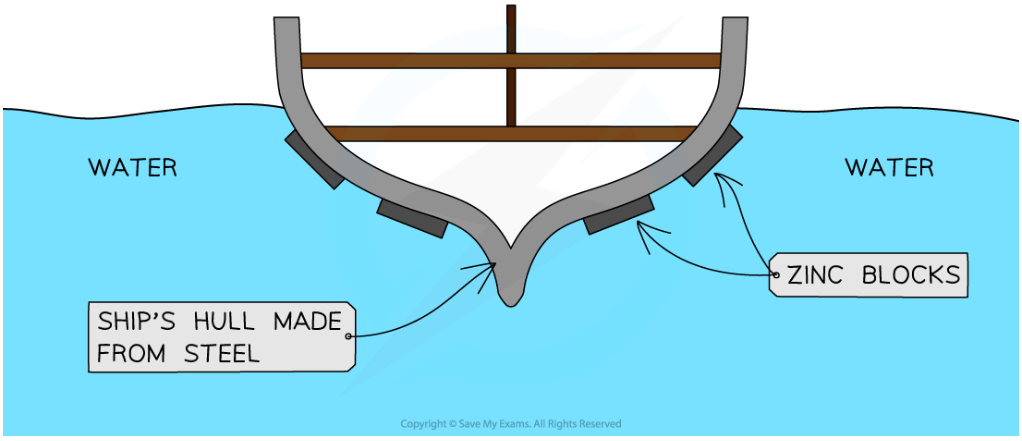

Diagram to show the use of zinc bars on the sides of steel ships as a method of sacrificial protection

- Zinc is more reactive than iron therefore will lose its electrons more easily than iron and is oxidised more easily:

$$Zn \rightarrow Zn^{2+} + 2e^{-}$$

- The iron is less reactive therefore will not lose its electrons as easily so it is not oxidised; the zinc is **sacrificed** to protect the steel
  - The zinc blocks do not need to cover the whole hull
  - As long as they are electrically connected to the steel, they can protect nearby areas
  - They are often placed on edges and joints where corrosion is most likely.
- For continued protection, the zinc bars have to be replaced before they completely corrode

Galvanising

- **Galvanising** is a process where the iron to be protected is coated with a layer of zinc
- This can be done by electroplating or dipping it into molten zinc
- $ZnCO_3$ is formed when zinc reacts with oxygen and carbon dioxide in the air and protects the iron by the barrier method
- If the coating is damaged or scratched, the iron is still protected from rusting by **sacrificial protection**

Examiner Tips and Tricks

You maybe asked to explain why a metal is/is not suitable as a method of preventing an iron/steel object from rusting. Remember that if it is higher in the reactivity series than iron, it will be suitable for sacrificial protection as it will be oxidised instead of iron. If it is lower in the reactivity series than iron, it would not be suitable as iron would be oxidised, causing it to rust.

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