EXAM PAPERS PRACTICE

4.1 Obtaining & Using Metals

YOUR NOTES

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4.1.1 REACTIVITY OF METALS

Reactivity of Metals

- The chemistry of the metals is seen by comparing their characteristic reactions
- 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, acids and salts

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The Relative Reactivity of Metals with Water and Acids

Metal	Reaction with water	Reaction with acid
Most reactive		
Potassium	Reacts violently	Reacts violently
Sodium	Reacts quickly	Reacts violently
Calcium	Reacts less strongly	Reacts vigorously
Magnesium		Reacts vigorously
Zinc		Reacts less strongly
Iron		Reacts less strongly
Hydrogen		
Copper		
Least reactive		

Reaction with water

- In general, when a metal reacts with water it produces a metal hydroxide and hydrogen gas
- The reactions of potassium and sodium are covered in more detail in another section, but the reaction with calcium and water is given here for reference:

Ca (s) + 2H2O (l) → Ca(OH)2 (aq) + H2 (g)

calcium + water → calcium hydroxide + hydrogen

- The reactions with magnesium, iron and zinc and cold water are very slow

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Reaction with dilute acids

- Only metals **above hydrogen** in the reactivity series will react with dilute 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:

metal + acid → salt + hydrogen

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

Acid-Metal Reactions Table

Acid	Sulfuric Acid	Hydrochloric Acid
Magnesium	$Mg + H_2SO_4 \longrightarrow MgSO_4 + H_2$	$Mg + 2HCl \longrightarrow MgCl_2 + H_2$
Zinc	$Zn + H_2SO_4 \longrightarrow ZnSO_4 + H_2$	$Zn + 2HCl \longrightarrow ZnCl_2 + H_2$
Iron	$Fe + H_2SO_4 \longrightarrow FeSO_4 + H_2$	$Fe + 2HCl \longrightarrow FeCl_2 + H_2$

Reaction with metal salts

- The reactivity between two metals can be compared using **displacement reactions** in salt solutions of one of the metals
- This is easily seen as the more reactive metal slowly **disappears** from the solution, **displacing** the less reactive metal
- For example, magnesium is a reactive metal and can displace copper from a copper sulfate solution:

Mg + CuSO4→ MgSO4 + Cu

- The blue color of the CuSO4 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

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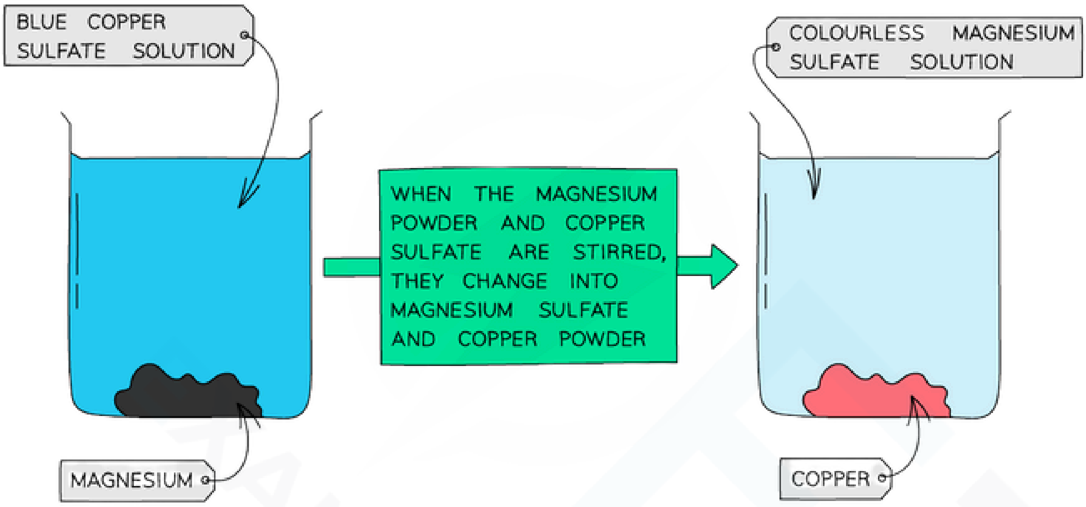

Diagram showing the colour change when magnesium displaces copper from copper sulfate

- 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	$Mg + FeSO_4 \longrightarrow MgSO_4 + Fe$
Zinc and Sodium Chloride	No Reaction as Sodium is above Zinc	—
Lead and Silver Nitrate	Lead (II) Nitrate and Silver	$Pb + 2AgNO_3 \longrightarrow Pb(NO_3)_2 + 2Ag$
Copper and Calcium Chloride	No Reaction as Calcium is more reactive than Copper	$Fe + CuSO_4 \longrightarrow FeSO_4 + Cu$
Iron and Copper (II) Sulfate	Iron (II) Sulfate and Copper	—

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- From this table we can see that the relative reactivity of the pairs of metals is
  - Mg > Fe
  - Pb > Ag
  - Fe > Cu

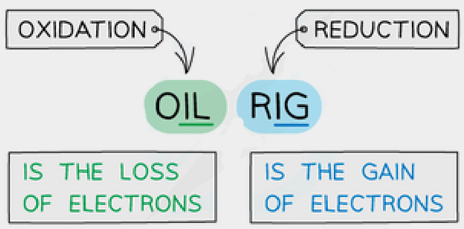
Explaining Reactivity

- In all these reactions the more reactive metals lose electrons to become cations
- The more reactive the metal the more easily it becomes a cation:

$$M \rightarrow M^{n+} + ne^-$$

- The loss of electrons is oxidation
- The higher up the metal is in the reactivity series the more easily it will undergo oxidation
- Unreactive metals are therefore more resistant to oxidation

Exam Tip



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4.1.2 METAL DISPLACEMENT REACTIONS & REDOX

Higher Tier Only

Displacement Reactions & Redox

- Using the principles of electron loss and gain it is possible to identify which species undergo oxidation and reduction in metal displacement reactions
- We have seen previously that the more reactive metals displace the less reactive metals, but how does this relate to redox?
- Remember that:
  - **Oxidation** is the **loss** of electrons
  - **Reduction** is the **gain** of electrons
- By identifying what has happened to the electrons in displacement reaction we can deduce the redox changes taking place
- Using the reaction between zinc and copper(II) sulfate as an example:
  - Zinc displaces copper from a solution of copper(II) sulfate
  - Using ionic equations, determine which species undergoes oxidation and which species undergoes reduction:

Deducing Redox Change in Displacement Reactions

Step	Working out
1. Write out the full equation	$Zn + CuSO_4 \longrightarrow ZnSO_4 + Cu$
2. Write out the ionic equation	$Zn(s) + Cu^{2+}(aq) + SO_4^{2-}(aq) \longrightarrow Zn^{2+}(aq) + SO_4^{2-}(aq) + Cu(s)$
3. Species oxidised	By analysing the ionic equation, it becomes clear that zinc has become oxidised as it has lost electrons: ◦ $Zn(s) \longrightarrow Zn^{2+}(aq)$
4. Species reduced	Copper has been reduced as it has gained electons: ◦ $Cu^{2+}(aq) \longrightarrow Cu(s)$

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Exam Tip

After writing half equations, you can see if they are correct by checking that the number of electrons on either side is the same, which should combine to give 0 charge.

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4.1.3 EXTRACTING METALS

Sources of Metals

- The Earth's crust contains metals and metal compounds such as gold, copper, iron oxide and aluminium oxide
- Useful metals are often **chemically combined** with other substances forming **ores**
- A metal ore is a rock that contains enough of the metal to make it worthwhile extracting
- They have to be extracted from their ores through processes such as **electrolysis**, using a **blast furnace** or by reacting with **more reactive** material
- In many cases the ore is an **oxide** of the metal, therefore the extraction of these metals is a reduction process since oxygen is being removed
- Common examples of oxide ores are **iron** and **aluminium** ores which are called **haematite** and **bauxite** respectively
- Unreactive metals do not have to be extracted chemically as they are often found as the **uncombined** element
- This occurs as they do not easily react with other substances due to their **chemical stability**
- Examples include **gold** and **platinum** which can both be mined directly from the Earth's crust

Extracting Metals

Extraction of metals and the reactivity series

- The most reactive metals are at the **top** of the series
- The tendency to become **oxidised** is thus linked to how **reactive** a metal is and therefore its **position** on the reactivity series
- Metals higher up are therefore **less resistant** to oxidation than the metals placed lower down which are **more resistant** to oxidation
- The position of the metal on the reactivity series determines the method of extraction
- Higher placed metals (above carbon) have to be extracted using **electrolysis** as they are too reactive and cannot be reduced by carbon
- Lower placed metals can be extracted by heating with carbon which **reduces** them

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Metals Extraction Method Table

Metal	Abbreviation
Most reactive	
Pottassium	Extracted by electrolysis of the moten chloride or molten oxide Large amounts of electricity required: expensive process
Sodium	
Lithium	
Calcium	
Magnesium	
Aluminium	
Carbon	
Zinc	Extracted by heating with a reducing agent such as carbon or carbon monoxide in a blast furnace
Iron	
Hydrogen	
Copper	
Silver	Found as pure elemets
Gold	
Least reactive	

The extraction method depends on the position of a metal in the reactivity series

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Exam Tip

Make sure you can explain why aluminium is extracted by electrolysis while iron is extracted by reduction as it is a question that often comes up.

4.1.4 BIOLEACHING & PHYTOMINING

Higher Tier Only

Bioleaching & Phytomining

- Extraction of metal ores from the ground is only economically viable when the ore contains sufficiently high proportions of the useful metal, such as iron ores and aluminium ores
- For low grade ores (ores with lower quantities of metals) other techniques are being developed to meet global demand
- This is happening in particular with nickel and copper as their ores are becoming more and more **scarce**
- **Phytoextraction** and **bioleaching** (bacterial) are two relatively new methods of extracting metals that rely on **biological processes**
- Both of these methods avoid the significant **environmental damage** caused by the more traditional methods of mining
- Traditional mining involves a great deal of digging, moving and disposing of large amounts of rock
- Biological methods are, however, very **slow** and also require either displacement or electrolysis to purify the extracted metal
- Both techniques are also used to extract metals from mining wastes, which may contain small quantities of metals or toxic metals that need to be removed from that environment

Phytomining

- This process takes advantage of how some plants **absorb metals** through their roots
- The plants are grown in areas known to contain metals of interest in the **soil**
- As the plants grow the metals are taken up through the plants vascular system and become **concentrated** in specific parts such as their **shoots** and **leaves**
- These parts of the plant are harvested, dried and burned
- The resulting ash contains metal compounds from which the useful metals can be extracted by displacement reactions or electrolysis

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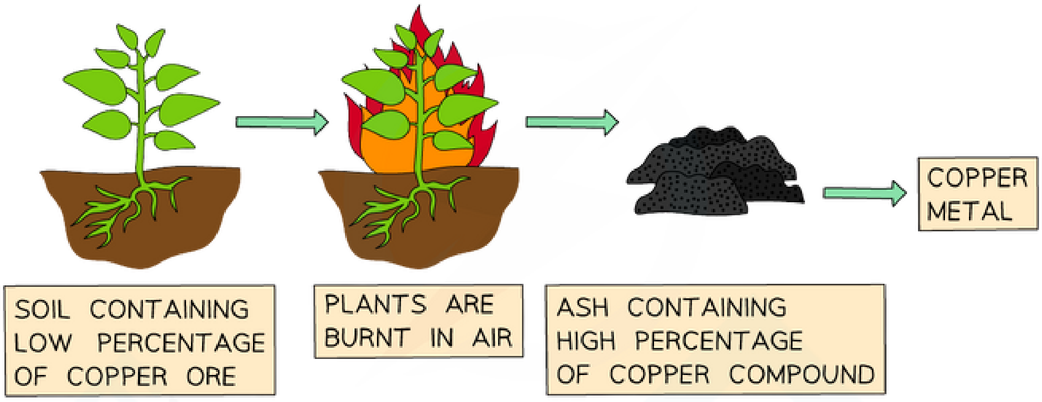

Copper in soil can be extracted by phytoextraction

Bioleaching

- Bioleaching is a technique that makes use of bacteria to extract metals from metal ores
- Some strains of bacteria are capable of breaking down ores to form acidic solutions containing metals ions such as copper(II)
- The solution is called a **leachate** which contains significant quantities of metal ions
- The ions can then be reduced to the solid metal form and extracted by displacement reactions or electrolysis
- This method is often used to extract metals from sulfides e.g. CuS or Fe2S
- Although bioleaching does not require high temperatures, it does produce toxic substances which need to be treated so they don't contaminate the environment
- Bioleaching is not only used for the primary extraction of metals, but it is also used in mining waste clean up operations

Exam Tip

Phytoextraction and bioleaching are principally used for copper extraction due to the high global demand for copper, but these methods can be applied to other metals.

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4.1.5 RECYCLING METALS

Recycling Metals

- Everyday materials such as metals are produced from **natural** but **finite** sources
- Some products made from these materials can be **reused** which saves energy and decreases the environmental impact
- Metals can be melted and **recast** into new shapes
- Sometimes the materials being recycled need to be kept separate, depending on what the use of the recycled material will be
- Iron for example can be recycled together with waste steel as both materials can be added to a blast furnace, reducing the use of iron ore
- Recycling has advantages and disadvantages

Economic Implications

- It is **economically beneficial** to recycle metals, especially those that are costly to extract such as aluminium
- Recycling is fast becoming a **major industry** and provides **employment** which feeds back into the economy

Environment

- Mining and extracting metal from ores has **detrimental** effects on the environment and ecosystems
- It is much more **energy efficient** to recycle metals than it is to extract them as **melting** and **re-moulding** requires less energy
- Recycling decreases the amount of waste produced, hence saving space at **landfill** sites and energy in **transport**

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Iron & steel are metals widely used in construction

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Raw Materials

- There is a **limited supply** of every material on Earth
- As global populations increase there is greater need for effective recycling methods to attain **sustainable development**
- Mining and extraction use up valuable **fossil fuels**, which contributes to **climate change**

Iron ore supplies can be conserved and will last longer if iron is recycled

Disadvantages

- Collection and transport of material to be recycled requires **energy** and **fuel**
- Workers, vehicles and worksites need to be organised and maintained
- Materials need to be sorted **before** they can be recycled which also requires **energy** and labour
- Products made from recycled materials may not always be of the **same quality** as the original

Exam Tip

You should be able to evaluate the advantages of recycling metals and how recycling can preserve both the environment and the supply of valuable raw materials.

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4.1.6 LIFE CYCLE ASSESSMENT

Life Cycle Assessment

- A life cycle assessment (LCA) is an analysis of the overall environmental impact that a product may have throughout its lifetime
- The cycle is broken down into four main stages which are:
  - Raw Materials
  - Manufacture
  - Usage
  - Disposal

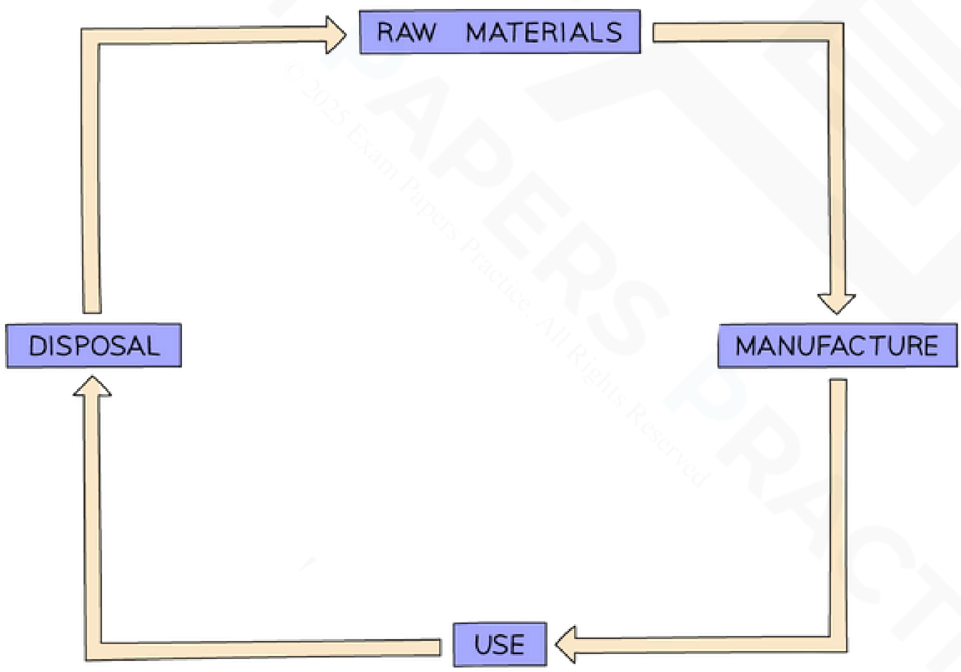

Diagram showing the four stages in a life-cycle assessment

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- Obtaining the necessary raw materials has an impact on the environment which may include:
  - Using up limited resources such as **ores** and **crude oil**
  - Damaging habitats through **deforestation** or **mining**
- Manufacturing processes also have an impact on the environment which may include:
  - Using up **land** for factories
  - The use of fossil fuelled machines for production and transport
- Usage of a product may also affect the environment although it depends on the type of product
- For example, a wooden desk has very little impact whereas a car will have a significant impact (air pollution)
- The disposal of outdated products has an impact on the environment which may include:
  - Using up space at **landfill sites**
  - Whether the product or its parts can be **recycled**
- A life cycle assessment is carried out using the data of a given product and the criteria of the assessment
- Rarely is there a perfect product with zero environmental impact, so often a compromise is made between environmental impact and economical factors

Exam Tip

Life cycle assessments are objective exercises as it is difficult to quantify each stage. LCA's can therefore be biased.

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Evaluating LCA

Example

An LCA can be carried out on plastic and paper shopping bags.

	Plastic	Paper
Raw Materials	Crude oil which is a finite source which requires a lot of energy to process	Recycled paper ot trees. Making paper requires more energy than recycling paper but much less than making plastics
Manufacture	Fractional distillation, cracking & polymerisation, not much waste as crude oil is completely used and cheap to manufacture	Pulping paper uses a lot of energy, sulfur dioxide and produes waste
Usage	Is reusable	Most are not reusable
Disposal	Can be recycled but is costly and produces pollution. Can be stored in a landfill, takes up space and is not biodegradable	Biodegradable, non-toxic and can be recycled

Conclusion

- Considering both life-cycle assessments, the plastic bag may be the better option. Even though they aren't biodegradable, they do have a **much longer lifespan** and thus are less harmful than paper bags
- Much depends on the usage of the item:
  - If the paper bag is recycled then it could be more favourable to use it
  - If the plastic bag is used only once, then then the argument for using plastic bags is less favourable