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TOPIC 8: METALS

THE ABOUT

CHAPTER ANALYSIS

TIME

- Heavy content chapter
- 5 **key** concepts
- 2 **advanced** concepts

EXAM

- Always tested in exams, MCQ and FRQ
- Require a little knowledge from chapters like:
  → Periodic Table, Oxidation & Reduction

WEIGHTAGE

- Heavy_Medium overall weightage
- Constitute to **5.5%** of marks for past 5 year papers

KEY CONCEPT

METALS
PHYSICAL PROPERTIES OF METAL ALLOYS

PHYSICAL PROPERTIES OF METAL

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1) Metals are **ductile** (able to be stretched into wires without losing toughness).

2) Metals are **malleable** (able to be bent into different shapes without breaking).

3) Metals are **good conductors of electricity and heat**.

4) Metals have **high melting and boiling points** and generally are solids at room temperature.

5) Metals have **high density.**

6) Metals are generally **strong and shiny**.

Exceptions:

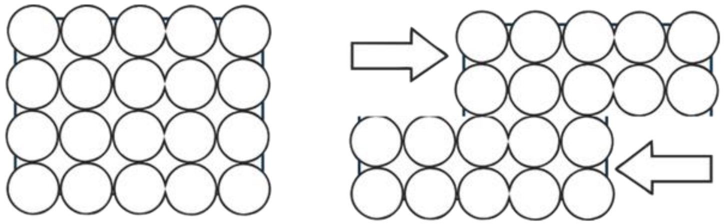
- Mercury has a low melting point (–39 ºC) and exists as a liquid at room temperature.

- Group I metals such as lithium, sodium and potassium have low densities and float on water.

ALLOYS

PURE METAL

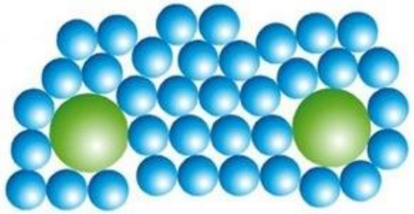
Pure metals are soft and as the **layers of metal atoms** would **slide over one another easily** when an external force is applied to them.



ALLOYS

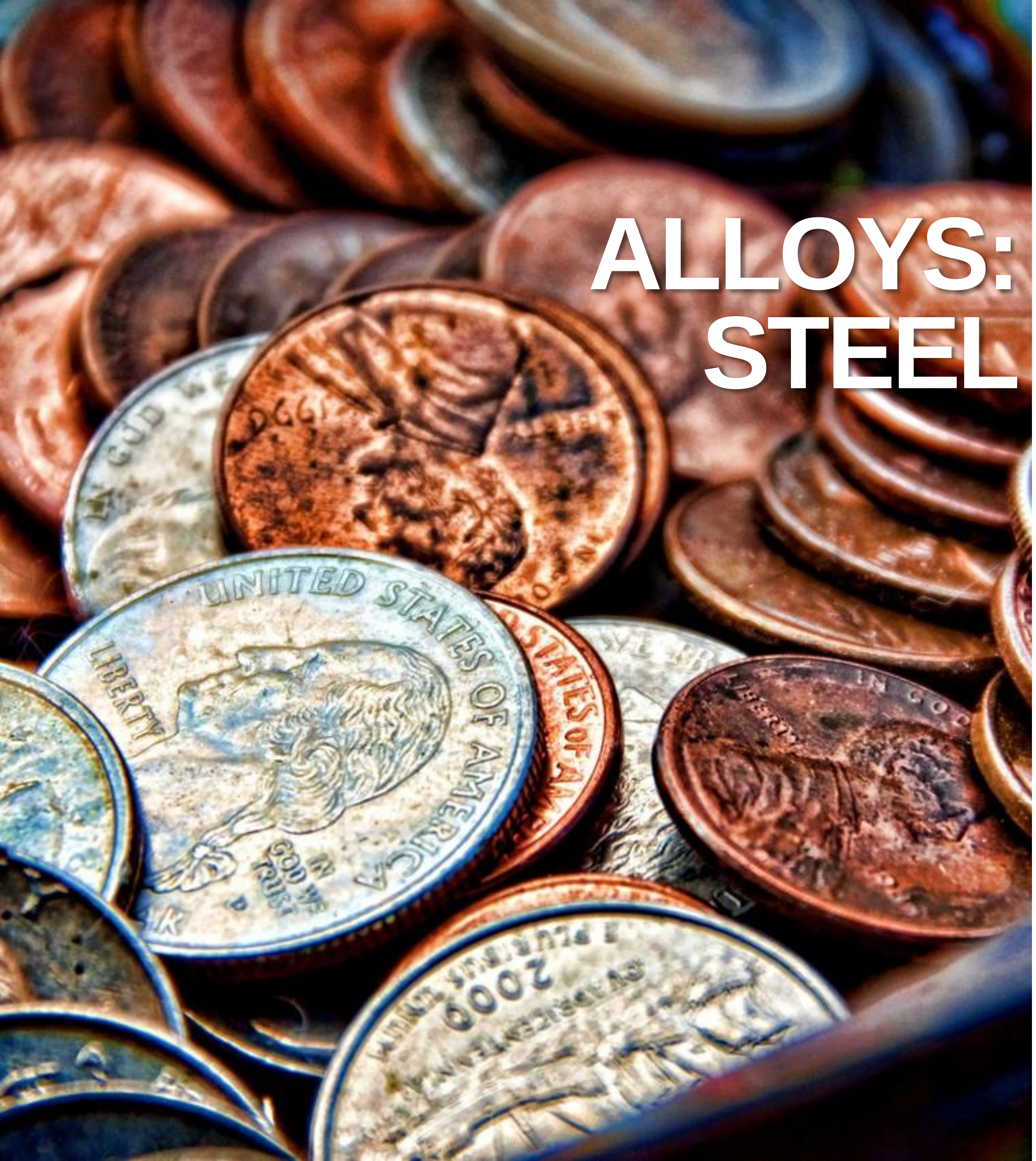
Alloys are a **mixtures of metals with other elements.**

In alloys, since the **atoms have different size**, the **orderly arrangement** of the metal atoms would be **disrupted**, making it tougher to slide over as easily. Hence, alloys are much **stronger and harder.**



Examples:

Steel: Iron, carbon (bodies of cars)
Stainless Steel: iron, carbon, chromium, nickel (medical instruments)
Brass: Copper, zinc (electrical plugs)
Bronze: Copper, tin (trophies)



ALLOYS: STEEL

STEEL

Steel is a good example of an alloy that is a mixture of iron with carbon or other metals.

By controlling the percentage of carbon in steel, it will form **high carbon** steels **or low carbon** steels**.**

Category	Type of Steel	Uses	Special Properties
Carbon Steels	**Mild Steel** *0.25% Carbon*	Car bodies and machinery	**Hard, strong and malleable**
	High Carbon Steel *0.45 – 1.5% Carbon*	Cutting and boring tools, e.g. knives, hammers	**Strong but brittle** (more carbon atoms to prevent sliding)
Alloy Steels	**Stainless Steel** *Alloy of iron, chromium, nickel & carbon.*	Equipments in chemical plants, cutlery, surgical instruments	Extremely **durable, resistant to rust and corrosion** even when heated

Qn: Explain how the properties of low carbon and high carbon steel differ.

Low carbon steel is softer as it is more malleable.

High carbon steel contains more carbon atoms which prevent sliding of the iron atoms. Hence, high carbon steel is harder but brittle.

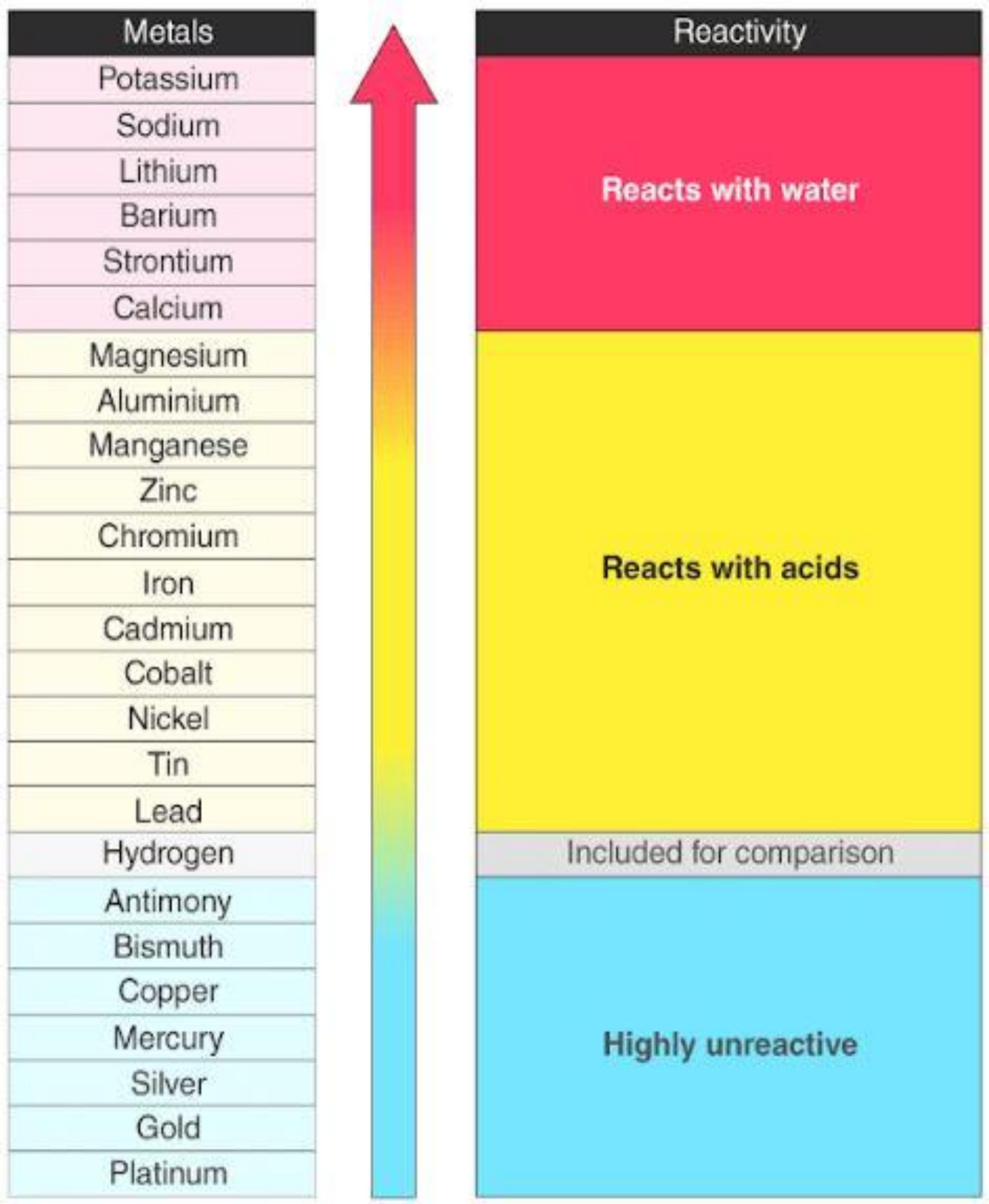
KEY CONCEPT

REACTIVITY SERIES
CHEMICAL REACTIONS OF METALS
DISPLACEMENT, DECOMPOSITION, RUSTING

MUST KNOW

Complete Summary Table

Acronym	Metal	Periodic Table	Stability	Reaction with water	Reaction with acid
Please	**Potassium (K)**	Group I	Compound broken down by electrolysis	Can react with cold water to form metal hydroxide	React with acid
Stop	**Sodium (Na)**				
Calling	**Calcium (Ca)**	Group II			
Me	**Magnesium (Mg)**			Can react with steam to form metal oxide	
A	**Aluminium (Al)**	Group III			
Cute	**Carbon (C)**	---	---		
Zombie	**Zinc (Zn)**	Transition Metals	Compound broken down by reduction with carbon		
I	**Iron (Fe)**				
Like	**Lead (Pb)**			Does not react with steam or cold water	
Hwa	**Hydrogen (H)**	---	---		---
Chong	**Copper (Cu)**	Unreactive Metals	Compound broken down by thermal decomposition		Does not react with acid
Sexy	**Silver (Ag)**				
Guys	**Gold (Au)**				



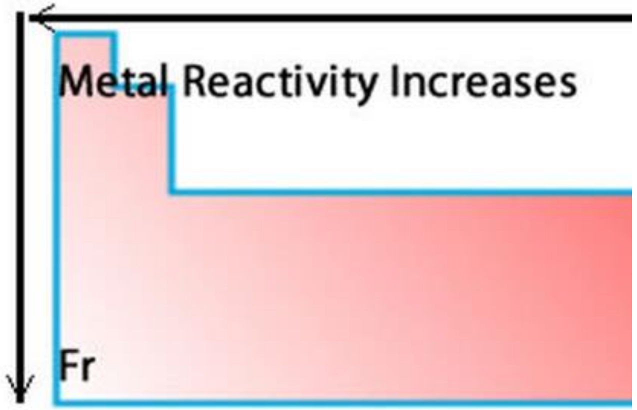
<u>REACTIVITY OF METALS</u>

Reactivity **increases going down the group** and from **right to left in the periodic table**.

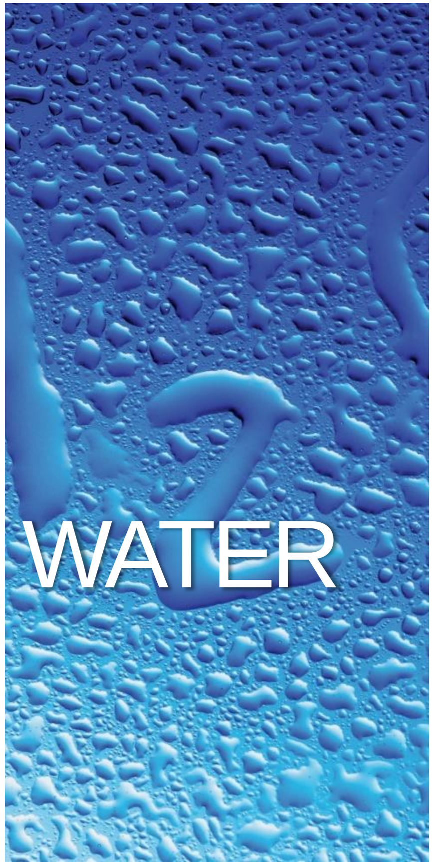
This means that **Group I metals have the best reactivity**.

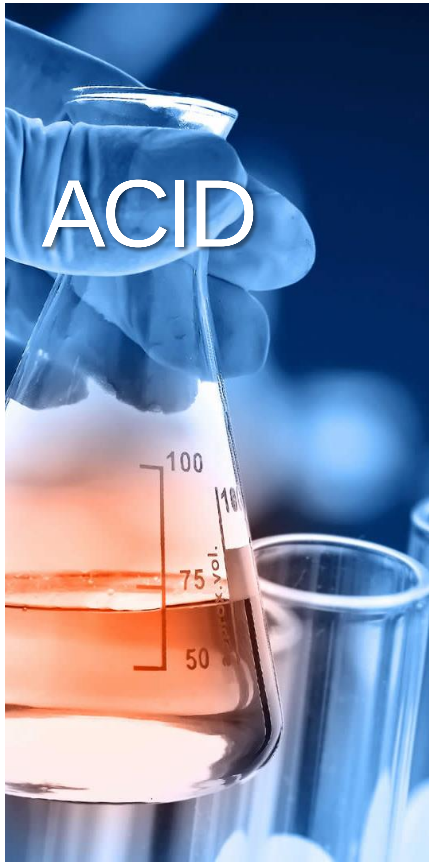
Going down the group, the metal has **more valence shells,** allowing it to **lose its valence electrons more readily,** hence it is more reactive.

(from chapter 'Periodic Table'.)



CHEMICAL REACTIONS OF METALS





METAL + WATER

METAL + WATER → METAL OXIDE / HYDROXIDE + HYDROGEN GAS

When metals react with water/steam, metal oxide or hydroxide is formed, along with hydrogen gas*.

Reactive metals (Group I and Ca) are able to react with cold H_2O.

Less reactive metals (Mg, Al and Zn) would only able to react with steam.

Unreactive metals (after Fe) are unable to react with water at all.

*Test for hydrogen gas using lighted splint, it should extinguish with 'pop sound.

METAL + WATER

Metal	Speed of Reaction	Observation	Chemical Equation
Potassium (K)	explosively in cold water	burns with lilac flame	$2K (s) + 2H_2O (l) \rightarrow 2KOH (aq) + H_2 (g)$
Sodium (Na)	violently in cold water	burns with yellow flame	$2Na (s) + 2H_2O (l) \rightarrow 2NaOH (aq) + H_2 (g)$
Calcium (Ca)	readily in cold water	vigorous effervescence	$Ca (s) + 2H_2O (l) \rightarrow Ca(OH)_2 (aq) + H_2 (g)$
Magnesium (Mg)	very slowly in cold water violently with steam	little effervescence burns with white glow	$Mg (s) + H_2O (g) \rightarrow MgO (s) + H_2 (g)$
Aluminium (Al)	readily in steam		$2Al (s) + 3H_2O (g) \rightarrow Al_2O_3 (s) + 3 H_2 (g)$
Zinc (Zn)	readily in steam	ZnO is yellow when hot white when cooled	$Zn (s) + H_2O (g) \rightarrow ZnO (s) + H_2 (g)$
Iron (Fe)	slowly in steam	requires constant heating	$3Fe (s) + 4H_2O (g) \rightarrow Fe_3O_4 (s) + 4H_2 (g)$

METAL + ACID

METAL + ACID → SALT + HYDROGEN GAS

When metals react with acid, salt and hydrogen gas* is produced.

More reactive metals (Group I and Ca) will result in a more vigorous/explosive reaction.

Less reactive metals (Zn, Fe) will have less effervescence of hydrogen gas from the reaction.

Less reactive metals (Pb) can only react with warm dilute hydrochloric acid.

*Test for hydrogen gas using lighted splint, it should extinguish with 'pop sound.

METAL + ACID

Metal	Speed of Reaction	Chemical Equation
Potassium (K)	Explosively in acid	$2\ K(s) + 2\ HCl\ (aq) \rightarrow 2KCl\ (aq) + H_2\ (g)$
Sodium (Na)	Explosively in acid	$2\ Na(s) + 2HCl\ (aq) \rightarrow 2NaCl\ (aq) + H_2\ (g)$
Calcium (Ca)	Violently in acid	$Ca(s) + 2HCl\ (aq) \rightarrow CaCl_2\ (aq) + H_2\ (g)$
Magnesium (Mg)	Rapidly in acid	$Mg(s) + 2HCl\ (aq) \rightarrow MgCl_2\ (aq) + H_2\ (g)$
Aluminium (Al)	Readily in acid	$4\ Al\ (s) + 6HCl\ (aq) \rightarrow 2\ Al_2Cl_3\ (s) + 3\ H_2\ (g)$
Zinc (Zn)	Moderately in acid	$Zn(s) + 2HCl\ (aq) \rightarrow ZnCl_2\ (aq) + H_2\ (g)$
Iron (Fe)	Slowly in acid	$Fe(s) + 2\ HCl\ (aq) \rightarrow FeCl_2\ (aq) + H_2\ (g)$
Lead (Pb)	Slowly in acid	$Pb(s) + 2\ HCl\ (aq) \xrightarrow[\text{heating}]{} PbCl_2\ (s) + H_2\ (g)$

RUSTING

The **corrosion of iron and steel** is called rusting. This occurs when iron corrodes due to a chemical reaction with oxygen in air and water.

After rusting occurs, iron becomes **hydrated iron(III) oxide,** a brown solid with the chemical formula:

$$Fe_2O_3 . xH_2O$$

Iron **must be in contact** with **both air (oxygen) and water** in order for it to rust.

Seawater will cause rusting faster due to the presence of ions in seawater that act as a charge carrier.

PREVENTING RUSTING

Surface Protection

Paint, oil, plastic and metal plating are some commonly used protective layers that would prevent air and water from coming into contact with iron (or steel) under the protective layer.

Sacrificial Metals

If iron is in contact with a **more reactive metal** like magnesium or zinc, then the rusting of iron is greatly minimised. These reactive metals would be diminished in place of iron.

Stainless Steel

Stainless steel is an **iron alloy** that consists of iron and chromium or nickel.

It does not rust easily, as these metals would react with the oxygen in the air to produce a **stable metal oxide layer**.

KEY CONCEPT

EXTRACTION OF METALS
ELECTROLYSIS, REDUCTION, HYDROGEN
BLAST FURNACE

EXTRACTION OF METALS

The method chosen to extract a given metal from its ore depends on the **reactivity of the metal** and the **stability of the metal oxides**.

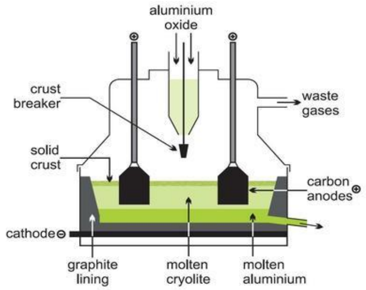
In general, very reactive metals can only be extracted using electrolysis, while less reactive metals would be extracted by reduction with carbon/hydrogen.

Metal	Extraction method	Reduction by hydrogen
Potassium (**K**)	**Electrolysis**	**Cannot be reduced by hydrogen**
Sodium (**Na**)		
Calcium (**Ca**)		
Magnesium (**Mg**)		
Aluminium (**Al**)		
Carbon (**C**)	---	
Zinc (**Zn**)	**Displacement / reduction with carbon**	
Iron (**Fe**)		**Reduced by hydrogen**
Lead (**Pb**)		
Hydrogen (**H**)	---	
Copper (**Cu**)	**Heating in air**	
Silver (**Ag**)	**Exist naturally as metal**	
Gold (**Au**)		

REDUCTION BY ELECTROLYSIS

Electrolysis is the most powerful extraction method. Due to the high usage of electricity, it is a highly expensive process.

Hence, electrolysis would only be utilised for the **most reactive metals** like potassium, sodium, calcium, magnesium and aluminium.



REDUCTION BY CARBON

Metals that can be extracted by this method are **zinc, iron, tin and lead.**

Lead(II) oxide is reduced by carbon to become pure lead metal.

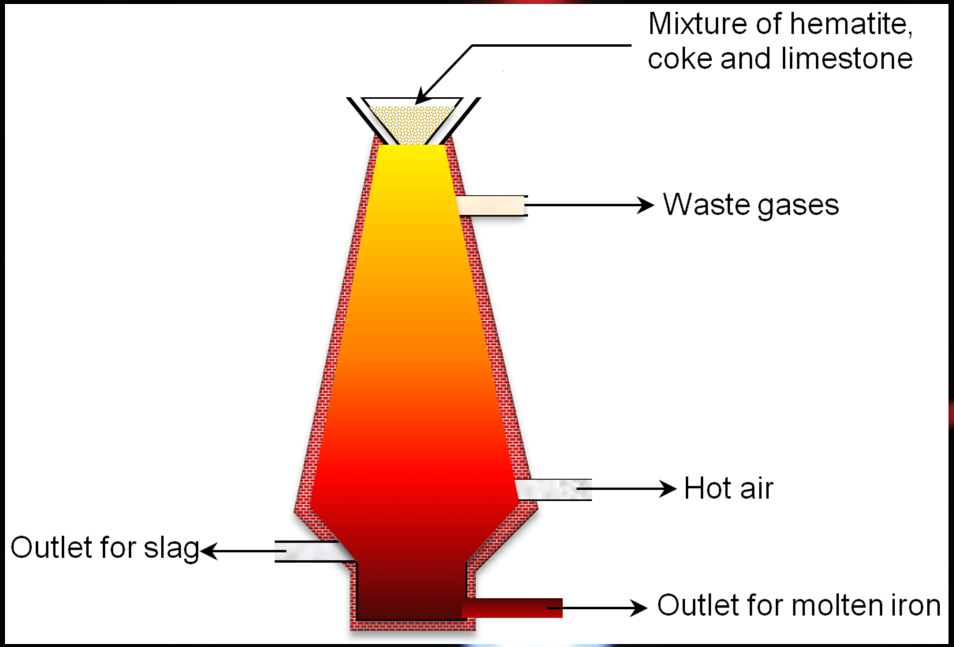
$$PbO\ (s) + C\ (s) \rightarrow Pb\ (s) + CO\ (g)$$

REDUCTION BY HYDROGEN

Metals that can be extracted by this method from their oxides are **iron, copper and lead.**

$$CuO\ (s) + H_2\ (g) \rightarrow Cu\ (s) + H_2O\ (g)$$

EXTRACTION OF IRON



BLAST FURNACE

Production of carbon dioxide

Carbon in coke reacts with oxygen in air to produce carbon dioxide.

$$C\ (s) + O_2\ (g) \rightarrow CO_2\ (g)$$

Limestone thermally decompose to form carbon dioxide and calcium oxide.

$$CaCO_3\ (s) \rightarrow CaO\ (s) + CO_2\ (g)$$

Production of carbon monoxide

Carbon dioxide reacts with more carbon in coke to form carbon monoxide.

$$CO_2\ (g) + C\ (s) \rightarrow 2\ CO\ (g)$$

The first 2 steps are meant to produce CO that will reduce the iron (III) oxide!

Reduction of haematite to iron

Carbon monoxide reduces iron(III) oxide in haematite to form molten iron.

$$Fe_2O_3\ (s) + 3CO\ (g) \rightarrow 2Fe\ (l) + 3CO_2\ (g)$$

Molten iron would sink to the bottom due to its high density and it exits through the bottom of the blast furnace.

Removal of impurities

Impurities such as silicon(IV) oxide are removed by reacting with calcium oxide.

$$CaO\ (s) + SiO_2\ (l) \rightarrow CaSiO_3\ (l)$$

$CaSiO_3$ is called calcium silicate or slag, would float on top of molten iron due to it being less dense, is removed separately.

RECYCLING

RECYCLING OF METALS

Metals are finite resources and would need to be conserved.

As the amount of metal ores in the Earth is limited, if metal extraction continues at the current rate, the supplies of many metals will run out in the future.

	Upside	Downside
Economic	Cost savings from extraction of new metals from their ores. Fewer landfills required.	Recycling is very expensive, such as costs from collection, transportation and separation of the scrap metals.
Social	Conservation of the limited non-renewable metals on Earth. More land will be available for other uses.	If done wrongly, separation of metal waste uses more effort and resources. Time and manpower to do recycling.
Environmental	Reduce greenhouse gas like CO_2 from combustion of fossil fuels to power extraction factories. Reduces production of waste gases like CO.	The recycling process may cause additional pollution if not handled properly.