

# Metallurgy

## Metals and Non-metals

### Position and characteristics of metals in the periodic table

Group		Alkali metals & Alkaline Earth metals – Elements on the extreme left	
1	2	Property	Reason
Li	Be	• Light -metals	• Large atomic size and so low density.
Na	Mg	• Soft –metals	• Possess 1 or 2 valence electrons which cannot bind atoms firmly so energy binding the atoms is low.
K	Ca	Low–melting points	
Rb	Sr	• Highly –reactive	• Large atomic size, 1 or 2 valence electrons can be easily removed i.e. have low ionization potential.
Cs	Ba	Strongly-electropositive	
Fr	Ra	Strong –reducing agents	

Group		Alkali metals & Alkaline Earth metals – Elements on the extreme left	
3 to 12		Property	Reason
Fe		• Heavy - hard metals	• Small atomic size, so high density and energy binding the atoms is high.
Zn		High - melting points	
		• Electropositive nature between -strong and weak	• Elements are between strongly electropositive group 1 and weakly electropositive group 13. I.P increases across the period.

Group		Alkali metals & Alkaline Earth metals – Elements on the extreme left	
13 to 16		Property	Reason
Al		• Weakly - electropositive	• Smaller atomic size, higher I.P, less tendency to lose 3 valence electrons

## Characteristics of Alkali Metals and Alkaline Earth Metals

	<b>Alkali metals</b>	<b>Alkaline earth metals</b>
<b>Position</b>	• Group I [IA]	• Group II [IIA]
<b>Properties</b>	<ul style="list-style-type: none"> <li>• Low density</li> <li>• Low melting point</li> <li>• Low boiling point</li> <li>• Characteristic colour</li> <li>• Strongly electropositive character</li> <li>• Highly reactive</li> </ul>	<ul style="list-style-type: none"> <li>• Higher density</li> <li>• Higher melting point</li> <li>• Higher boiling point</li> <li>• Mg and Be do not give characteristic colour</li> <li>• Less electropositive nature</li> <li>• Less reactive</li> <li>• Tarnish slowly and form a layer of oxide when exposed to moist air</li> </ul>
<b>Action of air</b>	$M + O_2 \rightarrow M_2O \rightarrow MOH$	$M + 2H_2O \rightarrow M(OH)_2 + H_2$ $M + H_2SO_4 \rightarrow MSO_4 + H_2$
<b>Action of water</b>	$2M + 2H_2O \rightarrow 2MOH + H_2$	
<b>Action of acids</b>	$M + 2HCl \rightarrow MCl_2 + H_2$	

## Comparison of Metals and Non-metals

### • Physical Properties of Metals and Non-metals

<b>Metals</b>	<b>Non-metals</b>
• Metals are generally hard solids and vaporise only at high temperature.	• Non-metals are generally soft and usually gases or liquids.
• Metals have a lustre called metallic lustre and can be polished.	• Non-metals lack lustre.
• Their melting and boiling points are high (except alkali metals and Hg).	• Non-metals usually have low melting and boiling points.
• Metals have high density except alkali metals such as Na, K etc.	• Non-metals generally have low density.
• Metals are generally malleable and ductile and have high tensile strength.	• Non-metals are non-malleable and non-ductile.
• Metals form alloys and amalgams. Bronze is an alloy of Copper, Tin and Zinc. Sodium amalgam is an alloy of Mercury and Sodium.	• Non-metals do not form alloys.
• Metals are hard but not brittle.	• Non-metals are brittle in nature.
• Metals are generally good conductors of heat and electricity.	• Non-metals are bad conductors of heat and electricity.
• Metals do not generally dissolve in liquids except by a chemical reaction.	• They are generally soluble in water or other solvents and do not react with them chemically, i.e. no chemical reaction occurs.

- Chemical properties of metals and non-metals

<i>Metals</i>	<i>Non-metals</i>
<ul style="list-style-type: none"> <li>Electronic configurations of metals have 1, 2 or 3 valence electrons.</li> </ul>	<ul style="list-style-type: none"> <li>Electronic configurations of non-metals have 4, 5, 6 or 7 valence electrons.</li> </ul>
<ul style="list-style-type: none"> <li>Metals are electropositive in nature. They readily lose electrons and form positively charged ions called cations.</li> </ul>	<ul style="list-style-type: none"> <li>Non-metals are electronegative in nature. They readily gain electrons and form negatively charged ions called anions</li> </ul>
<ul style="list-style-type: none"> <li>Because metals lose electrons during a chemical reaction, they are good reducing agents.</li> </ul>	<ul style="list-style-type: none"> <li>Non-metals possess a property to gain electrons; hence, they are good oxidising agents.</li> </ul>
<ul style="list-style-type: none"> <li>Oxides of metals may be basic in nature and dissolve in water to form an alkaline solution.</li> </ul>	<ul style="list-style-type: none"> <li>Non-metals generally form acidic oxides and dissolve in water to form an acidic solution.</li> </ul>
<ul style="list-style-type: none"> <li>Metals do not usually react with H<sub>2</sub>. Metals placed above hydrogen in the activity series react with dilute HCl and dilute H<sub>2</sub>SO<sub>4</sub> to liberate H<sub>2</sub> gas.  <math display="block">M + 2HCl \longrightarrow MCl_2 + H_2</math> <p style="text-align: center;">(dil.)</p> <math display="block">M + H_2SO_4 \longrightarrow MSO_4 + H_2</math> <p style="text-align: center;">(dil.)</p> </li> </ul>	<ul style="list-style-type: none"> <li>Non-metals do not react with dilute acids to liberate hydrogen.</li> </ul>
<ul style="list-style-type: none"> <li>Metals react readily with Cl<sub>2</sub> to form chlorides.</li> </ul>	<ul style="list-style-type: none"> <li>Non-metals usually form chlorides, which are volatile covalent liquids or gases.</li> </ul>
<ul style="list-style-type: none"> <li>Metals form electrovalent or ionic compounds. Metallic salts conduct electricity in the fused state or in solution because of the free electrons or ions. Examples: NaCl, CaCl<sub>2</sub>, MgCl<sub>2</sub>. When electric current is passed through molten calcium chloride, calcium metal is liberated at the cathode and chlorine at the anode.  <math display="block">CaCl_2 \longrightarrow Ca^{2+} + 2Cl^-</math> <p style="text-align: center;">(molten)</p> <p>At cathode:</p> <math display="block">Ca^{2+} + 2e^- \longrightarrow Ca</math> <p>At anode:</p> <math display="block">Cl^- - e^- \longrightarrow Cl</math> <math display="block">Cl + Cl \longrightarrow Cl_2</math> </li> </ul>	<ul style="list-style-type: none"> <li>Non-metals form covalent compounds which do not conduct electricity because there are no free electrons or ions to carry the current.</li> </ul>

## Study of Activity Series of Metals

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### Activity Series of Metals

Metals differ in tendency to lose electrons and hence can be arranged in a series according to their tendency to give up valence electrons.

### Activity Series

It is a series of metals arranged according to their decreasing reactivity.

The metals at the top of the series are

- Most easily oxidised
- Most electropositive
- Capable of displacing the metal below from its salt solution

### Reactions of Metals

Metals	Reaction with acid
K	Reacts explosively with dilute acid liberating hydrogen. $2\text{Na} + 2\text{HCl} \rightarrow 2\text{NaCl} + \text{H}_2$
Na	
Ca	
Mg	Calcium reacts less vigorously $\text{Ca} + 2\text{HCl} \rightarrow \text{CaCl}_2 + \text{H}_2$ Reacts with dilute acids less vigorously, liberating hydrogen. $\text{Mg} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2$
Al	Due to great affinity towards oxygen, a coating of oxide is formed which does not allow any further reaction with acid.
Zn	$\text{Zn} + 2\text{HCl} \rightarrow \text{ZnCl}_2 + \text{H}_2$
Fe	$\text{Fe} + 2\text{HCl} \rightarrow \text{FeCl}_2 + \text{H}_2$
Pb	Lead reacts with conc. HCl to liberate hydrogen. $\text{Pb} + 2\text{HCl} \rightarrow \text{PbCl}_2 + \text{H}_2$
[H]	Do not produce hydrogen on reaction with dilute or conc. acids.
Cu	
Hg	
Ag	
Pt	
Au	

## Characteristics of Metallic Compounds

	Oxides	Hydroxides	Carbonates	Nitrates
K Na	K, Na Stable to heat Soluble in water	K, Na Stable to heat Soluble in water	K, Na Stable to heat Soluble in water	K, Na Decomposes to give nitrite and oxygen $2\text{KNO}_3 \rightarrow 2\text{KNO}_2 + \text{O}_2$
Ca Mg Al Zn Fe Sn Pb [H] Cu	Ca to Cu Stable to heat	Ca to Cu Decomposes to give metal oxide and water $\text{Ca}(\text{OH})_2 \rightarrow \text{CaO} + \text{H}_2\text{O}$	Ca to Cu Decomposes to give metal oxide and $\text{CO}_2$ $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$	Ca to Cu Decomposes to give metal oxide and $\text{NO}_2$ $2\text{Ca}(\text{NO}_3)_2 \rightarrow 2\text{CaO} + 4\text{NO}_2 + \text{O}_2$
Hg Ag Pt Au	Hg to Au Decomposes to give metal and oxygen $2\text{Hg} \rightarrow 2\text{Hg} + \text{O}_2$	Hg to Au Hydroxides do not exist or are rarely formed Insoluble in water	Hg to Au Decomposes to give metal, $\text{CO}_2$ and $\text{O}_2$ Insoluble in water	Hg to Au Decomposes to give metal, $\text{NO}_2$ and $\text{O}_2$ $2\text{AgNO}_3 \rightarrow 2\text{Ag} + 2\text{NO}_2 + \text{O}_2$

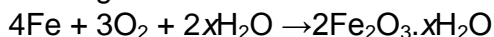
## Corrosion

When the surface of a metal is exposed to air, moisture or any other substance around it, the metal is said to corrode, and the phenomenon is known as corrosion.

- **Corrosion of Iron**

Corrosion of iron is known as rusting.

Rusting is the slow oxidation of iron by atmospheric oxygen in the presence of water.



- **Conditions Necessary for Rusting**

Presence of water (or moisture)

Presence of air (or oxygen)

- **Prevention of Corrosion**

**Barrier protection:** The process in which the metal surface is not allowed to come in contact with atmospheric agents such as air or water is known as barrier protection.

For example, the metal (iron) is coated with another metal by using electricity in the process called electroplating.

**Sacrificial protection:** The metal to be protected is covered with a more electropositive metal such as zinc or magnesium. For example, iron is coated with zinc in the process called galvanisation.

# Extraction of Metals Based on the Activity Series

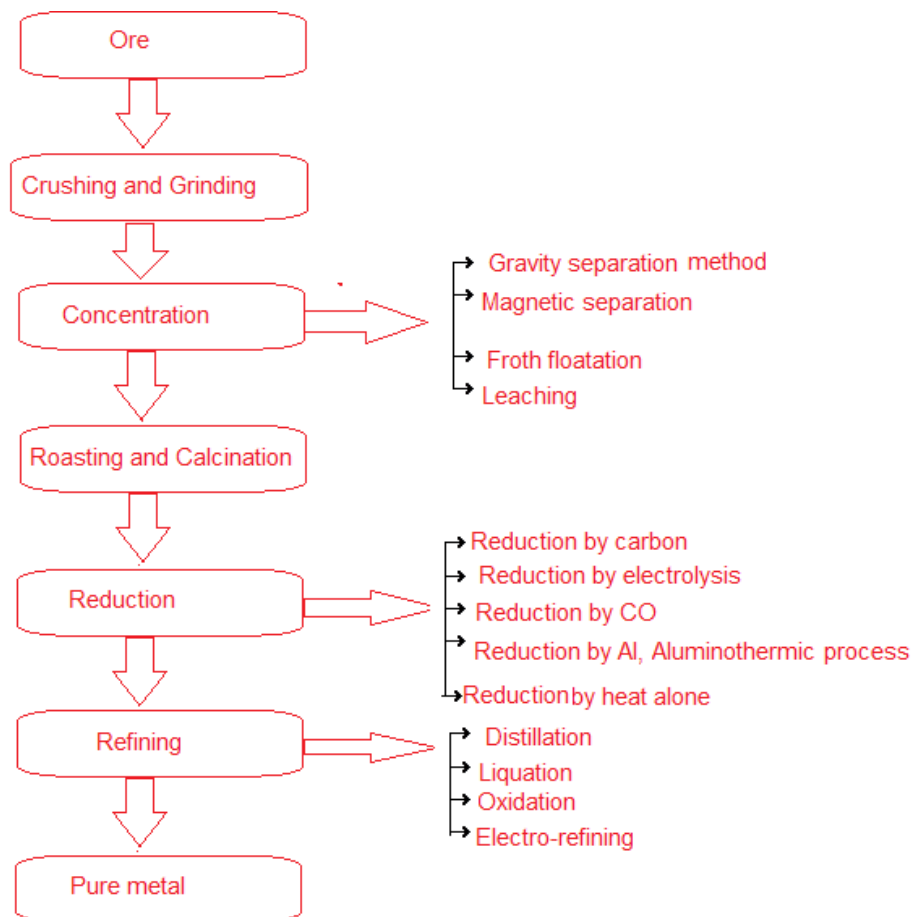
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## Common terms used in extraction

- **Metallurgy:** The process used for the extraction of metals in their pure form from their ores is called metallurgy.
- **Minerals:** The naturally occurring compounds of metals which are generally mixed with other matter such as soil, sand, limestone and rocks are known as minerals.
- **Gangue:** Earthy impurities, including silica and mud, associated with the ore is called gangue.
- **Ores:** Those minerals from which metals are extracted commercially at a comparatively low cost and with minimum effort are called ores.
- **Flux:** A flux is a substance which is added to the charge in a furnace to remove the gangue.
- **Slag:** It is the fusible product formed when flux reacts with impurities during the extraction of metals.
- **Smelting:** It is the process of reducing the roasted oxide ore and removing the gangue with the help of an appropriate flux added with the ore.

## Steps Involved in Extraction

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## Crushing and Grinding

Ores are crushed into a fine powder in big jaw crushers and ball mills. This process is called pulverisation.

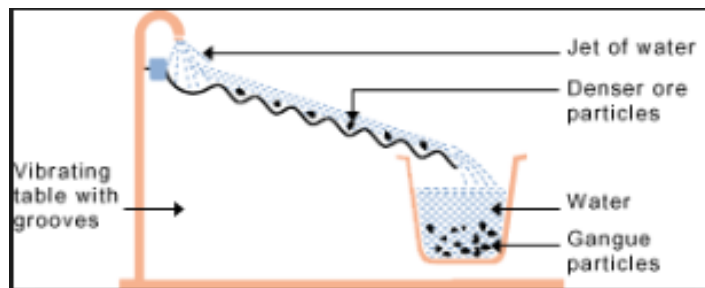
## Concentration of Ores

### Gravity separation

**Principle:** Separation of

- ORE - Denser ore particles settle in grooves on a vibrating sloped table.
- GANGUE - Lighter gangue particles washed down by water.

**Process:** The ore is poured over a vibrating sloped table with grooves, and a jet of water is allowed to flow over it. The dense ore particles settle down in the grooves.

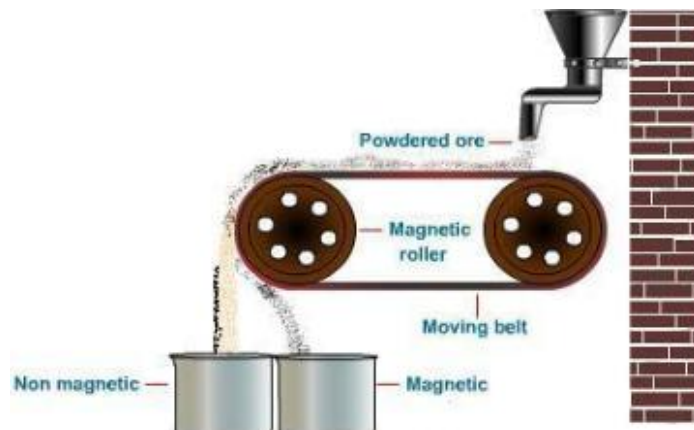


## Magnetic separation

**Principle:** Separation of

- ORE - Magnetic ore (e.g. iron ore)
- GANGUE - Non-magnetic

**Process:** The pulverised ore is placed on a conveyor belt. The magnetic particles are attracted to the magnetic wheel and fall away separately from the non-magnetic particles.

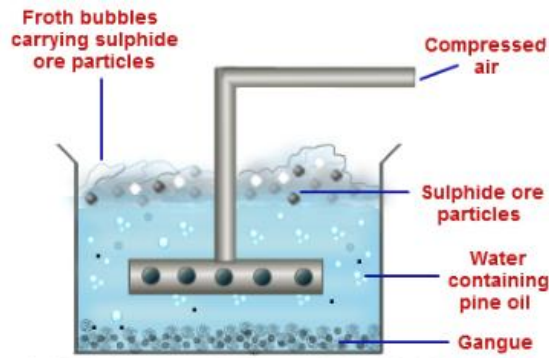


## Froth flotation

**Principle:** Separation of

- ORE - Preferentially wetted by the oil and hence floats on top as foam.
- GANGUE - Preferentially wetted by the water and settles down.

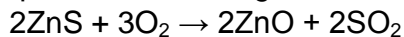
**Process:** This method is generally applied for sulphide ores. The ore is taken in a large tank containing oil and water and is agitated with a current of compressed air. The ore is wetted by the oil and separates from the gangue in the form of froth.



## Roasting and Calcination (If the ore is not an oxide)

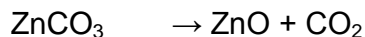
### A] Roasting

The process of heating the concentrated ore to a high temperature in the presence of excess air.



### B] Calcination

The process of heating the concentrated ore in the absence of air at a temperature not sufficient to melt the ore.

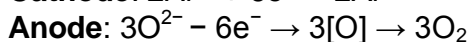
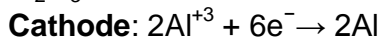
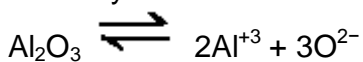


## Reduction in Metallic Oxides

### Reduction by electrolysis

Reduction in highly electropositive metals such as K, Na, Ca, Mg and Al oxides/halides.

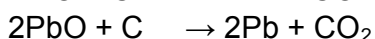
Electrolysis of fused metallic salts



Product at cathode: Pure aluminium metal

Product at anode: Oxygen gas

### Reduction by reducing agents





## Refining of Impure Metal

1. **Distillation:** For refining volatile metals. Examples: Zinc, mercury
2. **Liquation:** For refining low-melting-point metals. Examples: Lead, tin
3. **Oxidation:** For refining metals by oxidation of their impurities. Example: Iron
4. **Electrolytic refining:** For refining impure metals by electrolysis. Examples: Cu, Al, Pb

## Common Ores of Aluminium, Iron and Zinc

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Ore of Al	Chemical name	Formula
Bauxite	Hydrated aluminium oxide	$\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$
Cryolite	Sodium aluminium fluoride	$\text{Na}_3\text{AlF}_6$
Corundum	Anhydrous aluminium oxide	$\text{Al}_2\text{O}_3$

Ore of Fe	Chemical name	Formula
Red haematite	Anhydrous ferric oxide	$\text{Fe}_2\text{O}_3$
Brown haematite	Hydrated ferric oxide	$2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$
Magnetite	Triferric tetraoxide	$\text{Fe}_3\text{O}_4$
Iron pyrites	Iron disulphide	$\text{FeS}_2$
Siderite	Ferrous carbonate	$\text{FeCO}_3$

Ore of Zn	Chemical name	Formula
Zinc blende	Zinc sulphide	$\text{ZnS}$
Zincite	Zinc oxide	$\text{ZnO}$
Calamite	Zinc carbonate	$\text{ZnCO}_3$

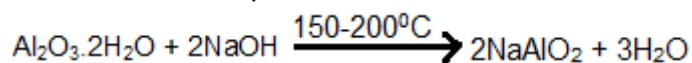
## Extraction of Aluminium

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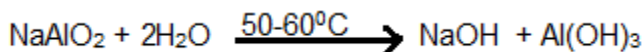
### Process for Extraction of Aluminium from Bauxite

#### 1. Concentration of Ore - Bayer process

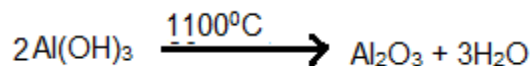
- i. Conversion of impure bauxite to sodium aluminate



- ii. Conversion of sodium aluminate to aluminium hydroxide



- iii. Conversion of  $\text{Al}(\text{OH})_3$  to pure alumina



## 2. Electrolytic Reduction in Metallic oxide – Hall Heroult process

**Electrolyte:** Mixture of molten alumina 20%, cryolite 60% and fluorspar 20%.

**Electrolytic cell:** Rectangular steel tank with carbon lining.

**Electrodes:**

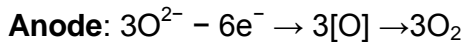
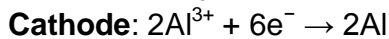
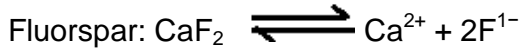
Cathode: Carbon lining (gas carbon)

Anode: Thick carbon (graphite)

**Temperature:** 950°C

**Current:** 100 amperes at 6–7 volts

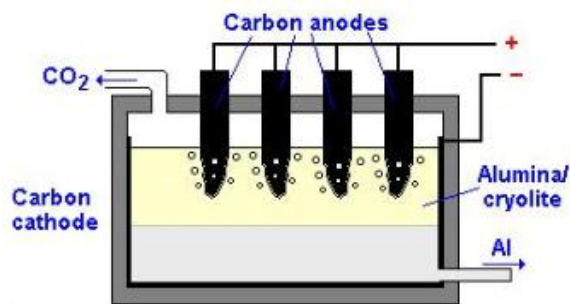
**Electrolytic reaction:**



Products formed:

At cathode: Pure aluminium metal

At anode: Oxygen gas



### Refining of Aluminium (Hoope's electrolytic process)

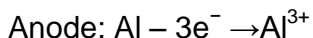
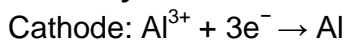
**Tank contains three immiscible layers**

**Upper layer:** Pure molten Al with carbon electrodes serves as cathode.

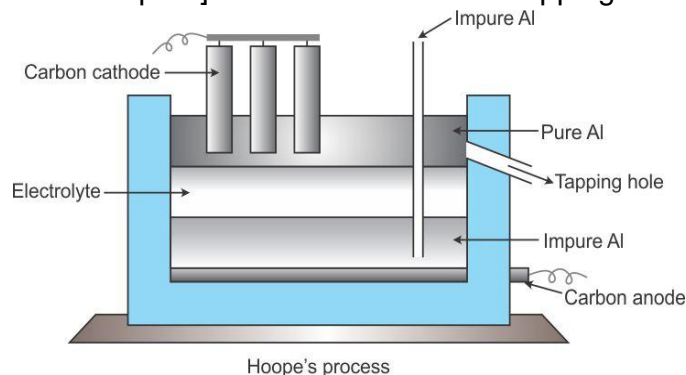
**Middle layer:** Mixture of cryolite, BaF<sub>2</sub>, AlF and CaF<sub>2</sub> serves as the electrolyte.

**Lower layer:** Impure Al at the bottom along with carbon lining acts as the anode.

**Electrolytic reaction:**



**Collection:** Pure Al [about 99.9% pure] is withdrawn from the tapping hole.



## Properties of Aluminium

### Physical properties

**Nature:** Silvery light metal, malleable and ductile

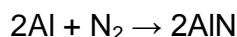
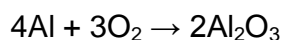
**Conductivity:** Good conductor of heat and electricity

**Boiling point:** 2050°C

**Melting point:** 660°C

### Chemical Properties

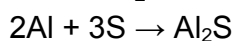
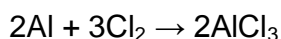
- **Action with Air**



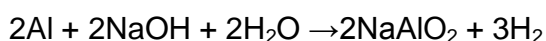
- **Action with Water**



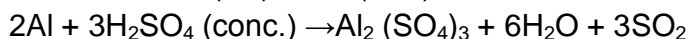
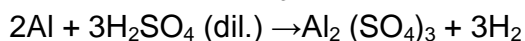
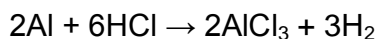
- **Action with Non-metals**



- **Action with Alkalis**



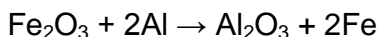
- **Action with Acids**



Nitric acid is rendered passive due to the formation of a thin aluminium oxide layer.

- **Reducing Action**

Reduces heated metallic oxides of Fe, Cr and Mn to metals.



## Uses of Metals and Alloys

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### Uses of Aluminium

- Being a strong, light and corrosion-resistant metal, it is used in alloys.
- Being a good conductor of electricity, it is used in the manufacture of cables for power transmission.
- Ships are made of alloys of aluminium because it is unaffected by sea water.

### Uses of iron

- Cast iron is used in drain pipes, gutter covers, weights and railings.
- Wrought iron is used in chains, horse shoes and electromagnets.
- Steel is used in the construction of buildings, overhead structures, machines and in various alloys.

### Uses of Zinc

- Mostly used for coating iron and steel sheets to prevent them from rusting.
- For making useful alloys such as brass, bronze and German silver.
- Zinc dust is used as a reducing agent for many organic reactions.
- Zinc compounds are used in paints, electroplating, preservatives for leather and a mordant for the dyeing of textiles.

## Alloys

An alloy is a homogeneous mixture of two or more metals or of one or more metals with certain non-metallic elements.

### • Reasons for Alloying

- i. To modify appearance and colour
- ii. To modify chemical reactivity
- iii. To modify casting ability
- iv. To lower the melting point
- v. To increase hardness and tensile strength
- vi. To increase resistance to electricity

### Some Important Alloys and their Uses

Name	Composition	Uses
Brass	Cu = 60–80% Zn = 40–20%	For making utensils, cartridges
Bronze	Zn = 2%, Cu = 80% Sn = 18%	For making utensils, statues and coins
Duralumin	Al = 95%, Cu = 4% Mn = 0.5%, Mg = 0.5%	For making bodies of aircrafts
Magnalium	Al = 95%, Mg = 5%	For making balance beams and light instruments
Solder	Pb = 50–40%, Sn = 50–60%	For soldering purposes
Stainless Steel	Fe = 73%, Cr = 18% C = 1%, Ni = 8%	For making cutlery, utensils
Type metal	Pb = 75%, Sn = 10%, Sb = 15%	For printing blocks
Manganese steel	Fe = 84%, Mn = 15%, C = 0.9–1.5%	For making safes, armour plates, rock drills
Tungsten steel	Fe = 77–89.5%, W = 10–20%, C = 0.9–1.5%	For making cutting tools and high-speed lathes
Alnico	Fe = 50%, Al = 20%, Ni = 20%, Co = 10%	For making powerful magnets
Gun metal	Cu = 88%, Sn = 10%, Zn = 1%, Pb = 1%	For making barrels of cannons, gears and bearings
German silver	Cu = 60–30%, Zn = 25–35%, Ni = 15–35%	For making rheostats, resistors and electric heaters
Bell metal	Cu = 80%, Sn = 20%	For making bells and gongs