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

Group		Alkali metals & Alkaline Earth metals – Elements on the extreme left
3 to 12	Property	Reason
Fe Zn	•Heavy - hard metals High - melting points •Electropositive nature between -strong and weak	• Small atomic size, so high density and energy binding the atoms is high. • 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

	Alkali metals	**Alkaline earth metals**
Position	• Group I [IA]	• Group II [IIA]
Properties		
• Density	• Low density	• Higher density
• Melting point	• Low melting point	• Higher melting point
• Boiling point	• Low boiling point	• Higher boiling point
• Flame test	• Characteristic colour	• Mg and Be do not give characteristic colour
• Electropositive character	• Strongly electropositive character	• Less electropositive nature
• Reactivity	• Highly reactive	• Less reactive
Action of air	$M + O_2 \rightarrow M_2O \rightarrow MOH$	• Tarnish slowly and form a layer of oxide when exposed to moist air
Action of water	$2M + 2H_2O \rightarrow 2MOH + H_2$	$M + 2H_2O \rightarrow M(OH)_2 + H_2$
Action of acids	$M + 2HCl \rightarrow MCl_2 + H_2$	$M + H_2SO_4 \rightarrow MSO_4 + H_2$

Comparison of Metals and Non-metals

- **Physical Properties of Metals and Non-metals**

Metals	***Non-metals***
• 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**

Metals	***Non-metals***
• Electronic configurations of metals have 1, 2 or 3 valence electrons.	• Electronic configurations of non-metals have 4, 5, 6 or 7 valence electrons.
• Metals are electropositive in nature. They readily lose electrons and form positively charged ions called cations.	• Non-metals are electronegative in nature. They readily gain electrons and form negatively charged ions called anions
• Because metals lose electrons during a chemical reaction, they are good reducing agents.	• Non-metals possess a property to gain electrons; hence, they are good oxidising agents.
• Oxides of metals may be basic in nature and dissolve in water to form an alkaline solution.	• Non-metals generally form acidic oxides and dissolve in water to form an acidic solution.
• Metals do not usually react with H_2. Metals placed above hydrogen in the activity series react with dilute HCl and dilute H_2SO_4 to liberate H_2 gas. $M + \underset{\text{(dil.)}}{2HCl} \longrightarrow MCl_2 + H_2$ $M + \underset{\text{(dil.)}}{H_2SO_4} \longrightarrow MSO_4 + H_2$	• Non-metals do not react with dilute acids to liberate hydrogen.
• Metals react readily with Cl_2 to form chlorides.	• Non-metals usually form chlorides, which are volatile covalent liquids or gases.
• 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, $CaCl_2$, $MgCl_2$. When electric current is passed through molten calcium chloride, calcium metal is liberated at the cathode and chlorine at the anode. $\underset{\text{(molten)}}{CaCl_2} \longrightarrow Ca^{2+} + 2Cl^-$ At cathode: $Ca^{2+} + 2e^- \longrightarrow Ca$ At anode: $Cl^- - e^- \longrightarrow Cl$ $Cl + Cl \longrightarrow Cl_2$	• Non-metals form covalent compounds which do not conduct electricity because there are no free electrons or ions to carry the current.

Study of Activity Series of Metals

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, Na	Reacts explosively with dilute acid liberating hydrogen. $2Na + 2HCl \rightarrow 2NaCl + H_2$
Ca	Calcium reacts less vigorously $Ca + 2HCl \rightarrow CaCl_2 + H_2$
Mg	Reacts with dilute acids less vigorously, liberating hydrogen. $Mg + 2HCl \rightarrow MgCl_2 + H_2$
Al	Due to great affinity towards oxygen, a coating of oxide is formed which does not allow any further reaction with acid.
Zn	$Zn + 2HCl \rightarrow ZnCl_2 + H_2$
Fe	$Fe + 2HCl \rightarrow FeCl_2 + H_2$
Pb	Lead reacts with conc. HCl to liberate hydrogen. $Pb + 2HCl \rightarrow PbCl_2 + H_2$
[H]	
Cu, Hg, Ag, Pt, Au	Do not produce hydrogen on reaction with dilute or conc. acids.

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 $2KNO_3 \rightarrow 2KNO_2 + O_2$
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 $Ca(OH)_2 \rightarrow CaO + H_2O$	Ca to Cu Decomposes to give metal oxide and CO_2 $CaCO_3 \rightarrow CaO + CO_2$	Ca to Cu Decomposes to give metal oxide and NO_2 $2Ca(NO_3)_2 \rightarrow 2CaO + 4NO_2 + O_2$
Hg Ag Pt Au	Hg to Au Decomposes to give metal and oxygen $2Hg \rightarrow 2Hg + O_2$	Hg to Au Hydroxides do not exist or are rarely formed Insoluble in water	Hg to Au Decomposes to give metal, CO_2 and O_2 Insoluble in water	Hg to Au Decomposes to give metal, NO_2 and O_2 $2AgNO_3 \rightarrow 2Ag + 2NO_2 + O_2$

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.

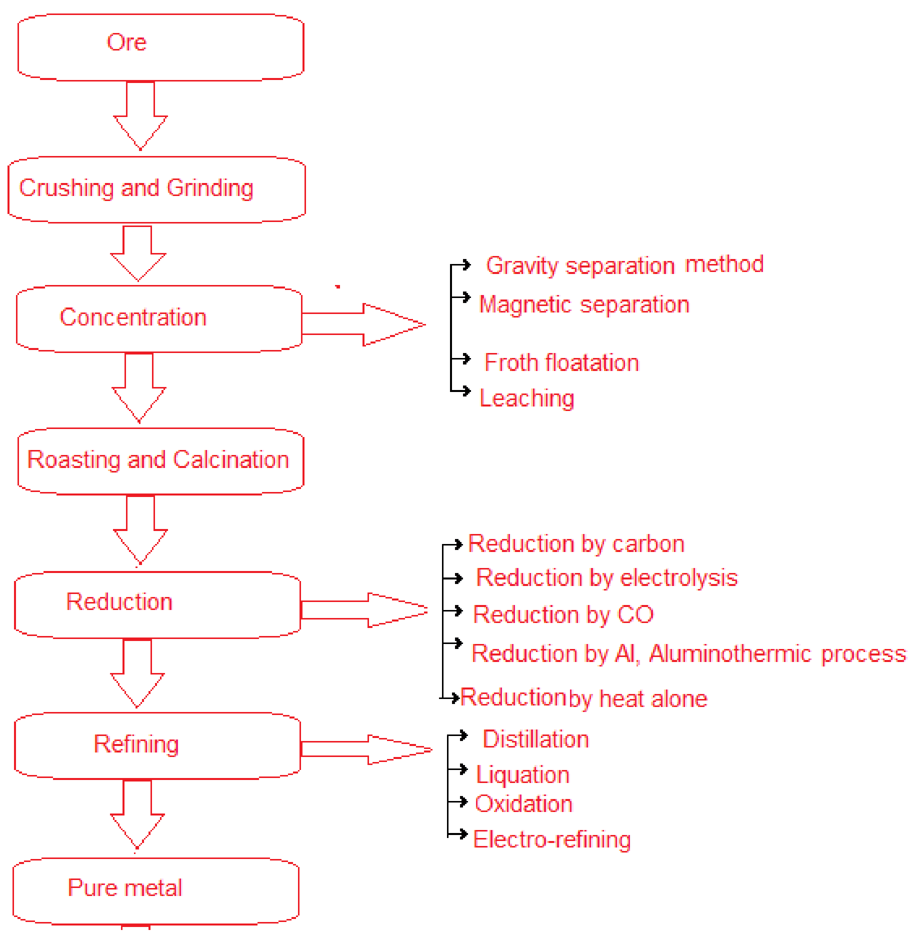
- **Corrosion of Iron**
  Corrosion of iron is known as rusting.
  Rusting is the slow oxidation of iron by atmospheric oxygen in the presence of water.
  $4Fe + 3O_2 + 2xH_2O \rightarrow 2Fe_2O_3.xH_2O$
- **Conditions Necessary for Rusting**
  Presence of water (or moisture)
  Presence of air (or oxygen)
- **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

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



Crushing and Grinding

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

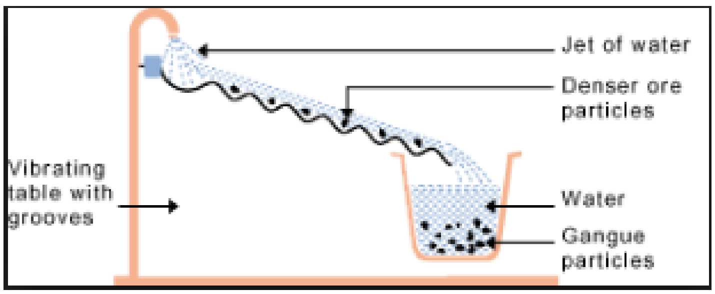
Concentration of Ores

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.

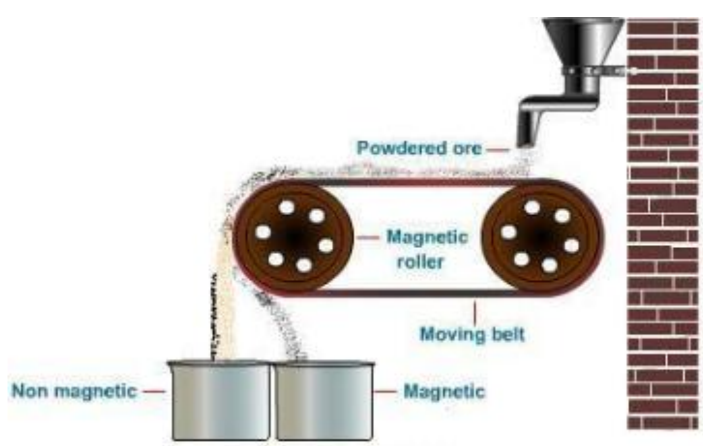


Magnetic separation

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.

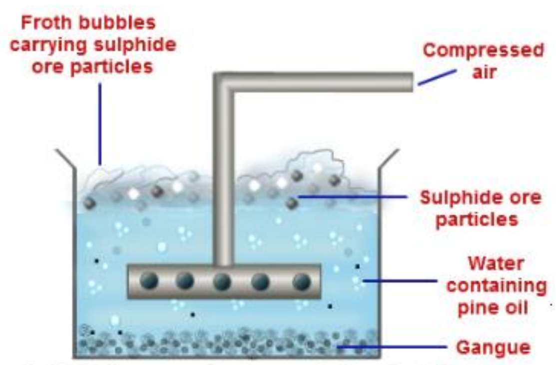


Froth flotation

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.

$2ZnS + 3O_2 \rightarrow 2ZnO + 2SO_2$

B] Calcination

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

$ZnCO_3 \rightarrow ZnO + CO_2$

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

$Al_2O_3 \rightleftharpoons 2Al^{+3} + 3O^{2-}$

Cathode: $2Al^{+3} + 6e^- \rightarrow 2Al$

Anode: $3O^{2-} - 6e^- \rightarrow 3[O] \rightarrow 3O_2$

Product at cathode: Pure aluminium metal

Product at anode: Oxygen gas

Reduction by reducing agents

$ZnO + C \rightarrow Zn + CO$

$2PbO + C \rightarrow 2Pb + CO_2$

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

Ore of Al	**Chemical name**	**Formula**
Bauxite	Hydrated aluminium oxide	$Al_2O_3.2H_2O$
Cryolite	Sodium aluminium fluoride	$Na3AlF_6$
Corundum	Anhydrous aluminium oxide	Al_2O_3

Ore of Fe	**Chemical name**	**Formula**
Red haematite	Anhydrous ferric oxide	Fe_2O_3
Brown haematite	Hydrated ferric oxide	$2Fe_2O_3.3H_2O$
Magnetite	Triferric tetraoxide	Fe_3O_4
Iron pyrites	Iron disulphide	FeS_2
Siderite	Ferrous carbonate	$FeCO_3$

Ore of Zn	**Chemical name**	**Formula**
Zinc blende	Zinc sulphide	ZnS
Zincite	Zinc oxide	ZnO
Calamite	Zinc carbonate	$ZnCO_3$

Extraction of Aluminium

Process for Extraction of Aluminium from Bauxite

1. Concentration of Ore - Bayer process

i. Conversion of impure bauxite to sodium aluminate

$$Al_2O_3.2H_2O + 2NaOH \xrightarrow{150\text{-}200^0C} 2NaAlO_2 + 3H_2O$$

ii. Conversion of sodium aluminate to aluminium hydroxide

$$NaAlO_2 + 2H_2O \xrightarrow{50\text{-}60^0C} NaOH + Al(OH)_3$$

iii. Conversion of $Al(OH)_3$ to pure alumina

$$2Al(OH)_3 \xrightarrow{1100^0C} Al_2O_3 + 3H_2O$$

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:

Cryolite: $Na_3AlF_6 \rightleftharpoons 3Na^{1+} + Al^{3+} + 6F^{1-}$

Fluorspar: $CaF_2 \rightleftharpoons Ca^{2+} + 2F^{1-}$

Alumina: $Al_2O_3 \rightleftharpoons 2Al^{3+} + 3O^{2-}$

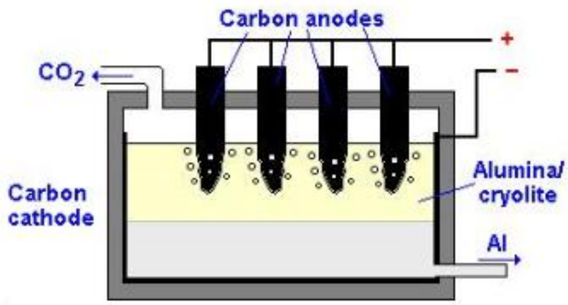
Cathode: $2Al^{3+} + 6e^- \rightarrow 2Al$

Anode: $3O^{2-} - 6e^- \rightarrow 3[O] \rightarrow 3O_2$

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_2, AlF and CaF_2 serves as the electrolyte.

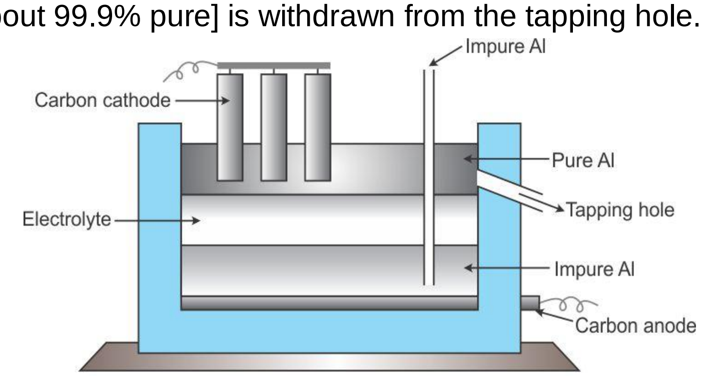
Lower layer: Impure Al at the bottom along with carbon lining acts as the anode.

Electrolytic reaction:

Cathode: $Al^{3+} + 3e^- \rightarrow Al$

Anode: $Al - 3e^- \rightarrow Al^{3+}$

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



Hoope's process

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**
  $4Al + 3O_2 \rightarrow 2Al_2O_3$
  $2Al + N_2 \rightarrow 2AlN$
- **Action with Water**
  $2\ Al + 3H_2O\ (steam) \rightarrow Al_2O_3 + 3H_2$
- **Action with Non-metals**
  $2Al + 3Cl_2 \rightarrow 2AlCl_3$
  $2Al + 3S \rightarrow Al_2S$
- **Action with Alkalis**
  $2Al + 2NaOH + 2H_2O \rightarrow 2NaAlO_2 + 3H_2$
- **Action with Acids**
  $2Al + 6HCl \rightarrow 2AlCl_3 + 3H_2$
  $2Al + 3H_2SO_4\ (dil.) \rightarrow Al_2\ (SO_4)_3 + 3H_2$
  $2Al + 3H_2SO_4\ (conc.) \rightarrow Al_2\ (SO_4)_3 + 6H_2O + 3SO_2$
  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.
  $Fe_2O_3 + 2Al \rightarrow Al_2O_3 + 2Fe$

Uses of Metals and Alloys

Uses of Aluminium

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

Uses of iron

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

Uses of Zinc

i. Mostly used for coating iron and steel sheets to prevent them from rusting.
ii. For making useful alloys such as brass, bronze and German silver.
iii. Zinc dust is used as a reducing agent for many organic reactions.
iv. Zinc compounds are used in paints, electroplast, 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