Introduction to metals

Metals possess many unique fundamental properties that make them an ideal material for use in a diverse range of applications.
Properties such as *high tensile strength, high fracture toughness*, *malleability and availability* are just some of the many advantages associated with metals.

Metals are generally *malleable* , they can be hammered or pressed permanently out of shape without breaking or cracking and
fusible (able to be fused or melted) and *ductile* .

Metals in general have *high electrical conductivity, high thermal conductivity, and high density* .

Metals are generally not used in their *pure state* but as mixtures of metals or metal and non metal constituents commonly referred to as *alloys*.

Mechanical properties of metals include *ductility*, i.e. their capacity for plastic deformation. Reversible elastic deformation in metals can be described by Hooke's Law for restoring forces, where the *stress is linearly proportional to the strain*. Forces larger than the elastic limit, or heat, may cause a permanent (irreversible) deformation of the object, known as plastic deformation or plasticity.

Most metals are *present in the Earth* as compounds of some sort,
such *as oxides or sulphides*.

The first metals were discovered accidentally more than 5,000 years ago.

Definition of metal

is a material (an element, compound, or alloy) that is typically hard, opaque, shiny, and has good electrical and thermal conductivity.

Below comparison between metals and non- metals materials:-

Metals	**Non-Metals**
Good conductors of heat and electricity	Poor conductors of heat & electricity
Malleable: can be beaten into thin sheets	Brittle: if solid
Ductile: can be stretched into wire	Non-ductile
Possess metallic luster	Do not possess metallic luster
Solid at room temperature (except Hg)	Solids, liquids or gases at room temperature

Property	Metals	Non metals
Appearance	Shiny	Dull
Melting and boiling points	High (they are all solid at room temperature, except mercury which is a liquid)	Lower than metals (bromine is a liquid at room temperature, and eleven others are gases).
Density	High (they feel "heavy" for their size)	Low (they feel "light" for their size)
Strength	Strong (they can hold heavy loads without breaking)	Not strong
Malleability	Malleable (they can be hammered into different shapes without breaking).	Brittle (they break or shatter when hammered).
Ductility	Ductile (they can be drawn out to make wires).	Not ductile.
Heat conductivity	Good	Poor
Electrical conductivity	Good	Poor (but graphite, a form of carbon, is an exception).

TABLE 23.1 Thermal Conductivity and Electrical Resistivity of Several Metals

Metal	Thermal Conductivity (W/cm · K)	Electrical Resistivity (Ω · cm)
Ag, silver	4.29	1.59
Cu, copper	4.01	1.67
Fe, iron	0.804	9.71
V, vanadium	0.307	24.8

Types of metals :-

1- *noble metals* - generally unreactive , e.g. silver, platinum , gold and palladium .
2- *alkali metals* - very reactive with low melting points and soft , e.g. potassium and sodium .
3- *alkaline earth metals* – less reactive, higher melting points and harder than alkali metals, e.g. calcium, magnesium and barium .
4- *transition metals* - hard, shiny, strong, and easy to shape, e.g. iron, chromium, nickel, and copper .

5-*other metals* – diverse properties, e.g. aluminum , gallium indium, tin, thallium, lead and bismuth.

General Properties of Metals

- opaque.
- good conductors of heat and electricity.
- high malleability and ductility.

Physical Properties of metals

1a) Physical properties of metals :-

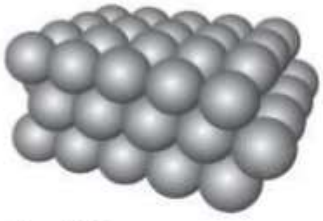
- **Metals are solids. (except mercury)**
- **Metals are hard. (except Lithium, Potassium, Sodium)**
- **Metals have metallic lustre. (shine)**
- **Metals are malleable. (can be beaten into thin sheets)**
- **Metals are ductile. (can be drawn into wires)**
- **Metals have high melting points. (Gallium and Ceasium have low melting points. They melt in the palm of the hand)**
- **Metals have high boiling points.**
- **Metals are good conductors of heat. (Best conductors are silver and copper. Poor conductors are Lead and Mercury)**
- **Metals are good conductors of electricity. (Best conductors are Silver and Copper)**
- **Metals are sonorus. (produce sound when beaten)**

Physical Properties of Metals

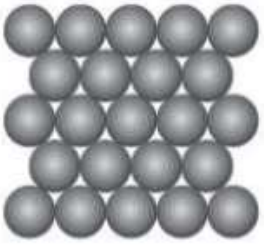
Property	Statement	Application
melting point	Solid at room temperature (except Hg)	Hg used in thermometers
density	Vary from less than water (sodium) to very dense (lead)	Al used in aircraft because of low density
thermal conductivity	All metals conduct heat well	Al and stainless steel used in cooking pans
malleability	Metals ca be bent into different shapes	Car bodies made of flat steel sheets
strength	Some metals are strong	Iron used to make girders and reinforce concrete
electrical conductivity	All good conductors as solid or liquid	Cu and Al used to make electrical wires

Physical Properties of Metals

- High Density
  - Atoms are usually packed together as closely as possible.
  - Most metals have a high density because there is little empty space between the closely packed atoms.



The 3-D arrangement of atoms in a typical metal



Simplified diagram of a metal structure. The atoms are packed together very closely.

Chemical Properties of metals

Chemical properties

Metals	Non-Metals
Have a tendency to donate electrons.	Have a tendency to receive electrons.
Displace hydrogen gas from dilute acids $Zn + 2HCl \dashrightarrow ZnCl_2 + h_2$	Don't displace hydrogen gas from dilute acids.
React with oxygen to produce basic oxides. $4\,Na + O_2 \dashrightarrow 2Na_2O$	React with oxygen to produce acidic oxides $C + O_2 \dashrightarrow CO_2$
React with hydrogen to produce Hydrides. $Ca + H_2 \dashrightarrow CaH_2$	React with hydrogen to produce co-valent compounds. $C + 2H_2 \dashrightarrow CH_4$

Material Properties

- Mechanical – strength, toughness, ductility, hardness, elasticity, fatigue, creep, ratios
- Physical – density, specific heat, thermal expansion, thermal conductivity, melting point, magnetic and electrical qualities
- Chemical – oxidation, corrosion, degradation, toxicity, flammability
- Manufacturing – manufacturability, effects on product properties, service life, cost

Metal Classification

All metals may be classified as ferrous or nonferrous.

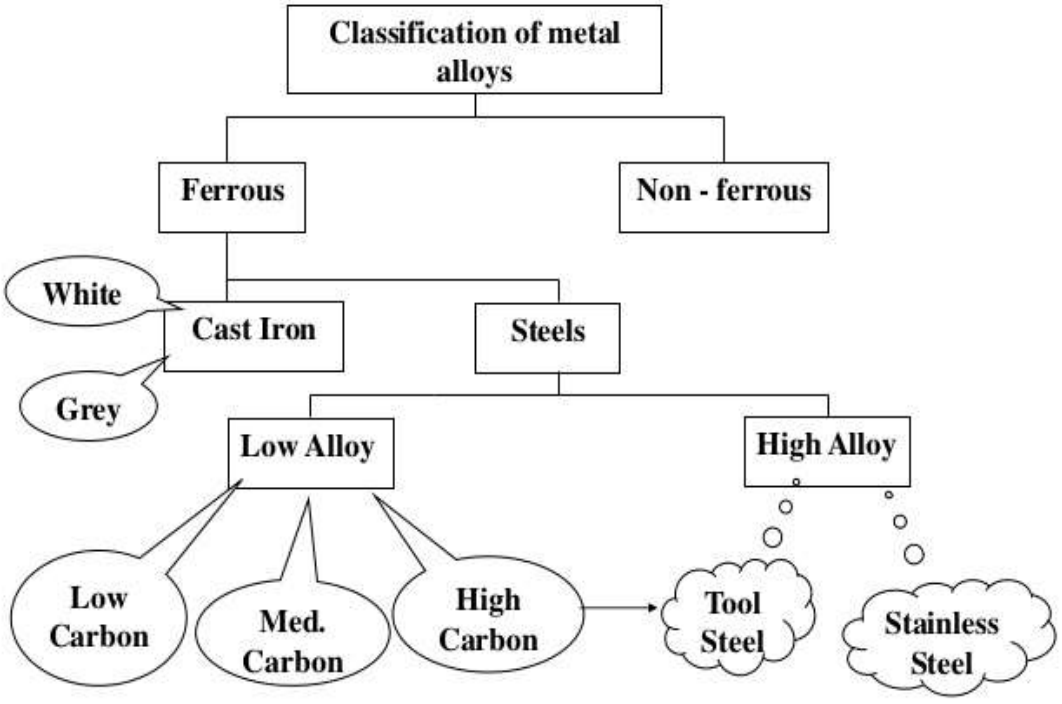
Ferrous metals

Ferrous metals include cast iron, steel, and the various steel alloys,
The only difference between iron and steel is the carbon content.
Cast iron contains more than 2-percent carbon, while steel contains less than 2 percent.

Non-Ferrous Metals

Nonferrous metals are metals that do not contain iron.
Examples include aluminum, zinc, copper and brass.

In general nonferrous metals do not corrode as quickly as ferrous metals due to the rapid formation of a thin protective oxide layer on their surface although they are still susceptible to corrosion when exposed to atmospheric conditions.
Due to the presence of the surface oxides, non-ferrous metals have different requirement for surface preparation and priming than ferrous metals.



Engineering Metallurgy

Metallurgy is a domain (field) of materials science and engineering that studies the physical and chemical behavior of metallic elements, their intermetallic compounds, and their mixtures, which are called alloys.

Metallurgy is also the technology of metals: the way in which science is applied to the production of metals, and the engineering of metal components for usage in products for consumers and manufacturers.

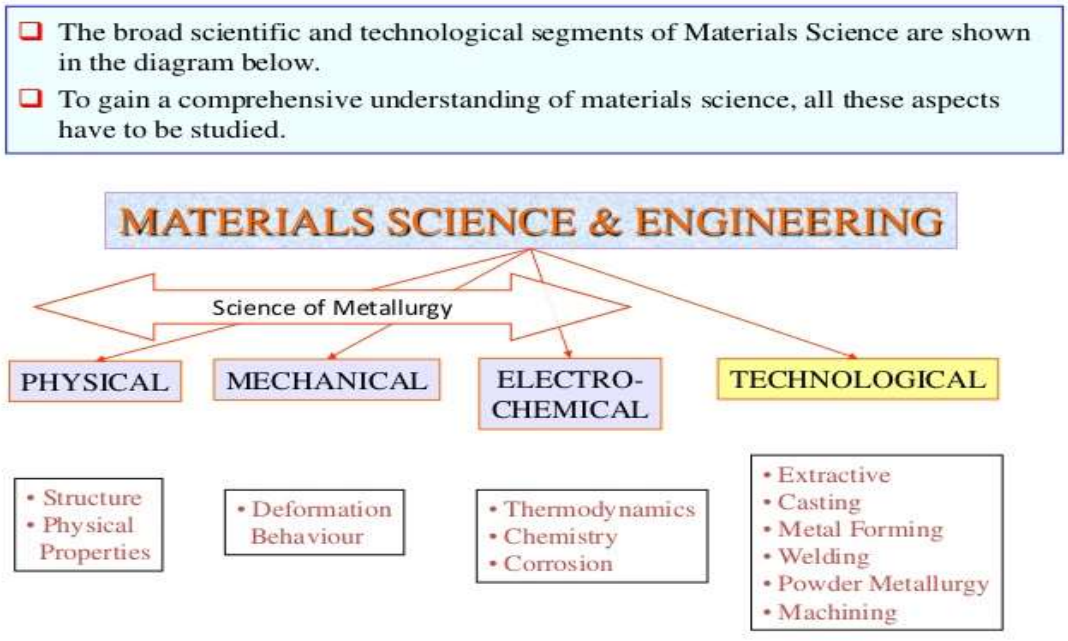
The production of metals involves the processing of ores to extract the metal they contain, and the mixture of metals, sometimes with other elements, to produce alloys.
Metallurgy can be separated (classified) into three basic components: *chemical, mechanical, and physical*.

- Chemical metallurgy deals primarily with the making of metals and alloys from their naturally occurring ores.

- Mechanical metallurgy deals with testing mechanical properties, the relationships between properties and engineering design, and the performance of metals in service.

- The final critical component of the science of metals is physical metallurgy.

This aspect deals with the internal world of metals and how internal structure can be designed and produced to give the best properties.



Alloys *:*

Is a homogeneous combination of two or more elements at least one of which is a metal has metallic properties.

Based on iron called (**ferrous alloy)**

Based on other metals (Al, Cu, Mg, Ti, Ni) **called (nonferrous alloy)**

Application of Major metallic alloys:-

all with distinctive properties, include:

1- Steel alloy – low cost , high strength. , Very wide used in ships, buildings, railway lines, reinforced concrete.

2- aluminum alloys – high specific strength, corrosion resistance, specific conductivity, used in Aerospace, packaging, sports equipment, energy, construction Aircraft, food containers, power cables.

3- titanium alloys – higher specific strength and higher temperature application, used as Biomedical, body implants & medical, aerospace .

4- copper alloy – high electrical & thermal conductivity, easy to form/cast, corrosion resistance, used in electronics, coins, wiring, circuit boards , electronic components.

5- nickel alloy – high temperature strength and creep resistance (super alloys) , used in Aerospace, Aircraft engines .

Properties of Alloys

Alloy	Composition	Properties	Uses
Bronze	• 90% copper • 10% tin	• Hard and strong • Doesn't corrode easily • Has shiny surface	• To build statues and monuments. • In the making of medals, swords and artistic materials.
Brass	• 70% copper • 30% zinc	• Harder than copper	• In the making of musical instruments and kitchenware.
Steel	• 99% iron • 1% carbon	• Hard and strong	• In the construction of building and bridges. • In the building of the body of cars and railway tracks.
Stainless steel	• 74% iron • 8% carbon • 18% chromium	• Shiny • Strong • Doesn't rust	• To make cutlery and surgical instruments.
Duralumin	• 93% aluminum • 3% copper • 3% magnesium • 1% manganese	• Light • Strong	• To make the body of aeroplanes and bullet trains.
Pewter	• 96% tin • 3% copper • 1% antimony	• Luster • Shiny • Strong	• In the making of souvenirs.

Distribution of Metals in Earth

- metals make up about 25% of the Earth's crust.
- aluminum is the most abundant.
- alkali and alkali earth metals make up about 1%.
- iron is only transition metal > 5%
- only Ni, Cu, Ag, Au, Pd, Pt found in native (nature) form
  - ✓ noble metals
- most metals found in solid structure
  - ✓ natural, homogeneous crystalline inorganic solids.

Challenges for the future:

according to legislation (تشريع) – Kyoto agreement (ended in 2012 and future very uncertain - Paris, 2015); ***Challenges for the future*** are increasingly important because of:-

1- Missing greater awareness (وعي) and consumer pressure.
2- Scarcity (شحة) in major metals.
3- Not economic alternatives (البدائل) exist.
4- Needed to large energy to extract – and to shape.
5- "Gases " emissions when extracting and shaping (specially CO_2)

See Figs. 1.1 and 1.2 on next page.

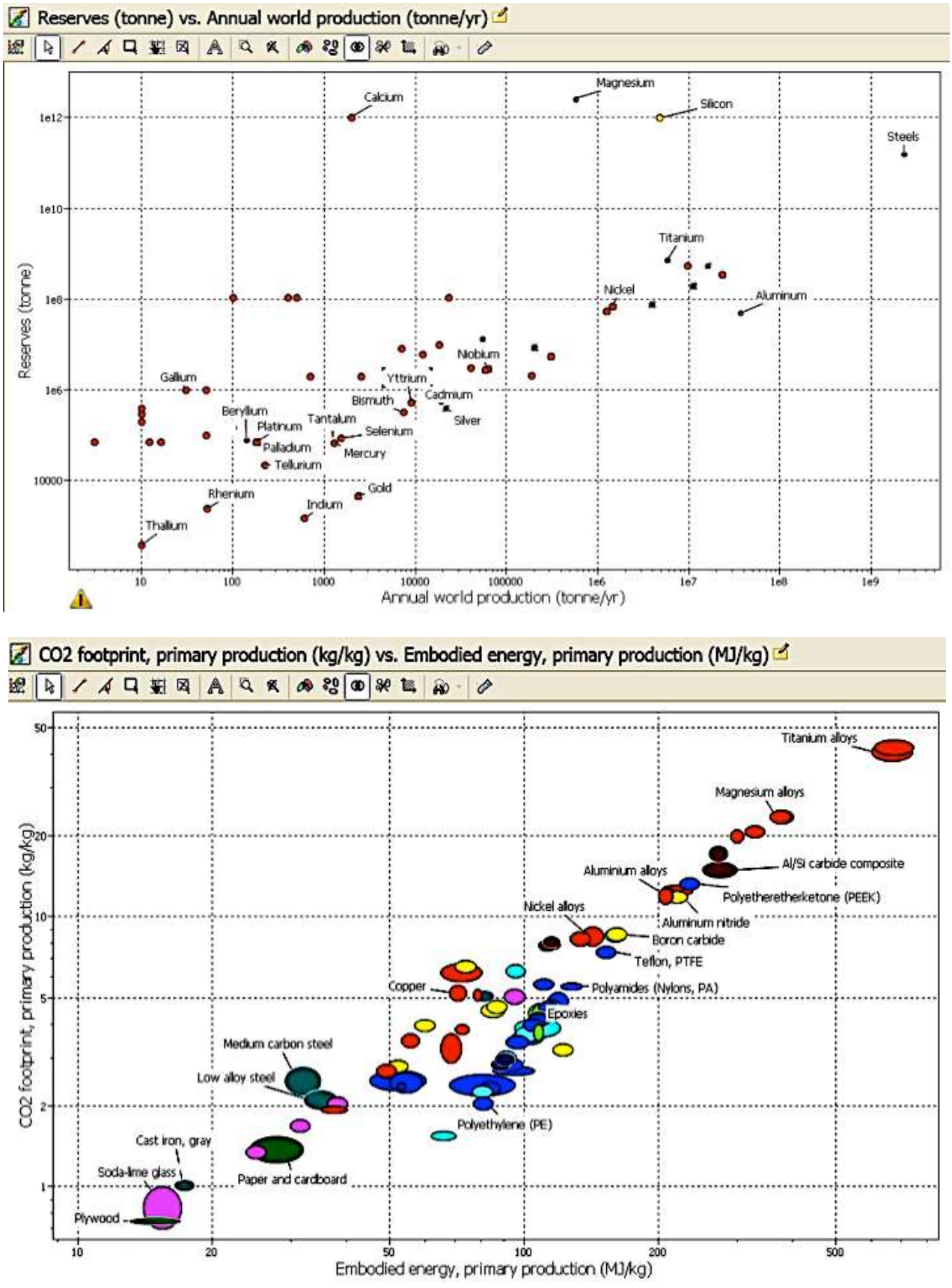


Figure 1.2 CO_2 emissions versus embodied energy, both for primary production.

Metals in the Periodic Table

About 91 of the 118 elements in the periodic table are metals, the others are nonmetals . Some elements appear in both metallic and non-metallic forms.

Metals fall into groups in the periodic table determined by similar arrangements of their orbital electrons and a consequent similarity in chemical properties.

Groups of similar metals include the alkali metals (Group 1 in the periodic table), the alkaline-earth metals (Group 2 in the periodic table), and the rare-earth metals (the lanthanide and actinide series of Group 3). Most metals other than the alkali metals and the alkaline earth metals are called transition metals (see transition elements).