Alloys

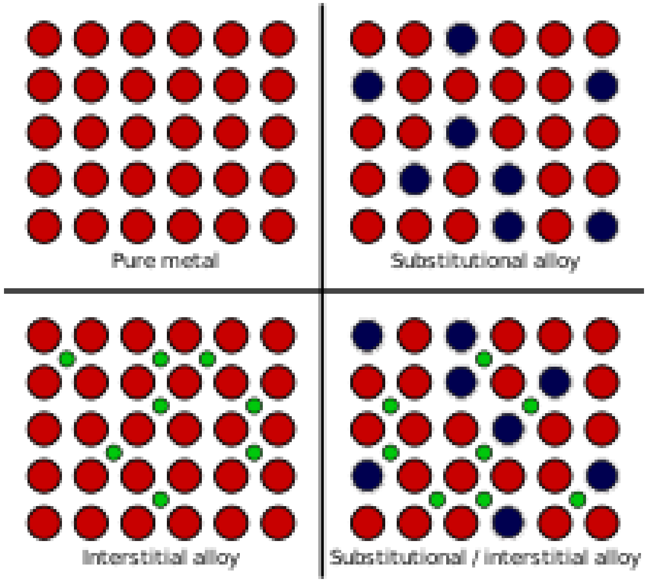
Alloy is a homogeneous substance formed by mixing two or more elements, at least one of them being a metal.

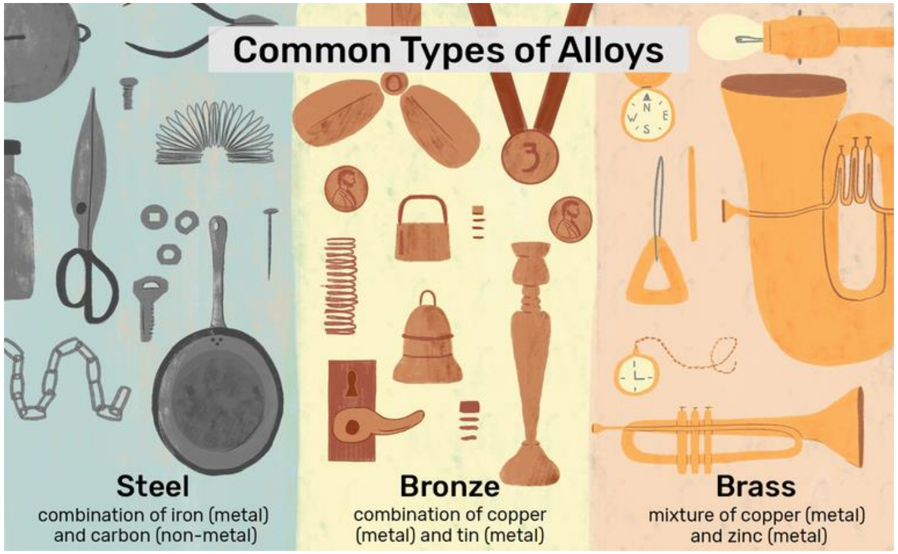
Alloys are of three types:

a) Alloys which are formed by **two or more metals**; *e.g.* Cu-Zn (Brass)

b) Alloys which are formed between **a metal and a non-metal**; *e.g.* Steel

c) Alloys which are formed between **mercury and another metal**; *e.g.* Zinc amalgam





Alloys

Purpose of alloying is to get

a) Increased mechanical strength

b) Reduced chemical reactivity

c) Improved corrosion resistance

d) Better hardenability

e) Increased/Reduced electrical conductivity

f) Increased/Reduced temperature stability

g) Grain size control

h) Improved machine ability

i) Improved ductility

j) Better wear resistance

Characteristics of alloys

a) **Hardness and tensile strength** of the alloy is **higher** then its constituents

- Tensile strength of iron is increased by 10 fold by alloying with 1% Carbon

b) **Melting points of alloys** is generally **lower** than the melting points of the constituents

- Solder melts at 183^oC while its constituents Pb melts at 327^oC and Sn melts at 232^oC

c) **Alloys are less conductive** than pure metals

- Small quantity of impurities in copper will reduce its conductivity

d) **Colour of alloy gets modified** as compared to the individual metals

- Red coloured copper and Silver white Zinc will get modified to Yellowish brown in brass

e) **Chemical Properties are modified** i.e. either enhanced or depressed

- Dissolution of alloy in HCl is lower compared to its constituent metals

f) **Corrosion:**

- The most useful property of alloying is its ability to resist corrosion.
- Generally alloys are more resistant to corrosion than pure metals.

e.g. Stainless steel (an alloy of Fe, C, Ni and Cr) is not corroded by atmospheric conditions though pure Fe corrodes heavily in moist environment.

g) **Solidification character** of an alloy is more suitable for making a casting.

Significance of Alloying

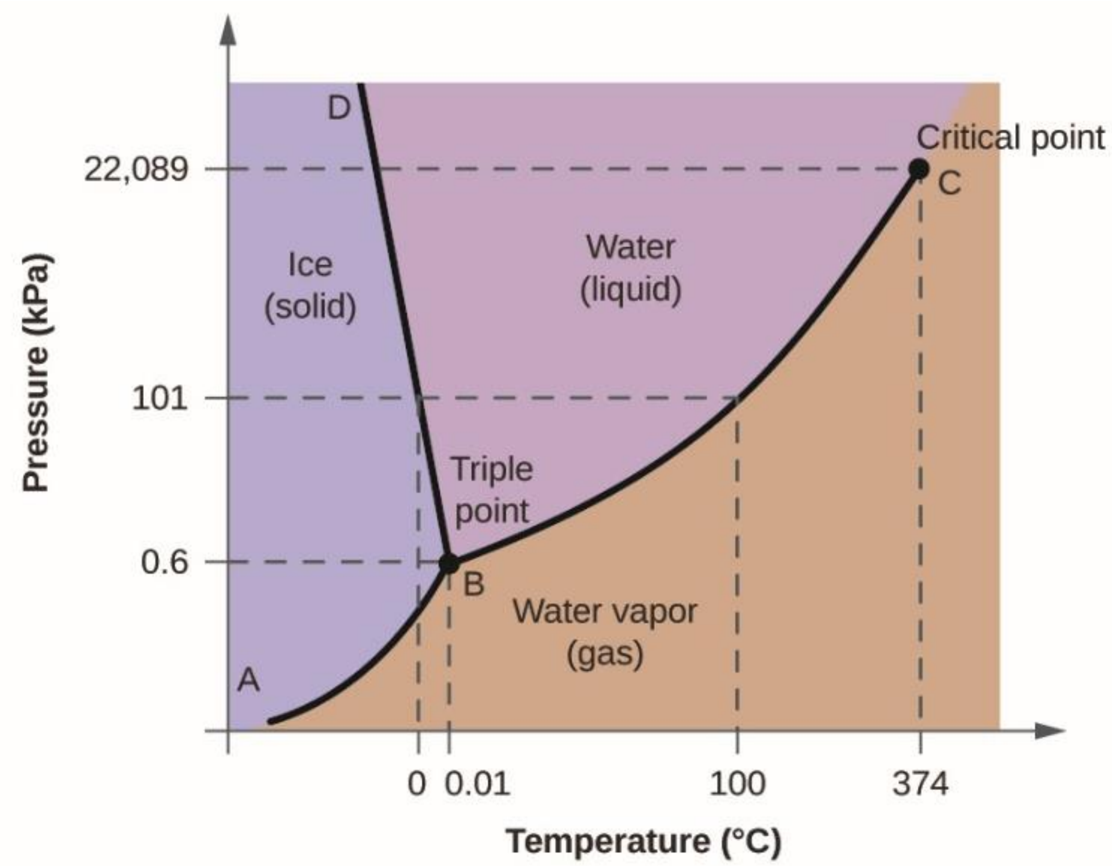
The alloy coatings bring **quality, reliability** and **durability** for process vessel linings and pipe linings along with the surface protection of components and equipment **against extreme conditions such as high temperature, higher abrasion or high acidity surroundings**.

Examples

- **Lead-Tin** alloys are used for **soldering purpose**
- **Nickel alloys** are known for **resistance to extreme corrosion** and high temperature requirements.
- **Copper-nickel** alloys are used for **anti-fouling**.
- **Iron-nickel alloys** show **low thermal expansion**.
- **Nickel-titanium alloys** (**Nitinol**) exhibit **shape memory**.

Phase Diagram

Phase diagram is a graphical representation of the physical states of a substance under different conditions of temperature and pressure.



Phase diagram of water

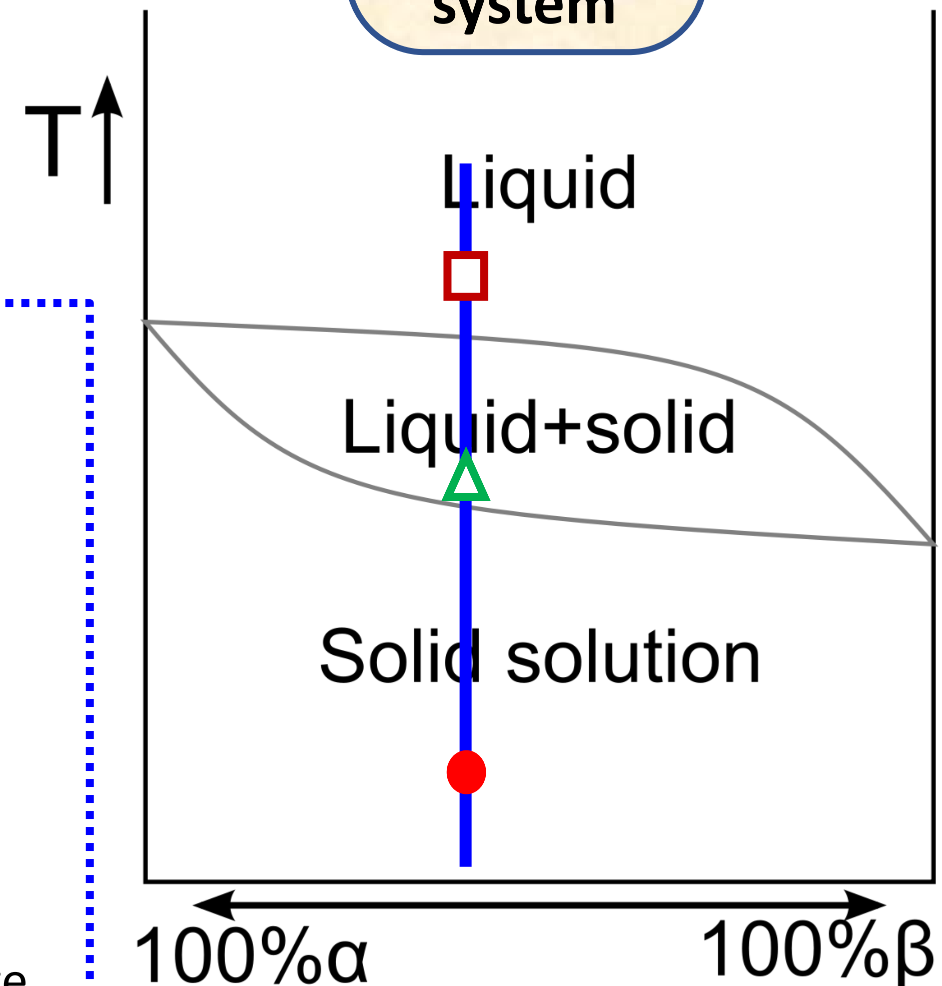
One component system

Alloying Phase Diagram

Two component system

Composition Vs Temperature diagram

Physical and chemical state of elements at different temperatures and concentrations



Along blue line, Composition of metal α and β is fixed

Points

A - • - Solid solution of metal α and β (Solid state solution, crystal structure of major component remains unchanged, single homogeneous phase)

B – Δ – Liquid + Solid

C – □ - both the metals are in liquid state

Phase Diagram of alloys

- Phase diagrams of alloys can be used to predict the phase changes in an alloy which exposes to a particular heat treatment process.
- This is important because the properties of a metal component depend on the phases present in the metal.
- Phase diagrams are useful for selection of alloys with a specific composition.
- They are also used to troubleshoot quality problems.

Binary phase diagram

1. Isomorphous phase diagrams
2. Eutectic phase diagrams (& Basic concepts)

Specific examples of

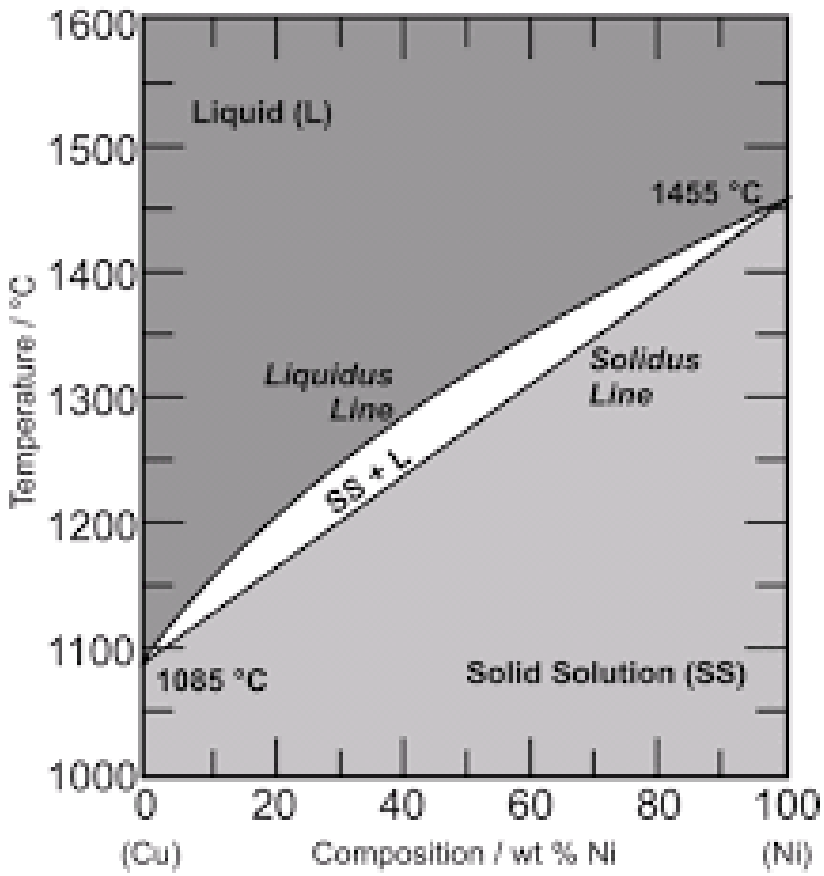
1. Ferrous alloys
2. Non-Ferrous alloys

Binary Phase Diagrams

1. Isomorphous phase diagrams

Complete solubility of one component in another

Example: Cu-Ni Alloys follow Hume-Rothery rules

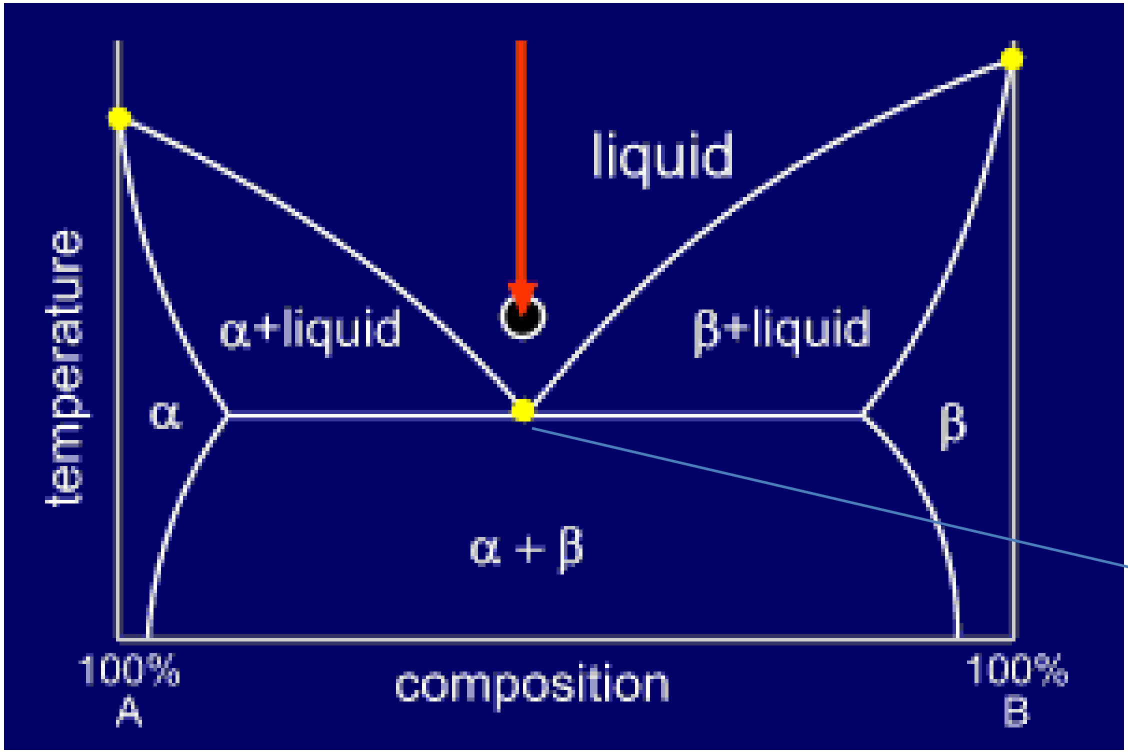


Hume-Rothery rules for solid solutions

1. The atomic radius of the solute and solvent atoms must differ by no more than 15%.
2. The crystal structures of solute and solvent must be similar.
3. Complete solubility occurs when the solvent and solute have the same valency. (A metal of higher valency is more likely to dissolve in a metal with lower valency).
4. The solute and solvent should have similar electronegativity (If the electronegativity difference is too great, the metals tend to form intermetallic compounds instead of solid solutions).

2. Eutectic phase diagrams

- **The binary eutectic phase diagram explains the chemical behaviour of two immiscible (unmixable) crystals from a completely miscible (mixable) melt.**



Eutectic Point

A (α) and **B** (β) are two different metals.

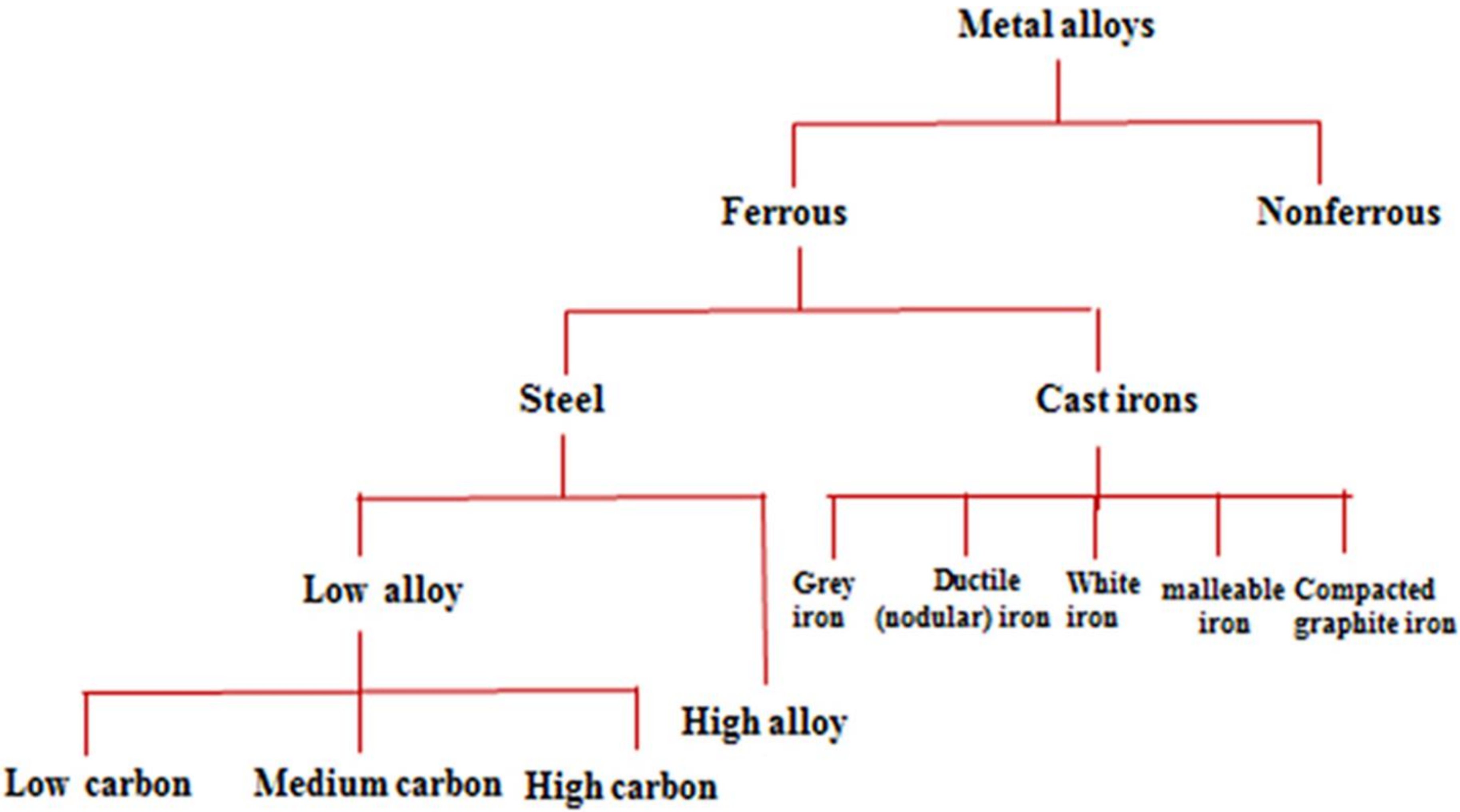
Basic concepts of Eutectic composition

The melting point of the **eutectic alloy** is lower than that of the components (eutectic = easy to melt in Greek).

Eutectic mixture. A **mixture** of two or more substances which melts at the lowest freezing point of any **mixture** of the components. This temperature is the **eutectic** point. The liquid melt has the same composition as the solid.

- **Eutectic alloys** have two or more materials and have a **eutectic composition**.
- When a well-mixed **eutectic** alloy melts, it does so at a single and sharp temperature.
- Conversely, when a **non-eutectic** alloy solidifies, its components solidify at different temperatures.

Alloys classification

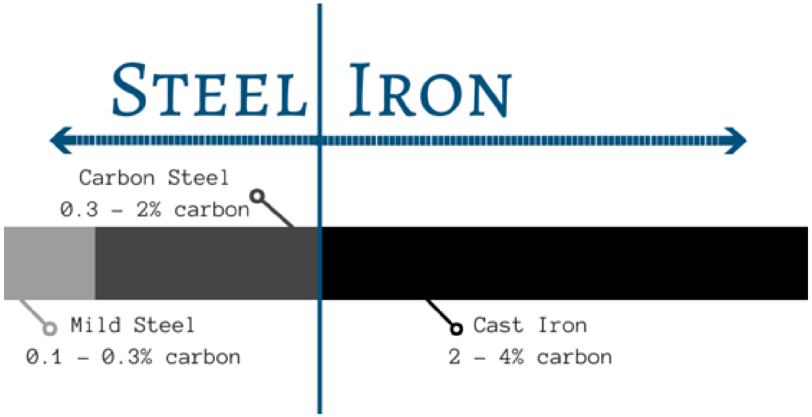


(a) Ferrous Alloys

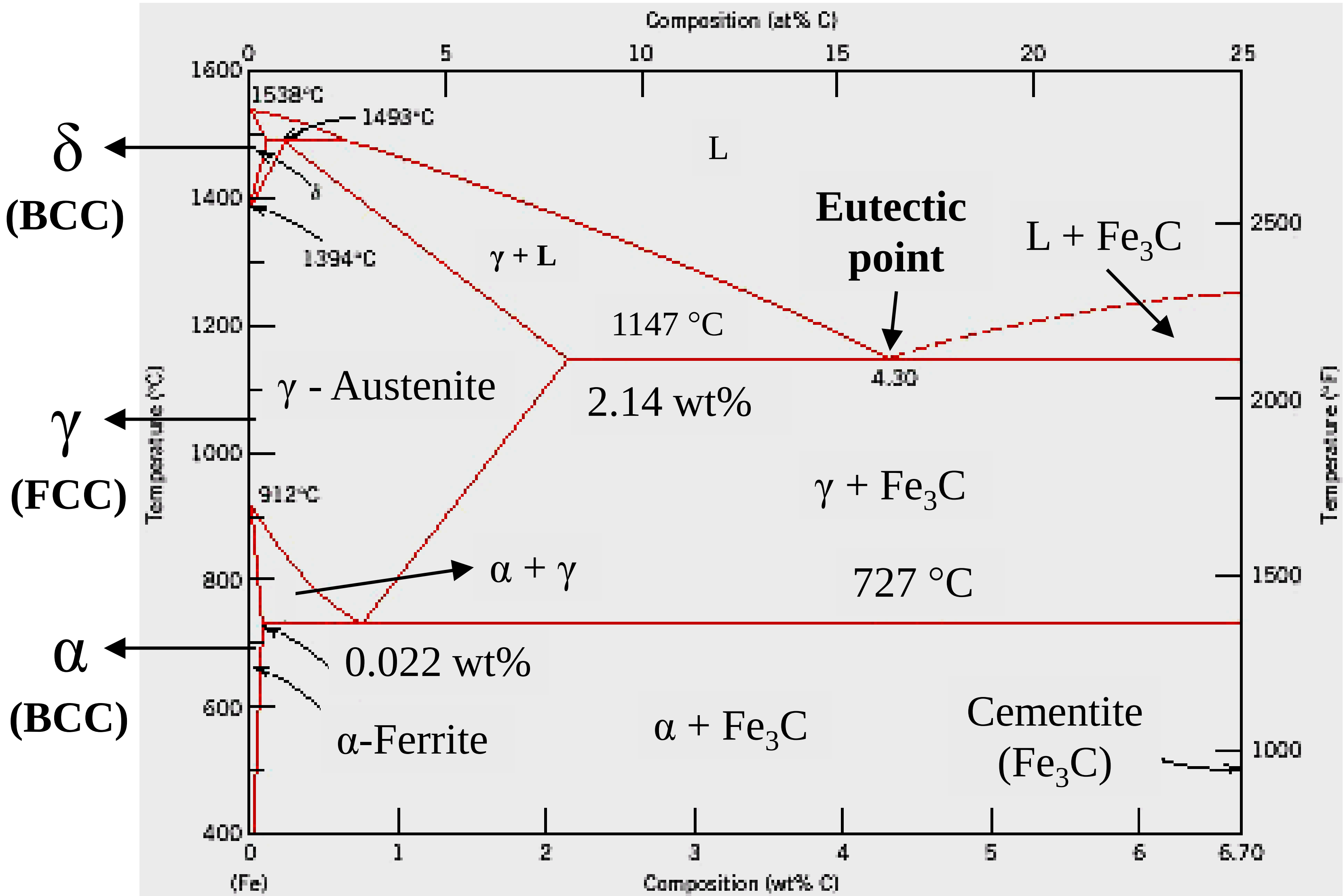
- Ferrous alloys contain ***Iron*** as the major component.
- They have small amounts of other metals or elements added, to give the required properties.
- Generally, the Ferrous alloys are magnetic and give little resistance to corrosion.

Some examples of the ferrous alloys are:

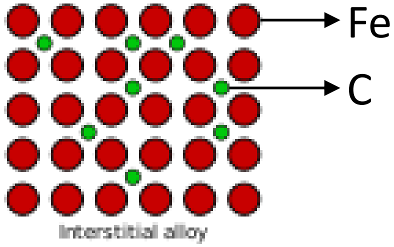
- Mild steel
- Carbon steel
- Cast iron



The Iron (Fe) - Iron Carbide (Fe_3C) Phase Diagram



Comments on Fe–Fe_3C system



- Carbon is an interstitial impurity in Fe.
- It forms a solid solution with α, γ, δ phases of iron
- Maximum solubility in BCC α-ferrites 0.022 wt% at 727 °C.
- BCC: relatively small interstitial positions
- Maximum solubility in FCC austenite is 2.14 wt% at 1147 °C
- FCC has larger interstitial positions
- Mechanical properties: Cementite(Fe_3C) is hard and brittle: strengthens steels).
- Mechanical properties also depend on microstructure: how ferrite and cementite are mixed.
- Magnetic properties: α-ferrite is magnetic below 768 °C, austenite is non-magnetic

Applications of Ferrous alloys

- Ferrous steel is produced as sheet for automobiles, appliances, and containers.
- As plates for ships, boilers and bridges, as a structural member (such as I- beams).
- Bar products for leaf springs, gears axles, crank shaft and railroad rails.
- As stock for tools and dies.
- As music wire and as fasteners such as bolts, rivets and nuts.
- Ferrous materials comprise 70% to 85% by weight of virtually all structural members and mechanical components.
- Carbon steels are least expensive.

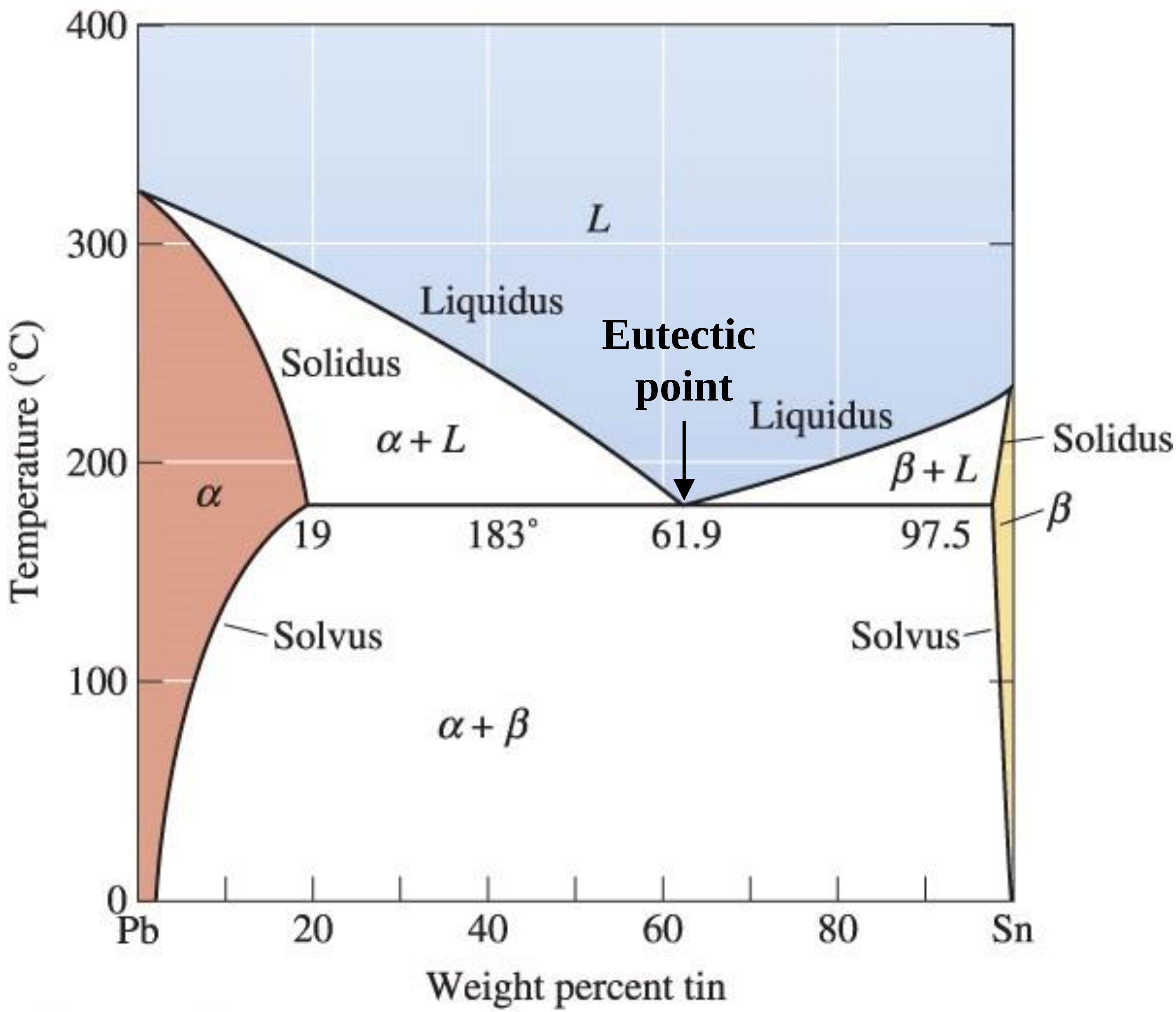
(b) Non-Ferrous Alloys

Non-Ferrous alloys are not iron based.

Some examples of **Non-Ferrous alloys** are:

- **Lead-Tin alloy for solder**
- Aluminium Alloys
- Copper Alloys
- Magnesium Alloys
- Beryllium Alloys
- Nickel and Cobalt Alloys
- Titanium Alloys

Lead (Pb) – Tin (Sn) alloy



Some applications of non-ferrous alloys

Copper Alloys:

- One of the largest uses of Cu is probably in coins.
- The various Euro coins are made of Cu-Ni, Cu-Zn-Ni or Cu-Al-Zn-Sn alloys.
- Brasses and Bronzes are most commonly used alloys of Cu.
- Brass is an alloy with Zn. Bronzes contain tin, aluminium, silicon or beryllium.
- Other copper alloy families include copper-nickels and nickel silvers.
- More than 400 copper-base alloys are recognized.

Magnesium Alloys:

- Aerospace industry
- High speed machinery
- Transportation and materials handling equipment

Nickel Alloys:

- Corrosion resistant parts: Valves, pumps, vanes Heat exchangers, shafts, impellers
- Heat treatment equipment, Gas turbines, Chemical reactor components