ME3392

ENGINEERING MATERIALS AND METALLURGY

UNIT-1

CONSTITUTION OF ALLOYS

VEERAPANDIAN.K
AP/MECH

ALLOY OF METAL

- **Alloy is made up of two or more materials to get required properties in metal**

An alloy is a mixture of two or more elements in solid solution in which the major component is a metal.

Why we go to ALLOYING?

- Because the Pure metals always have low strength and high ductility and it is practically impossible to use them in industrial applications.

Advantages of alloying

- Hardness,
- Toughness,
- Corrosion Resistance
- Ductility.
- Malleability

are improved

SOLID SOLUTIONS

A solid solution describes a family of materials which have a range of compositions and a single crystal structure.

A solid solution is a homogeneous mixture of two or more kinds of atoms in a solid state or more than two types of atoms combined in a single-space lattice.

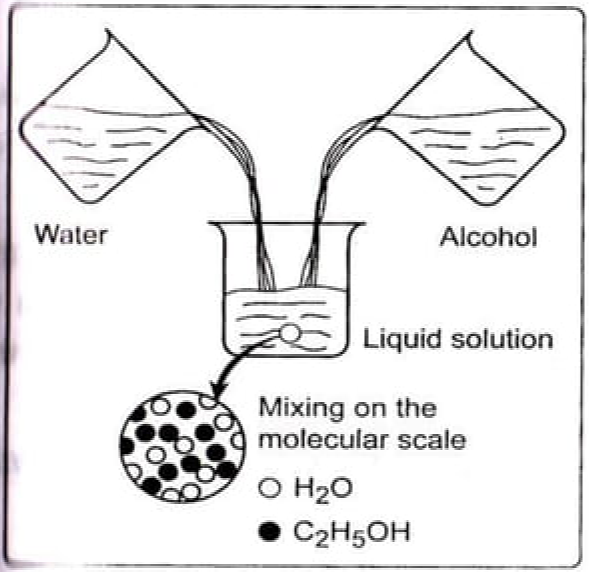


Fig. 1.1. Forming a liquid solution of water and alcohol

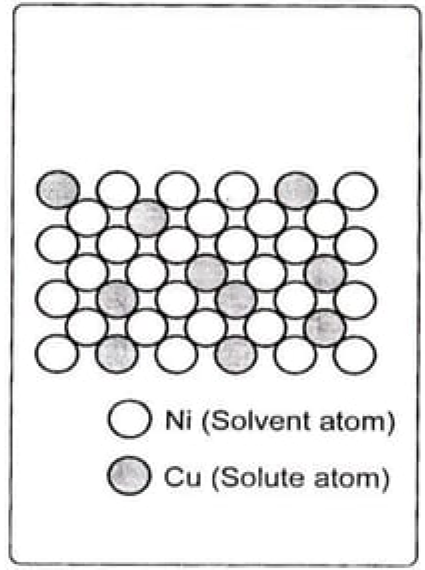


Fig. 1.2. Solid solution of copper in nickel

Types of Solid Solution

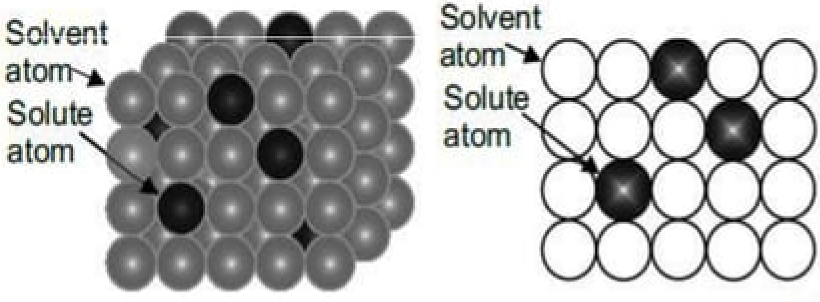
(a) Substitutional solid solutions.

- Disordered substitutional solid solution
- Ordered substitutional solid solution.

(b) Interstitial solid solutions.

SUBSTITUTIONAL SOLID SOLUTION

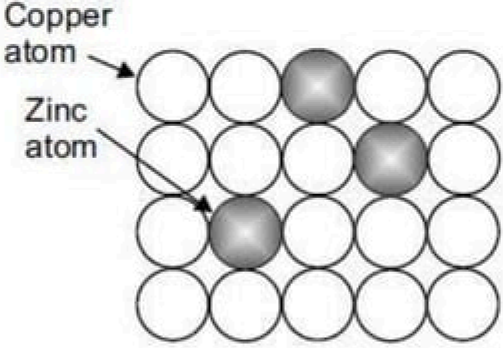
Here ,the solute atom substitutes the atoms of solvent in the crystal structure. The crystal structure of the parent element is unchanged, but the **lattice** (பின்னல்) may be distorted by the presence of the solute atoms. In a substitutional solid solution, the two atoms (solvent and solute)are equal or approximately equal in diameter and the crystal structure of the two elements must be the same. Brass is alloy of copper and zinc. The atomic diameter of copper is 1.278 Å and that of zinc is1.332 Å and the two metals form substitutional solid solution. Figure shows that the zinc atoms replace some copper atoms in the lattice structure of copper.



(a) (b)

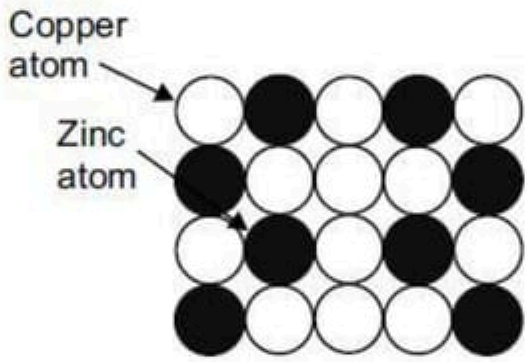
Disordered Substitutional Solid Solution

Here, the **solute atoms** do not follow any specific order, but the atoms are distributed **randomly** **in the lattice structure of the solvent.**

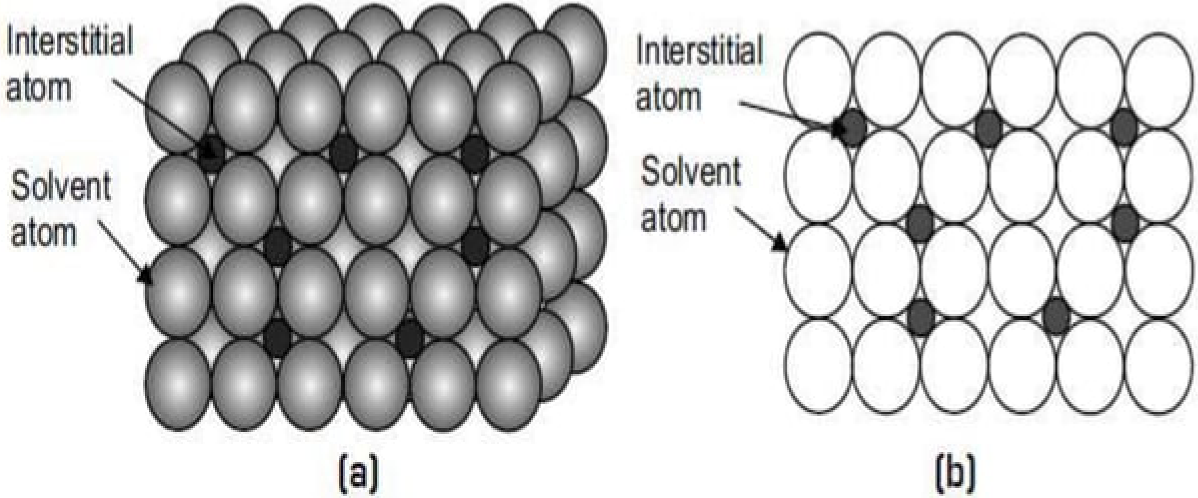


Ordered Substitutional Solid Solution

Here, the solid solution is **heated to its recrystallization temperature and then cooled very slowly,** the atoms are rearranged due to the diffusion that takes place during cooling. This results in **uniformity and definite ordering** of the atoms in the lattice structure.



INTERSTITIAL SOLID SOLUTION



Phase Diagram (constitutional diagram)

- The solidification of a metal or an alloy is clearly understood by means of a phase diagram. A plot with the temperature on the vertical scale and the percentage of composition by weight on the horizontal scale is termed a phase diagram.

Cooling curve

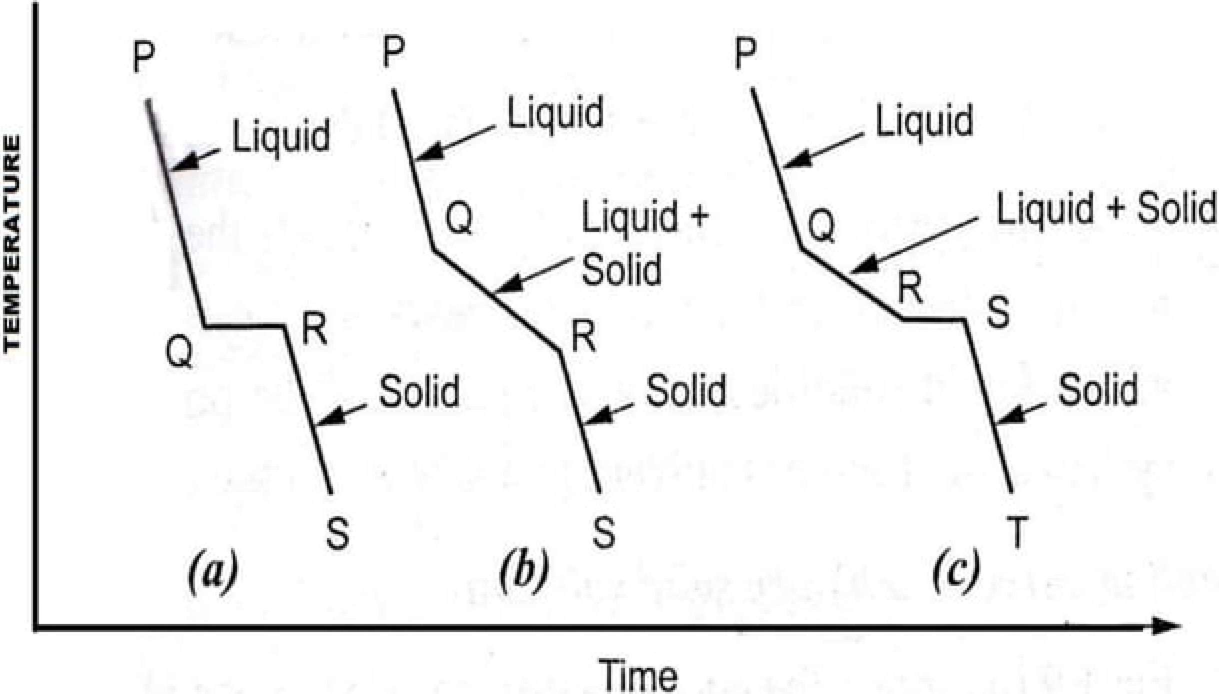
- The solidification of molten metal is plotted as a graph is called cooling curve.

- X – axis – Time
- Y – axis - Temperature

This curve is used for studying the changes that occur during the solidification of alloys. If a plot is drawn between temperature and time at a constant composition, the resulting cooling curve shows a **change of slope when a phase change occurs**.

Types of cooling curve

1. Cooling curve for Pure metal or compound (liquid , solid)
2. Cooling curve of a binary solution (liquid, solid ,liquid + solid)
3. Cooling curve of a binary Eutectic system (liquid, solid ,liquid + solid)


TEMPERATURE
P
Liquid
Q
R
Solid
S
(a)
P
Liquid
Q
Liquid +
Solid
R
Solid
S
(b)
P
Liquid
Q
Liquid + Solid
R
S
Solid
T
(c)
Time

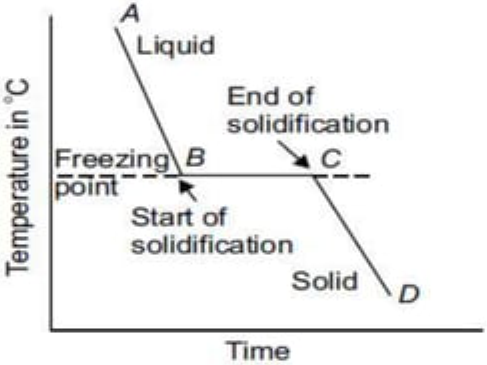
Cooling Curve for Pure Metals or Solidification of Pure Metals

Liquid metal cools from A to B.

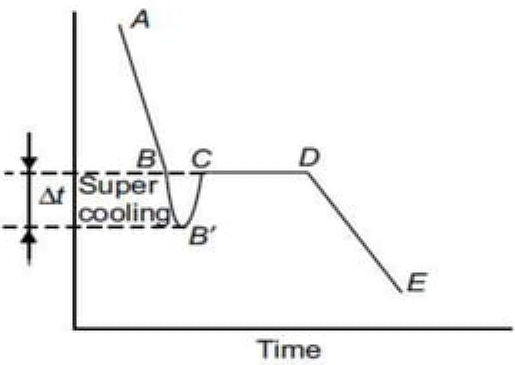
The crystal begins to form at B.

From B to C molten metal liberates latent heat of fusion and the temperature remains constant until the entire liquid metal is solidified.

Between B and C, the metal is partially solid and partially liquid. On further cooling, i.e., from C to D, solid metal tends to reach the room temperature.



(a)



(b)

Cooling Curve for Binary Alloy (Type-1)

A - Cooling started

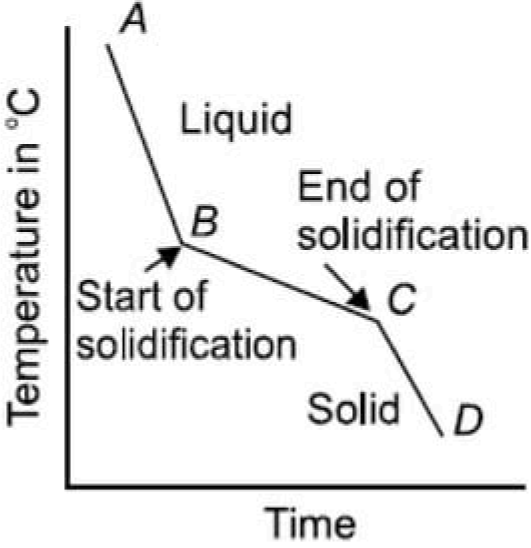
B - Crystals begin to form

B-C-Temperature is not constant

(Partially liquid and solid)

C-D – further Solidification

D – Becomes solid



The Cu–Ni system is an example .

Solidification of Alloy—Type 2 (Eutectic Solidification)

A-B - Cooling started

B - Crystals begin to formation in one metal

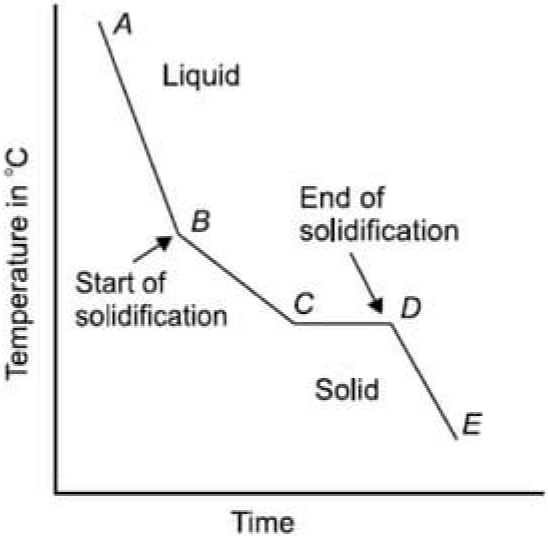
B-C-Temperature is not constant

(Partially liquid and solid)

C-D – further Solidification

D – Becomes solid

D-E – Metal Cools to Room Temperature



The Cd–Bi system is an example of two metals completely soluble in liquid state but partially soluble in solid state.

CONSTRUCTION OF PHASE DIAGRAM

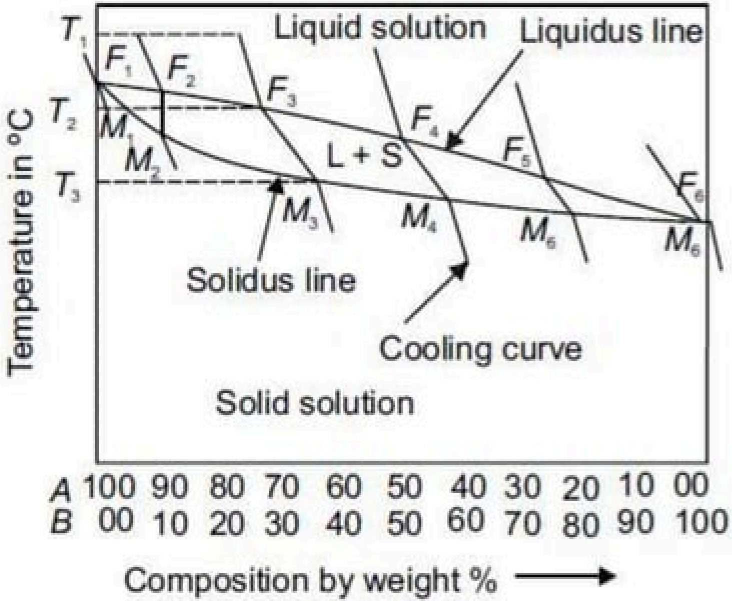
- while constructing the **alloy diagram** of the nickel–copper alloys, approximately, the following steps have to be followed:
- **Construct the cooling curve of pure metal A**
- **Construct the cooling curve of pure metal B**
- Construct the cooling curves of about 10 different alloys of A and B,
- for example, an alloy of 90% A with 10% B;

  an alloy of 80% A and 20% B;

  and so on.

Phase diagram for two metals completely soluble both in liquid and solid phases

A and B are mixed in proper proportion and heated above the melting temperature of that alloy. Molten alloys are allowed to cool

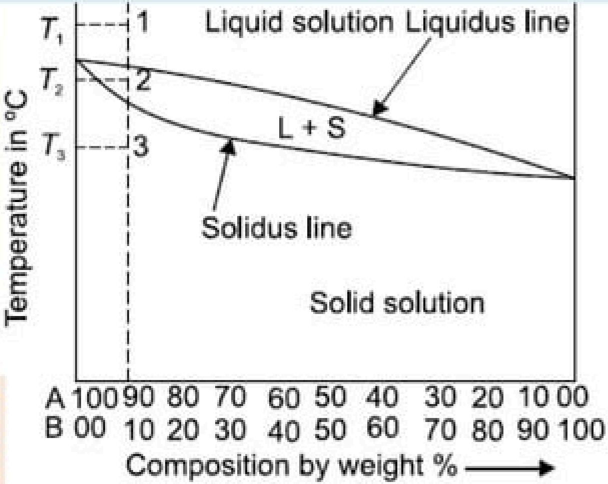


INTERPRETATION OF PHASE DIAGRAM

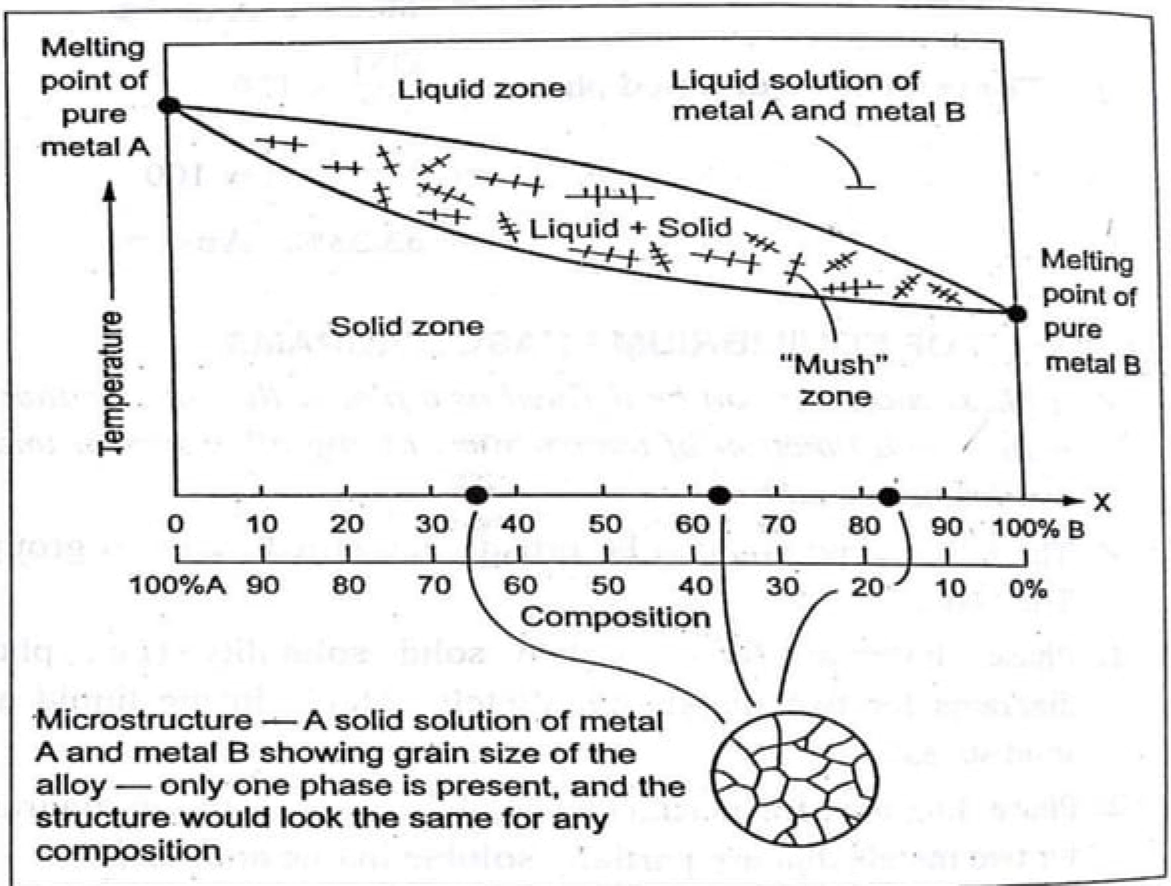
Prediction of Phase

At point 1 – Above liquid line, its in liquid state - 90% of *A* and 10% of *B* at T_1°C

At point 2 - it is between the solidus and liquid us lines. It consists of liquid solid inter phase with 90% of *A* and 10% of *B* at T_2°C.

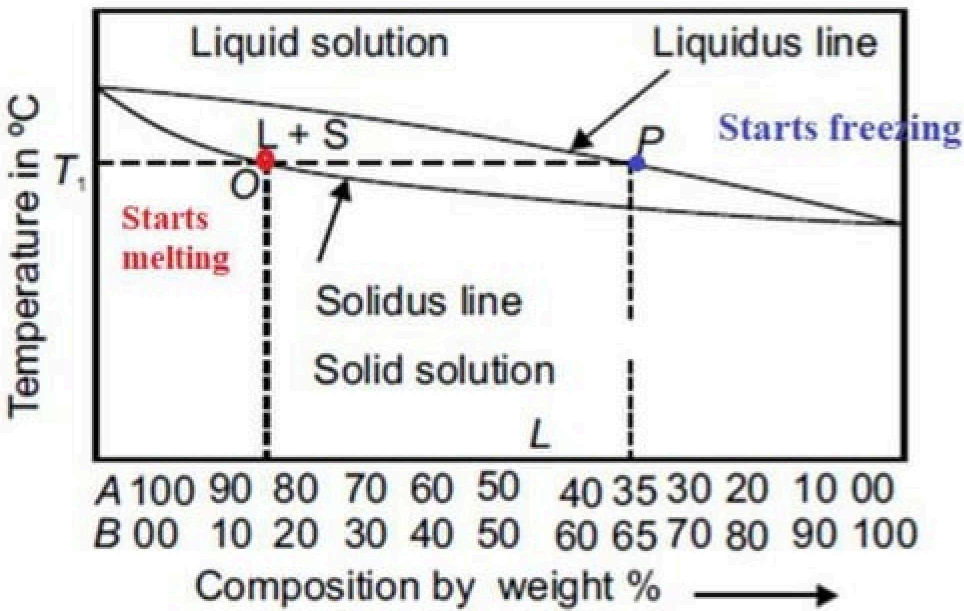


At point 3, it is below the solidus line, so it consists only solid solution of 90% of A and 10% of B at T3°C.

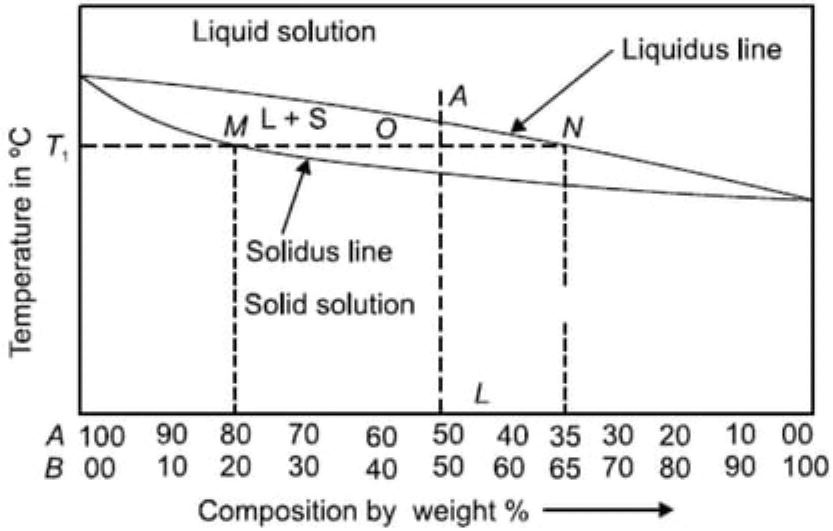


Melting point of pure metal A
Liquid zone
Liquid solution of metal A and metal B
Liquid + Solid
Melting point of pure metal B
Solid zone
"Mush" zone
Temperature
X
0 10 20 30 40 50 60 70 80 90 100% B
100%A 90 80 70 60 50 40 30 20 10 0%
Composition
Microstructure — A solid solution of metal A and metal B showing grain size of the alloy — only one phase is present, and the structure would look the same for any composition

Draw a horizontal line, that intercepts at O and P on solidus and liquid us line. From the points O and P, project vertical lines to confirm the composition. At point P, the composition 35% of A and 65% of B starts freezing. The composition 80% of A and 20% of B starts melting.



Prediction of Amount of Phase (Lever-arm Rule)



Mathematically, the lever rule can be expressed as
Total amount of solid phase = (ON/MN) × 100
Total amount of liquid phase = (OM/MN) × 100

GIBBS PHASE RULE

The number of variable factors which define the state of a system is called the **degree of freedom.**

$$P + F = C + N$$

Where,

F = number of degrees of freedom **or** number of physical variables

C = number of components in the system

P = number of phases in the system

N = number of external factors -temperature and pressure.

$$P + F = C + 1$$

or

$$F = C + 1 - P$$

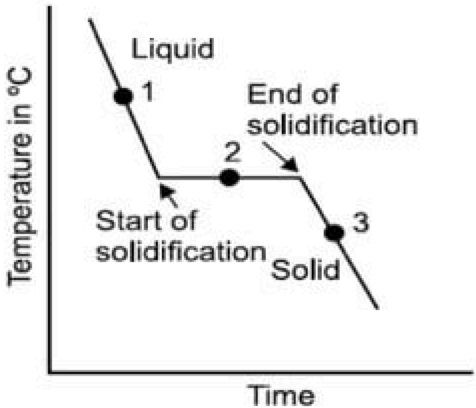
The number of degrees of freedom cannot be less than 0. So,

$$C + 1 - P \geq 0$$

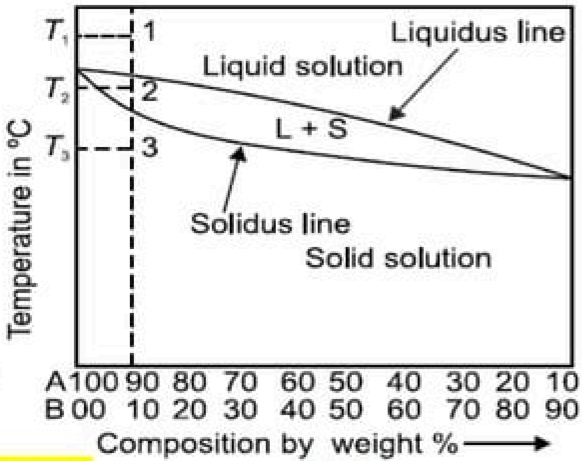
or

$$P \leq C + 1$$

Verification of Gibbs phase rule: (a) Cooling curve for pure metal and (b) phase diagram of two metals completely soluble both in liquid and solid states



(a)

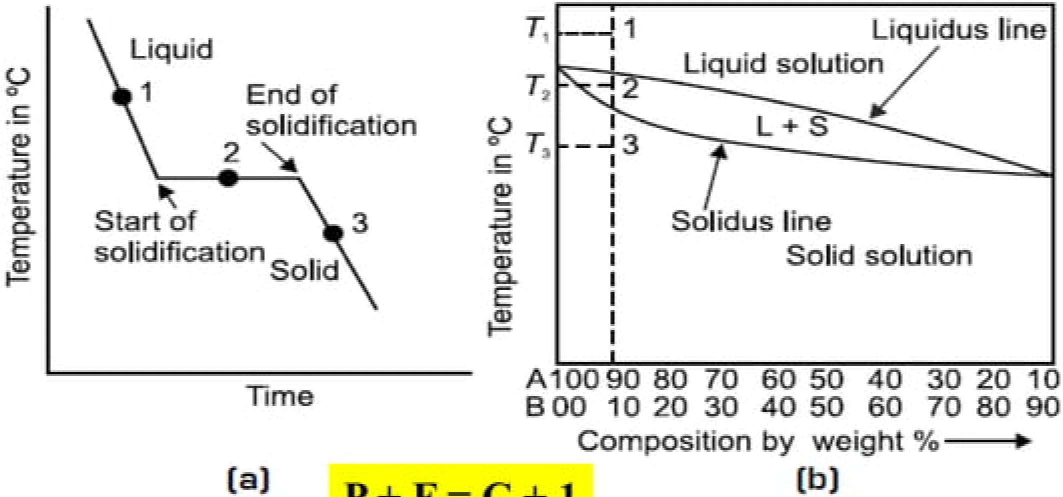


(b)

$$P + F = C + 1$$

The degrees of freedom at Point 1 becomes

$$F_1 = C + 1 - P$$
$$F_1 = 1 + 1 - 1$$
$$F_1 = 1$$

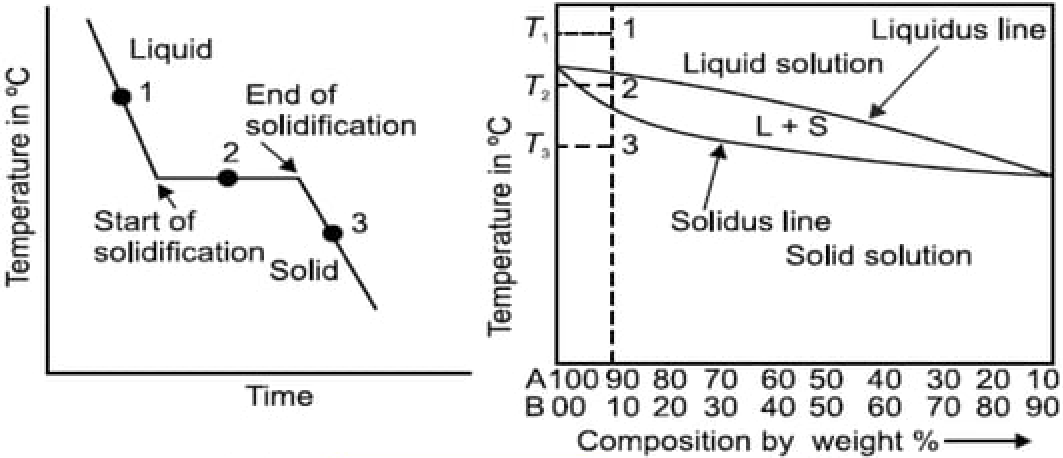


$$P + F = C + 1$$

has two (liquid and solid) phases.

The degrees of freedom at Point 2 becomes

$$F_2 = C + 1 - P$$
$$F_2 = 1 + 1 - 2$$
$$F_2 = 0$$



(a) (b)

$$P + F = C + 1$$

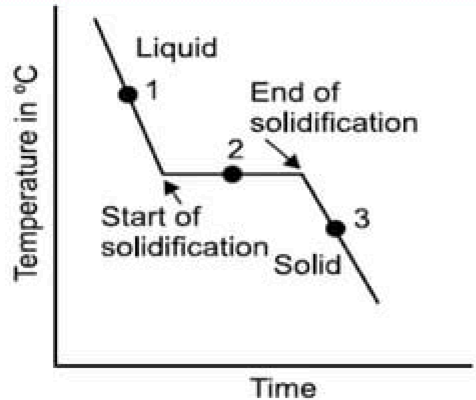
The degrees of freedom at Point 3 becomes

$$F_3 = C + 1 - P$$

$$F_3 = 1 + 1 - 1$$

$$F_3 = 1$$

Verification of Gibbs phase rule: (a) Cooling curve for pure metal and (b) phase diagram of two metals completely soluble both in liquid and solid states



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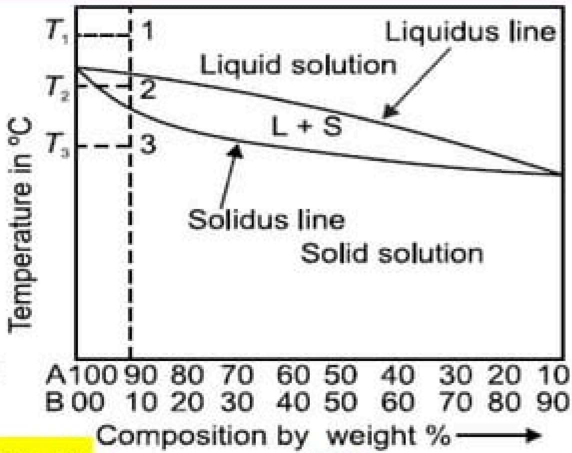


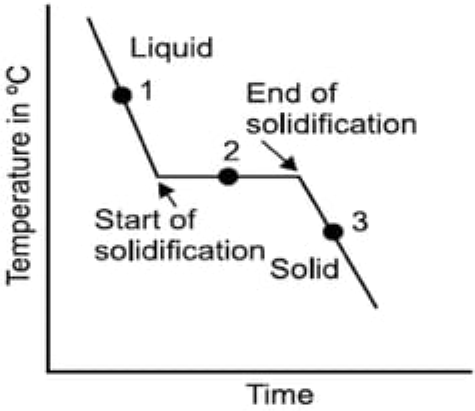
(b)

$$P + F = C + 1$$

Binary Solid Solution → has a single liquid phase.

The degrees of freedom at Point 1 becomes

$$F_1 = C + 1 - P$$
$$F_1 = 2 + 1 - 1$$
$$F_1 = 2$$



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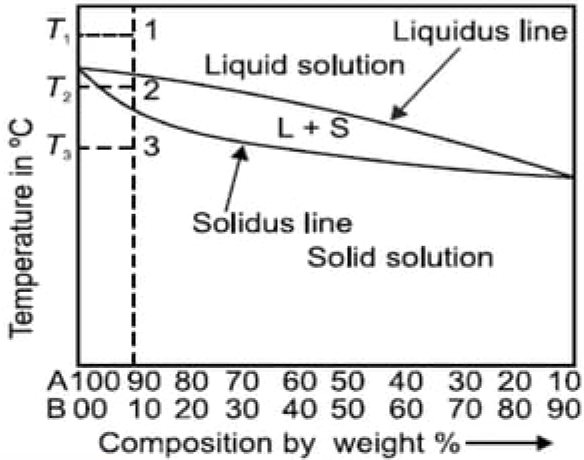


(b)

$$P + F = C + 1$$

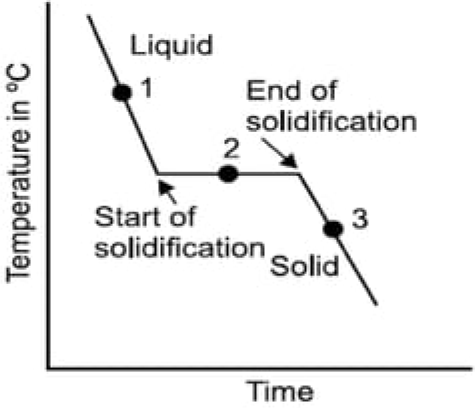
Binary Solid Solution → Two phase two component system.

The degrees of freedom at Point 2 becomes

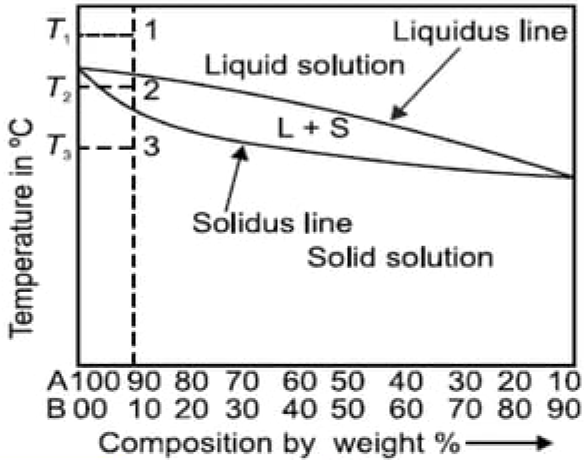
$$F_2 = C + 1 - P$$

$$F_2 = 2 + 1 - 2$$

$$F_2 = 1$$



(a)



(b)

$$P + F = C + 1$$

Binary Solid Solution → Only Solid phase

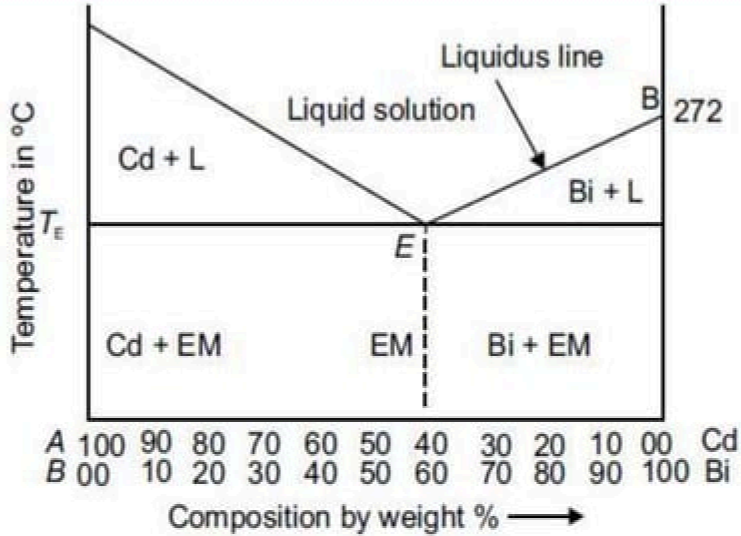
The degrees of freedom at Point 3 becomes

$$F_3 = C + 1 - P$$

$$F_3 = 2 + 1 - 1$$

$$F_3 = 2$$

LIQUID AND SOLID-STATE TRANSFORMATION



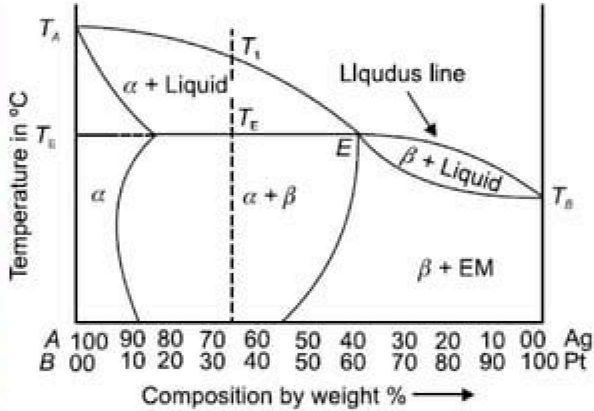
Eutectic Reaction (Transformation)

$$\text{Liquid} \xrightleftharpoons[\text{Heating}]{\text{Cooling}} \text{Solid1} + \text{Solid2}$$

Peritectic Reaction

Here the liquid phase reacts with the solid phase to give a **solid phase of different structure,** at a constant temperature.

Consider a liquid of composition of 25% silver and75% platinum. The solidification starts at T_1°C and 'α' begins to form till peritectic temperature (T_E). At this temperature, the 'α' crystals begin to react with remaining liquid and form δ solid solution.



$$\text{Solid} + \text{Liquid} \underset{\text{Heating}}{\overset{\text{Coling}}{\rightleftarrows}} \text{New Solid}$$

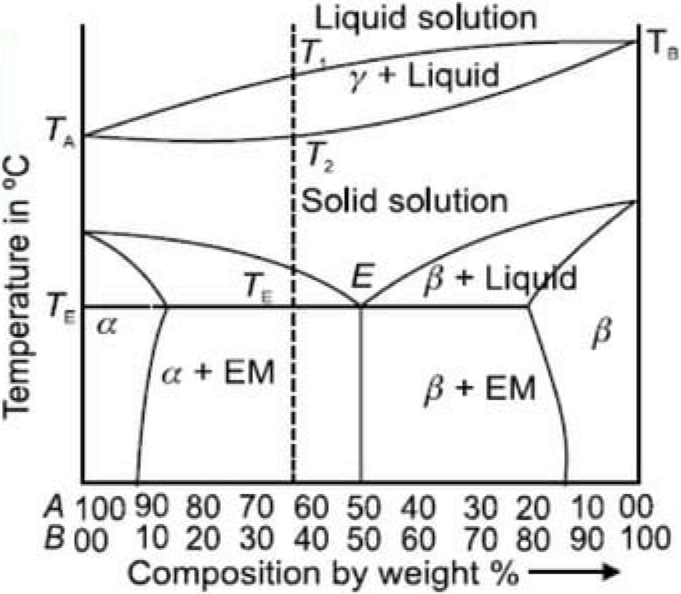
$$\alpha + \text{Liquid} \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftarrows}} \delta$$

Eutectoid Reaction

The solid-state transformations is the **eutectoid reaction** in which one solid phase decomposes isothermally into a mixture of **two solid phases**.

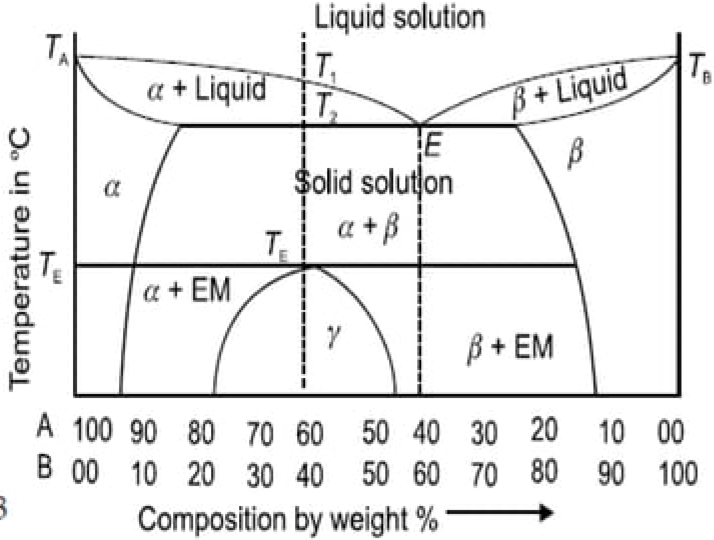
$$\text{Solid1} \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftarrows}} \text{Solid2} + \text{Solid3}$$

$$\gamma \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftarrows}} \alpha + \text{EM}$$



Peritectoid Reaction

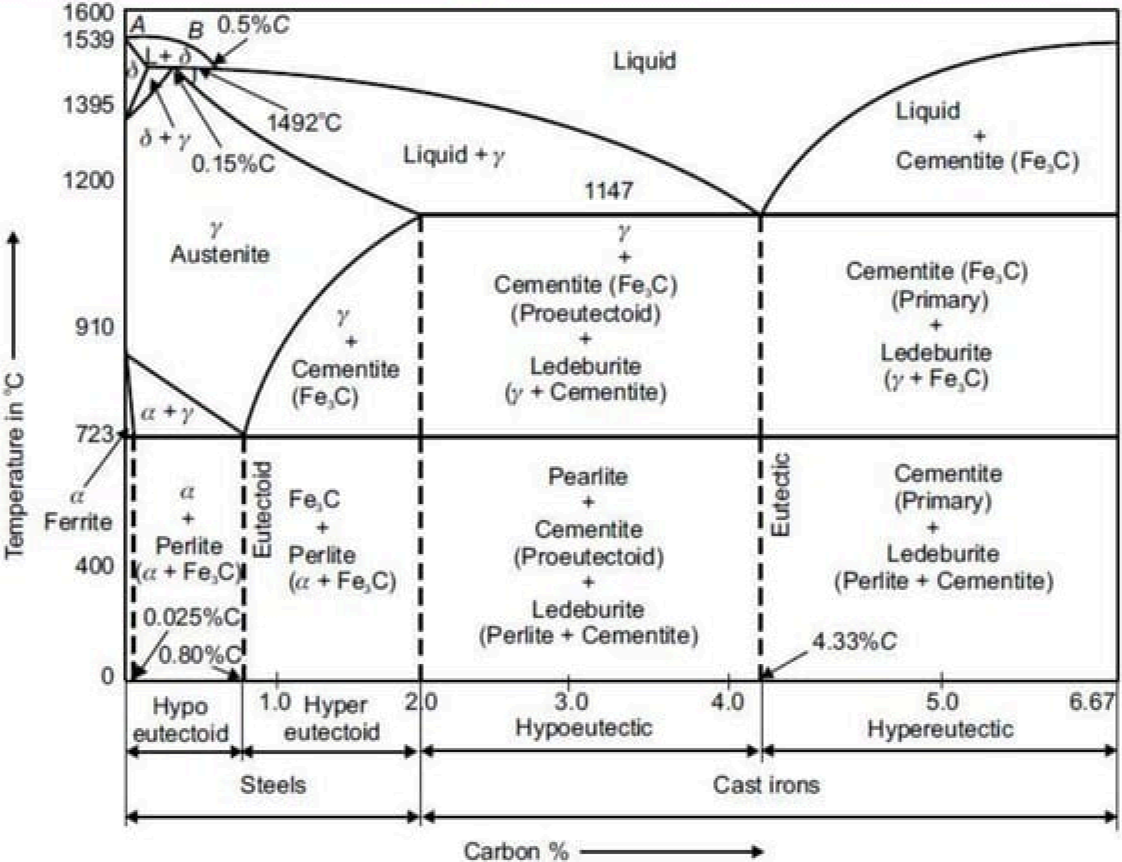
It is a very rare reaction. Here the two solid phases, a pure metal and the other solid solution, react at peritectoid temperature to form a new solid phase.

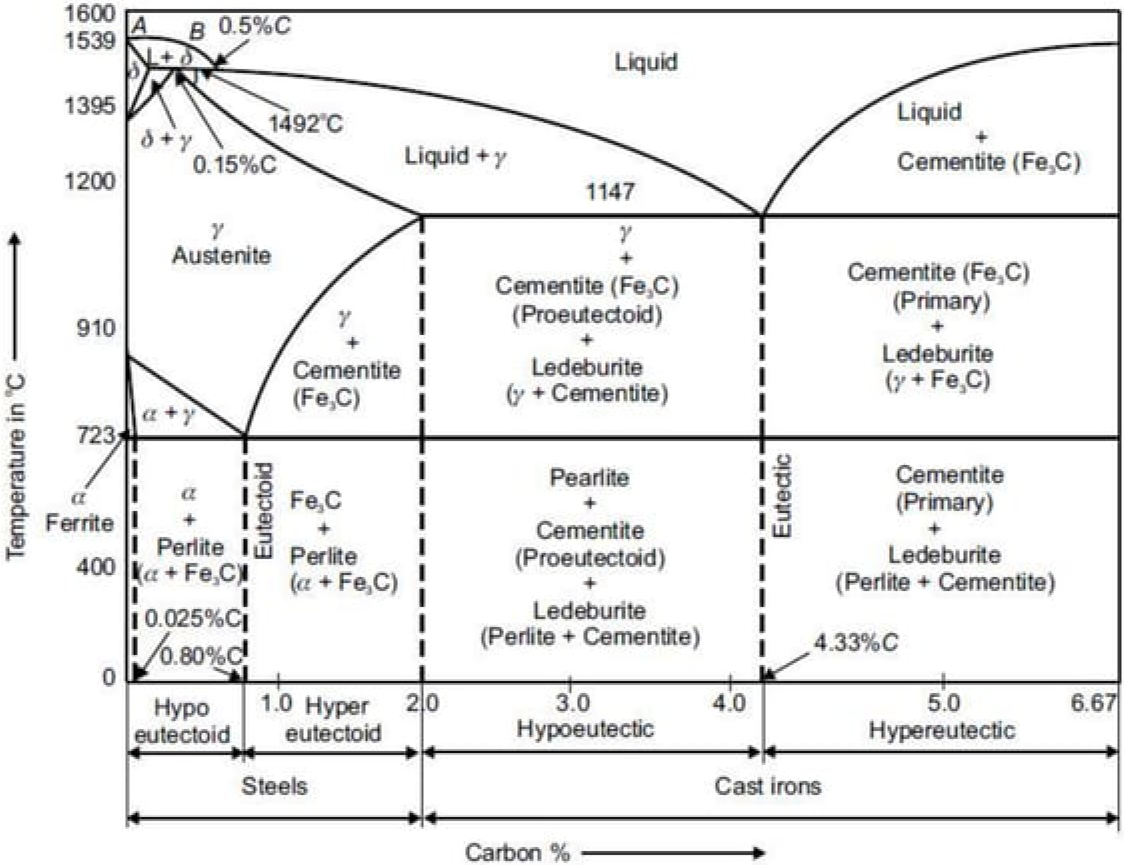


$$\text{Solid1} + \text{Solid2} \;\frac{\text{Cooling}}{\text{Heating}} \rightleftarrows \text{New solid3}$$

$$\alpha + \beta \;\frac{\text{Cooling}}{\text{Heating}} \rightleftarrows \gamma$$

IRON CARBON EQUILIBRIUM DIAGRAM





1600
1539
1395
1200
910
723
400
0
A
B
0.5%C
L + δ
δ
1492°C
δ + γ
0.15%C
Liquid
Liquid + γ
Liquid
+
Cementite (Fe3C)
1147
γ
Austenite
γ
+
Cementite
(Fe3C)
γ
+
Cementite (Fe3C)
(Proeutectoid)
+
Ledeburite
(γ + Cementite)
Cementite (Fe3C)
(Primary)
+
Ledeburite
(γ + Fe3C)
α + γ
α
Ferrite
α
+
Perlite
(α + Fe3C)
Eutectoid
Fe3C
+
Perlite
(α + Fe3C)
Pearlite
+
Cementite
(Proeutectoid)
+
Ledeburite
(Perlite + Cementite)
Eutectic
Cementite
(Primary)
+
Ledeburite
(Perlite + Cementite)
0.025%C
0.80%C
4.33%C
1.0
2.0
3.0
4.0
5.0
6.67
Hypo
eutectoid
Hyper
eutectoid
Hypoeutectic
Hypereutectic
Steels
Cast irons
Temperature in °C
Carbon %

Phases in Iron Carbide –Phase Diagram

The phases that occur in iron carbon alloys are

molten alloys,

austenite,

ferrite,

cementite,

ledeburite

pearlite.

δ-Ferrite –

- **at 1539°C** - **BCC crystal -** called **δ-ferrite**.
- At 1492°C, solubility of carbon 0.1% and 0.15%.
- It is soft, ductile and converted into γ solid solution by reacting with residue liquid of iron at 1395°C.

Austenite–

- **at 1147°C** - **FCC crystal -** called **Austenite**
- solubility of carbon up to 2 %
- It is a nonmagnetic iron
- On cooling below 723°C, it starts transferring into ferrite and pearlite.

Ferrite –

- The structural modification of **pure iron** at room temperature is known as ferrite.
- **BCC crystal**
- solubility of carbon 0.025% at **723°C**
- It is soft, ductile and low strength

Cementite

- When carbon in iron exceeds the solubility limit, it forms ----- carbon up to 6.67%
- This is also called iron carbide (Fe3C)
- low tensile strength but high compressive strength and ferromagnetic
- It is hardest structure in iron carbide system.

Pearlite –

- The mixture of ferrite and cementite formed at 727°C on very slow cooling. **Alternate layers have seen.**
- Pearlite is fairly soft and its hardness lies between that of ferrite and cementite.
- It appears like a **fingerprint** in structure.

Ledeburite

- mixture of austenite and cementite
- It contains 6.67% carbon and is formed at 1147°C
- ledeburite is **unstable and transfers** into ferrite and cementite at 726°C.
- It is hard and brittle.

REACTIONS IN IRON CARBON SYSTEM

- **Peritectic reaction**
  - Liquid & Solid to another Solid Transformation

  at 1492°C

$$\text{Liquid} + \delta \underset{\text{Heating}}{\overset{\text{Cooling}}{\rightleftarrows}} \gamma \text{ (Austenite)}$$

- **Eutectic reaction**
  - Solid to Solid Transformation

  at 723°C

$$\gamma\text{(Austenite)} \rightleftarrows \frac{\text{Cooling}}{\text{Heating}} \alpha\text{(Ferrite)} + Fe_3C \text{ (Cementite)}$$

- **Eutectoid reaction.**
  - Liquid to Solid Transformation

  at 1147°C

$$\text{Liquid} \frac{\text{Cooling}}{\text{Heating}} \rightleftarrows \gamma\text{(Austenite)} + Fe_3C \text{ (Cementite)}$$

STEELS

- **Steels** ----- Carbon 0.008% to 2%

low carbon steels	—	0.2% – 0.3% carbon,
medium carbon steels	—	0.3% – 0.6% carbon
high carbon steels	—	0.6% – 1.7% carbon.

Hypoeutectoid steel - Steels with carbon content from **0.025% to 0.8%**

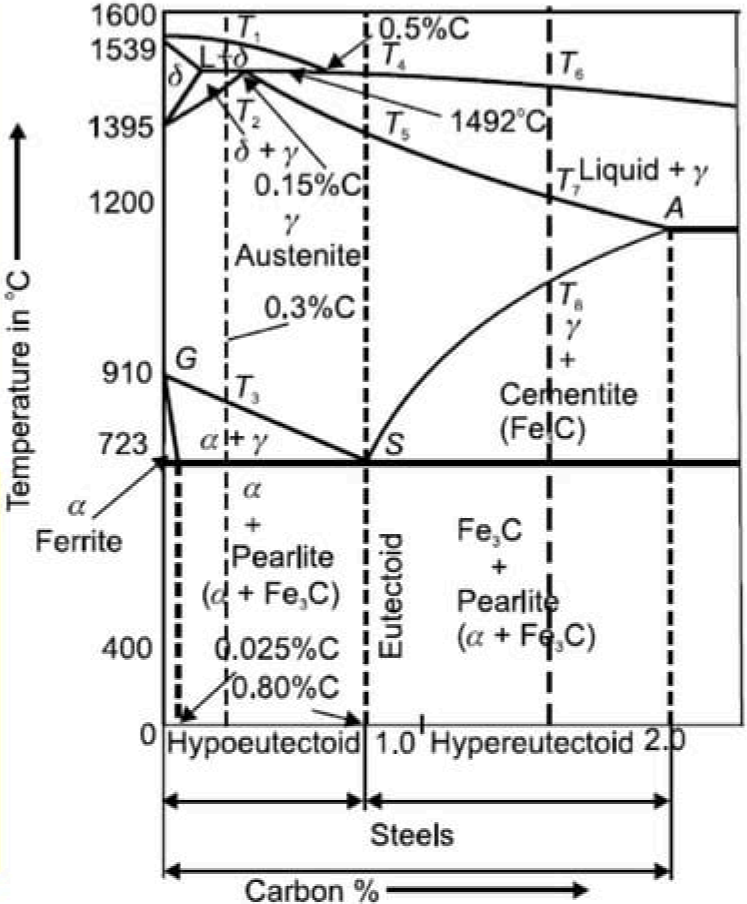
Hypereutectoid steel - Steels with carbon content from **0.8% to 2 %**

Hypoeutectoid Steel

(upto 0.8% Carbon in Steel)

Hypereutectoid Steel

(0.8 % - 2 % Carbon in Steel)

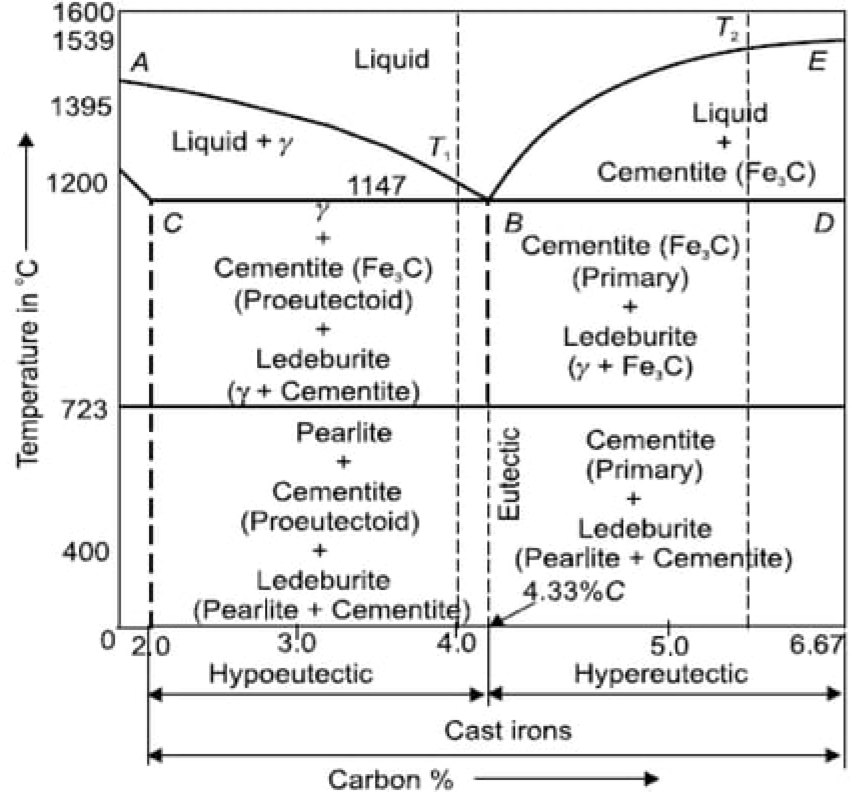


CAST IRON

- **Hypoeutectic cast iron** has carbon content between 2% and 4.33%

Hypereutectic cast iron has carbon content between 4.33% and 6.67%.

CAST IRON



- **Pearlite** - mixture of Ferrite and cementite
- **Ledeburite** - mixture of austenite and cementite

FERRITE AND AUSTENITE STABILIZERS

- **Stabilizing** – means making particular phase more available in room temperature for certain application

Ferrite – BCC structure

Ti, Cr, Mo, Al will help in stabilizing ferrite at room temperature.

Austenite – FCC structure

Si, Mn, Ni, C will help in stabilizing austenite at room temperature.