

**UNIT:I ALLOYS AND PHASE DIAGRAMS**

- Constitution of alloys-Solid solution, substitutional and interstitial-Phase diagrams, Isomorphous, eutectic, peritectic, and peritectoid reactions, Iron-Iron carbon equilibrium diagram.
- Classification of steel and cast Iron, Microstructure, Properties and applications.

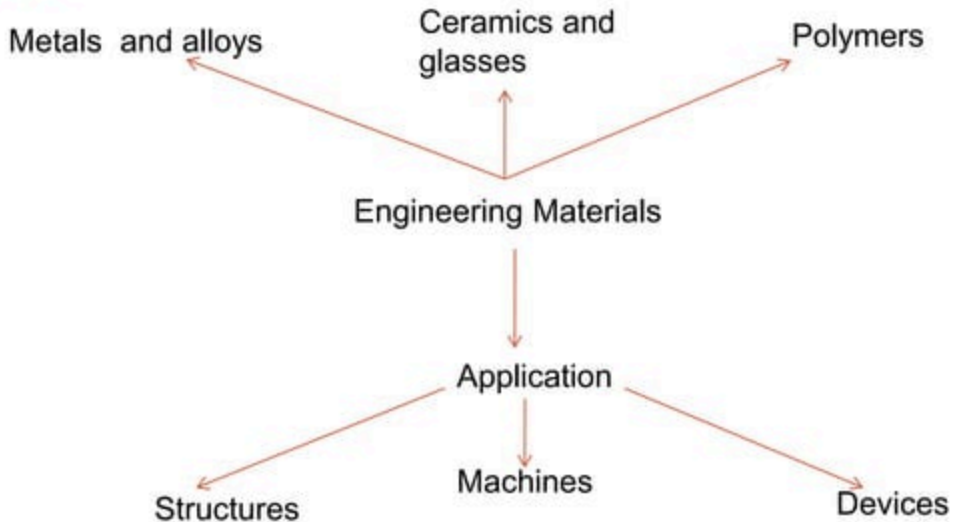
## ENGINEERING MATERIALS AND METALLURGY

### UNIT:II            **HEAT TREATMENT**

**Definition**-Full annealing, stress relief, recrystallisation and spheroidizing-normalising, hardening and tempering of steel. Isothermal transformation diagrams-cooling curves superimposed on I.T.diagram, CCR-Hardenability, Jominy and quench test- Austempering, Martempering-case hardening-carburising, nitriding, cyaniding, carbonitriding, flame and induction hardening .

# ENGINEERING MATERIALS AND METALLURGY

Each category of engineering application requires material from any or all of these three group of materials



# ENGINEERING MATERIALS AND METALLURGY

## **Metals and alloys**

Steels, aluminum,  
copper, silver  
,gold, Brasses,,  
bronze s, maganin  
invar, super alloys  
boron rare earth  
magnetic alloys

## **Ceramic and glasses**

Mgo, cds,  
Al<sub>2</sub>O<sub>3</sub>,  
S iC, BaTiO<sub>3</sub>,Silica,  
soda-time-glass,  
Concrete, cement  
ferrites and garnets  
ceramic  
superconductors

## **Organic polymers**

Plastics,  
Pvc,PTFE,  
polyethylene

Fibers:Terylene,nylo  
n,cotton,  
natural, and  
synthetic  
rubbers ,  
leathers

# CONSTITUTION OF ALLOYS AND PHASE DIAGRAMS

CONSTITUTION OF ALLOYS:

**CONSTITUTION**- establishment, foundation, creation, formation, structure.

**ALLOY:** An alloy is defined as a combination of two or more elements, of which one of the element should be a metal in major proportion.

The others could be metals or non-metals, for eg:

Brass (Cu-Zn), Steel (Fe-C)

## CONSTITUTION OF ALLOYS

A solid solution may be defined as a solid that consist of two or more elements atomically dispersed in a single-phase structure.

A solid solution is composed of two parts.

**1.Solute:** A solute is the minor part of the solution or the material which is dissolved.

**2.Solvent:** Solvent constitutes the major portion of the solution.

Both the solute and the solvent can be solid,liquid or gas.

## CONSTITUTION OF ALLOYS

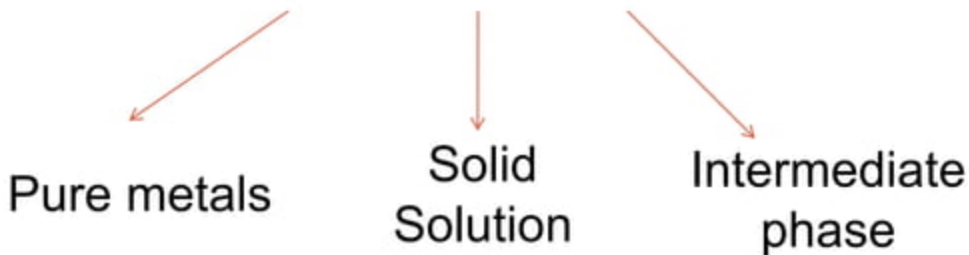
The major element which is large in amount is called base metal or parent metal or solvent.

The other element that is lesser in amount is called the alloying element or solute, it is the minor part (such as salt or sugar which is less in amount, being mixed in water- solvent).

# CONSTITUTION OF ALLOYS

## CLASSIFICATION OF ALLOYS

### CLASSIFICATION OF ALLOYS



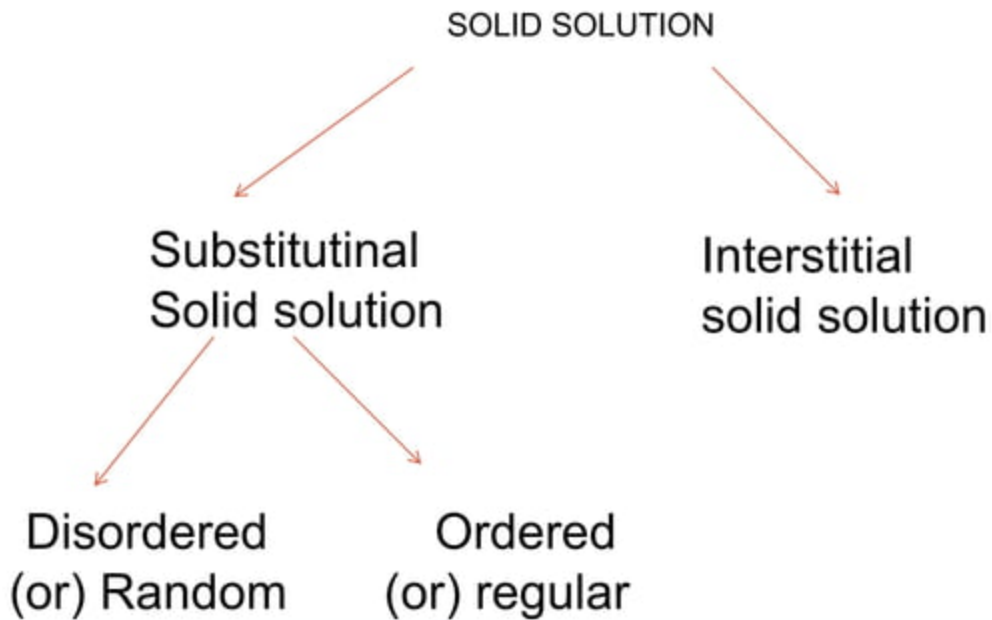


# CONSTITUTION OF ALLOYS AND PHASE DIAGRAMS

## Solid solutions:

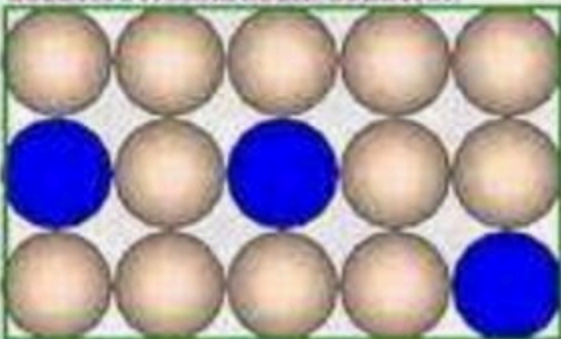
- A solid solution is the simplest type of alloys.
- A Solution can be defined as a homogeneous mixture in which the atoms or molecules of one substance are dispersed at random into another substance.

# CONSTITUTION OF ALLOYS AND PHASE DIAGRAMS



## Substitutional Solid solution

*SUBSTITUTIONAL SOLID SOLUTION*



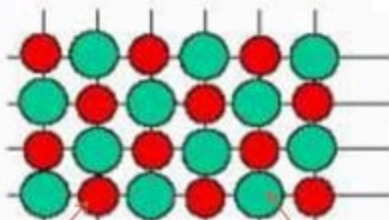
As atoms of the parent metal ( or solvent metal) are replaced or substituted by atoms of the alloying metal (solute metal)

In this case, the atoms of the two metals in the alloy, are of almost same size.

## Ordered Substitutional and Interstitial Compounds

### Substitutional

'an element replaces host atoms in an orderly arrangement'

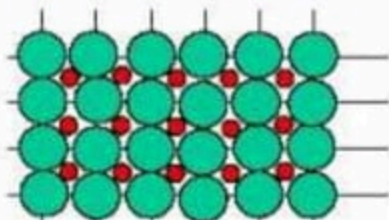


*e.g.*,  $\text{Ni}_3\text{Al}$  (hi-T yield strength),  
 $\text{Al}_3(\text{Li}, \text{Zr})$  (strengthening)

Atoms of  
solute

### Interstitial

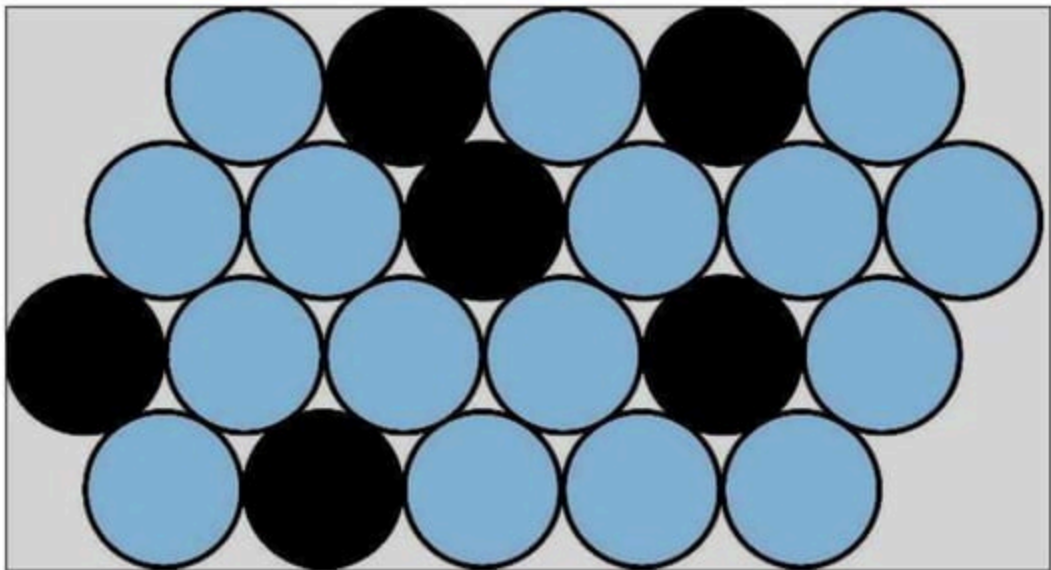
'an element goes into holes in an orderly arrangement'



*e.g.*, small impurities, clays  
ionic crystals, ceramics.

Atoms of Parent  
metal or solvent

## Disordered (or) Random



## SOLID SOLUTION

- Solid solutions are conductors, but not so good as the pure metals on which they are based.

Some examples of solid solutions are:

- Cu-Zn alloys (Brasses)
- Ni-Cu alloys (Monel metal)
- Au-Ag alloys (Sterling silver)
- Fe-Cr-Ni alloys (Certain stainless steels)
- Fe-C alloys (Steels)

## INTERSTITIAL SOLID SOLUTION

- The four elements hydrogen, carbon, nitrogen, and boron have such small diameters that they can occupy the empty spaces (Interstices) in the crystal lattices of many metals.

## INTERSTITIAL SOLID SOLUTION

- Interstitial solid solution usually have a limited composition range and are generally considered of secondary importance, but there are a few instances worthy of special attention.



## INTERSTITIAL SOLID SOLUTION

- The interstitial solution of carbon in iron constitutes the basis of steel hardening.
- Very small amount of hydrogen introduced into steels during acid pickling(cleaning), plating, or welding operations causes a Sharpe decrease in ductility, known as hydrogen embrittlement.

## POSSIBILITIES OF SOLID SOLUTIONS

There are three possible solid solutions based on the amount of their elements. They are:

### 1. unsaturated solid solution

Solvent is dissolving small amount of solute as well as at a given temperature and pressure, it is called unsaturated solid solution

2. Saturated solid solution: solvent is dissolving limiting amount of solute, it is called saturated solid solution.

3. Supersaturated solid solution: If the solvent is dissolving more of solute than it should, under equilibrium, it is called supersaturated solid solution.

## PHASE DIAGRAM

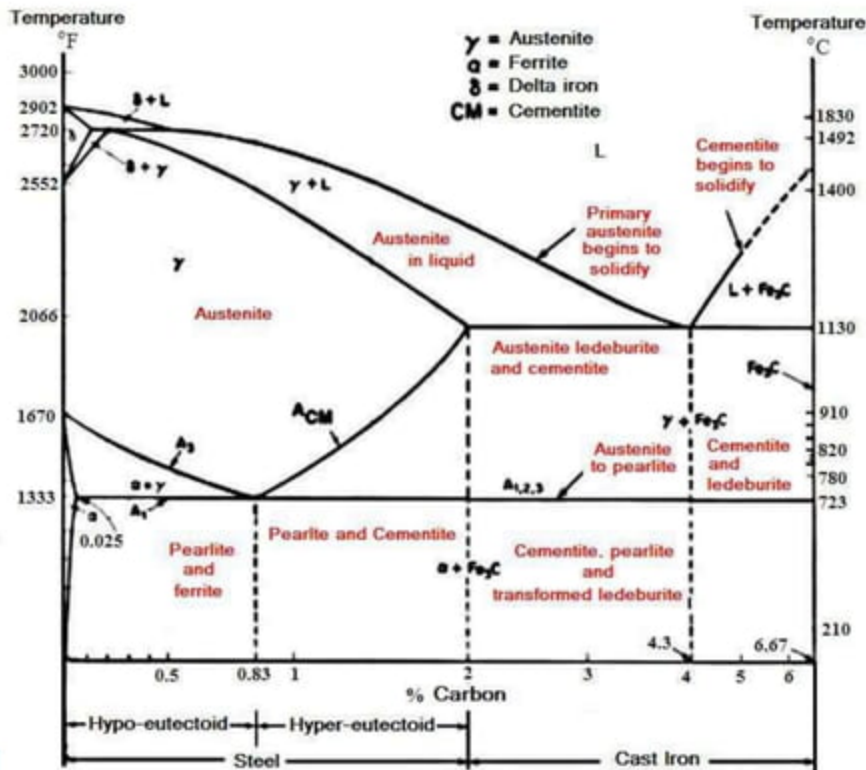
Phase diagrams are graphical representation of what phases are present in an alloy system at various Temperatures, pressures, and compositions.

(OR)

A phase diagram is a map showing the structure or phase present as the temperature and overall composition of the material are varied.

Phase diagrams are also known as equilibrium diagrams or constitutional diagrams.

# IRON/CARBON ALLOY PHASE DIAGRAM (OR) Iron-Carbon equilibrium diagrams



## VARIOUS MICRO-CONSTITUENTS OF IRON-CARBON ALLOYS ARE:

1. Ferrite
2. Austenite
3. Cementite
4. Pearlite
5. Ledeburite
6. Martensite
7. Troosite
8. Sorbite and
9. Bainite

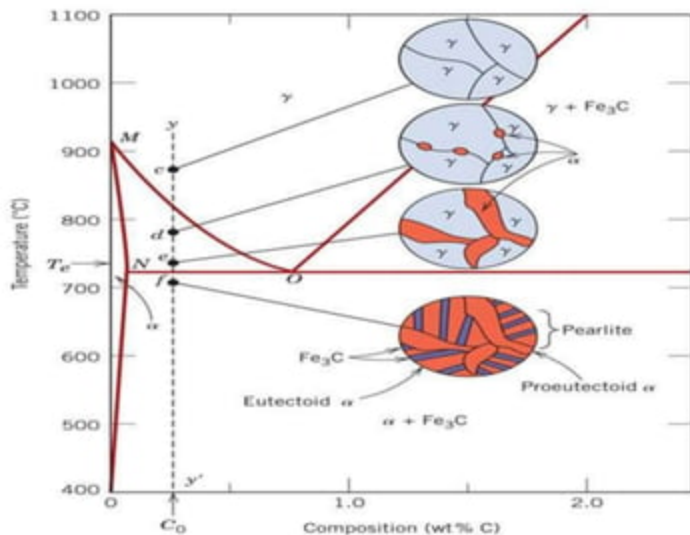


Fig. 2.5 Schematic representations of the microstructures for an iron–carbon alloy of hypoeutectoid composition (containing less than 0.76 wt% C) as it is cooled from within the austenite phase region to below the eutectoid temperature.

## **Phases in Fe–Fe<sub>3</sub>C Phase Diagram**

### **$\alpha$ -ferrite - solid solution of C in BCC Fe**

- Stable form of iron at room temperature.
- The maximum solubility of C is 0.022 wt%
- Transforms to FCC  $\gamma$ -austenite at 912 °C

### **$\gamma$ -austenite - solid solution of C in FCC Fe**

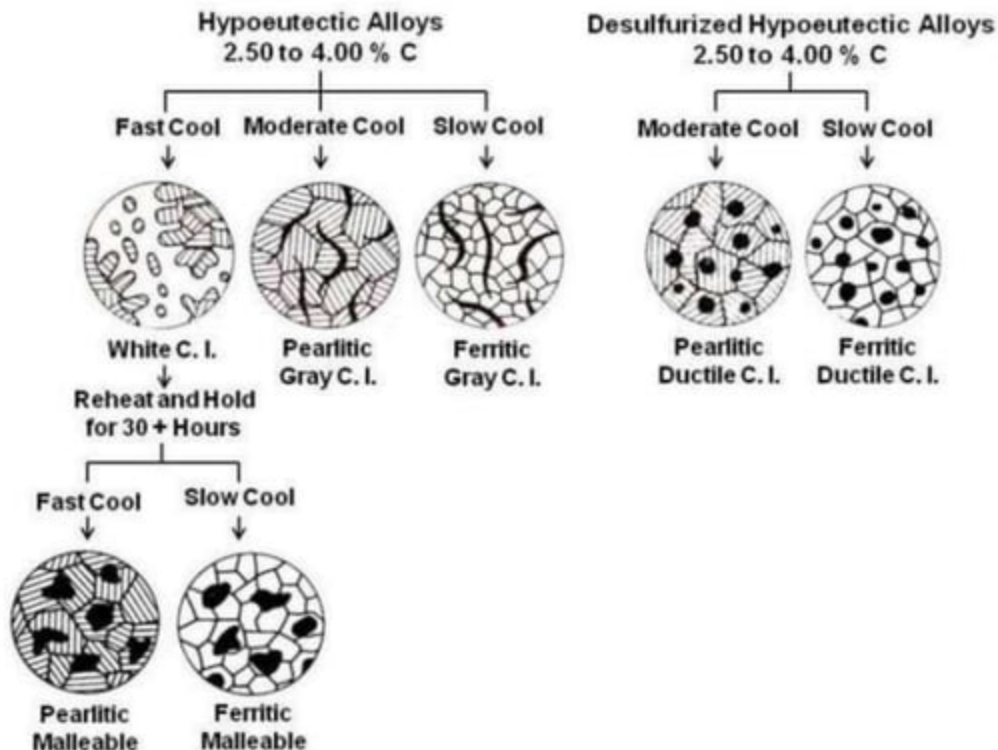
- The maximum solubility of C is 2.14 wt %.
- Transforms to BCC  $\delta$ -ferrite at 1395 °C
- Is not stable below the eutectic temperature (727 °C) unless cooled rapidly (Chapter 10)

### **$\delta$ -ferrite solid solution of C in BCC Fe**

- The same structure as  $\alpha$ -ferrite
- Stable only at high T, above 1394 °C
- Melts at 1538 °C

### **Fe<sub>3</sub>C (iron carbide or cementite)**

- This intermetallic compound is metastable, it remains as a compound indefinitely at room T, but decomposes (very slowly, within several years) into  $\alpha$ -Fe and C (graphite) at 650 - 700 °C



**Summary of Cast Iron Microstructure**



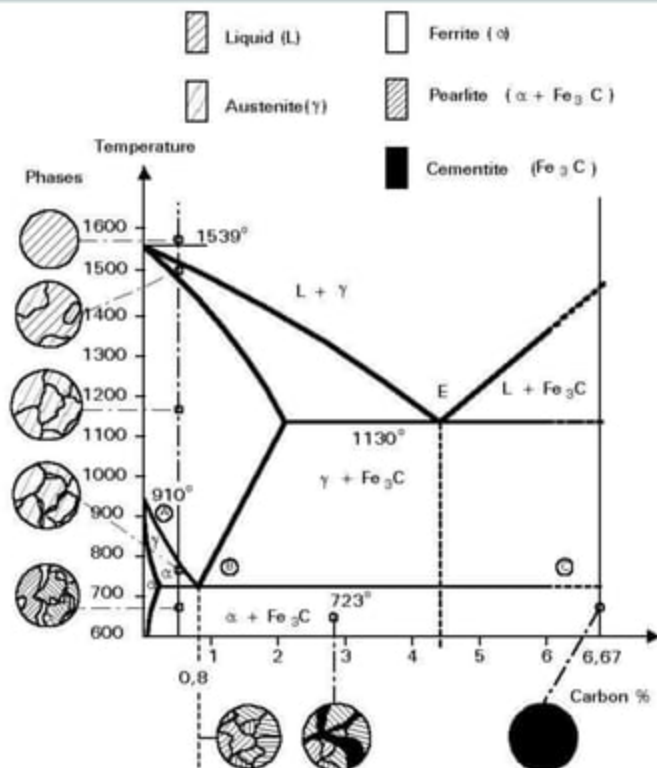


Figure 6 Iron-carbon phase diagram

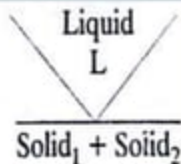
Sectors	Steel applications
Construction	<ul style="list-style-type: none"> <li>•low and high-rise buildings,education and hospital buildings</li> <li>•sports stadiums, stations,reinforced concrete</li> <li>•bridge deck plates,piers and suspension cables</li> <li>•Harbors,cladding and roofing,Offices,tunnels,security fencing</li> <li>•coastal and flood defenses.</li> </ul>
Transport	•Trucks,transmissions,trains,rails,ships,anchor chains,aircraft undercarriages,jet engines components
Energy	<ul style="list-style-type: none"> <li>•oil and gas wells and platforms,pipelines,electricity power turbine components,electricity pylons,wind turbines</li> <li>•transmission towers,electromagnets,transformer cores</li> <li>•electromagnetic shields</li> </ul>
Packaging	•Steel packaging protects goods from water, air, and light exposure, and is fully recyclable.
Appliances and Industry	About 75% of the weight of typical household appliances comes from steel. Steel is found in appliances like fridges, washing machines, ovens, microwaves, sinks, cutlery etc

Different reactions like  
eutectic , eutectoid ,  
Peritectoid , peritectic ,  
non equilibrium cooling

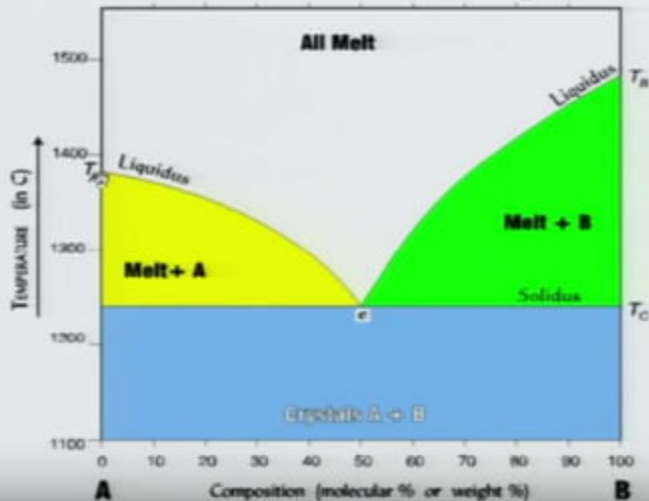
# Eutectic



- In an eutectic reaction, when a liquid solution of fixed composition, solidifies at a constant temperature, forms a mixture of two or more solid phases without an intermediate pasty stage. This process reverses on heating.




## Eutectic Phase Diagram



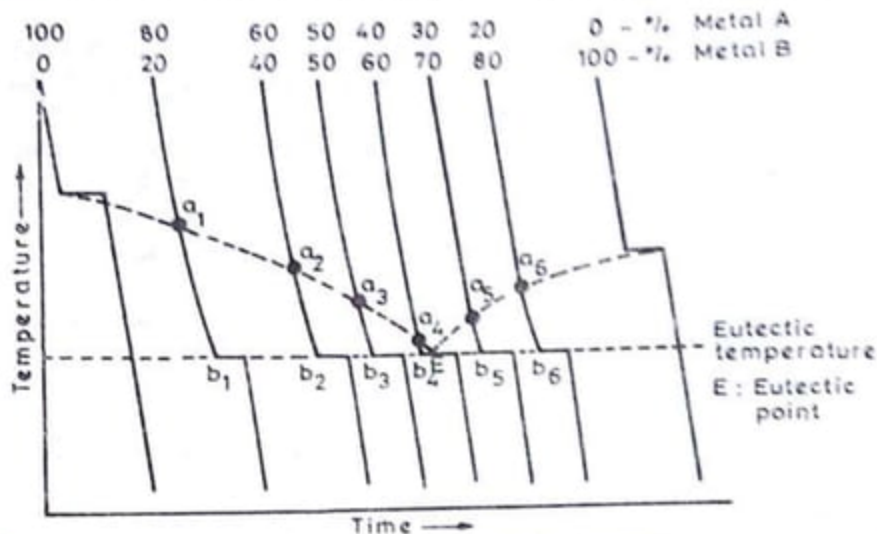
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- 
- ▶ In eutectic system, there is always a specific alloy, known as eutectic composition, that freezes at a lower temp. than all other compositions.
  - ▶ At the eutectic temp. two solids form simultaneously from a single liquid phase.
  - ▶ The eutectic temp. & composition determine a point on the phase dia, called the eutectic point.

► Binary alloy eutectic system can be classed as:

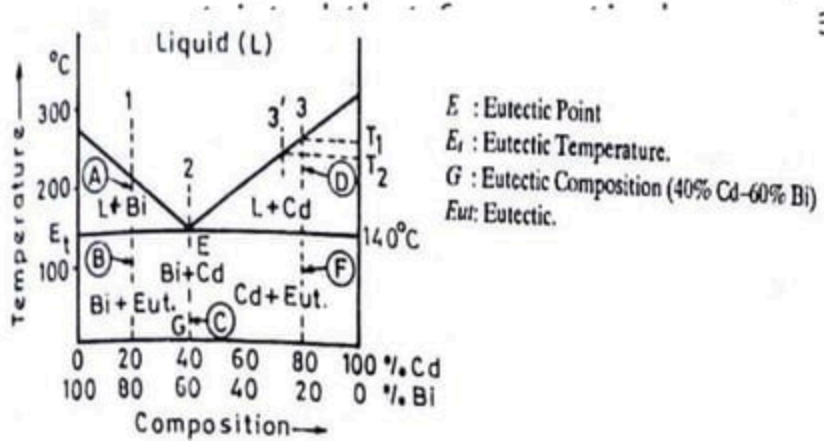
1. One in which, two metals are completely soluble in the liquid state but are insoluble in each other in the solid state.
2. two metals are completely soluble in the



Cooling curves for two metals insoluble in solid state.

1. Two metals completely soluble in the liquid state but completely insoluble in the solid state.

- ▶ Technically, no two metals are completely insoluble in each other. However, in some cases the solubility is



The Bismuth-Cadmium Equilibrium Diagram.



#### Alloy-1: 20% Cd and 80% Bi

- ▶ Contrary to alloy 3, in this case crystal of pure Bi form first, enriching the melt with Cd.
- ▶ The composition of the melt (or liquid) moves to right until Ultimately the point E is reached and the remaining liquid solidi-fies as eutectic (40% Cd and 60% Bi).

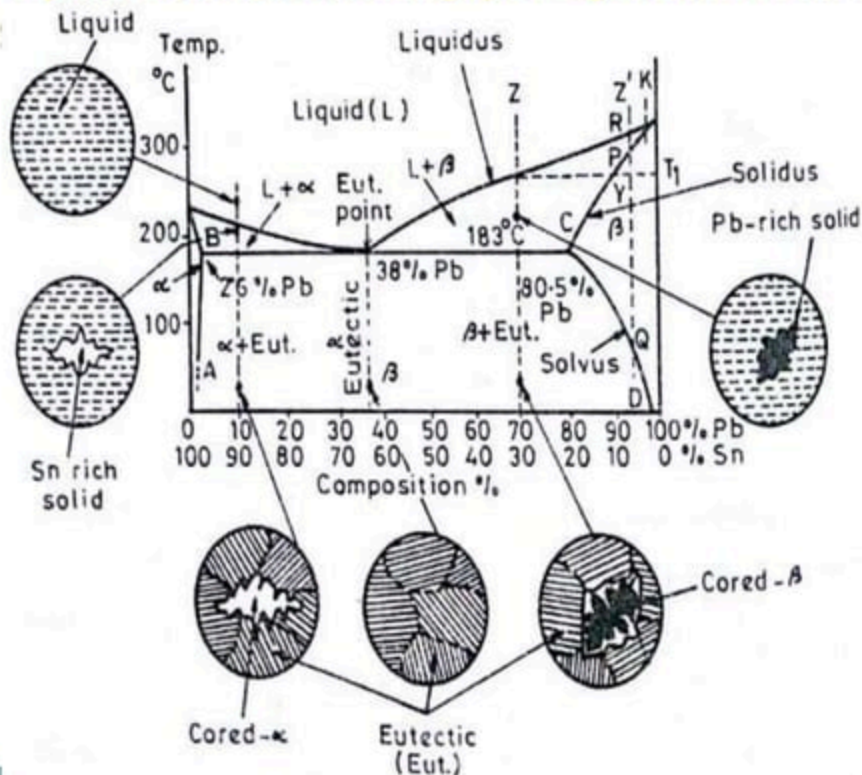
#### Alloy-2: 40% Cd and 60% Bi (eutectic alloy)

- ▶ No solidification occurs until the melt reaches the eutectic temperature ( $140^{\circ}$ )
- ▶ At the eutectic temperature, the two pure metals crystallize together to give a characteristically line aggregate known as eutectic.
- ▶ Eutectic consists of alternate layers of Cd and Bi which form at the eutectic temperature ( $140^{\circ}\text{C}$  in this case).

### ► Alloy-3: 80% Cd and 20% Bismuth.

- As the temperature falls to  $T_1$ , crystal nuclei of pure Cd begin to form. Since pure Cd is deposited, it follows that the liquid becomes richer in Bi; the composition of liquid moves to left 3' and as indicated by the diagram, no further Cd deposits until temperature falls to  $T_2$ .
- At  $T_2$  more Cd is deposited and dendrites begin to develop from the already formed nuclei.
- The growth of the Cd dendrites, on the one hand, and the consequent enrichment of the remaining liquid in Bi, on the other, continues until the temperature has fallen to  $140^{\circ}\text{C}$ , the eutectic temperature in this case.
- The remaining liquid then contains 40% Cd and 60% Bi, the eutectic composition.

## 2. Two metals completely soluble in the liquid state, but only partly soluble in the solid state



The Tin-lead equilibrium diagram.

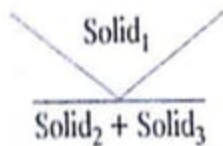
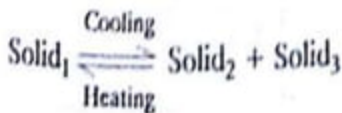
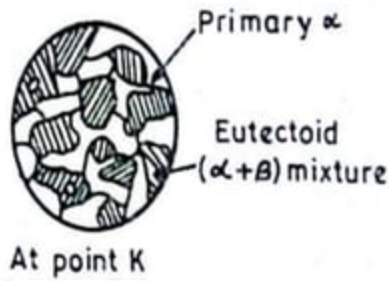
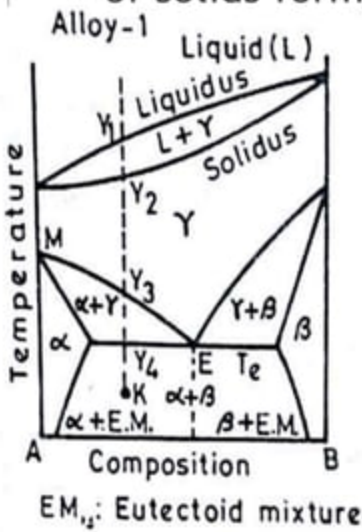
- ▶ Since most metals show some solubility for each other in the solid state, this type is the most common and, therefore, the most common alloy system.
  - ▶ Metals such as Pb-Sn and Pb-Sb are partly soluble in each other in the solid state.
  - ▶ Fig. shows the Tin-Lead equilibrium diagram with micro-structures (of course) obtained under non-equilibrium condition of solidification.
- I. Tin will dissolve up to maximum of 2.6% Pb at the temperature, forming the solid solution  $\alpha$ .
  - II. Lead will dissolve up to a maximum of (100-80.5) i.e. 19.5% tin at the eutectic temperature, giving the solid solution  $\beta$ .
  - III. Slope of BA and CD indicate that the solubility of Pb in Sn ( $\alpha$ ) and that of Sn in Pb ( $\beta$ ) decrease as temperature falls
- ▶ **Consider an alloy of composition Z (70% Pb-30% Sn). As the melt temperature falls to  $T_1$ , dendrites of composition Y will deposit.**

- ▶ The alloy solidifies as a solid solution until at  $183^{\circ}\text{C}$ , the last layer of solid to form is of composition C (80.5% Pb-19.5% Sn).
- ▶ The remaining liquid which has the eutectic composition (38% Pb-62% Sn) then solidifies by depositing, in the form of a eutectic, i.e., alternate layers of  $\alpha$  and  $\beta$ , of compositions B and C respectively.
- ▶ If cooled slowly to room temperature the compositions of the solid solutions  $\alpha$  and  $\beta$  will follow the line BA and CD, i.e.,  $\alpha$  will become progressively poorer in lead and  $\beta$  in tin.
- ▶ Take another alloy of composition Z' (95% Pb-5% Sn). When cooled slowly, solidification starts at R and is complete at P, the resultant solid being a homogeneous single phase, the  $\beta$  solid solution.
- ▶ As the alloy cools, the solvus line is reached at point Q. The  $\beta$  solution is now saturated in tin. Below this temperature, under conditions of slow cooling, the excess tin must come out of solution. Since tin is soluble in lead, the precipitate does not come out as the pure metal tin, but rather the  $\alpha$  solid solution.



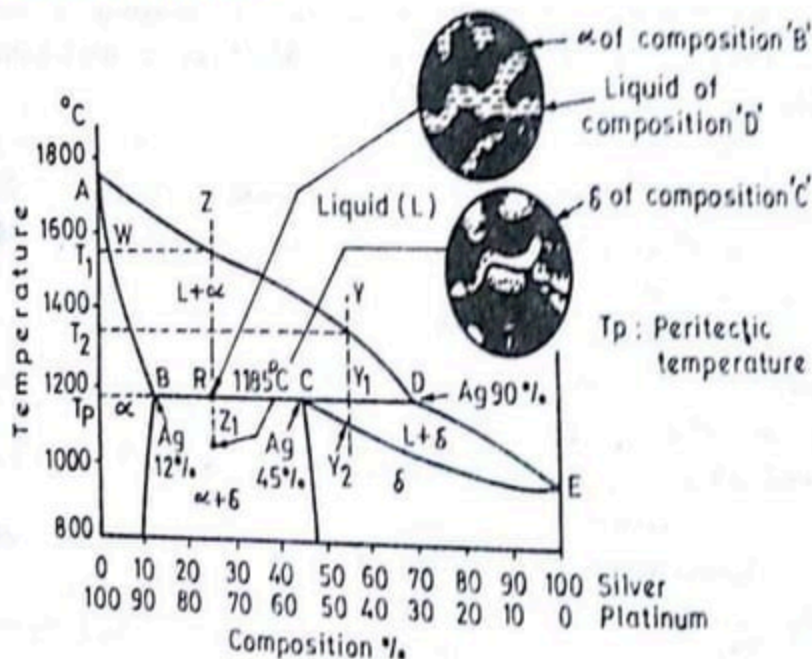
## Eutectoid Transformation:

- ▶ Eutectoid reaction is an isothermal reversible reaction in which a solid phase (usually solid solution) is converted into two or more intimately mixed solids on cooling, the number of solids formed being the same as the number

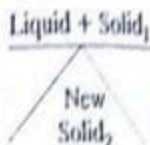


An eutectoid diagram.

## Peritectic reaction:



Peritectic Reaction (Platinum-Silver Equilibrium Diagram).

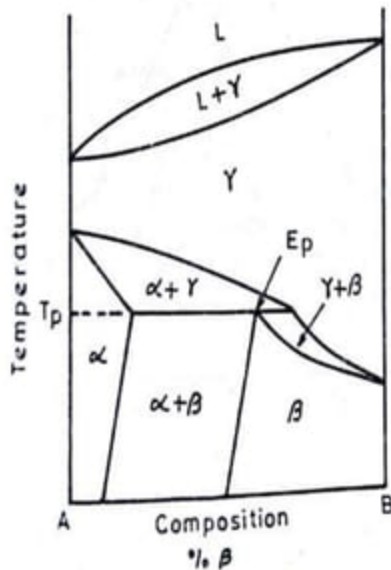
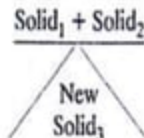
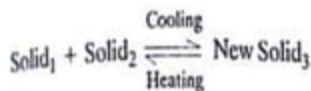


- ▶ It is the reaction that occurs during the solidification of some alloys where the liquid phase reacts with a solid phase to give a solid phase of different structure.
- ▶ Assuming very slow rates of cooling, the peritectic reaction will occur only in those Pt-Ag alloys that contain between 12 and 69% silver (Ag).
- ▶ Consider a liquid (melt) of composition Z, i.e., containing 25% Ag. Solidification commences at  $T_1$  and dendrites of  $\alpha$ , initially of composition W, begin forming.
- ▶ Selective crystallization of  $\alpha$  continues down to  $T_p$ , the peritectic temperature; when the alloy reaches this temperature, it is composed of solid  $\alpha$ -dendrites of composition B and liquid of composition D in the proportion  $\alpha : \text{liquid} = RD : RB$ .



## ▶ Peritectoid Transformation:

- ▶ The peritectoid reaction is the transformation of two solid into a third solid.





*Thank you*