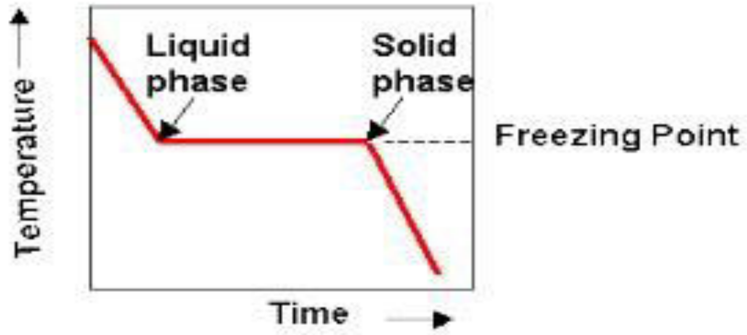
Cooling Curve

- A cooling curve is a graphical plot of the changes in temperature with time for a material over the entire temperature range through which it cools.
- **Cooling Curve for Pure Metals is shown here.**

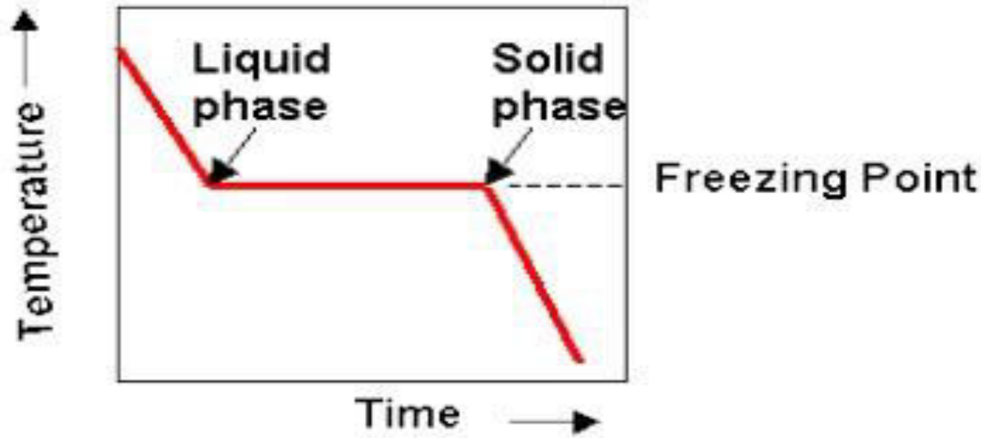


Cooling Curve

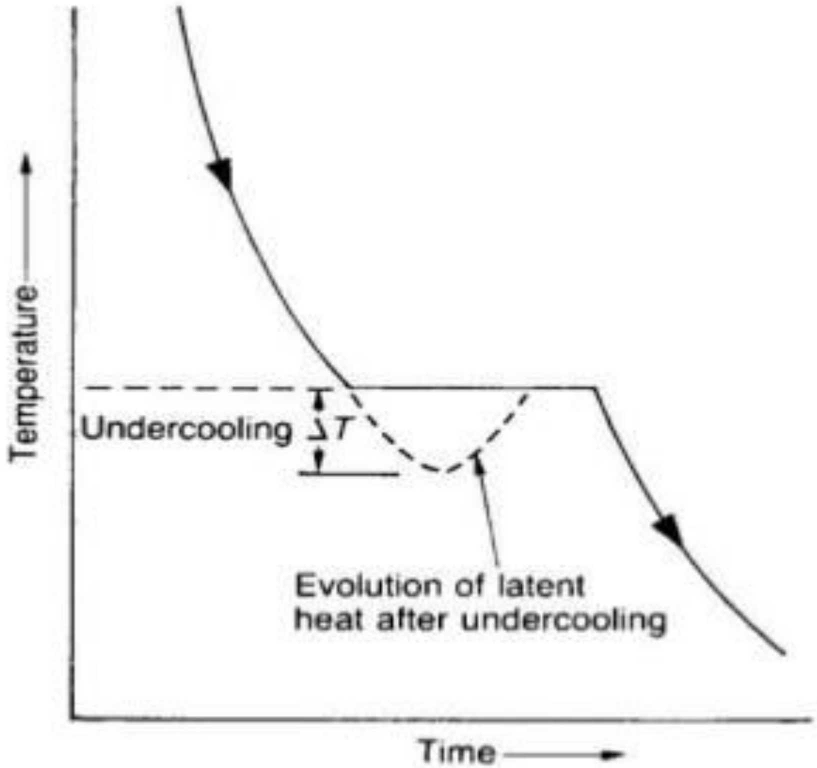
- This is by far the most widely used experimental method.
- It relies on the information obtained from the cooling process.
- In this method, alloys with different compositions are melted and then the temperature of the mixture is measured at a certain time interval while cooling back to room temperature.
- A cooling curve for each mixture is constructed and the initial and final phase change temperatures are determined. Then these temperatures are used for the construction of the phase diagrams

Cooling curve for the solidification of a pure metal

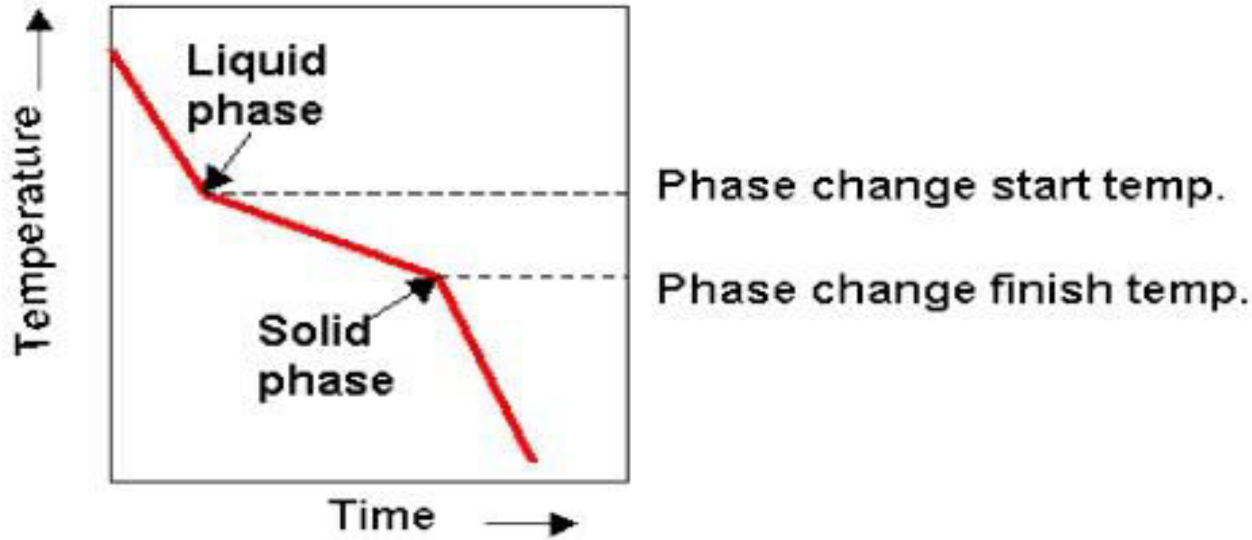
Under equilibrium conditions, all metals exhibit a definite melting or freezing point. If a cooling curve is plotted for a pure metal. It will show a horizontal line at the melting or freezing temperature.



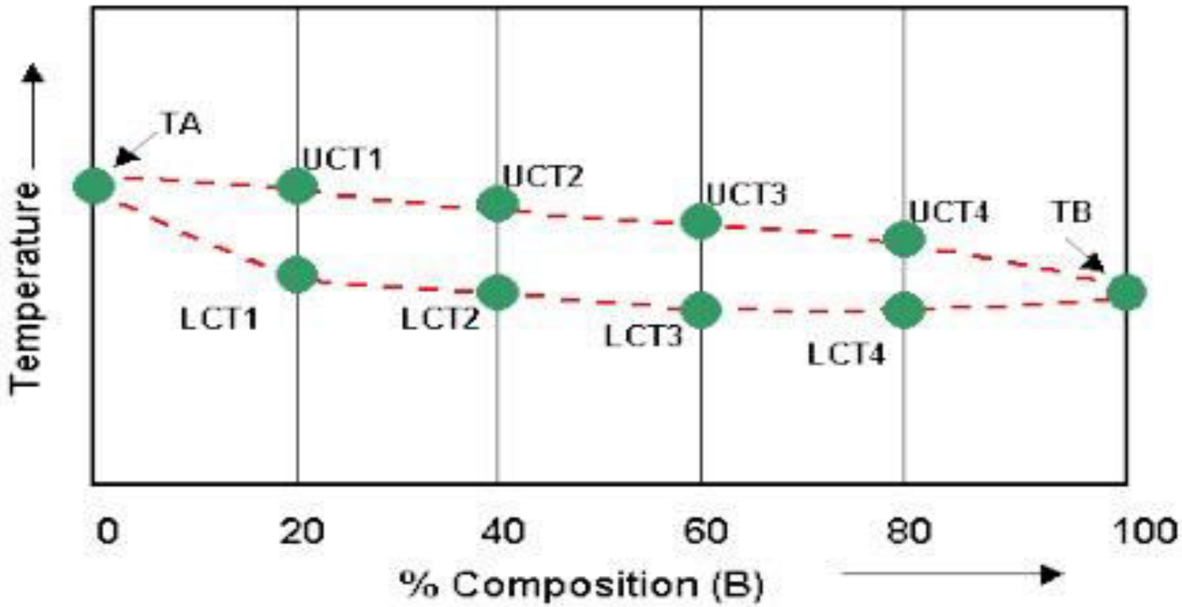
Cooling curve for a pure metal showing possible undercooling.



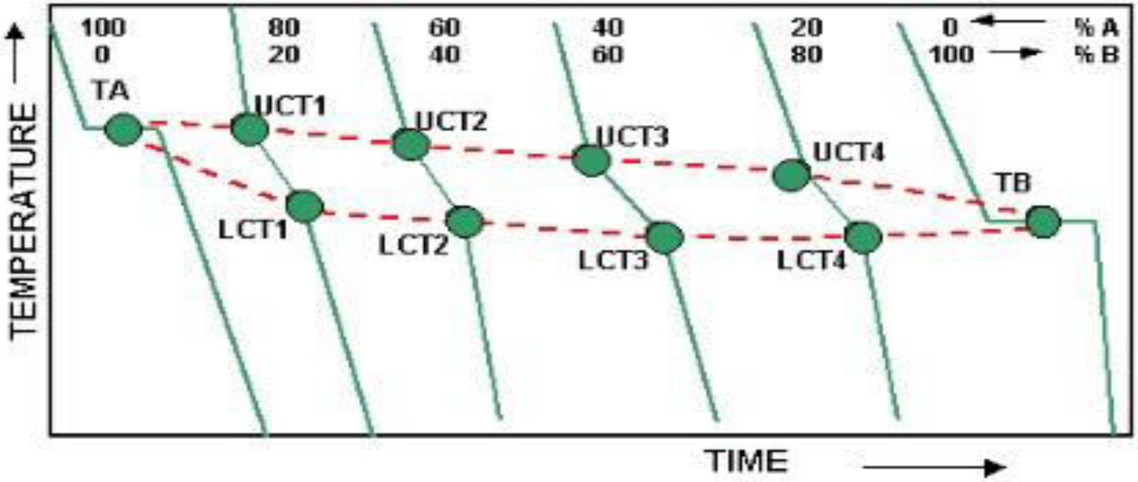
Cooling curve for a solid solution.



Phase Diagram of alloy A+B



Series of cooling curves for different alloys in a completely soluble system. The dotted lines indicate the form of the phase diagram



LCT=Lower Critical Temperature

UCT=Upper Critical Temperature

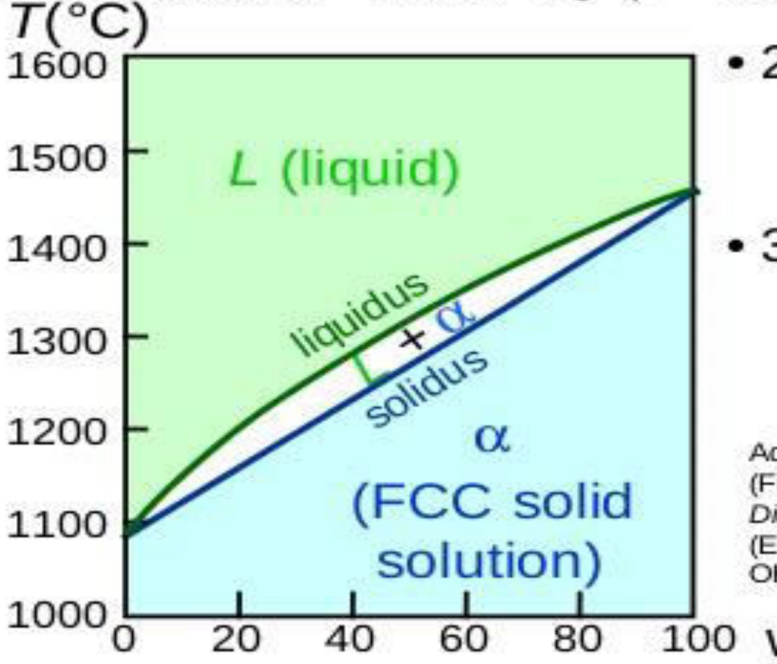
TA=Melting Temperature of Alloy A

TB=Melting Temperature of Alloy B

Phase Diagrams

- Indicate phases as function of T, C_o, and P.
- For this course:
  - -binary systems: just 2 components.
  - -independent variables: T and C_o (P = 1 atm is almost always used).

- Phase Diagram for Cu-Ni system



- 2 phases:
  - L (liquid)
  - α (FCC solid solution)
- 3 phase fields:
  - L
  - $L + \alpha$
  - α

Adapted from Fig. 9.3(a), *Callister 7e.* (Fig. 9.3(a) is adapted from *Phase Diagrams of Binary Nickel Alloys*, P. Nash (Ed.), ASM International, Materials Park, OH (1991).

Determination of phase(s) present

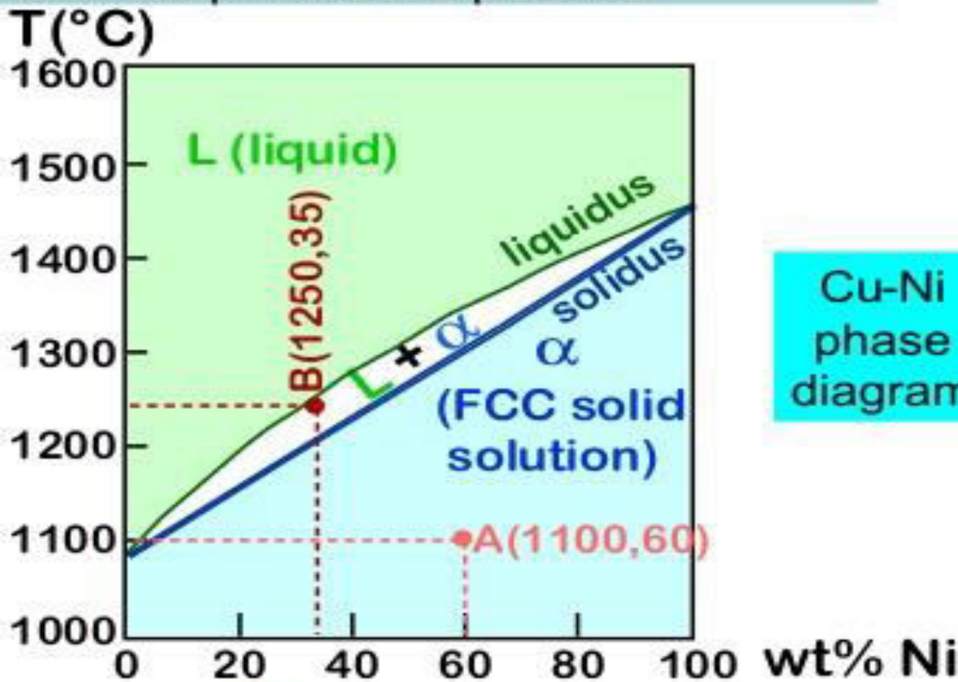
- Rule 1: If we know T and C_o, then we know:
  --how many phases and which phases are present.

- Examples:

A(1100, 60):
1 phase: α

B(1250, 35):
2 phases: L + α

Melting points: Cu = 1085°C, Ni = 1453 °C



Cu-Ni phase diagram

Solidus - Temperature where alloy is completely solid. Above this line, liquefaction begins.
Liquidus - Temperature where alloy is completely liquid. Below this line, solidification begins.

Phase Diagrams: composition of phases

- Rule 2: If we know T and C_o, then we know:
  --the composition of each phase.

- Examples:

At T_A = 1320°C:

Only Liquid (L) present

$C_L = C_0$ (= 35 wt% Ni)

At T_D = 1190°C:

Only Solid (α) present

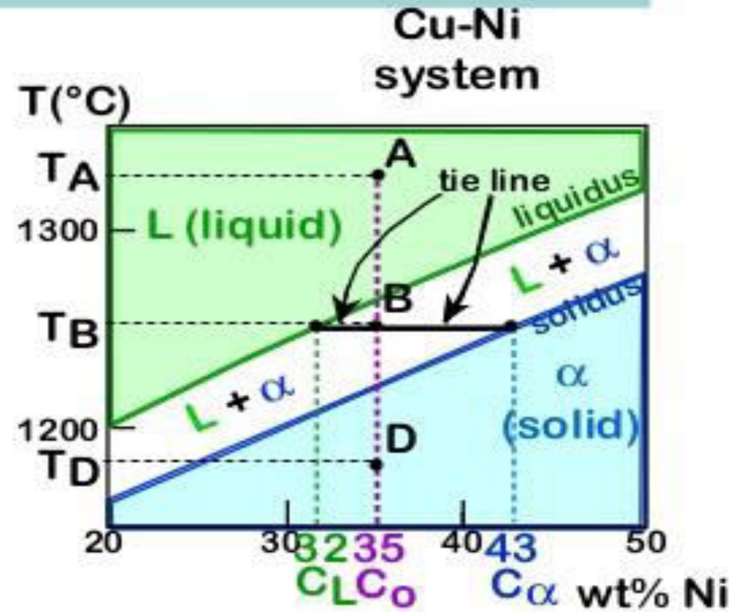
$C_\alpha = C_0$ (= 35 wt% Ni)

At T_B = 1250°C:

Both α and L present

$C_L = C_{liquidus}$ (= 32 wt% Ni)

$C_\alpha = C_{solidus}$ (= 43 wt% Ni)



Phase Diagrams: weight fractions of phases

- Rule 3: If we know T and C_o, then we know:
  --the amount of each phase (given in wt%).
- **Examples:**

C_o = 35wt%Ni

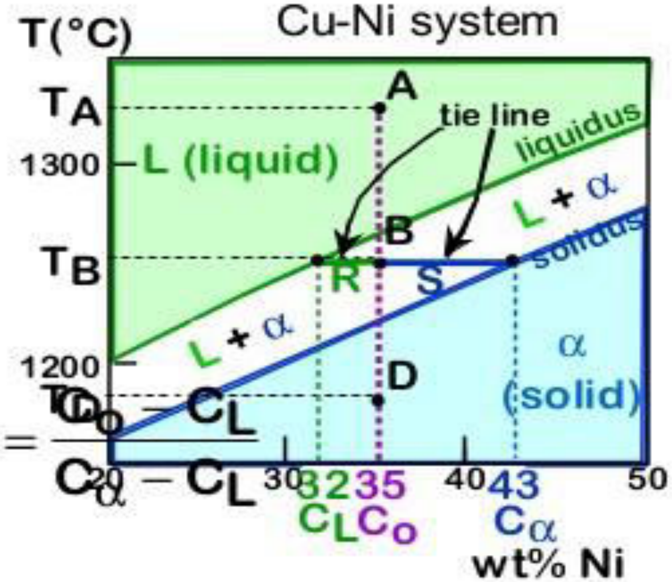
At T_A: Only Liquid (L)

W_L = 100wt%, W_α = 0

At T_D: Only Solid (α)

W_L = 0, W_α = 100wt%

At T_B: Both α and L



$$W_L = \frac{C_\alpha - C_o}{C_\alpha - C_L} = \frac{43-35}{43-32} = 73\,\text{wt}$$

$$W_\alpha = \frac{C_o - C_L}{C_\alpha - C_L}$$

$$W_\alpha = \frac{C_o - C_L}{C_\alpha - C_L}$$

= 27wt %

Importance of Phase Diagrams

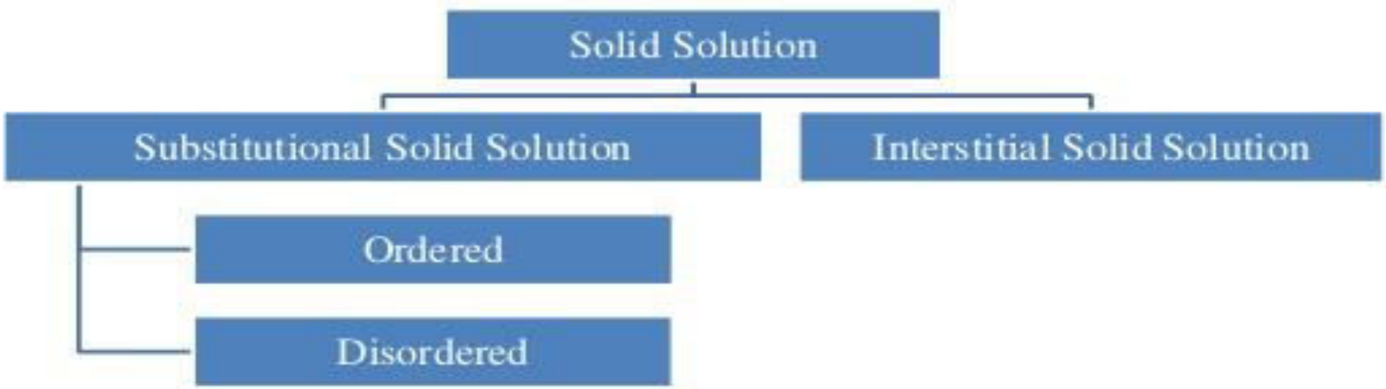
- There is a strong correlation between microstructure and mechanical properties, and the development of alloy microstructure is related to the characteristics of its phase diagram.
- Phase diagrams provide valuable information about melting, casting, crystallization and other phenomena.

Microstructure

- In metal alloys, microstructure is characterized by the number of phases, their proportions, and the way they are arranged.
- The microstructure depends on:
  - Alloying elements
  - Concentration
  - Heat treatment (temperature, time, rate of cooling)

Solid solutions

- A solid solution is simply a solution in the solid state that consists of two kinds of atoms combined in one type of space lattice.
- There is a homogeneous distribution of two or more constituents in the solid state.
- A solid solution is the result of, metals dissolving in each other's crystal lattice.



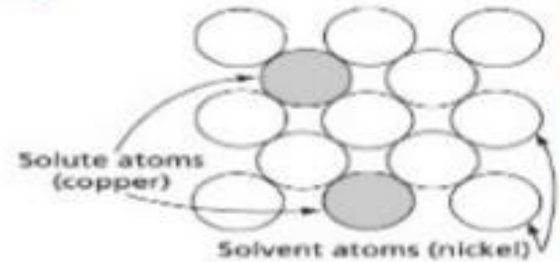
Prof. Naman M. Dave

Types of solid solution

1. Substitution solid solution (brass)

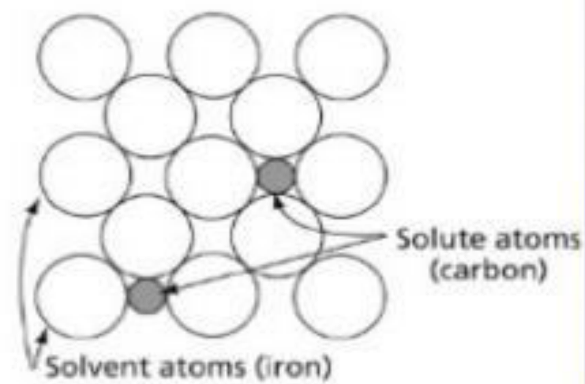
   i. Disordered (b)

   ii. Ordered (c)



(A)
Substitutional solid solution

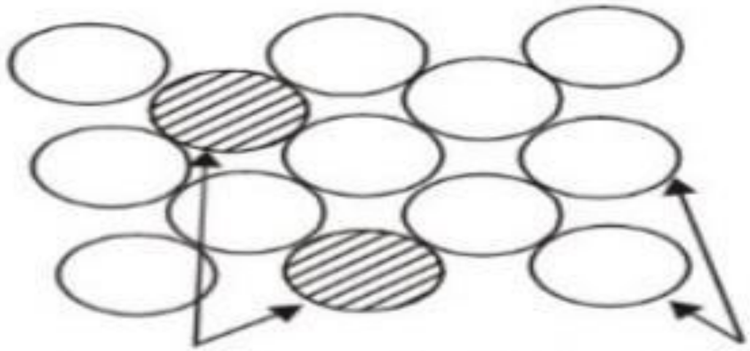
2. Interstitial solid solution



(B)
Interstitial solid solution

1. Substitutional solid solution

One type of atom for another so that solute(cu) enter the crystal to take positions normally occupied by solvent atoms (nickel)

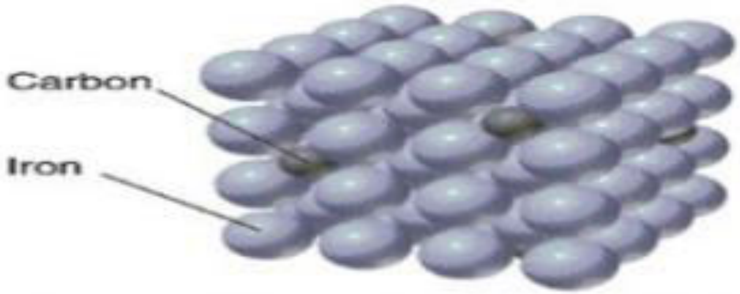


Substitutional solid solution

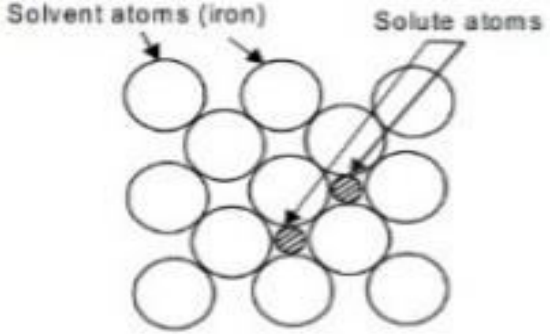
The great majority of the solid solution are substitutional type
Example:-Cu-Ni,Cd-mg.

INTERSTITIAL SOLID SOLUTION

- Small solute vs. large solvent
- More common for C, N, O, and H as solutes
- More easily dissolved in transition metal solvent
- Solubility is limited
- Solute diffuses easily via interstitial diffusion route.



B Carbon steel, an interstitial alloy



Interstitial solid solutions

Hume Rothery's Rules

❖ Types of Hume Rothery's Rules :

1. Crystal Structure Factor

2. Relative Size Factor

3. Chemical-affinity Factor

William Hume-Rothery (1899-1968)

4. Relative Valence