ATME
College of Engineering

9001:2015

Material Science & Engg.
BME303

Module-2
Physical Metallurgy

Prof. DEVARAJ M R
Associate professor,
Dept. of Mechanical Engineering,
ATMECE, Mysuru

MODULE-2

Physical Metallurgy

Alloy Systems: Classification of Solid solutions, Hume- Rothery Rules

Diffusion: Diffusion Mechanisms: Vacancy Diffusion and Interstitial Diffusion, Fick's laws of diffusion, Factors affecting diffusion.

Phase Diagrams: Gibbs Phase Rule, Solubility limit, phase equilibrium and Phase Diagrams: Isomorphous systems, Invariant Binary Reactions: Eutectic reaction, Eutectoid reaction and Peritectic reaction, Lever Rule, Iron-Carbon Diagram. Effect of common alloying elements in steel.

Numerical on Lever rule.

Solid Solution

When two metals are mixed together, they form an alloy if one metal is soluble in the other one in solid state. Therefore, an alloy is a solid solution of two or more metals.

Solid solution is a combination of two metals which are completely soluble in both the solid and liquid states.

Solid solution is a phase, where two or more elements are completely soluble in each other. Depending on the ratio of the solvent (matrix) **metal** atom size and solute element atom size, two types of **solid solutions** may be formed: substitution or interstitial.

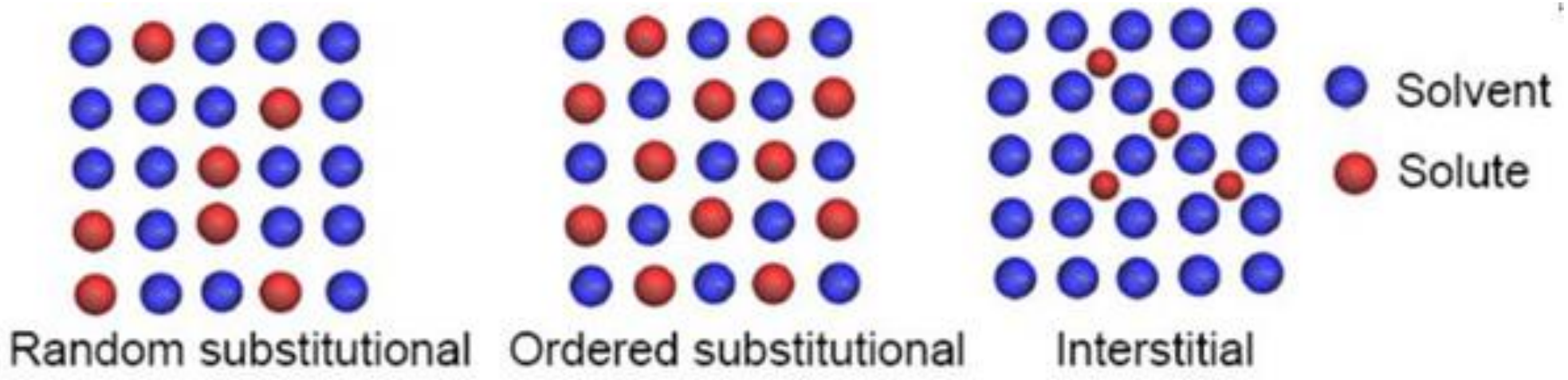
- The term solid solution is used just as liquid solution, because the solute and solvent atoms (applying the term solvent to the element in excess) are arranged in random.
- The difference between a solid and liquid solution is that, in solid solution, the size of the solute atoms greatly affect the solubility of the element which is of little consequence I liquid solutions.
- The solid solubility of one metal in another depends on a number of factor a set of rules were formulated and these are usually called the Hume-Rothery rules.

Primarily there are two types of solid solutions -

Substitutional – Solute atoms occupy the regular lattice sites of the parent metal (solvent).

Substitutional solid solutions can be random (Cu-Ni) or ordered (Cu-Au) and Au-Ag and Cu-Ag.

Interstitial – Solute atoms occupy the interstitial positions (Steel – C solute atoms in Fe)



1) Substitutional

- Solute atoms replace solvent atoms.
- It can be formed with limited solubility

  e.g. Bronze (Sn in Cu)

  or unlimited solubility e.g. Brass (Zn in Cu), in this case both atoms have nearly the same size.

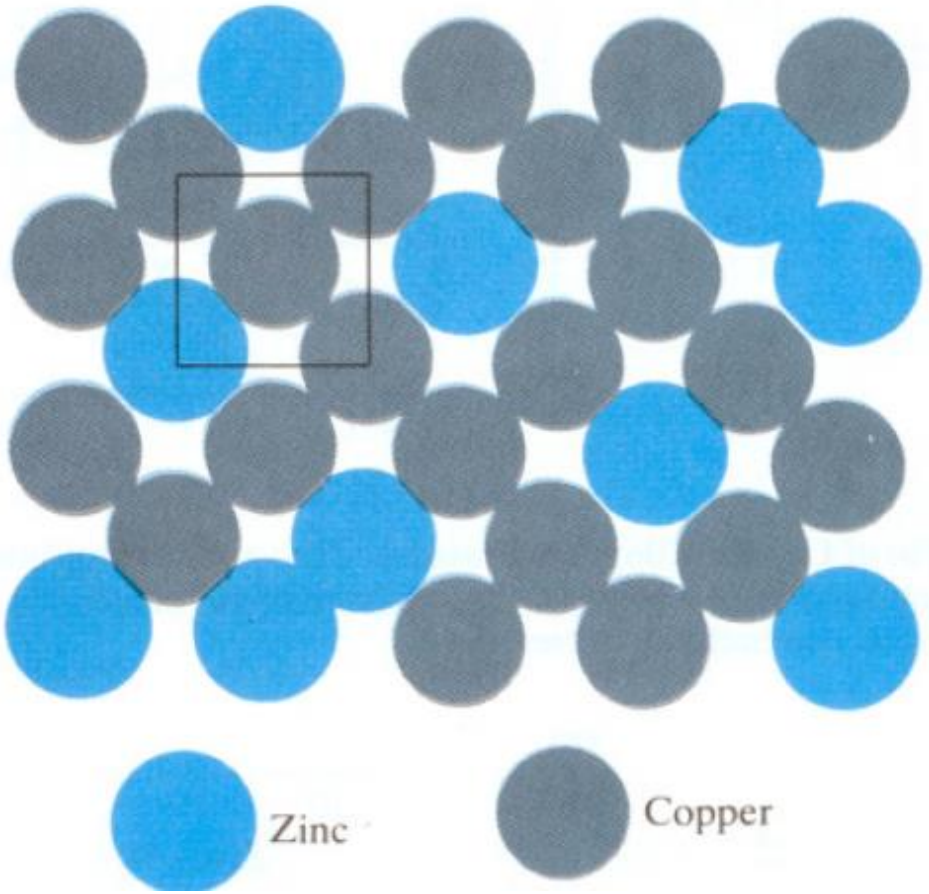
2) Interstitial solid solutions

Small atoms located at the interstices between larger atoms. E.g. C in Fe

3) Ordered solid solutions

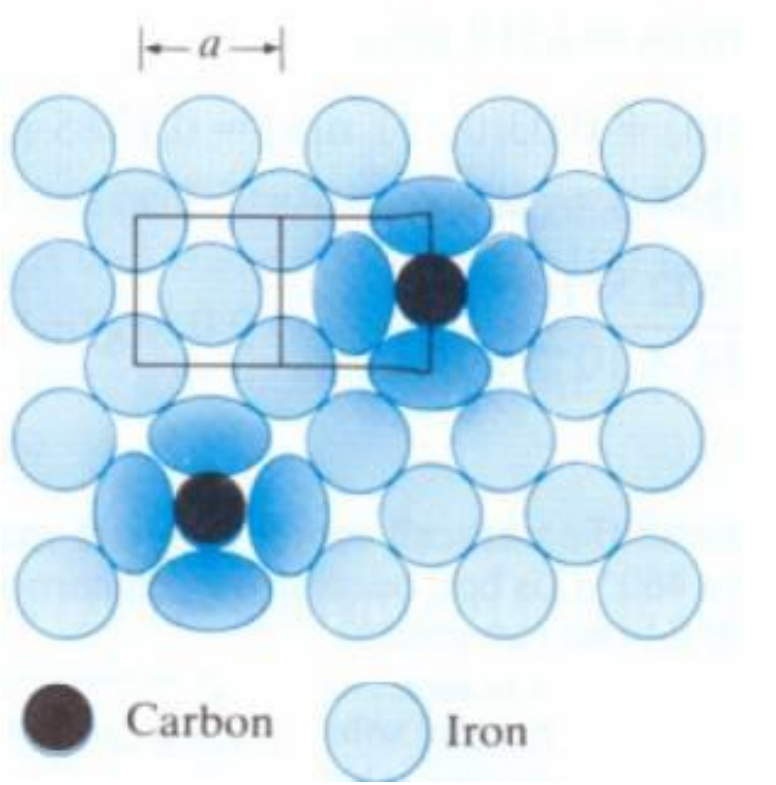
The two types of atoms arranged in a specific order.

Heating always destroys the ordering in the solution.



Random Substitutional Solid Solution (Zinc in Copper; i.e., Brass). The crystal pattern is not altered.

Interstitial solid solutions



Interstitial-Solid Solution (Carbon in fcc Iron).

In brief these rules (Hume-Rothery rules) are as follows:

- Crystal structure
- The atomic size factor
- The electrochemical effect
- Relative valence factor
- Electro-negativity

Solid solutions, in accordance with the Hume-Rothery rules, may form if the solute and solvent have:

- Similar atomic radii (15% or less difference)
- Same crystal structure
- Similar electronegativities
- Similar valency

Hume-Rothery Rule 1:Atomic Size Factor (the 15%) Rule.

Extensive substitutional solid solution occurs only if the relative difference between the atomic diameters (radii) of the two species is less than 15%. If the difference > 15%, the solubility is limited. Comparing the atomic radii of solids that form solid solutions, the empirical rule given by Hume-Rothery is given as:

$$Mismatch = \left(\frac{r_{solute} - r_{solvent}}{r_{solvent}} \right) \times 100 \leq 15\%$$

Hume-Rothery Rule 2:Crystal Structure Rule .

For appreciable solid solubility, the crystal structures of the two elements must be identical.

Hume-Rothery Rule 3: Valency Rule .

A metal will dissolve a metal of higher valency to a greater extent than one of lower valency. The solute and solvent atoms should typically have the same valence in order to achieve maximum solubility.

Hume-Rothery Rule 4: The Electronegativity Rule .

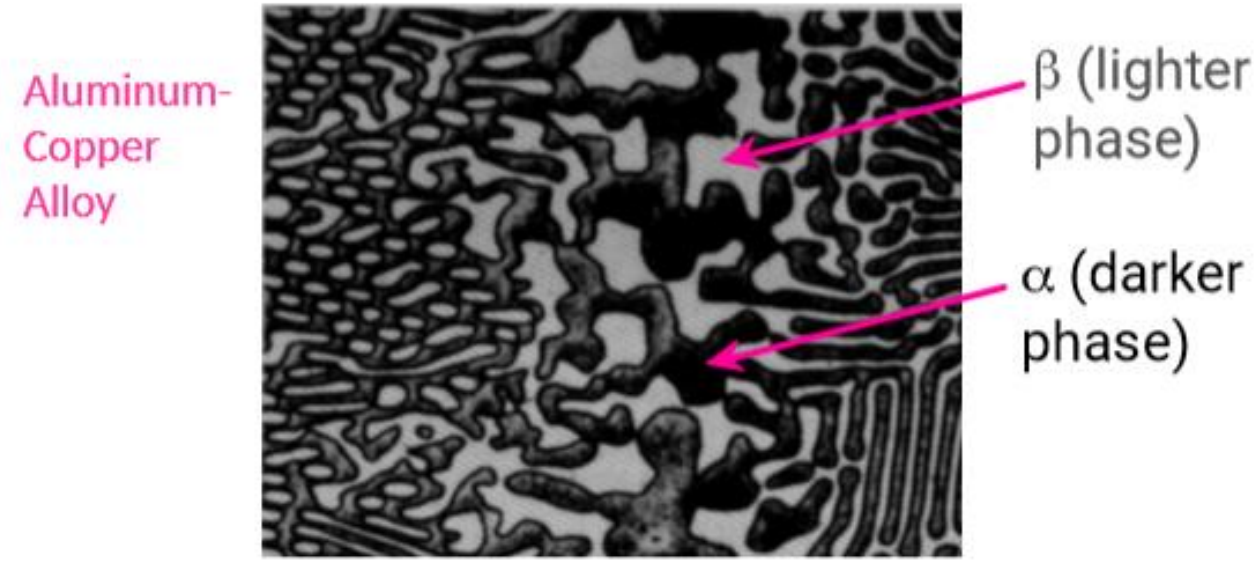
Electronegativity difference close to 0 gives maximum solubility. The more electropositive one element and the more electronegative the other, the greater is the likelihood that they will form an intermetallic compound instead of a substitutional solid solution. The solute and the solvent should lie relatively close in the electrochemical series.

Phase

- A phase can be defined as a physically distinct and chemically homogeneous portion of a system having its own boundry, that has a particular chemical composition and structure.
- A solid phase has its own crystal structure and its set of individual properties.
- Example: α-Ferrite, Fe_3C, Austinite and homogenous liquid etc.
- Water in liquid or vapor state is single phase. Ice floating on water is an example two phase system.

Phases:

A phase is a homogenous, physically distinct and mechanically separable portion of the material with a given chemical composition and structure.



- **Component**

  – is either pure metal and/or compounds of which an alloy is composed. The components of a system may be elements, ions or compounds. They refer to the independent chemical species that comprise the system.

- **Components:**

  The elements or compounds that are mixed initially (Al and Cu).

- **System**

  – it can either refer to a specific body of material under consideration or it may relate to the series of possible alloys consisting of the same components but without regard to alloy composition.

Terminology

Solid solution	A solution that contains two or more types of atoms or ions that are dispersed uniformly throughout the material
Solute	The impurities that may occupy regular lattice sites in the crystal or interstitial sites
Alloys	A material made from multiple elements that exhibits properties of a metallic material
Stainless steels	Alloys that usually contain iron (Fe), carbon (C), chromium (Cr), nickel (Ni), and some other elements
Single-phase alloy	An alloy consisting of one phase
Multiple-phase alloy	An alloy that consists of two or more phases

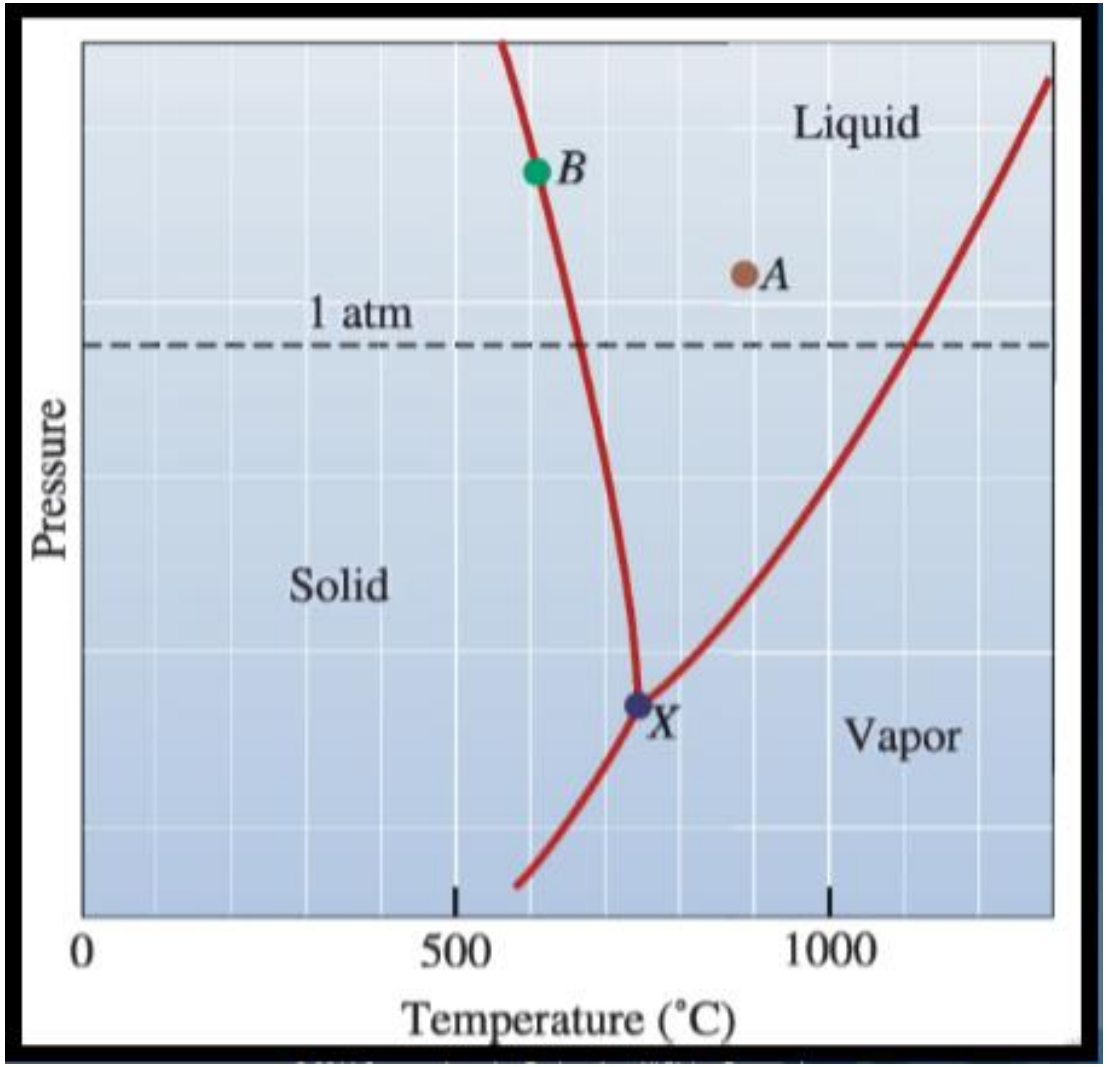
A phase diagram is essentially a graphical representation of an alloy system. Phase diagrams are also called as equilibrium diagrams or constructional diagrams.

Phase diagrams are classified as:

- **Unary Phase diagram**
- **Binary Phase diagram**
- **Ternary Phase diagram**

Unary Phase diagram *is nothing but the* ***Pressure-Temperature diagram of a pure metal.***

Unary Phase diagram



Phase Equilibria: Solubility Limit

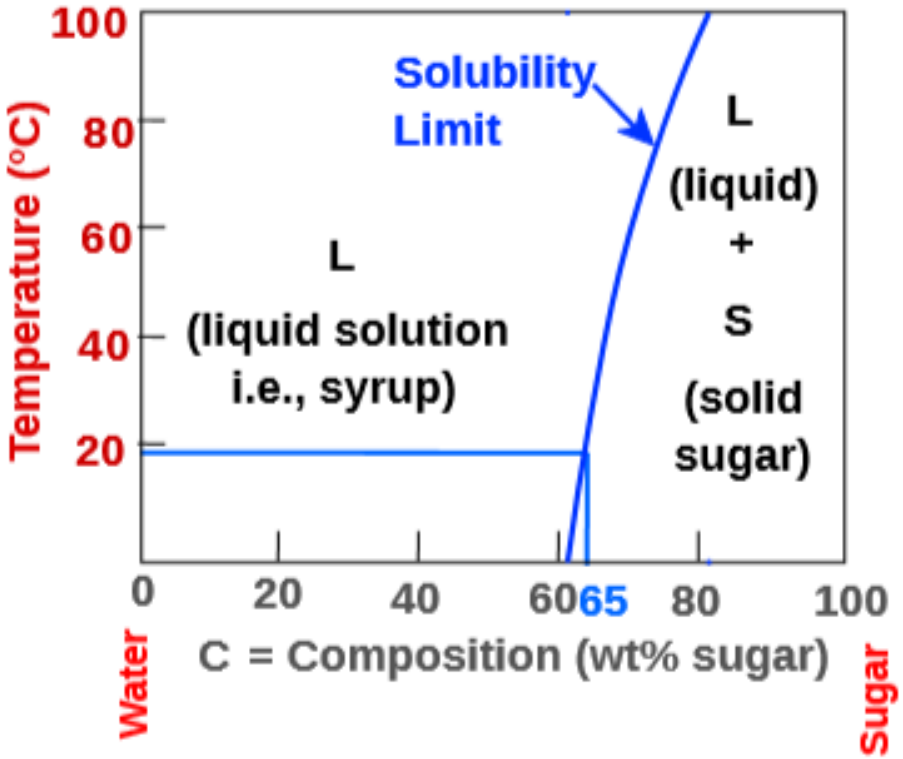
- Solution – solid, liquid, or gas solutions, single phase
- Mixture – more than one phase

- Solubility Limit:
  Maximum concentration for which only a single phase solution exists.

Question: What is the solubility limit for sugar in water at 20°C?

Answer: 65 wt% sugar.
At 20°C, if C < 65 wt% sugar: syrup
At 20°C, if C > 65 wt% sugar: syrup + sugar

Sugar/Water Phase Diagram



Equilibrium

- A system is at equilibrium if its free energy is at a minimum, given a specified combination of temperature, pressure and composition.
- The (macroscopic) characteristics of the system do not change with time — the system is stable.
- A change in T, P or C for the system will result in an increase in the free energy and **possible changes to another state** whereby the free energy is lowered.

- The Nature and occurrences of these phases in turn is a function of different independent variables such as temperature, pressure and composition.
- So in order to predict the properties of materials,

it is important to know the following:

- The conditions under which different phases exist.
- The conditions under which a change of phase will occur.

Therefore phase diagrams are constructed to provide the following information.

Therefore phase diagrams are constructed to provide the following information.

- The different phases existing in the alloy for any combination of temperature and composition.
- (Pressure is assumed to be constant at atmospheric value.)
- Temperature at which different compositions begin and end solidification.
- To study and control process such as solidification and heat treatment of metals and alloys.

A phase diagram is essentially a ***graphical representation of an alloy system.***

Phase diagrams are also called as ***equilibrium diagrams or constructional diagrams.***

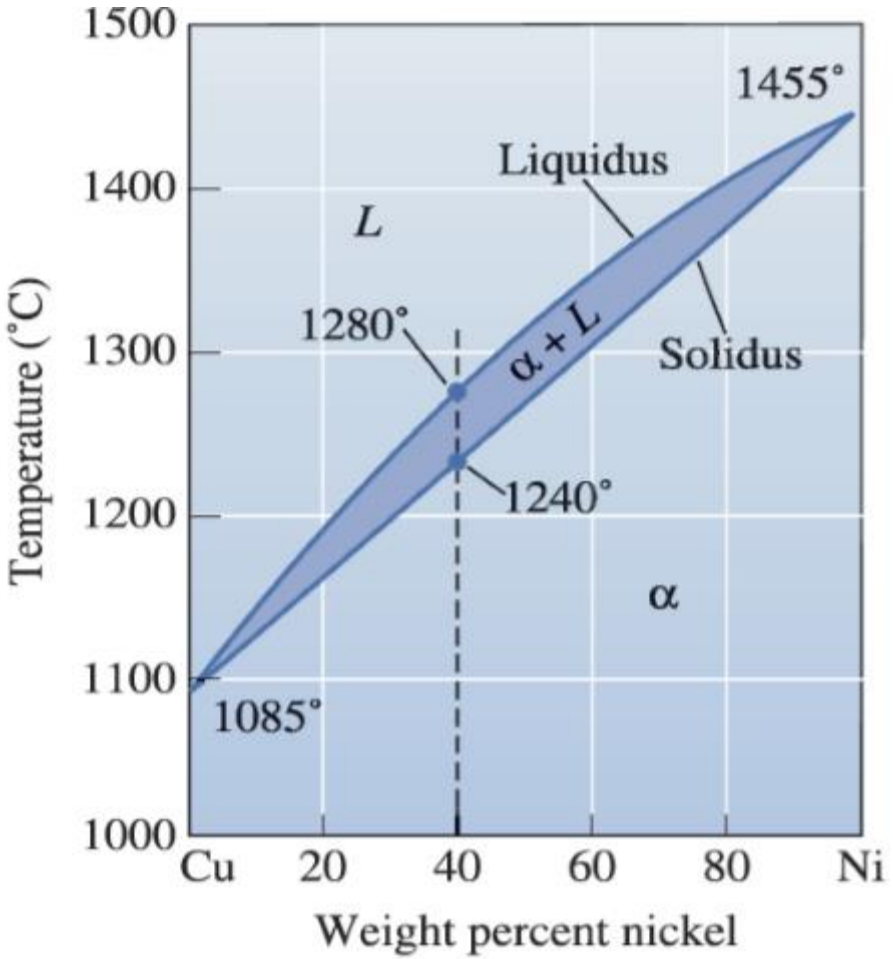
Classification of Binary Phase Diagrams

All binary phase diagrams can be classified according to the appearance of the following reactions or Transformations in them.
These include:

- **Solid solution or Isomorphous phase diagram**
- **Eutectic system(Eutectic type phase diagram)**
- **Eutectoid transformation**
- **Peritectic reaction**
- **Peritectoid transformation**

Solid solution or Isomorphous phase diagram

Solid solution is a combination of two metals which are completely soluble in both the solid and liquid states



Thank You