Solid Solution

❖ A solid solution is formed when two metals are completely soluble in liquid state and also completely soluble in solid state. In other words, when homogeneous mixtures of two or more kinds of atoms (of metals) occur in the solid state, they are known as **solid solutions.**

Solvent and Solute

❖ The more abundant atomic form is referred as **solvent** and the less abundant atomic form is referred as **solute**.

Types of Solid Solution

➢ Solid solutions are of two types. They are

    (*a*) Substitutional solid solutions.
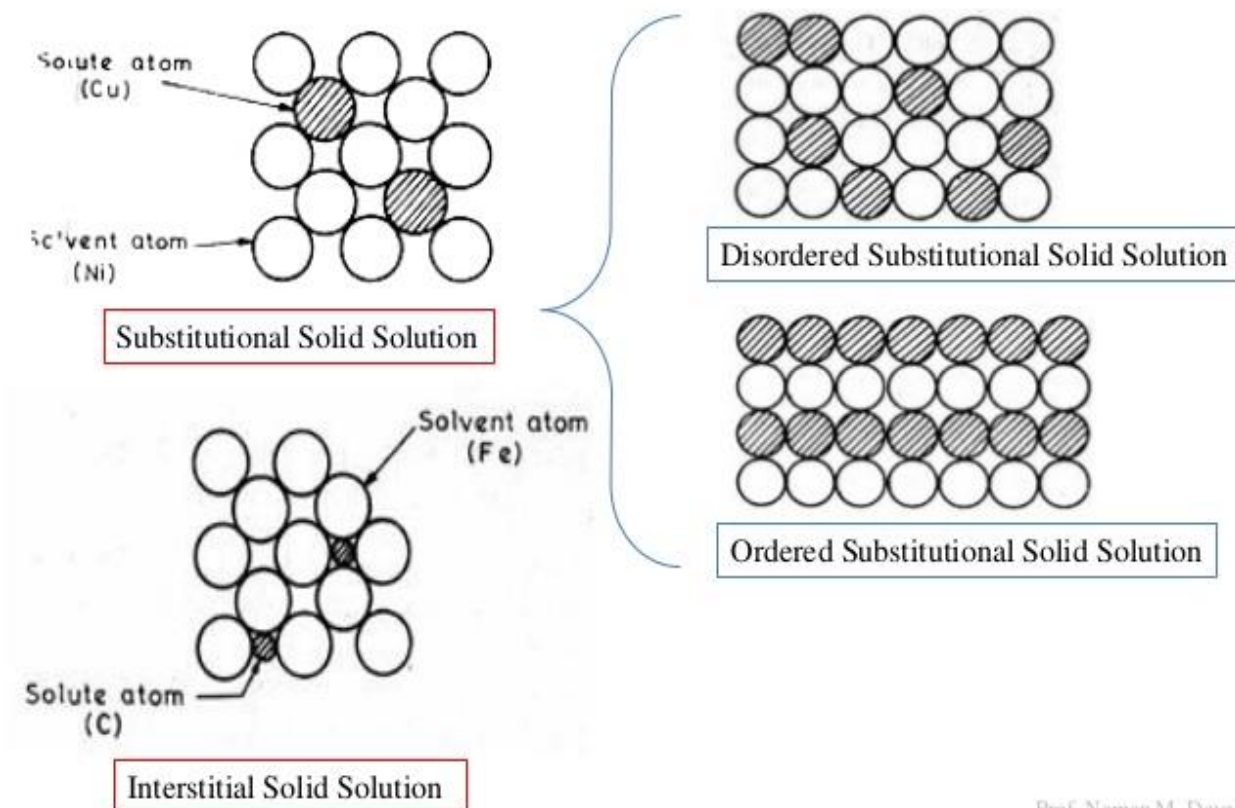
    (*b*) Interstitial solid solutions.

Substitutional Solid Solution

❖ If the atoms of the solvent or parent metal are replaced in the crystal lattice by atoms of the solute metal then the solid solution is known as **substitutional solid solution.**

❖ For example, copper atoms may substitute for nickel atoms without disturbing the F.C.C. structure of nickel

❖ In the substitutional solid solutions, the substitution can be either disordered or ordered.

❖ Figure 1.1 shows disordered substitutional solid solution. Here the solute atoms have substituted disorderly for the solvent atoms on their lattice site.

❖ Fig.1.1 shows an ordered substitutional solid solution. Here the solute atoms have substituted in an orderly manner for the solvent atoms on their lattice site.

Interstitial Solid Solutions

❖ In interstitial solid solutions, the solute atom does not displace a solvent atom, but rather it enters one of the holes or interstices between the solvent atoms. An excellent example is iron-carbon system which is shown in Fig 1.1.

❖ In this system the carbon (solute atom) atom occupies an interstitial position between iron (solvent atom) atoms. Normally, atoms which have atomic radii less than one angstrom are likely to form interstitial solid solutions.

❖ Examples are atoms of carbon (0.77 A°), nitrogen (0.71 A°), hydrogen (0.46 A°), Oxygen (0.60 A°) ec.

Figure 1.1 solid solution and its types

Hume Rothery rules for the formation of substitutional solid solutions

- By studying a number of alloy systems, Hume Rothery formulated certain rules which govern the formation of substitutional solid solutions. These are:

(a) Crystal structure factor:

❖ *For complete solid solubility, the two elements should have the same type of crystal structure* *i.e.*, both elements should have either F.C.C. or B.C.C. or H.C.P. structure.

(b) Relative size factor:

❖ As the size (atomic radii) difference between two elements increases, the solid solubility becomes more restricted. *For extensive solid solubility the difference in atomic radii of two elements should be less than about 15 percent.* If the relative size factor is more than 15 percent, solid solubility is limited. For example, both silver and lead have F.C.C. structure and the relative size factor is about 20 percent. Therefore the solubility of lead in solid silver is about 1.5 percent and the solubility of silver in solid lead is about 0.1 percent. Copper and nickel are completely soluble in each other in all proportions. They have the same type of crystal structure (F.C.C.) and differ in atomic radii by about 2 percent.

Comparing the atomic radii of solids that form solid solutions, the empirical rule given by Hume-Rothery is given as:

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

(c) Chemical affinity factor:

❖ *Solid solubility is favoured when the two metals have lesser chemical affinity.* If the chemical affinity of the two metals is greater then greater is the tendency towards compound formation. Generally, if the two metals are separated in the

periodic table widely then they possess greater chemical affinity and are very likely to form some type of compound instead of solid solution.

(d) Relative valence factor:

❖ A metal of higher valency can dissolve a small amount of lower valency metal. ***The solute and solvent atoms should typically have the same valence in order to achieve maximum solubility.***

❖ For example in aluminium-nickel alloy system, nickel (lower valance) dissolves 5 percent aluminium but aluminium (higher valence) dissolves only 0.04 percent nickel.

Gibbs phase rule

➢ Gibbs' phase rule describes the possible no of degrees of freedom (F) in a closed system at equilibrium, in terms of the number of separate phases (P) and the number of chemical components (C) in the system.

➢ Thermodynamically derived *Gibbs phase rule*:

$$F = C - P + 2$$

➢ Where, F is no of degrees of freedom or variance

P is no of phases

C is no of components

Degree of freedom F

• Degree of freedom (or variance) F is the number of variables (Temperature, pressure, and composition) that can be changed independently without changing the phases of the system.

Component

- Component is the minimum no of species necessary to define the composition of the system.

- Example H_2O C=1

        (i) P=1, F=2;   (ii) P=2, F=1;   (iii) P=3, F=0

Condensed Gibbs phase rule (Reduced phase rule)

➢ In practical conditions for metallurgical and materials systems, pressure can be treated as a constant (1atm.).

➢ Thus Condensed Gibbs phase rule is written as

$$F = C - P + 1$$