Chemical compounds are formed by the combination of two or more atoms (or ions), and the formation of a stable compound occurs when the combination results in a lower energy than the total energy of the separated atoms (or ions). Interatomic (or interionic) net attractive forces that hold atoms (or ions) in solids together are called *chemical bonds*.

Chemical bonds usually involve only the valence electrons (s and p electrons in the outermost orbitals) of an atom. Physical and chemical properties of all substances depend on the character of the chemical bonds that hold them together.

Types of Bonds:

Much of the bonding in solids of geochemical interest can be described in terms of two end-member types: ionic (electrovalent) bonds and covalent bonds. Other types of bonds that will be discussed briefly in this chapter include metallic bonds, Van der Walls bonds, and hydrogen bonds.

1. *Ionic (electrovalent or heteropolar) Bonds:* In this type of bonds, the atoms are in the ionized state i.e they acquire either a positive or a negative charge. This bond exists because of electrostatic attraction between cations and anions formed by transfer of one or more electrons between atoms. These are non-directional bonds. These are common in inorganic compounds and are therefore important in the structure of minerals. They never occur between similar elements. No molecules are formed. These minerals are mechanically strong and have high melting points and good electrical conductivity.
2. *Covalent (homopolar) Bonds:* In this type of bonding, stability is attainedby the sharing of electrons between the two atoms and that result from overlap of orbitals from the two atoms. These are directional bonds in which molecules are formed. These are common in organic compounds but rare in minerals (e.g. diamond). Minerals of this type are good electrical insulators.
3. *Metallic Bonds:* In this type of bonding, the metallic atoms attain a positive charge by losing electrons. These electrons are free to move about the atomic nuclei and the aggregate cloud of electrons binds the nuclei together. No directional forces are involved and no molecules are formed.
4. *Van der Walls Bonds:* The molecules of some substances, particularly organic compounds and elements that normally are gaseous at ordinary temperatures may be tightly bonded by covalent bonds, but the individual molecules are loosely held together by cohesive forces called Van der Walls Bonds.
5. *Hydrogen Bonds:*It is a type of weak chemical bond in which a hydrogen atom that has a covalent link with one of the electronegative atoms (F, N, O) forms an electrostatic link another electronegative atom in the same or another molecule.

Ionic-Atomic substitutions

1. *Camouflage:* It is a type of substitution that takes place in two atoms having same charge and similar radius.

Al^{+3} ↔ Ga^{+3}
(0.51Å) (0.62Å)

2. *Capture:* It takes place in atoms having (i) higher charge and similar radius; or (ii) same charge and lower radius.

K^{+} ↔ Ba^{+2}
(1.33Å) (1.34Å)

3. *Admittance:* It takes place in atoms having (i) lower charge and similar radius; or (ii) same charge and higher radius.

Mg^{+2} ↔ Li^{+}
(0.66Å) (0.68Å)

Ca^{+2} ↔ Sr^{+2}
(0.99Å) (1.12Å)

Diadochy: It is the ability of different elements to occupy the same lattice position in a crystal. Thus, Mg, Fe and Mn are diadochic in the structure of dolomite.

Isomorphism:

It is the phenomenon whereintwo minerals have the same general internal structure, closely similar external morphology and similar X-ray diffraction patterns. The cause of the phenomenon is that anions and cataions of the same relative size and in the same numbers tend to crystalize in the same structure type. Example: Carbonate minerals: Calcite-Aragonite and Magnesite-Siderite. Isomorphism is common in plagioclase feldspars and pyroxenes also. In isomorphism, the similarity in the size of the two ions is an important factor rather than a chemical similarity. Thus, many calcium (Ca^{2+}=0.99Å) and magnesium (0.66Å) compounds are not isomorphous although their chemical behaviour is similar.

Polymorphism:

The phenomenon of the existence of a compound in more than one crystal form possessing different physical properties but identical chemical properties is known as polymorphism. Two polymorphs contain the same number of atoms, but with different alignments in the crystal structure. When polymorphism occurs in elements it is described as Allotrophy. $CaCO_3$ is dimorphic (Calcite-Aragonite); TiO_2 is trimorphic (Anatase, Rutile, Brookite). As different polymorphs of the same substances are formed under different P-T conditions and chemical environment, they serve as very good geologic thermometers.

A reversible polymorphic transformation at a transition temperature is described as Enantiotropy. Quartz → Tridymite → Cristobalite (with increasing temperature)

** High temperature polymorphs of silica are Tridymite, Cristobalite

**High pressure polymorphs of silica are Stishovite, Cohesite

- An irreversible polymorphic transformation is referred as Monotropy, example Diamond → Graphite.
- Polytypism (one dimensional polymorphism) occurs when two polymorphs differ only in the stacking of identical two-dimensional sheets, ex. In case of Mica.
- Order-disorder type of polymorphism occurs when two different ions occupy the same structural site. Ex. Al^{3+} substitutes for Si^{4+} in the tetrahedral coordination.

Solid Solution:

Solid solution can be defined as a homogenous crystalline solid of variable composition. It is a solid-state solution of one or more solutes in a solvent. Such a multi-component system is considered a solution rather than a compound when the crystal structure of the solvent remains unchanged by addition of the solutes, and when the chemical components remain in a single homogeneous phase.

- *Normal or extensive solid solution*: In this case, there is a continuous replacement of ions. Ex. In Olivine and plagioclase.
- *Limited solid solution*: there is a partial replacement of one ion by another in a coupled substitution. Ex. Albite-Orthoclase.
- *Interstitial solid solution*: foreign ions or atoms fit into the intersticies of the crystal lattice. Ex. In Zeolites.
- *Defect or omission solid solution*: there is a systematic omission of one ion coupled with a valence change in another. Ex. In Pyrrhotite.
- *Exsolution or Unmixing solid solution*: here two different elements are completely inter-replaceable at higher temperatures, but not at lower temperatures. The initially homogenous solution will tend to break down on cooling into at least two separate phases, one rich in the first mineral and the other rich in the second without the addition or removal of any materials. . Ex., The sodium-rich feldspar albite ($NaAlSi_3O_8$) and the potassium-rich feldspar orthoclase ($KAlSi_3O_8$), for example, may exist in a homogeneous solid solution above 650° C (1,200° F), but below that temperature exsolution will occur.