Chemical Bonding

A chemical bond is defined as the attractive force that holds two or more atoms together in a molecule or an ion.

Why do atoms combine?
By a close study of atoms and molecules it has been found that atoms combine chemically for the following reasons:

1) Net attractive force between atoms:
Atoms consist of strongly positive nucleus and negative electrons. When two atoms come closer to combine with each other to form a bond between them, the **attractive** and **repulsive** forces begin to operate between them. The attractive forces are between the electrons of one atom and the nucleus of other atom while the repulsive forces are between the electrons or the nuclei of the two atoms.

When the two atoms approach each other these forces counteract each other. The net result of these forces may be either attraction or repulsion between the atoms.
If the attractive forces become dominant over the repulsive forces, the net result is the attraction between the atoms and hence they combine together to form a chemical bond between them.

On the other hand if the repulsive forces become dominant over the attractive forces the atom do not combine and hence no chemical bond is established between them.

For example in case of hydrogen atoms the net result is attraction and two hydrogen atoms combine together to form H_2 molecule. On the other hand in case of He atom the net result is repulsion and hence two He atoms do not combine together to form He_2 molecule.

2) Octet rule or rule of eight:
The atoms of noble gases do not normally react with other atoms to form compounds. It is assumed that the outermost shell configuration of the atoms of noble gases is a stable configuration of 8 electrons which is known as **octet**. The two electrons in case of He is also stable as octet which is known as **doublet**.

Noble gas	Atomic No	Electronic configuration
He	2	2
Ne	10	2,8
Ar	18	2,8,8
Kr	36	2,8,18,8
Xe	54	2,8,18,18,8
Rn	86	2,8,18,32,18,8

The tendency of the atoms to have 8 electrons in their outermost shell is known as **octet rule** or **rule of eight**. Since helium atom has two electrons, this rule is called **doublet rule** or **rule of two**.

Octet rule was given in the form of a theory which is known as **octet theory of valency** or **electronic theory of valency** which states that:

"In the formation of a chemical bond, atoms interact with each other by losing, gaining or sharing of electron to acquire a stable outer shell of eight electrons".

The **main points** of this theory can be summarized as follows:

i) Atoms with eight electrons in the outermost shell (2 in case of He) are chemically stable and hence are incapable of chemical combination.

ii) An atom having less than 8 electrons in its outer most shell is chemically active and hence has a tendency to combine with other atoms.

The atoms possessing less than 4 electrons generally tends to lose them while those having more than 4 electrons in the outer most shell tends to gain the electrons during the chemical combination or bond formation to attain stable configuration of the nearest inert gas.

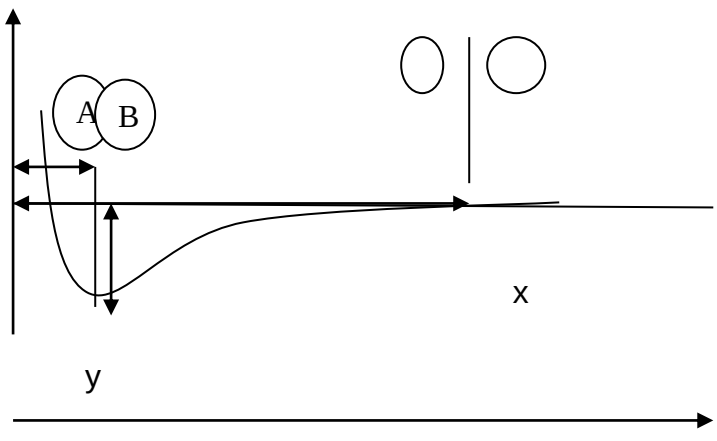
iii) Atoms combine chemically as a result of transferring of electrons from the outer most shell of one atom to that of the other or by sharing one, two or three electron pairs between the valence-shell of the combining atoms.

The transfer of electrons or sharing of electrons pairs gives a stable configuration of eight electrons to valence shell of both the atoms.

iv) The tendency of an atom for transference or sharing its electron pair is a measure of its chemical activity.

3) Lowering of energy of combining atoms:
When two atoms combine together to form a bond there is an overall decrease in the potential energy of the combining atoms, which has greater stability.

Potential energy curve:



The curve shown above represents the variation of potential energy between the nuclei of the two atoms **A** and **B** which are approaching closer to each other to form a bond between them.
The trend of the curve from right to left should be observed.

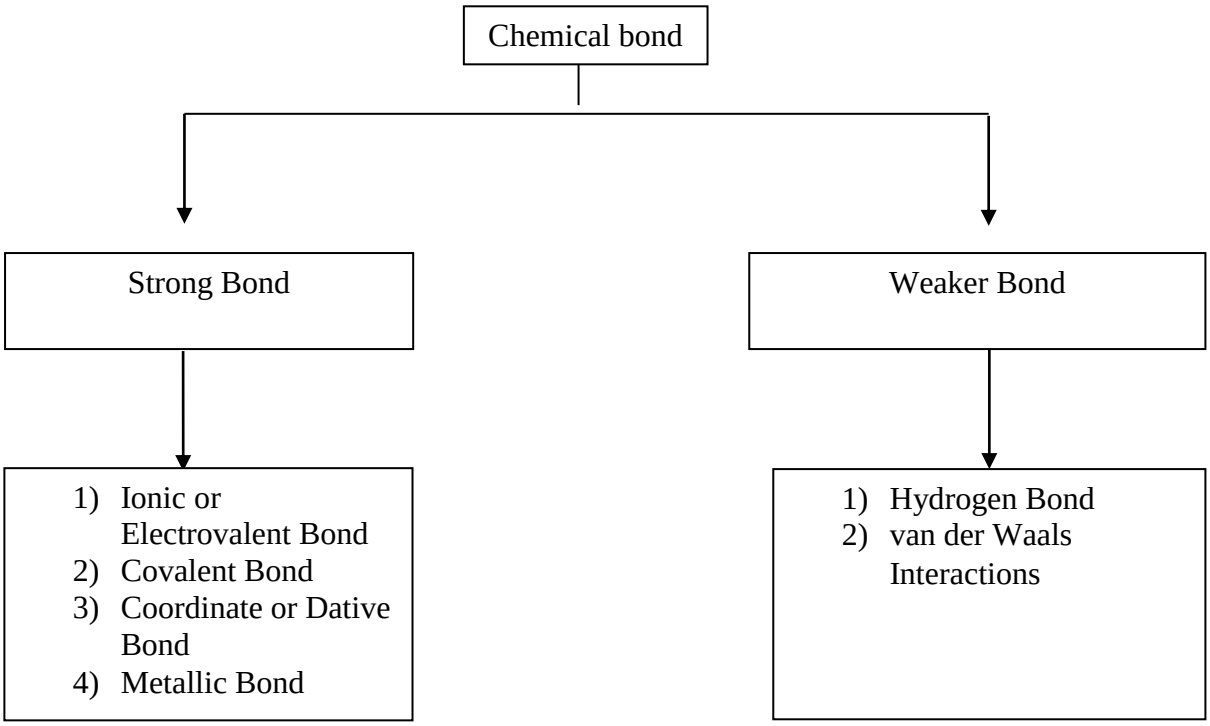
When two atoms A and B are far away, say at an infinite distance from each other the attraction between them is zero. Hence there is no possibility of formation of bond between them. This situation has been represented by **X**
As the two atoms brought closer to each other i.e. as the distance between the atoms is decreased, the attractive forces between the nucleus and the electrons become more dominant than the repulsive forces operating between the electrons of the two atoms and hence energy of the system goes on decreasing as shown by the downward trend of the curve. This decrease of energy continues till a certain minimum value shown by **Y** in the curve is obtained.

Now if the atoms are brought still closer the repulsive forces between the two nuclei at such small inter-nuclear distance becomes dominant and hence the energy of the system starts increasing as shown by the upward trend of the curve.

Point **Y** which is the minimum of the curve has the following characteristics:

- At this point the attractive and repulsive forces are in equilibrium and hence a bond is said to be established between the atoms at this point.
- The overlapping between the orbitals of the two atoms is maximum at this point.
- The energy of the system at this point is minimum and hence AB molecule is in the most stable position. The inter-nuclear distance is also minimum at this point.
- The minimum energy value and the internuclear distance corresponding to this point are called **bond energy** and **bond length** of AB molecule respectively. For H_2 molecule the bond energy is 103.2 kcal/mole and bond length is 0.74 A°.

Classification of Chemical Bond:



Ionic Bond

The chemical bond formed between two atoms by transfer of one or more valence electrons from one atom to the other is called ionic bond.
This bond is *formed by the electrostatic force of attraction between positive and negative ions.*

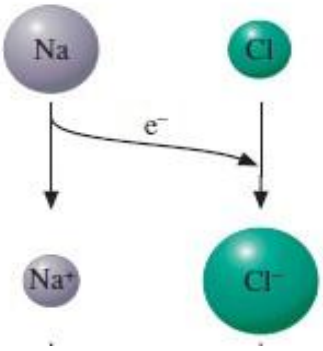
- The bond forms between two atoms when one or more electrons are transferred from the valence shell of one atom to the valence shell of the other.
- The atom that loses electrons becomes a *cation* (positive ion), and the atom that gains electrons becomes an *anion* (negative ion).
- In general, *metals form cations and non-metals form anions*.

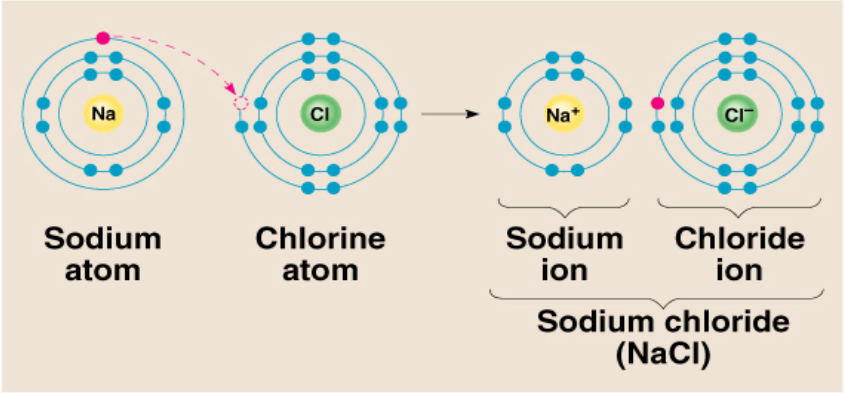
Why ionic bonding occurs?

Consider the transfer of a valence electron from a sodium atom to the valence shell of a chlorine atom.

$$Na([Ne]3s^1) + Cl([Ne]3s^23p^5) \longrightarrow Na^+([Ne]) + Cl^-([Ne]3s^23p^6)$$

As a result of the electron transfer, ions are formed, each of which has a noble-gas configuration.





- The sodium atom will lose its electron from outer most shell (3s) and the Cl atom will gain that electron into its 3*p* subshell and has taken on the argon configuration.
- Thus the Na atom will be converted into its cation Na^+ ion and Cl atom will be converted into anion Cl^- .
- Both of them have electronic configuration of their nearest inert element (Ne and Ar).
- The resulting positive ion and negative ion are held together by electrostatic force of attraction which is called ionic bond or electrovalent bond.

- The **lattice energy** is *the change in energy that occurs when an ionic solid is separated into isolated ions in the gas phase.*
  For example,

$$NaCl(s) \longrightarrow Na^+(g) + Cl^-(g)$$

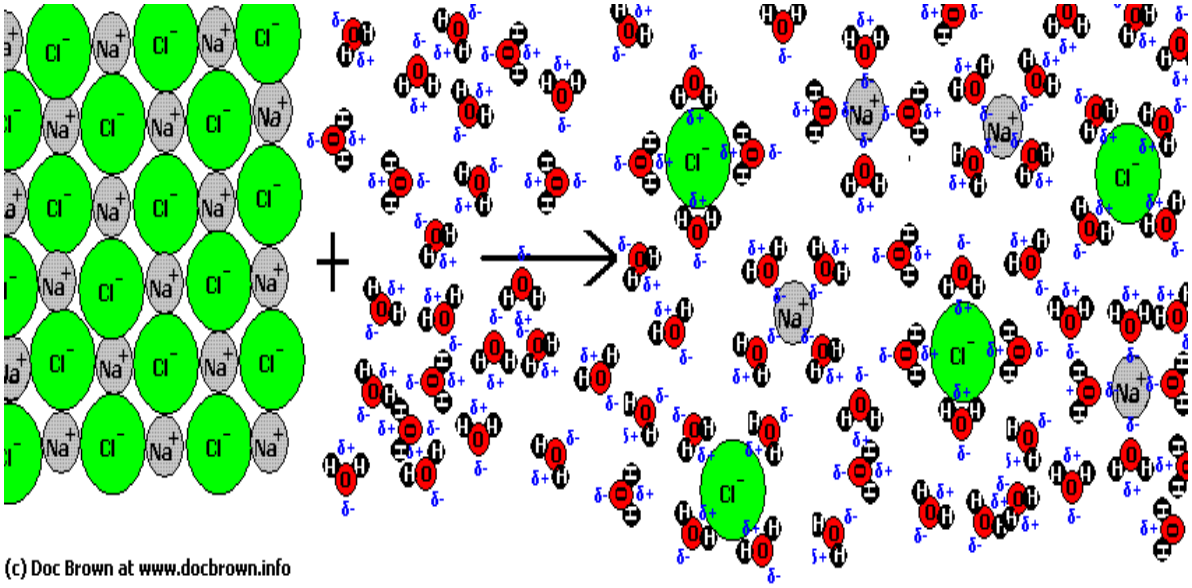
Properties of ionic compounds

1. Physical state: Ionic compounds are crystalline solids at room temperature.

2. Electrical conductivity: Ionic compounds do not conduct electricity when they are in the solid state. The ionic solids conduct electricity when they are water solution or in the molten state.

3. They are quite hard, have low volatility and high melting and boiling points.

4. Most ionic compounds are soluble in polar and insoluble in non polar solvent. Ionic solids are freely soluble in polar solvents like H_2O, liquid ammonia etc.



The solubility of ionic solids in a polar solvent like water can be explained by saying that a water molecule is a dipole and hence the positive end of the dipole interacts with the negative ion of the ionic solids and the negative end of the dipole interacts with the positive ion of the same crystal.
The interaction between the water dipole and the ions of the crystal lowers down the energy of the system and thus the force of attraction between the cation and anions of the ionic solid is weakened. Consequently the water molecules tear off the ions from the crystal lattice and make them float in the bulk of the water.

On the other hand ionic solids are insoluble or slightly soluble in nonpolar solvents (organic solvents) such as C_6H_6, CCl_4 etc. Such solvents due to their low value of dielectric constant do not allow the ions to move freely and interact with them to form the solvated ions.

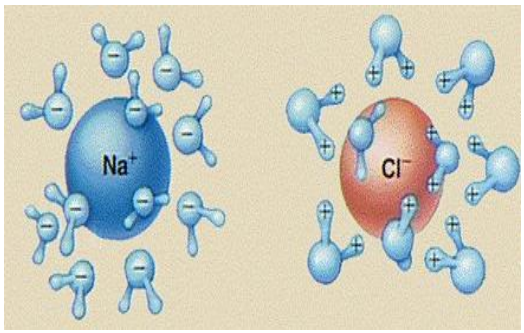


Fig.1

After breaking out from the crystal, the ions get surrounded by a definite number of solvent molecules (Fig.1). This process is called solvation and when water is the solvent, the process is called **hydration**. This is an exothermic process and the energy released is called **hydration energy** in case of water.

5. Ionic compounds are very stable.

6. Crystal structure: Ionic solids do not exist as individual neutral independent molecules rather they exist as three dimensional solid aggregates which have definite geometric shape.

6. Highly brittle: Ionic solids are highly brittle, i.e. if a little external force is applied on ionic crystals, they are easily broken.

7. High density: The electrostatic force of attraction existing between the cation and anion in an ionic crystal bring these ions very close to each other. This decreases the volume of crystal and as a consequence this ionic crystal has high density.

Factors favoring the formation of ionic bond:

1) Number of Valence electron

The atom which is converted into cation should posses 1, 2 or 3 valence electrons while the atom which is converted into anion should have 5, 6 or 7 valence electrons.
The element of group IA, IIA and IIIA satisfy this condition for the cation and those of group VA,VIA and VIIA satisfy this condition for anion.

2) The ionization energy of the metal atom should be low.

3) Electron affinity of the nonmetal should be high.

4) The lattice energy of the ionic compound formed should be high:

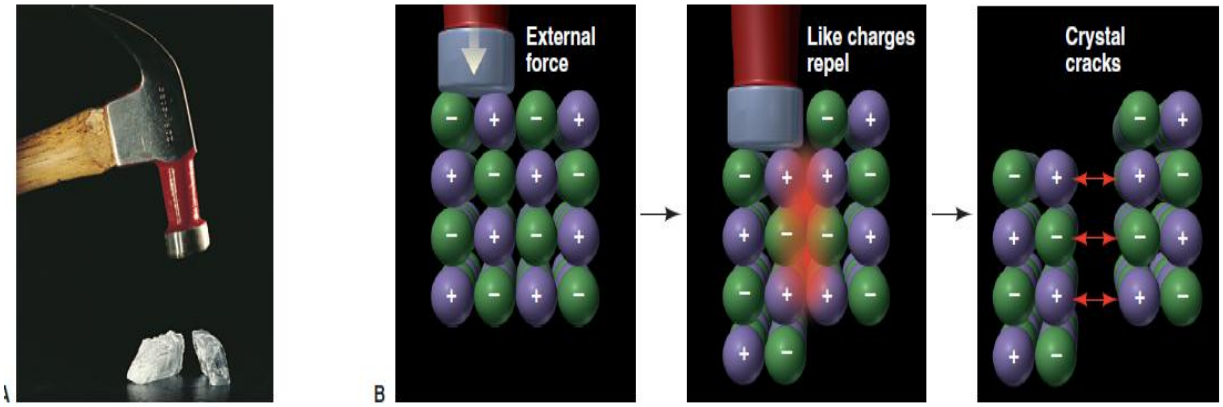
The energy released when one gram mole a crystal is formed from its gaseous ions is called the lattice energy of the crystal. Thus:

$A^+(g) + B^-(g) \longrightarrow A^+B^-(crystal) + Energy\ released.\ (Lattice\ energy)$

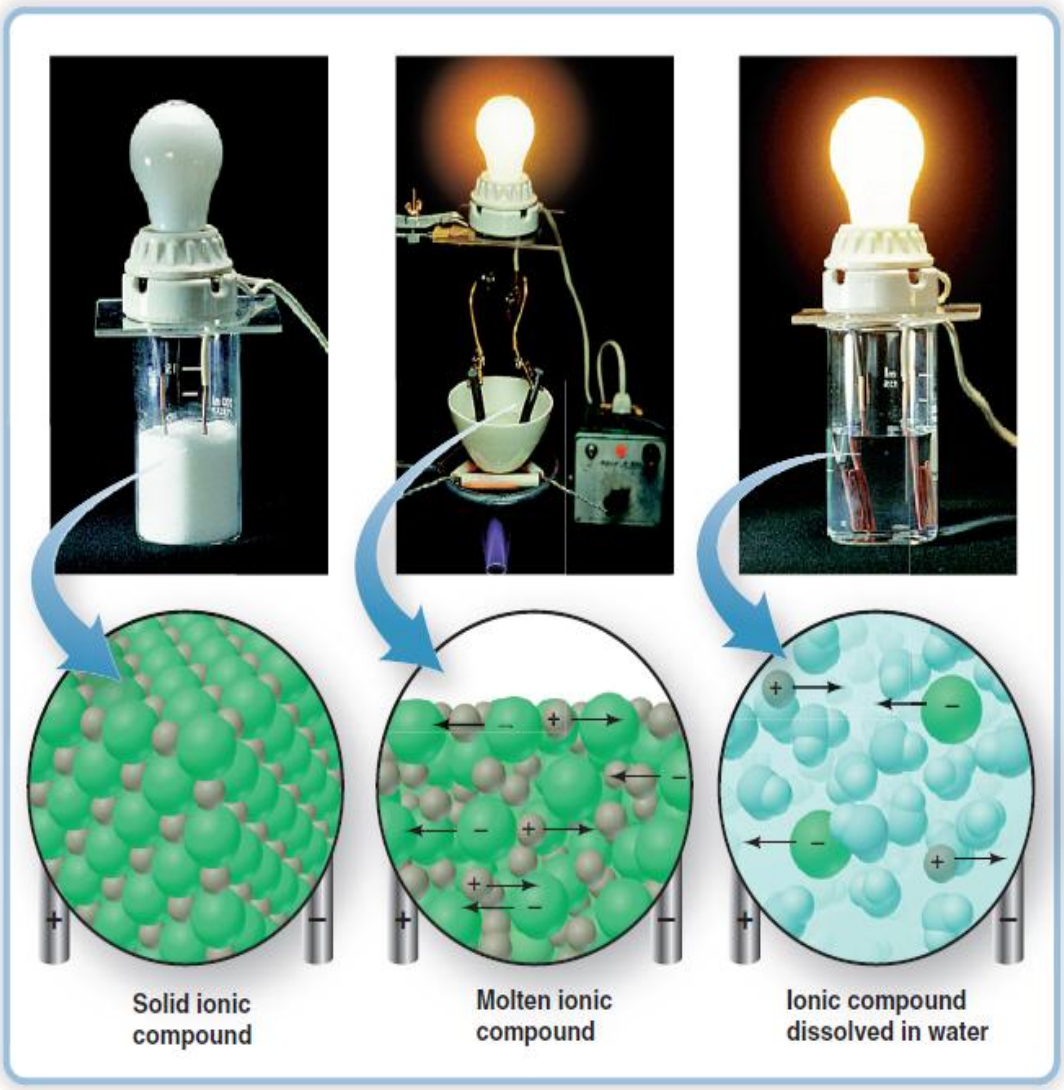
Higher the value of the lattice energy of a crystal, the greater is the ease of its formation i.e. greater will be the stability of the crystal.

5) Electronegativity difference of the two atoms forming the ionic bond should be high:

In fact a difference of 2 or more is essential for the formation of ionic bond. For example, since the electronegativity difference between Na and Cl is 2.1 (Na = 0.9, C l= 3.0) Na and Cl will form an ionic bond in NaCl molecule.



Why ionic compounds crack. A, Ionic compounds crack when struck with enough force. B, When a force moves like charges near each other, repulsions cause a crack.



Electrical conductance of ionic compound