Ionic Bond

(Electrostatic bond or electrovalent bond):

- Ionic bond was explained by Kossel.
- The strong electrostatic force of attraction between oppositely charged ions which are formed by the transfer of the electrons is called Ionic bond.
- Ionic bond is formed between different atoms i.e atoms of different electronegativities.

It is generally formed between metal atom & non-metal atom.

- It cannot be formed between same or similar atoms.
- There is no 100% ionic compound. Most ionic compound is CsF (Cesium fluoride)
- To form an ionic bond, the electronegatives between combining atoms should be greater than 1.7.
- Ionic bond is generally formed between electropositive & electronegative element or less electronegative and more electronegative elements.

    Ionic bond is generally formed between

    IA and VIIA group

    IA and VIA group

    IIA and VIIA group

    IIA and VIA group

    Ionic bond is non-directional as it involves electrostatic attraction.

FACTORS FAVOURABLE FOR IONIC BOND FORMATION

- The ease of formation of ionic bond depends on the case of formation of cation & anion.

Conditions favourable for cation	Conditions favourable for anion
1) **Size:** Larger atoms will form cations readily Eg.: Li < Na < K < Rb < Cs	**Size:** Smaller atoms will form anion readily Eg.: F > Cl > Br > I
2) Ionisation potential: Atoms with low I.Ps will form cations readily. Eg.: Na > Mg > Al IP $\rightarrow$ increases Ease of formation decreases.	**Electron affinity:** Atoms with high electron affinity will form anion readily. Eg.: Cl > Br > I Electron affinity decreases Ease of formation decreases.
3) **Charge:** Cation with less positive charge is readily formed Eg.: Na^+ > Mg^{2+} > Al^{3+} Ease of formation increases with decrease in the charge.	**Charge:** Anion with less negative charge is readily formed. Eg.: F^- > O^{-2} > N^{-3} Ease of formation increases with decrease in the charge.
4) **Electronic configuration:** Cation with inert gas configuration is more stable and more readily formed than cation with pseudo inert gas configuration	

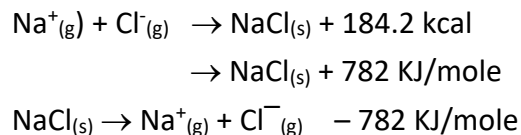a) Ca^{+2} > Zn^{2+}

     2, 8, 8   2, 8, 18

     Inert gas configuration   Pseudolnert gas configuration

b) Na^+ > Cu^+

     2.8   2.8.18

     Inert gas configuration   Pseudolnert gas configuration

Higher lattice energy also favours ionic bond formation

LATTICE ENERGY:- (ν)

The amount of energy released when the oppositely charged gaseous ions combine to form one mole of solid ionic crystal (or)

The amount of energy absorbed to separate one mole of solid ionic crystal into oppositely charged gaseous ions is called lattice energy.

$$Na^+_{(g)} + Cl^-_{(g)} \rightarrow NaCl_{(s)} + 184.2 \text{ kcal}$$
$$\rightarrow NaCl_{(s)} + 782 \text{ KJ/mole}$$
$$NaCl_{(s)} \rightarrow Na^+_{(g)} + Cl^-_{(g)} \quad -782 \text{ KJ/mole}$$

- In a given ionic crystal, there are attractions between opposite charges and repulsions between electron clouds of cation & anion.
- Thus, lattice energy is the sum of potential energy due to attractions & potential energy due to repulsions.

$$PE_{att}n = -\frac{NAZ^+Z^-e^2}{r}$$

$$PE_{rep}n = +\frac{NBe^2}{r^n}$$

Lattice energy (u) $= -\frac{NAZ^+Z^-e^2}{r} + \frac{NBe^2}{r^n}$

Where
- N → Avagadro's number
- A → Madelung's constant
- Z^+ → Positive charge
- Z^- → Negative charge
- e → Charge of e^-
- B → Repulsive co-efficient
- n → Born exponent

- Lattice energy is inversely proportional to the sum of radii of cation & anion.

$$u\alpha \frac{1}{r^+ + r^-}$$

u ⏹⏹charge, u ⏹$\frac{1}{size}$

- Generally, the ion, (cation or anion) with **smaller size & more charge will have greater lattice energy.**

Born-Haber's cycle:

The basis for Born-Haber's cycle is Hess's law. It states that the heat energy change will remain constant whether a chemical reaction occurs in one step or several steps.

Lattice energy cannot be determined by direct experimental methods.

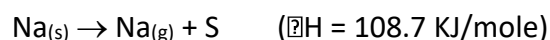- But it can be determined by using Born- Haber's cycle. Eg.: Formation of NaCl

1st way:

$$Na(s) + \frac{1}{2}Cl_2(g) \rightarrow NaCl(s)$$

$$(Q = -410.5 \text{ KJ / mole})$$
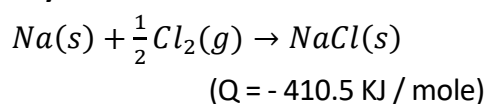
- One mole sodium reacts with half mole chlorine gas to form solid NaCl crystal.

2ⁿᵈ way:

1) **Sublimation of sodium.**

   Solid sodium on heating directly changes to vapour state & the heat energy is called sublimation energy.

   $Na_{(s)} \rightarrow Na_{(g)} + S$ (ΔH = 108.7 KJ/mole)
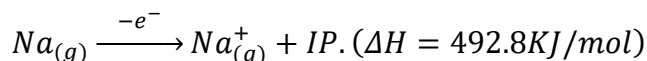
2) **Dissociation of Cl_2**

   Cl_2 molecule dissociate into Cl - atoms.

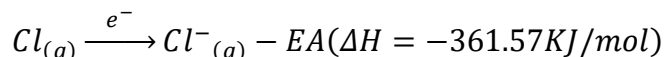   The energy required for dissociation of molecules into atoms is called dissociation energy.

   $\frac{1}{2}Cl_{2(g)} \rightarrow Cl_{(g)} + \frac{D}{2}.(\Delta H = 119.55 KJ/mol)$
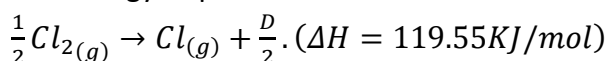
3) **Ionisation of Na**

   Electron is removed from Na to form sodium cation.
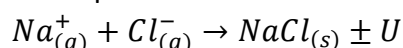
   $Na_{(g)} \xrightarrow{-e^-} Na^+_{(g)} + IP.(\Delta H = 492.8 KJ/mol)$

4) **Electron affinity of Cl :**

   Neutral gaseous Cl atom gains an e⁻ to give Cl⁻ ion & the energy released is called EA.

   $Cl_{(g)} \xrightarrow{e^-} Cl^-_{(g)} - EA(\Delta H = -361.57 KJ/mol)$

5) **Lattice energy :**

   $Na^+_{(g)}$ & $Cl^-_{(g)}$ will combine to form one mole of solid ionic crystal of NaCl. Energy released in the process is called lattice energy.
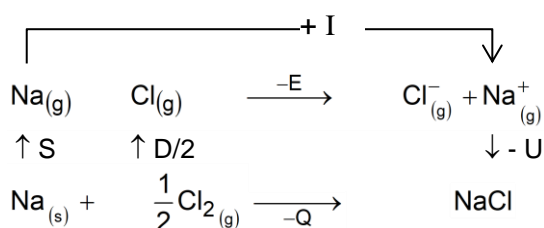
   $Na^+_{(g)} + Cl^-_{(g)} \rightarrow NaCl_{(s)} \pm U$

   Acc. to Hess' law,

   $- Q = +S + \frac{D}{2} + I - E - U$

   $- 410.5 = 108.7 + 119.5 + 492.82 - 316.57 - U$

   ∴ U = - 770 KJ / mole

   All the above changes can be schematically represented in the form of following cycle.

Crystal structures:

The three dimensional network in which the cations and anions are arranged at optimum distances is called crystal lattice.

Co-ordination number:

The number of oppositely charged ions that surround a particular ion in the ionic crystal.

Generally, a cation is surrounded by specific number of anions and anion is surrounded by a specific number of cations.

a) Co-ordination number of NaCl is 6.

Each Na^+ ions is surrounded by $6Cl^-$ ions & each Cl^- ion by 6 Na^+ ions.

b) Co-ordination number of CsCl is 8.

- In some ionic crystals like CaF_2 and Na_2O, co-ordination numbers are different for cation and anion.

    Eg:1) CaF_2

    co-ordination number of Ca^{2+} is 8.

    F^- is 4.

    2) Na_2O

    co-ordination number of Na^+ is 4.

    O^{2-} is 8.

- The co-ordination number of any ionic crystal depends on ratio of size of cation to size of anion. $\frac{r_c}{r_a}$ = limiting radius.

    With increase in $\frac{r_c}{r_a}$, i.e. with increase in size of cation, co-ordination number increases.

$\dfrac{r_c}{r_a}$	co-ordination		Shape
upto 0.155	2	–	Linear
0.155 - 0.225	3	B_2O_3	Trigonal Planar
0.225 - 0.414	4	ZnS	Tetrahedral
0.414 – 0.732	6	NaCl	Octahedral (F.C.C)
0.732 - 0.999	8	CsF, CsCl	B.C.C.

Most common co-ordination numbers are 6 and 8.

UNIT CELL:

Smallest fraction of crystal lattice which gives the whole lattice arrangement is called unit cell. These unit cells in repetitions in 3 dimensions will give entire crystal lattice

CRYSTAL STRUCTURE OF NaCl: NaCl has face centered cubic lattice structure (FCC)

- Co-ordination number is 6 because $\frac{r_c}{r_a}$ is 0.52. Each Na^+ ion is surrounded by six Cl^- and each Cl^- ion is surrounded by 6 Na^+ ions.

- The number of formula units or molecules or ion pairs of NaCl for unit cell = 4.

    Contribution of body central Na^+ ion towards 1 unit cell = $1 \times 1 = 1$.

    Contribution of Na^+ ion on edges towards 1 unit cell = $12 \times \frac{1}{4} = 3$.

    Contribution of face central ions towards 1 unit cell = $6 \times \frac{1}{2} = 3$.

Contribution of corner ions towards one unit cell = $8 \times \frac{1}{8} = 1$.

CRYSTAL STRUCTURE OF CsCl : CsCl has body centered cubic lattice [BCC]

Its co-ordination number is 8 $\quad \because \frac{r_c}{r_a} = 0.92$

Each Cs^+ ion is surrounded by 8 Cl^- ions and vice versa.

Number of ion pairs or formula units or molecules per unit cell = 1.

Contribution of body centred Cs^+ ion towards one unit cell = $1 \times 1 = 1$

Contribution of corner Cl^- ions towards one unit cell = $8 \times \frac{1}{8} = \frac{8}{8} = 1$

Properties of Ionic compounds:

1) Physical state :

    They exist as crystalline solids due to close packing structure & strong interionic attractions.

2) Melting & boiling points:

    Ionic compounds have high MPs & BPs due to strong interionic attractions.

3) Electrical conductance:

    Ionic compounds are good conductors in fused or aqueous state due to presence of ions & free flow of ions.

4) Ionic bond is non-directional in nature :

    As the ionic bond is non directional in nature. Ionic compounds do not exhibit space isomerism.

5) Reactions of Ionic compounds :

    Reactions in between Ionic compounds are very fast in aqueous solution because they does not involve any reshuffling of bonds. In aqueous solution, ions are free & they are just exchanged in reaction.

6) Solubility:

    Ionic compounds dissolve in polar solvents like H_2O due to ion-dipole interactions. Ionic compounds are generally insoluble in non-polar solvents like $CHCl_3$, CCl_4, CH_3OH, C_6H_6, etc.