UNIT 2

Ionic bond

An ionic bond is a chemical bond formed when one atom transfers an electron to another, resulting in the formation of positively charged ions (cations) and negatively charged ions (anions). This bond typically occurs between metals and non-metals. The attraction between these oppositely charged ions forms the ionic bond, leading to the creation of stable compounds like sodium chloride. Ionic compounds are usually crystalline solids with high melting and boiling points and can conduct electricity when dissolved in water or melted.

Properties of Ionic Compounds

1. **Structure Like a 3D Grid**: Think of ionic compounds as tiny, orderly structures. They form a lattice that looks like a 3D grid, with positive ions (cations) and negative ions (anions) arranged in an alternating pattern. This neat arrangement makes them solid at room temperature.
   Ex: Sodium chloride (NaCl) is a classic example, where sodium and chloride ions form a structured, alternating 3D lattice, illustrating the organized nature of ionic compounds.
2. **High Melting and Boiling Points**: Ionic compounds need a lot of heat to melt or boil. This is because the ions are strongly attracted to each other in the lattice, making it tough to break them apart.
   Ex: Magnesium oxide (MgO) has very high melting and boiling points due to the strong electrostatic forces between magnesium and oxygen ions, requiring a lot of energy to break apart.
3. **Conducts Electricity in Water**: When you dissolve ionic compounds in water, they break free from their rigid structure. The ions start moving around in the water, allowing the solution to conduct electricity.
   Ex: Sodium chloride (NaCl) demonstrates this property by dissolving in water to release sodium and chloride ions that move freely, allowing the solution to conduct electricity.
4. **Hard but Brittle**: These compounds are hard due to the strong bonds between the ions. But, if you apply force, they can shatter easily. This is because pushing the ions together causes the like-charged ones to repel and break the structure.
   Ex: Calcium fluoride (CaF_2) shows the hardness due to strong ionic bonds but becomes brittle under force, as like-charged ions repel each other, causing the structure to shatter.

Factors favouring the formation of ionic compounds:

The ease with which atoms can lose or gain electrons to become cations or anions, respectively, and the resulting electrostatic attraction between these oppositely charged ions favor the formation of ionic compounds.

Factors Favoring the Formation of Cations:

1. **Low Ionization Energy:** Atoms that can easily lose an electron to form a positively charged ion have low ionization energies. This is a characteristic of metals, especially those in groups 1 and 2 of the periodic table, such as sodium (Na) and calcium (Ca). The lower the ionization energy, the more readily an atom will lose an electron to form a cation.
2. **Metallic Character:** Elements with a strong metallic character, which is typically found in the left and middle sections of the periodic table, are more likely to form cations. These elements have loosely held valence electrons that are easily removed.
3. **Size of the Atom:** Larger atoms tend to lose electrons more easily than smaller atoms because the outer electrons are further from the nucleus and are less tightly bound by the nuclear charge. This makes the outer electrons of larger atoms more easily removable.

Factors Favoring the Formation of Anions:

1. **High Electron Affinity/Electronegativity:** Atoms that can easily gain an electron (or electrons) to form a negatively charged ion (anion) have high electron affinities or electronegativities. This is a characteristic of nonmetals, especially those in groups 16 and 17 of the periodic table, such as chlorine (Cl) and oxygen (O). The higher the electron affinity or electronegativity, the more readily an atom will gain an electron to form an anion.
2. **Non-metallic Character:** Elements with a strong non-metallic character, which is typically found in the right section of the periodic table, are more likely to form anions. These elements have a high tendency to attract and gain electrons.
3. **Size of the Atom:** Smaller atoms tend to gain electrons more easily than larger atoms because the added electron is closer to the nucleus and more strongly attracted by the nuclear charge.

Lattice energy:

Lattice energy is a term used in chemistry to describe how much energy is needed to break apart an ionic compound into its ions. Imagine ionic compounds as a tightly packed structure where positive and negative ions are held together strongly.

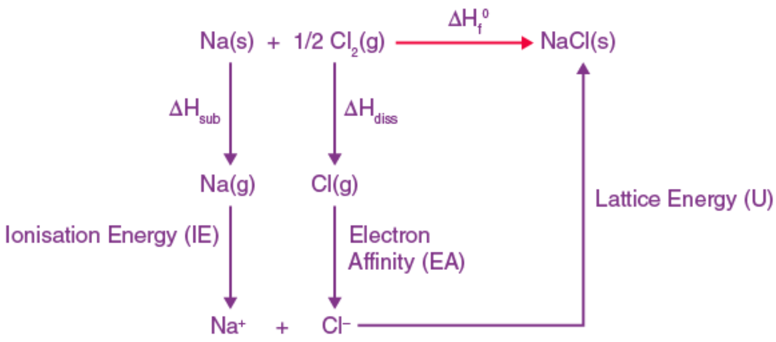
Factors that affect lattice energy are:

1. **Size of the Ions:** Smaller ions are closer together in the lattice, so they have stronger attractions and higher lattice energy. Larger ions are further apart, so their attractions are weaker, leading to lower lattice energy.
   Ex: Lithium fluoride (LiF) showcases high lattice energy due to the small size of Li^+ and F^- ions, leading to strong attractions between them.
2. **Charge of the Ions:** More charged ions (like 2+ or 2- instead of 1+ or 1-) have stronger attractions to each other. So, compounds with ions that have higher charges have higher lattice energy.
   Ex: Magnesium oxide (MgO) has a high lattice energy because of the higher charges (+2 and -2) of Mg^{2+} and O^{2-} ions, increasing their electrostatic attraction.

3. **Polarizability of the Ions:** This refers to how easily the electron cloud of an ion can be distorted by another ion. Larger ions with more electrons can be more easily polarized. When ions are easily polarizable, the attraction between them is stronger, increasing the lattice energy.
   Ex: Potassium iodide (KI) demonstrates increased lattice energy due to the high polarizability of the large I^- ion, enhancing the electrostatic forces within the compound.
4. **Crystal Structure of the Compound:** The arrangement of ions in the crystal lattice also influences lattice energy. Different structures distribute the ions in unique ways, affecting how closely they can pack together and how they interact. Some arrangements allow ions to be closer, leading to stronger attractions and higher lattice energy.
   Ex: The different structures of sodium chloride (NaCl) and cesium chloride (CsCl) affect their lattice energies by altering ion distances and coordination numbers, with NaCl's close-packed arrangement leading to strong ionic attractions.

Born-Haber cycle:

The Born-Haber cycle is a way to understand how ionic compounds form and how stable they are. It is like following a step-by-step illustration to calculate the enthalpy of formation.



Born Harber Cycle for Sodium Chloride

Steps in the Born-Haber Cycle:

1. **Sublimation of the Solid Metal:** The first step involves converting the solid metal (e.g., sodium) into its gaseous form. This step requires energy, known as sublimation energy.
   $$M_{(s)} \rightarrow M_{(g)} \qquad \text{enthalpy change: } \Delta H_{sub}$$
2. **Ionization of the Metal Atom:** The gaseous metal atoms are then ionized by removing electrons to form cations. This process is endothermic and is quantified by the ionization energy.
   $$M_{(g)} \rightarrow M_{(g)}^{+} + e^{-} \qquad \text{enthalpy change: } \Delta H_{ion,M}$$
3. **Dissociation of the Non-metal Molecule:** For non-metal elements that exist as diatomic molecules (e.g., chlorine in Cl_2), this step involves breaking these molecules into individual atoms. This step requires bond dissociation energy.
   $$\tfrac{1}{2} X_{2(g)} \rightarrow X_{(g)} \qquad \text{enthalpy change: } \Delta H_{diss,X}$$
4. **Electron Gain by the Non-metal Atom:** The non-metal atoms gain electrons to form anions. This step releases energy, known as the electron affinity.

$X_{(g)} + e^- \rightarrow X_{(g)}^-$ enthalpy change: $\Delta H_{ea,X}$

5. **Formation of the Ionic Compound:** Finally, the cations and anions combine to form the ionic compound, releasing a significant amount of energy, termed lattice energy (U_o).

$M_{(g)}^+ + X_{(g)}^- \rightarrow MX_{(s)}$ enthalpy change: $-U_o$

Enthalpy of Formation: The enthalpy of formation (ΔH_f) of an ionic compound is the total enthalpy change for the formation of one mole of the compound from its elements in their standard states. It is calculated by summing the enthalpy changes of all the steps in the Born-Haber Cycle.

$$\Delta H_f = \Delta H_{sub} + \Delta H_{ion,M} + \Delta H_{diss,X} + \Delta H_{ea,X} - U_o$$

Importance for Stability: The Born-Haber Cycle is crucial for understanding the stability of ionic compounds. A compound is considered stable if the overall enthalpy change (enthalpy of formation) is negative, indicating that energy is released when the compound forms. The greater the lattice energy, the more stable the compound tends to be.

Stability of ionic compounds in terms of ΔH_f and U_o:

When discussing the stability of ionic compounds, two key terms are often mentioned: ΔH_f and U_o. These terms are central to understanding why some ionic compounds are more stable than others.

Enthalpy of Formation (ΔH_f):

- ΔH_f stands for the change in enthalpy (or heat content) when one mole of an ionic compound is formed from its elements in their standard states.
- A negative value of ΔH_f indicates that the formation of the compound is exothermic, meaning energy is released during the formation. This release of energy is a sign of stability; the more negative the ΔH_f, the more stable the compound.

Lattice Energy (U_o):

- U_o, or lattice energy, refers to the energy released when one mole of an ionic solid forms from its gaseous ions.
- Lattice energy is a measure of the strength of the forces holding the ions together in the solid. A higher lattice energy means stronger ionic bonds and, consequently, a more stable compound.

Relationship between ΔH_f and U_o:

- The stability of an ionic compound can be analyzed by considering both ΔH_f and U_o. A highly negative ΔH_f and a high U_o typically indicate a very stable ionic compound.
- The Born-Haber Cycle can be used to relate these two terms. The cycle shows that ΔH_f is influenced by several factors, including lattice energy (U_o), ionization energy, electron affinity, and sublimation energy.

Solubility and Thermal Stability of Ionic Compounds

Solubility of Ionic Compounds: Solubility refers to the ability of a substance to dissolve in a solvent, like water. In ionic compounds, solubility depends on two main factors: the lattice energy of the compound and the hydration energy.

1. **Lattice Energy (U_o):** This is the energy required to break the ionic bonds in a compound. Higher lattice energy means stronger ionic bonds, which usually leads to lower solubility.
2. **Hydration Energy:** When an ionic compound dissolves in water, the ions are surrounded by water molecules. This process releases energy known as hydration energy. Higher hydration energy can increase solubility, as it helps to overcome the lattice energy.

The solubility of an ionic compound is determined by the balance between these two energies. If the hydration energy is greater than the lattice energy, the compound is likely to be soluble.

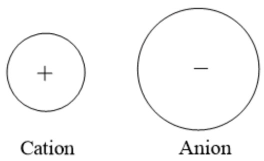
Thermal Stability of Ionic Compounds: Thermal stability refers to how well a compound can withstand heat without decomposing. In ionic compounds, this is influenced by factors like lattice energy and the size and charge of the ions.

1. **Lattice Energy:** Compounds with higher lattice energy are usually more thermally stable. This is because more energy is needed to break the strong ionic bonds.
2. **Size and Charge of Ions:** Smaller ions with higher charges form stronger ionic bonds, leading to greater thermal stability. Larger ions with lower charges form weaker bonds, resulting in lower thermal stability.

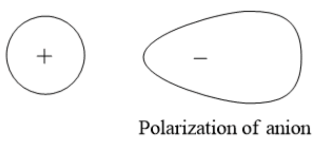
Covalent Character in Ionic Compounds: Polarization and Fajan's Rules:

In chemistry, compounds are often classified as either ionic or covalent based on the nature of bonding between their atoms. However, this distinction is not always clear-cut. Many ionic compounds exhibit some degree of covalent character due to polarization. Fajan's rules help in understanding this phenomenon.

Polarization in Ionic Compounds: Polarization refers to the distortion of the electron cloud of an anion (negatively charged ion) by a cation (positively charged ion). This distortion leads to a shift in electron density towards the cation, introducing a partial covalent character to the bond. The extent of polarization depends on several factors, including the size and charge of the ions involved.



Before Polarization



After Polarization

Fajan's Rules: Fajan's rules provide a guideline to predict the covalent character of ionic compounds. These rules are based on the properties of the ions forming the compound:

1. **Size of the Cation:** Smaller cations have a higher charge density and can polarize the electron cloud of the anion more effectively, leading to a greater covalent character.
2. **Charge on the Cation:** Higher charge on the cation enhances its polarizing power, increasing the covalent character of the bond.
3. **Size of the Anion:** Larger anions are more easily polarizable due to their more diffused electron cloud. This increases the covalent character of the bond.
4. **Electronic Configuration of the Cation:** Cations with inert gas configuration have lesser polarizing power compared to those with pseudo-noble gas configuration.

Effects of Polarization on Ionic Compounds: Solubility, Melting Points, and Thermal Stability

Polarization in ionic compounds occurs when the electron cloud of an anion is distorted by a cation. This effect can significantly alter the properties of the compound, such as solubility, melting points, and thermal stability.

1. Solubility:

- **Explanation:** The solubility of ionic compounds in solvents like water depends on the balance between the ionic bonds in the compound and the interaction between the ions and the solvent. Higher polarization increases covalent character, which can decrease solubility in polar solvents.
- **Example:** Silver chloride (AgCl) is less soluble in water compared to sodium chloride (NaCl). This is because Ag^+ has a higher polarizing power than Na^+, leading to a greater covalent character in AgCl.

2. Melting Points:

- **Explanation:** Melting points of ionic compounds are influenced by the strength of the ionic bonds. Greater polarization leads to increased covalent character, which can lower the melting point as covalent bonds are typically not as strong as ionic bonds.
- **Example:** Calcium fluoride (CaF_2) has a higher melting point than calcium chloride ($CaCl_2$). The smaller fluoride ion is less polarizable than the chloride ion, resulting in CaF_2 having more ionic character and thus a higher melting point.

3. Thermal Stability:

- **Explanation:** Thermal stability refers to the ability of a compound to maintain its chemical structure at high temperatures. Compounds with higher ionic character are generally more thermally stable. Increased polarization, which enhances covalent character, can reduce thermal stability.
- **Example:** Sodium nitrate ($NaNO_3$) is more thermally stable than potassium nitrate (KNO_3). The smaller Na^+ ion polarizes the NO_3^- ion less than the larger K^+ ion, resulting in higher thermal stability for $NaNO_3$.