

Lecture 3 — Ionic Bonding

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- What is Ionic Bonding?
 - Ionic Bonding occurs when electrons are transferred from one atom to another, creating oppositely charged ions that attract each other
 - Typically occurs between a metal (donates electrons) and a nonmetal (accepts electrons)
 - How it happens:
 - * Metal (like Sodium) loses an electron \rightarrow forms a positively charged ion (Na^+)
 - * Nonmetal (like Chlorine) gains an electron \rightarrow forms a negatively charged ion (Cl^-)
 - * Attraction: electrostatic forces hold the ions together
- Role of Electronegativity
 - A measure of an atom's ability to attract and hold electrons in a bond
 - Higher electronegativity \rightarrow stronger pull on electrons
 - Electronegativity Difference
 - * Ionic bonding occurs when there is a large difference in electronegativity (> 1.7) between two atoms
 - * Metal: Low electronegativity \rightarrow tends to lose electrons (for example, sodium has an electronegativity of .9)
 - * Nonmetal: High electronegativity \rightarrow tends to gain electrons (for example, chlorine has an electronegativity of 3.0)
- Coulomb's Law
 - Formula:

$$\vec{F} = \frac{k|q_1q_2|}{r^2}$$

- * k is the Coulomb constant ($8.987 \cdot 10^9 [\text{N m C}^{-2}]$)
- * q_1 and q_2 are the charges on the ions
- * r is the ionic radius
- * F is the force between the two ions
- Related to the lattice energy:

$$E_L \propto \frac{k|q_1q_2|}{r}$$

- Explains the high melting points and stability of ionic solids
- Predicts relative strength of ionic compounds for different applications

- Polyatomic Ions

- Groups of atoms covalently bonded together that act as a single charged unit; Examples:
 - * Ammonium (NH_4^+): Acts as a cation
 - * Nitrate (NO_3^-): Acts as an anion
 - * Sulfate (SO_4^{2-}): Double negative charge

- High Melting and Boiling Points

- Strong Electrostatic Force
 - * Ionic compounds are held together by strong electrostatic attractions between oppositely charged ions
 - * Overcoming these forces requires significant energy, resulting in high melting and boiling points
- Lattice Structure and Stability
 - * 3D Crystal Lattice: tightly packed lattice structure maximizes attractions and minimizes repulsions, enhancing stability
 - * The lattice's stability translates into higher energy requirements for breaking bonds
- Impact of Ionic Charge and Size
 - * Higher charges: Compounds with higher ionic charges have stronger attractions and higher melting/boiling points compared to singly charged ions
 - * Smaller ions: Smaller ionic radii allow ions to pack more closely, increasing bond strength and thermal stability

- Brittleness

- Nature of Ionic Bonds

- * Ions in the crystal lattice are held in fixed positions by strong electrostatic forces
- Response to Stress
 - * When force is applied, layers of ions shift relative to each other
 - * This causes like-charged ions to align, resulting in strong repulsive forces
 - * The repulsion causes the lattice to fracture
- Electrical Conductivity
 - Conductivity in Different States
 - * Solid State
 - Ionic compounds do not conduct electricity in the solid state
 - Reason: Ions are fixed in the crystal lattice and can not move freely
 - * Molten or Dissolved State
 - Ionic compounds conduct electricity when melted or dissolved in water
 - Reason: Ions are free to move, allowing the flow of charge
- Solubility in Polar Solvents
 - Ionic Compounds are Soluble in Polar Solvents
 - * Polar Nature of the Solvent
 - Polar solvents like water have molecules with partial positive ($\delta+$) and partial negative ($\delta-$) charges
 - These charges interact with the ions in the ionic compound, breaking the lattice apart
 - * Ion-Dipole Interaction
 - Positive ions are surrounded by the partial negative charges of water molecules (oxygen)
 - Negative ions are surrounded by the partial positive charges of water molecules (hydrogen)
 - * Why Polar Solvents are Effective
 - The strong dipole moment of water (or other polar solvents) provides the necessary energy to disrupt the ionic lattice
- Hardness and Density
 - Hardness of Ionic Compounds
 - * Ionic compounds are hard because of the strong electrostatic forces holding the ions in a rigid, 3D lattice structure
 - * Displacing ions requires significant energy to overcome these forces

- Density of Ionic Compounds
 - * Ionic lattices are closely packed due to the strong attraction between ions
 - * Smaller ions or higher charges increasing packing efficiency
- Thermal Stability
 - The ability of a compound to withstand high temperatures without decomposing or breaking down into its elements
 - Stability of Ionic Compounds
 - * Strong Ionic Bonds
 - The electrostatic forces between oppositely charged ions require significant energy to overcome
 - * Lattice Energy
 - High lattice energy contributes to stability by tightly binding ions in the lattice
 - Factors Influencing Thermal Stability
 - * Ionic Charge
 - Higher charges lead to stronger bonds and greater stability
 - * Ionic Radius
 - Smaller ions lead to closer packing and stronger bonds, enhancing stability
- Optical Transparency
 - The ability of a material to allow light to pass through without significant scattering or absorption
 - Some Ionic Compounds are Transparent
 - * Large Band Gaps: Ionic compounds like NaCl and MgO have large energy band gaps between their valence and conduction bands
 - * These gaps prevent absorption of visible light, allowing it to pass through
 - * Ordered Lattice: Regular arrangement of ions minimizes scattering, enhancing transparency
- Crystal Lattice Structures
 - Formed to minimize energy by maximizing attractive forces and minimizing repulsive forces
 - Crystal Lattice in Ionic Compounds:
 - * Cation-Anion Arrangement: Positive ions and negative ions alternate to create a stable structure
 - Types of Crystal Structures in Ionic Solids

- * Simple Cubic: Cations and anions alternate in a simple cube arrangement
- * Face-Centered Cubic (FCC): Each ion is surrounded by six oppositely charged ions in a cubic structure
- Lattice Energy and Stability
 - What is Lattice Energy?
 - * The energy released when one mole of an ionic compound forms from its gaseous ions
 - * Represents the strength of bonds in the ionic lattice
 - * Higher lattice energy → stronger ionic bonds → greater stability
 - Factors Influencing Lattice Energy
 - * Ionic Charge: Higher charges increase electrostatic attraction
 - * Ionic Radius: Smaller ions result in shorter distances between ions, increasing attraction
 - Trends in Lattice Energy:
 - * Across a Period: Lattice energy increases as ionic radius decreases
 - * Down a Group: Lattice energy decreases as ionic radius increases
- Dielectric Materials in Capacitors
 - What are Dielectric Materials?
 - * Insulating materials placed between the plates of a capacitor to increase its capacitance
 - * Dielectrics are often ionic or polar materials that can be polarized under an electric field
 - Role of Dielectrics in Capacitors
 - * Energy Storage
 - * Preventing Current Flow
- Insulating Materials
 - What are Insulating Materials?
 - * Materials with high resistivity that prevent the flow of electric current
 - * Used to protect electrical components and ensure efficient energy transmission