Lecture 3 — Ionic Bonding

Michael Brodskiy
Professor: J. Adams

January 9, 2025

- 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 ($8.987 \cdot 10^9 [\mathrm{N\,m\,C^{-2}}]$)
    * 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:

$$E_L \propto \frac{k|q_1 q_2|}{r}$$

  - 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