



Lecture1: Atomic Structure and Atomic Bonding

Introduction

Understanding the atomic structure and atomic bonding is fundamental to materials science and engineering. The physical, mechanical, electrical, and magnetic properties of engineering materials are directly related to the arrangement of atoms and the forces that bind them together. This lecture provides an overview of atomic structure and the main types of atomic bonding, forming a foundation for studying material behavior and applications.

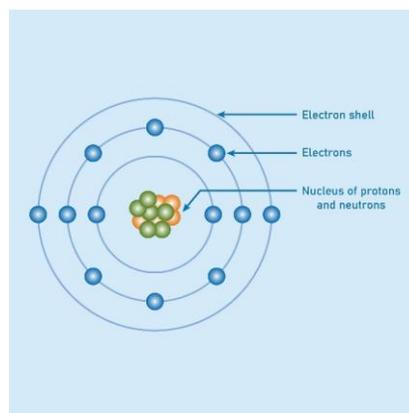
1. Atomic Structure

1.1 Basic Atomic Components

An atom is the smallest unit of matter that retains the properties of an element. It consists of three main subatomic particles:

- Protons: Positively charged particles located in the nucleus.
- Neutrons: Neutral particles located in the nucleus.
- Electrons: Negatively charged particles that orbit the nucleus in specific energy levels.

The number of protons determines the atomic number and identifies the element, while the combination of protons and neutrons determines the atomic mass.





1.2 Electron Energy Levels

Electrons occupy discrete energy levels or shells around the nucleus. These shells are divided into subshells (s, p, d, f), each with a specific energy and capacity.

- The valence electrons, located in the outermost shell, play a critical role in atomic bonding.
- The chemical reactivity and bonding behavior of an element depend mainly on its valence electron configuration.

1.3 Atomic Stability

Atoms tend to achieve a stable electron configuration, usually by filling their outer shell. This drive for stability is the main reason atoms form bonds with one another.

2. Atomic Bonding

Atomic bonding refers to the attractive forces that hold atoms together in molecules or solids. These bonds result from interactions between electrons and nuclei.

2.1 Primary Bonds

2.1.1 Ionic Bonding

Ionic bonding occurs when one atom transfers one or more electrons to another atom.

- Typically occurs between metals and non-metals.
- Results in the formation of positive and negative ions.
- The bond is based on electrostatic attraction.
- Common in ceramic materials.

Characteristics:

- High melting point
- Brittle behavior
- Poor electrical conductivity (except in molten or dissolved states)



2.1.2 Covalent Bonding

Covalent bonding occurs when atoms share electrons.

- Common in non-metallic elements.
- Bonds are directional and strong.
- Found in materials such as silicon, polymers, and diamond.

Characteristics:

- Low to moderate melting point
- Poor electrical conductivity
- Strong directional bonds

Covalent and Ionic Bonds

Water molecule

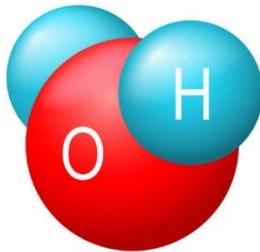
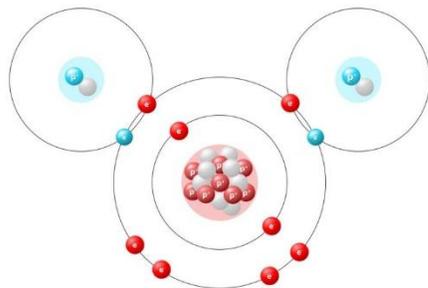
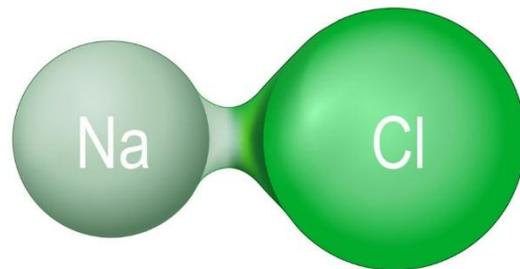
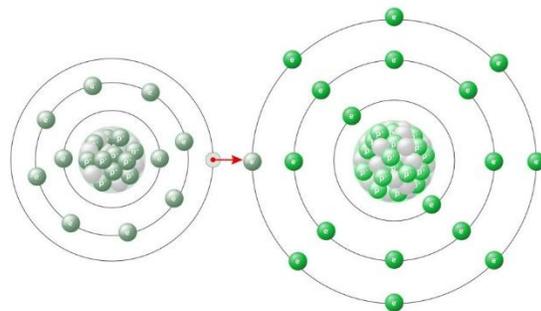


Table salt



Covalent bond



Ionic bond



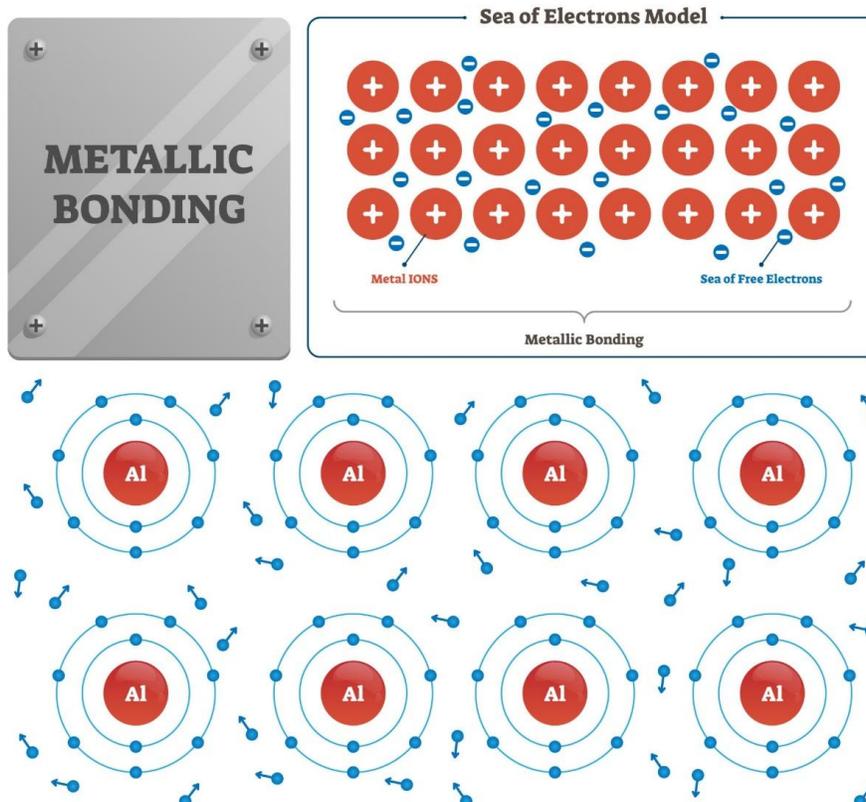
2.1.3 Metallic Bonding

Metallic bonding is formed by a “sea of free electrons” shared among a lattice of positive metal ions.

- Characteristic of metallic materials.
- Explains high electrical and thermal conductivity.

Characteristics:

- Good electrical and thermal conductivity
- Ductility and malleability
- Ability to deform plastically





2.2 Secondary Bonds

Secondary bonds are weaker than primary bonds and include:

- Dipole–dipole interactions
- Hydrogen bonding
- Van der Waals forces

These bonds are important in polymers, molecular solids, and biological materials.

3. Relationship Between Atomic Bonding and Material Properties

3.1 Mechanical Properties

- Strong bonds → high strength and hardness.
- Directional bonds → brittleness.
- Non-directional bonds → ductility.

3.2 Electrical Properties

- Free electrons in metallic bonds lead to high electrical conductivity.
- Covalent and ionic bonds generally result in insulating behavior.
- Semiconductors depend on controlled electron movement.

3.3 Magnetic Properties

Magnetic behavior is influenced by electron spin and orbital motion, which are directly related to atomic structure and bonding.

4. Importance in Engineering Applications

Understanding atomic structure and bonding helps engineers:

- Select suitable materials for specific applications.
- Predict material behavior under mechanical, thermal, or electrical loading.
- Develop new materials with tailored properties.



Compare metallic bonding and covalent bonding.

Feature	Metallic Bonding	Covalent Bonding
Electrons	Free-moving	Shared
Direction	Non-directional	Directional
Conductivity	High	Low
Materials	Metals	Non-metals, semiconductors

References

- Engineering Materials: An Introduction to Their Properties and Applications
- Materials Science
- Engineering Metallurgy
- Materials for the Engineering Technician
- Electrical and Magnetic Properties of Materials
- Principles of Metallurgy

Questions

1. Which subatomic particle determines the atomic number of an element?
2. Which type of bonding is characterized by a “sea of free electrons”?
3. Define atomic structure.
4. What is the role of valence electrons in bonding?
5. State two characteristics of covalent bonding.
6. Why are metals good electrical conductors?
7. Explain the basic structure of an atom.
8. Describe ionic bonding and list its main properties.
9. Compare metallic bonding and covalent bonding.
10. How does atomic bonding affect mechanical properties of materials?