Unit 5

CHEMICAL BONDING

5.1 Chemical Bonding

Chemical Bonding and Chemical Reactions

The material world around us is in constant flux due to chemical and physical changes. Chemical changes involve alterations in the composition of elements, leading to new substances. These changes are called chemical reactions. Atoms are the smallest particles of matter involved in these reactions, while molecules are the smallest units of substances that can exist independently and exhibit their properties.

Why Atoms Form Chemical Bonds

Most elements in nature are not found as individual atoms because they are often unstable on their own. Atoms tend to combine to achieve greater stability. This stability is often reached when atoms form bonds, which are the forces holding them together in molecules or compounds. Chemical bonds are formed through interactions between atoms' valence electrons, which can be shared, gained, or lost.

Octet Rule

Gilbert Lewis proposed the octet rule, which states that atoms form bonds to achieve eight valence electrons, similar to the electron configuration of noble gases (except helium). Most elements follow this rule to achieve stability. For example, noble gases are chemically inert because they naturally have a full valence shell of eight electrons.

How Atoms Satisfy the Octet Rule

Atoms can achieve a stable electron configuration through:

1. **Losing Valence Electrons:** Atoms of metals lose their valence electrons to become stable. For example, sodium (Na) loses its single valence electron to achieve a stable configuration.
2. **Gaining Valence Electrons:** Atoms of non-metals gain electrons to fill their valence shell. For instance, oxygen (O) gains two electrons to achieve stability.
3. **Sharing Valence Electrons:** Atoms can share electrons with other atoms to complete their valence shell. This is common in covalent bonding.

5.2 Ionic Bonding

What Are Ions?

Ions are atoms or molecules with a net electric charge due to an imbalance between protons and electrons. A positive ion (cation) has more protons than electrons, while a negative ion (anion) has more electrons than protons.

Types of Ions

1. **Anions:** Negatively charged ions with more electrons than protons (e.g., Cl^-, I^-).
2. **Cations:** Positively charged ions with more protons than electrons (e.g., Na^+, Ca^{2+}).

How Ions Form

Ions form through ionization, where atoms gain or lose electrons to achieve stable electronic configurations. For example:

- Sodium (Na) loses an electron to become Na^+.
- Chlorine (Cl) gains an electron to become Cl^-.

Ionic Bond Formation

Ionic bonds form when atoms with opposite charges attract each other. For example, sodium loses an electron to become Na^+, while chlorine gains that electron to become Cl^-. The electrostatic attraction between these ions forms sodium chloride (NaCl).

Lewis Formulas of Ionic Compounds

Lewis Dot Formula

Gilbert N. Lewis proposed using dot diagrams to represent atoms and their valence electrons. Each dot represents an electron, and these diagrams help visualize how atoms bond.

Lewis Symbols

In the Lewis dot formula:

- **Cations** are shown with fewer electrons than the neutral atom.
- **Anions** are shown with extra electrons.

Examples of Ionic Compounds

The Lewis dot formula can illustrate the transfer of electrons between atoms, such as in the formation of NaCl (sodium chloride) and $CaCl_2$ (calcium chloride).

5.2.3 General Properties of Ionic Compounds

Properties of Ionic Compounds

Ionic compounds have unique properties due to the strong electrostatic forces between cations and anions:

- **Form Crystals:** They typically exist as solid crystals with a regular, repeating pattern.
- **High Melting and Boiling Points:** They require a lot of energy to melt or boil due to the strong ionic bonds.
- **Hard and Brittle:** They are hard but can break easily when struck, due to repulsive forces between like-charged ions.
- **Solubility in Polar Solvents:** They dissolve well in polar solvents like water.
- **Electrical Conductivity:** They conduct electricity when dissolved in water or melted, as the ions are free to move.

5.3 Covalent Bonding

To achieve stability, atoms follow the octet rule, which involves having eight electrons in their valence shell. Unlike noble gases, most elements form bonds to satisfy this rule. This section focuses on **covalent bonding**, which is one method atoms use to become stable, along with **Lewis dot formulas**, **polarity in covalent molecules**, **coordinate covalent bonds**, and **general properties of covalent compounds**.

5.3.1 Formation of Covalent Bond

A covalent bond forms when two atoms share one or more pairs of electrons to achieve a stable electron configuration. The shared electrons, called **bonding electrons**, are counted in the valence shell of both atoms, helping them achieve stability.

Types of Covalent Bonds:

- **Single Bond**: One pair of electrons is shared (e.g., hydrogen molecule H_2).
- **Double Bond**: Two pairs of electrons are shared (e.g., oxygen molecule O_2).
- **Triple Bond**: Three pairs of electrons are shared (e.g., nitrogen molecule N_2).

Example of Single Bond Formation:

In a hydrogen molecule H_2 , two hydrogen atoms each contribute one electron to form a shared pair. The bond can be shown as H−H or H:H, indicating a single covalent bond.

Example of Double Bond Formation:

In an oxygen molecule O_2 , two oxygen atoms each share two pairs of electrons, forming a double bond. This arrangement helps both atoms achieve the noble gas electron configuration.

Example of Triple Bond Formation:

In a nitrogen molecule N_2 , two nitrogen atoms each share three pairs of electrons, resulting in a triple bond. This sharing allows both nitrogen atoms to fill their valence shells.

5.3.2 Lewis's Formula of Covalent Molecules

Lewis Dot Structures show the bonding between atoms and the lone pairs of electrons that may exist. The number of bonds an atom can form typically correlates with the number of electrons it needs to achieve a full valence shell.

- **Hydrogen (H)**: Forms one single bond.
- **Nitrogen (N)**: Forms three bonds to complete its octet.
- **Oxygen (O)**: Forms two bonds to complete its octet.

Examples:

- **Hydrogen Molecule (H_2)**: Lewis structure is H:H or H−H.
- **Nitrogen Molecule (N_2)**: Lewis structure is :N≡N:
- **Water (H_2O)**: Lewis structure is H:O:H.

5.3.3 Polarity in Covalent Molecules

Polarity refers to the distribution of electron density in a covalent bond. A bond is polar if the electrons are not shared equally between the two atoms, resulting in partial positive and negative charges.

- **Nonpolar Covalent Bonds**: Electrons are shared equally (e.g., H_2 , O_2).
- **Polar Covalent Bonds**: Electrons are shared unequally due to differences in electronegativity (e.g., HCl, H_2O).

Example:

- **Water (H_2O)**: The oxygen atom is more electronegative than the hydrogen atoms, creating a polar molecule with a bent shape. This results in a partial negative charge on the oxygen and partial positive charges on the hydrogens.

5.3.4 Coordinate Covalent Bond (Dative Bond)

A **coordinate covalent bond** is a type of covalent bond where both electrons in the bond come from the same atom.

Conditions for Formation:

1. One atom must have a lone pair of electrons.
2. The other atom must have an empty orbital to accept the electron pair.

Example:

- **Formation of NH_3 with BF_3** : Ammonia (NH_3) has a lone pair of electrons that can be donated to boron trifluoride (BF_3), which has an empty orbital.

Diagram:

- **$BF_3 + NH_3 \rightarrow [BF_3\text{-}NH_3]$**: The lone pair from NH_3 forms a coordinate covalent bond with BF_3.

Unit Summary: Chemical Bonding

1. Introduction to Chemical Bonding In this unit, we explore how the association of electrons determines the properties of elements and the formation of chemical bonds. Each element has a unique number of electrons, influencing its chemical behavior and reactivity. Only valence electrons, which are the electrons in the outermost shell, are involved in bonding.

2. The Octet Rule Atoms generally aim to achieve a stable electron configuration similar to that of noble gases, which have eight valence electrons. This tendency is known as the octet rule. Most elements follow this rule by sharing, losing, or gaining electrons to complete their valence shell.

3. Formation of Ions Atoms or molecules with a net charge are called ions. The net electric charge is calculated by: Net electric charge=number of protons−number of electrons.

- **Anions**: Atoms or groups of atoms with a net negative charge (gain electrons).
- **Cations**: Atoms or groups of atoms with a net positive charge (lose electrons).

Ionization is the process where atoms lose or gain electrons to form ions.

4. Ionic Bonds An ionic bond forms between two oppositely charged ions due to electrostatic forces. This type of bond typically occurs between metallic and non-metallic elements.

5. Lewis Symbols and Dot Formula The Lewis symbol represents an atom's chemical symbol surrounded by dots that indicate its valence electrons. This notation helps in visualizing the bonding in molecules.

6. Properties of Ionic Compounds Ionic compounds have distinctive properties:

- **Crystal formation**: They form crystalline structures.
- **Melting and boiling points**: High due to strong ionic bonds.
- **Hardness**: They are hard and brittle.
- **Solubility**: Soluble in polar solvents.
- **Electrical conductivity**: Conduct electricity when dissolved in water or melted.
- **Density**: Generally high.

7. Covalent Bonds Covalent bonds are formed when two atoms share one or more pairs of electrons. They are classified based on the number of shared electron pairs:

- **Single bond**: One pair of electrons.
- **Double bond**: Two pairs of electrons.
- **Triple bond**: Three pairs of electrons.

8. Polar and Nonpolar Covalent Bonds

- **Polar Covalent Bond**: Occurs when there is a significant difference in electronegativity between the two atoms, leading to unequal sharing of electrons (e.g., HF).
- **Nonpolar Covalent Bond**: Electrons are shared equally between identical atoms (e.g., H_2).

The bond is considered polar if the electronegativity difference is between 0.5 and 2.0, and ionic if it is 2.0 or more.

9. Coordinate Covalent Bonds A coordinate covalent bond, or dative bond, forms when one atom provides both electrons for the bond, and the pair is shared by both atoms. Once formed, it is indistinguishable from other covalent bonds.

10. Properties of Covalent Compounds Covalent compounds exhibit different properties compared to ionic compounds:

- **State**: They can be gases or liquids.
- **Melting and boiling points**: Generally low.
- **Electrical conductivity**: Poor conductors of electricity.

- **Solubility**: Soluble in non-polar solvents, insoluble in polar solvents.
- **Density**: Typically lower than ionic compounds.

11. Metallic Bonds Metallic bonds occur between metal atoms. These bonds are characterized by strong forces of attraction between positive metal ions and delocalized valence electrons. This bonding results in metals having unique properties such as high electrical and thermal conductivity.