Unit 3
IMPORTANT INORGANIC COMPOUNDS

3.1 Introduction to Inorganic Compounds

Inorganic compounds are chemical compounds that generally do not contain carbon, with a few exceptions like carbonates (e.g., $CaCO_3$), oxides of carbon (e.g., CO_2), and carbides (e.g., SiC). These compounds mainly consist of mineral constituents of the Earth and are usually found in non-living things. In contrast, organic compounds are typically found in living organisms (details on organic compounds are covered in Unit 6).

Most metal compounds are considered inorganic. Inorganic compounds are commonly found in nature in forms such as silicates, oxides, carbonates, sulfides, sulfates, chlorides, and nitrates. These compounds are generally classified into four main groups:

1. **Oxides**
2. **Acids**
3. **Bases**
4. **Salts**

These categories are essential in understanding the chemical behavior of various substances in our daily lives. For example:

- **Oxides**: Carbon dioxide (CO_2), used in fire extinguishers.
- **Acids**: Acetic acid (CH_3COOH), responsible for the sour taste of vinegar.
- **Bases**: Sodium hydroxide (NaOH), used in soap production.
- **Salts**: Sodium chloride (NaCl), commonly used as table salt.

This unit will explore the chemical nature and formation of oxides, acids, bases, and salts in more detail.

3.2 Oxides

Oxides are compounds formed by the reaction of oxygen with another element. Oxygen is highly reactive and forms oxides with almost all elements, except for noble gases and some inactive metals like gold, platinum, and palladium.

Types of Oxides

Oxides are binary compounds, meaning they consist of two elements: oxygen and another element, which can be a metal, non-metal, or metalloid. Based on their chemical properties, oxides are classified into the following categories:

1. **Acidic Oxides**:
   - Formed by the combination of oxygen with non-metals (typically from Groups 14-17 of the periodic table).
   - These oxides are also known as acid anhydrides because they form acidic solutions when dissolved in water. Examples include carbon dioxide (CO_2), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2).
   - Not all non-metal oxides are acidic. For example, carbon monoxide (CO) and nitrous oxide (N_2O) are neutral oxides.

   Chemical Properties of Acidic Oxides:

   - Dissolve in water to form acids:

     $CO_2+H_2O \rightarrow H_2CO_3$ (Carbonic acid)

     $SO_2+H_2O \rightarrow H_2SO_3$ (Sulfurous acid)

   - React with basic oxides to form salts:

     $CO_2+Na_2O \rightarrow Na_2CO_3$ (Sodium carbonate)

   - React with bases in a neutralization reaction to form salt and water:

     $SO_2+2NaOH \rightarrow Na_2SO_3+H_2O$

2. **Basic Oxides**:
   - Formed by the combination of oxygen with metals.
   - These oxides typically dissolve in water to form alkaline (basic) solutions and are known as basic anhydrides. Examples include lithium oxide (Li_2O), sodium oxide (Na_2O), and calcium oxide (CaO).

   Chemical Properties of Basic Oxides:

   - Dissolve in water to form bases (alkali):

     $Li_2O+H_2O \rightarrow 2LiOH$

     $CaO+H_2O \rightarrow Ca(OH)_2$

- React with acidic oxides to form salts: $BaO+SO_3 \rightarrow BaSO_4$
- React with acids in a neutralization reaction to form salt and water:

  $CaO+2HCl \rightarrow CaCl_2+H_2O$

3. **Amphoteric Oxides**:
   - These oxides show both acidic and basic properties and can react with both acids and bases to form salts. Examples include aluminum oxide (Al_2O_3) and zinc oxide (ZnO).
4. **Neutral Oxides**:
   - These oxides do not exhibit acidic or basic properties and do not react with acids or bases to form salts. Examples include water (H_2O), carbon monoxide (CO), and nitrous oxide (N_2O).
5. **Peroxides**:
   - Peroxides contain oxygen with an oxidation state of -1 and include a characteristic O–O bond. Examples include hydrogen peroxide (H_2O_2) and sodium peroxide (Na_2O_2).

In summary, oxides play a crucial role in chemistry due to their varied properties and reactions with other substances, making them essential in understanding the chemical behavior of different elements.

3.3 Acids

Introduction to Acids

Acids are substances that play significant roles in our daily lives, whether in our bodies, homes, or laboratories. They are known for their sour taste, which is why unripe citrus fruits or lemon juice have a sour flavor due to the presence of citric acid. Acids are commonly found in various foods, like vinegar (acetic acid) and citrus fruits (citric acid). They are also present in our stomachs as hydrochloric acid (HCl), which aids digestion, and in carbonated beverages as phosphoric acid, which adds flavor.

Arrhenius Definition of Acids

The simplest definition of an acid was proposed by Swedish chemist Savante Arrhenius. According to Arrhenius, an acid is a substance that releases hydrogen ions (H^+) or hydronium ions (H_3O^+) in an aqueous solution. The ionization of acids can be represented as:

- $HA(aq) \rightarrow H^+(aq) + A^-(aq)$
- Or, $HA(aq) + H_2O(l) \rightarrow H_3O^+(aq) + A^-(aq)$

For a substance to be considered an Arrhenius acid, it must contain ionizable hydrogen. Examples of Arrhenius acids include nitric acid (HNO_3), sulfuric acid (H_2SO_4), phosphoric acid (H_3PO_4), and hydrofluoric acid (HF).

Classification of Acids

Acids can be classified based on the number of ionizable hydrogen atoms per molecule or the number of elements they contain.

A. Classification Based on Ionizable Hydrogen Atoms

1. **Monoprotic Acids:** Contain only one ionizable hydrogen atom per molecule, e.g., HCl, HNO_3.
2. **Diprotic Acids:** Contain two ionizable hydrogen atoms, e.g., H_2SO_4.
3. **Triprotic Acids:** Contain three ionizable hydrogen atoms, e.g., H_3PO_4.
4. **Polyprotic Acids:** Contain more than one ionizable hydrogen atom, including diprotic and triprotic acids.

B. Classification Based on Elements Contained

1. **Binary Acids:** Composed of two elements, hydrogen and a non-metal, e.g., HCl, HF.
2. **Ternary Acids (Oxy-acids):** Composed of three elements, typically hydrogen, oxygen, and a non-metal, e.g., H_2SO_4, H_3PO_4.

General Properties of Acids

1. **Sour Taste:** Acids generally have a sour taste, as evident in lemon and orange juice, which contain citric acid.
2. **Color Change with Indicators:** Acids change the color of acid-base indicators. For example, blue litmus paper turns red in an acidic solution.
3. **Reaction with Metals:** Acids react with active metals like zinc, magnesium, and iron to produce hydrogen gas and a salt.
4. **Reaction with Carbonates:** Acids react with carbonates and hydrogen carbonates to form salt, water, and carbon dioxide gas.
5. **Neutralization:** Acids react with bases (such as metal oxides and hydroxides) to form salts and water in a process known as neutralization.
6. **Electrical Conductivity:** Aqueous solutions of acids are electrolytes, meaning they can conduct electricity. Strong acids dissociate completely in water and are strong electrolytes, while weak acids partially dissociate and are weak electrolytes.

Strength of Acids

Acids are classified as strong or weak based on their degree of dissociation in aqueous solution:

- **Strong Acids:** Completely dissociate in water, producing a large amount of H^+ ions, e.g., HCl, HNO_3.
- **Weak Acids:** Partially dissociate in water, producing fewer H^+ ions, e.g., acetic acid (CH_3COOH).

3.4 Bases

Bases are substances that are either oxides or hydroxides of metals, known as basic oxides and hydroxides. They are crucial in both chemical industries and our daily lives. For example:

- **Sodium hydroxide (NaOH)** is used in soap production, paper manufacturing, and textiles.
- **Potassium hydroxide (KOH)** is used in making soft soap and fertilizers.
- **Calcium hydroxide ($Ca(OH)_2$)** is used in mortar, bleaching powder, and soil treatment.

Arrhenius Definition of Bases

According to the **Arrhenius theory**, a base is a substance that produces a hydroxide ion (OH^-) when dissolved in water. Soluble bases are called **alkalis**. For example:

- $NaOH\ (aq) \rightarrow Na^+\ (aq) + OH^-\ (aq)$
- $KOH\ (aq) \rightarrow K^+\ (aq) + OH^-\ (aq)$

Ammonia (NH_3), although not ionic, reacts with water to produce NH_4^+ and OH^- ions:

- $NH_3\ (aq) + H_2O\ (l) \rightleftharpoons NH_4^+\ (aq) + OH^-\ (aq)$

General Properties of Bases

1. **Taste and Feel:** Bases have a bitter taste and feel slippery like soap in aqueous solutions. Strong bases, like NaOH and KOH, are corrosive and should not be touched or tasted.
2. **Color Change in Indicators:** Bases change the color of indicators, such as turning red litmus paper blue and phenolphthalein pink.
3. **Hydroxide Ion Release:** Bases release OH^- ions in aqueous solutions, responsible for their characteristic properties.
4. **Neutralization of Acids:** Bases neutralize acids to form salt and water.
5. **Electrical Conductivity:** Solutions of strong bases conduct electricity well, whereas weak bases conduct poorly.

Strength of Bases

- **Strong Bases:** These bases ionize completely in water, producing a large number of hydroxide ions. Examples include NaOH and KOH.
- **Weak Bases:** These bases partially ionize, producing fewer hydroxide ions. Examples include NH_4OH and $Mg(OH)_2$.

Concentration of Bases

- **Concentrated Bases:** Contain a large amount of base per liter of solution.
- **Dilute Bases:** Contain a small amount of base per liter of solution.

Both strong and weak bases can be either concentrated or dilute, depending on the number of moles of the base present per liter.

Precautions in Handling Bases

- Wear protective gear like goggles and gloves.
- Immediately clean any spills.
- In case of contact, wash the area with water and seek medical help if needed.

pOH

The pOH of a solution is a measure of its hydroxide ion concentration, defined as the negative logarithm of the OH^- concentration. The relationship between pH and pOH is given by:

- **pH + pOH = 14**

Preparation of Bases

1. **Reaction of Reactive Metals with Water:** Produces metal hydroxide and hydrogen gas.
   - Example: $2Na+2H_2O \rightarrow 2NaOH+H_2$
2. **Reaction of Metal Oxides with Water:** Produces metal hydroxides.
   - Example: $Na_2O+H_2O \rightarrow 2NaOH$
3. **Double Displacement Reaction:** Produces soluble bases and insoluble salts.
   - Example: $Ba(OH)_2+K_2SO_4 \rightarrow 2KOH+BaSO_4$

Common Uses of Bases

- **NaOH:** Used in making soaps, detergents, and cleaners.
- **$Ca(OH)_2$:** Used in cement production, soil treatment, and CO_2 detection.

3.5 Salts

Definition and Formation of Salts Salts are ionic compounds typically formed by the neutralization of an acid with a base. The name of a salt derives from the metal ion (from the base) and the acid radical (from the acid). For example, sodium chloride (NaCl) is formed from sodium (Na+) from sodium hydroxide (NaOH) and chloride (Cl-) from hydrochloric acid (HCl). The general reaction for salt formation can be represented as:

- **Base + Acid → Salt + Water**

For example:

- $NaOH+HCl \rightarrow NaCl+H_2O$
- $KOH+HNO_3 \rightarrow KNO_3+H_2O$

Classification of Salts

Salts are classified into three main types:

1. **Normal (Neutral) Salts**: Formed by the complete replacement of the ionizable hydrogen ions of an acid by metal ions or ammonium ions (NH_4^+). These salts are neutral in nature.

   Example: $HCl+KOH \rightarrow KCl+H_2O$

2. **Acidic Salts**: Formed by the partial replacement of hydrogen ions in an acid by metal ions. These salts still contain replaceable hydrogen ions, making them acidic in nature.

   Example: $H_2SO_4+KOH \rightarrow KHSO_4+H_2O$

3. **Basic Salts**: Formed when not all hydroxide ions in a base are replaced by the acid's anion. These salts are basic because they still contain hydroxide ions.
   - Example: $Al(OH)_3+HCl \rightarrow Al(OH)_2Cl+H_2O$

Methods for Preparing Salts

1. **Preparation of Soluble Salts**:

- **Reaction of an Acid with a Metal**: A reactive metal displaces hydrogen from the acid to form a salt and hydrogen gas.
    - Example: $Zn+H_2SO_4 \rightarrow ZnSO_4+H_2$
- **Reaction of an Acid with a Base (Neutralization)**: An acid reacts with a base to form a salt and water.
    - Example: $HCl+NaOH \rightarrow NaCl+H_2O$
- **Reaction of an Acid with a Metal Oxide**: Metal oxides react with acids to form a salt and water.
    - Example: $CuO+H_2SO_4 \rightarrow CuSO_4+H_2O$
- **Reaction of an Acid with a Carbonate or Bicarbonate**: Acids react with carbonates or bicarbonates to produce salt, water, and carbon dioxide.
    - Example: $Na_2CO_3+HCl \rightarrow NaCl+H_2O+CO_2$

2. **Preparation of Insoluble Salts by Double Decomposition (Precipitation)**:
    - When solutions of two soluble salts are mixed, the exchange of ions can produce an insoluble salt, which precipitates out of the solution.
        - Example: $AgNO_3+NaCl \rightarrow AgCl+NaNO_3$

Properties of Salts

1. **Solubility**: Salts have varying solubilities in water—some are highly soluble, while others are slightly soluble or insoluble.
2. **Hygroscopicity, Deliquescence, and Efflorescence**:
    - **Hygroscopic Salts** absorb moisture from the air but remain solid (e.g., anhydrous copper sulfate).
    - **Deliquescent Salts** absorb moisture and dissolve in it to form a solution (e.g., calcium chloride).
    - **Efflorescent Salts** lose water of crystallization to the atmosphere (e.g., washing soda).
3. **Electrical Conductivity**: Aqueous solutions of salts conduct electricity due to the presence of mobile ions.
4. **Thermal Stability**: Different salts show varying stability when heated. Some salts decompose into metal oxides and gases, while others remain stable.
    - **Thermal Decomposition of Carbonates**: Carbonates of Group II elements decompose upon heating to form metal oxides and carbon dioxide.
        - Example: $CaCO_3 \rightarrow CaO+CO_2$
    - **Thermal Decomposition of Nitrates**: Group II nitrates decompose to form metal oxides, nitrogen dioxide, and oxygen.
        - Example: $Ca(NO_3)_2 \rightarrow CaO+2NO_2+O_2$