Unit 5

METALS AND NONMETALS

5.1 Introduction to Natural Resources

Natural Resources are materials that exist naturally in the environment without human intervention. They include:

- **Sunlight**
- **Land**
- **Fossil Fuels** (crude oil, coal, and natural gas)
- **Water**
- **Air**
- **Crops**

Classification of Natural Resources:

1. **Renewable Resources:** These resources can be replenished naturally. Examples include:
    - **Water**
    - **Air**
    - **Plant Materials** (biomass)
2. **Non-Renewable Resources:** These resources exist in fixed amounts and cannot be replenished within a human lifetime. Examples include:
    - **Fossil Fuels** (coal, oil, natural gas)
    - **Nuclear Energy**
    - **Metallic Minerals** (e.g., iron, aluminum)
    - **Non-Metallic Minerals** (e.g., limestone, salt)

Minerals:

- **Metallic Minerals:** Contain metallic elements (e.g., iron from haematite, aluminum from bauxite).
- **Non-Metallic Minerals:** Do not contain metals (e.g., diamond, gravel, mica).

Seawater and Atmosphere:

- Metals and non-metals can also be found in seawater.
- Non-metallic elements such as oxygen and nitrogen are found in the atmosphere.

5.2 Properties and Extraction of Metals

Properties of Metals:

A. Physical Properties:

- **Lustrous:** Shiny appearance (e.g., gold, silver).
- **Malleable:** Can be hammered into thin sheets (e.g., aluminum foils).
- **Ductile:** Can be drawn into wires (e.g., copper).
- **Hard and Dense:** Generally hard and have high density, except some metals like lithium.
- **Sonorous:** Produce a metallic sound when struck (e.g., school bells).

B. Chemical Properties:

- **Positive Valency:** Tend to lose electrons.
- **Oxidation:** React to form basic oxides and some amphoteric oxides.
- **Electrovalent Chlorides:** Form true salts and ionic hydrides.
- **Reaction with Acids:** Most metals react with dilute acids to produce hydrogen (exceptions include copper, silver, and gold).

C. Reactivity Series:

- Metals are arranged in a series based on their reactivity. Metals at the top are highly reactive and can displace other metals from their compounds (e.g., potassium). Metals at the bottom are less reactive (e.g., gold).

D. Natural Occurrence and Extraction:

- **Noble Metals:** Can exist in a free state (e.g., gold, silver).
- **Active Metals:** Found in compounds (e.g., sodium in halite, calcium in limestone).
- **Metallurgy:** The science of extracting metals from ores involves three main steps:
    1. **Preparation (Concentration)**: Techniques include oil flotation and magnetic separation.
    2. **Production**: Methods such as roasting and calcination.
    3. **Purification**: Techniques like chemical and electrolytic reduction.

Extraction of Highly Active Metals: Metals like potassium and sodium are extracted through electrolysis due to their high reactivity.

5.2.2 Alloys

Alloys are mixtures of two or more metals or a metal with a non-metal. They are created by melting the components together and solidifying them.

Characteristics of Alloys:

- **Increased Hardness and Strength:** The presence of different sized atoms prevents layers from sliding over one another.
- **Modified Properties:** Alloys often have altered melting points, colors, and resistance to corrosion compared to their component metals.

Examples:

- **Amalgam:** An alloy of mercury and another metal.
- **Gun Metal:** Composed of copper (87%), tin (10%), and zinc (3%).
- **Solder:** Contains 67% tin and 33% lead, used for joining wires.
- **Gold Alloys:** Gold is alloyed with copper or silver for hardness. Carats measure gold content (e.g., 24 carat gold is pure gold).

5.2.3 Production of Aluminum, Iron, and Copper

A. Aluminum:

Occurrence and Extraction:

- **Abundance:** Aluminum is the third most abundant element in the earth's crust.
- **Main Ore:** Bauxite ($Al_2O_3 \cdot 2H_2O$).
- **Extraction Process:**
    1. **Purification:** Bauxite is treated with sodium hydroxide to remove impurities.
    2. **Electrolysis:** Aluminum oxide is electrolyzed to obtain pure aluminum. Cryolite is used to lower the melting point and improve conductivity.

Properties:

- **Physical:** Soft, silvery-white, light, density 2.7 g/cm^3, melts at 660°C.
- **Chemical:** Reacts with oxygen to form a protective oxide layer, burns in nitrogen to form aluminum nitride, and reacts with acids to release hydrogen.

Uses:

- Widely used in transportation, packaging, cookware, and construction. Also used in thermite welding for its high reactivity.

B. Iron:

Occurrence and Extraction:

- **Abundance:** Iron is the second most abundant metal in the earth's crust.
- **Chief Ores:** Hematite (Fe_2O_3), magnetite (Fe_3O_4), and siderite ($FeCO_3$).
- **Extraction Process:** Carried out in a blast furnace where iron ore, coke, limestone, and hot air are used. The reactions involve the reduction of iron oxides by carbon monoxide and the decomposition of limestone to remove impurities.

Iron Production:

- **Pig Iron:** The initial product from the blast furnace, containing impurities.

Steel Making from Pig Iron (Purification of Pig Iron)

Pig iron, produced in a blast furnace, has a high carbon content making it hard and brittle. To convert pig iron into steel, which is less brittle and more useful for a variety of applications, a purification process is employed. This process involves removing impurities and adjusting the composition of the iron. The three primary techniques used for this conversion are the Bessemer Converter, Open-Hearth Furnace, and Basic Oxygen Process.

1. The Bessemer Converter

- **Process**: Molten pig iron is transferred to a cylindrical vessel with a refractory lining made of magnesium carbonate ($MgCO_3$) and calcium carbonate ($CaCO_3$).
- **Purification**: Hot air is blown through small holes at the bottom of the vessel. The oxygen reacts with impurities in the pig iron:
    - **Silicon, phosphorus, and sulfur** are converted into their oxides, which then react with the lining to form slag.
    - **Carbon** is oxidized to carbon monoxide (CO), reducing its concentration.
- **Time**: This process takes about 15 minutes.
- **Challenges**: The reaction is difficult to control, and the quality of steel produced can vary.

2. The Open-Hearth Furnace

- **Process**: The furnace has a large, shallow hearth lined with basic oxides like magnesium oxide (MgO) and calcium oxide (CaO). It is charged with a mixture of pig iron, iron(III) oxide (Fe_2O_3), scrap iron, and limestone.
- **Purification**: Hot air and burning fuel keep the mixture molten. Impurities are oxidized:
  - **Carbon** and **sulfur** are converted to carbon dioxide (CO_2) and sulfur dioxide (SO_2) respectively.
  - **Silicon** and **phosphorus** oxides combine with lime to form slag.
  - Reactions include:
    - $C+O_2 \rightarrow CO_2$
    - $S+O_2 \rightarrow SO_2$
    - $3Si+2Fe_2O_3 \rightarrow 3SiO_2+4Fe$
    - $P_4O_{10}+6CaO \rightarrow 2Ca_3(PO_4)_2$
- **Time**: This process takes 8 to 10 hours and allows for better control of steel quality, with the addition of various elements to form steel alloys.

3. Basic Oxygen Process

- **Process**: A mixture of powdered calcium oxide (CaO) and oxygen gas is forced into the surface of molten pig iron.
- **Purification**: The oxygen reacts exothermically with impurities:
  - **Carbon** and **sulfur** are converted to CO_2 and SO_2 respectively.
  - **Silicon** and **phosphorus** oxides form slag with lime.
- **Time**: The entire process takes about 20 to 25 minutes and is much faster than the open-hearth process.

Tempering of Steel

- **Purpose**: Tempering is used to adjust the hardness of steel by heating it to a specific temperature and then cooling it at a controlled rate.
- **Process**: Some carbon in steel is present as cementite (Fe_3C), which makes the steel hard but brittle. Tempering removes some of this cementite, improving the steel's toughness.

Activity 5.6

1. **Which form of iron is the purest: wrought iron, pig iron, steel?**
   - Steel is the purest form of iron.
2. **Prepare a list of materials made of steel and describe their uses. Discuss in groups and give a presentation to the class.**
   - Examples include structural beams (construction), car parts (automobiles), and kitchen utensils (household use).

Physical Properties of Iron

- **Appearance**: Gray, lustrous metal.
- **Characteristics**: Malleable, ductile, good conductor of heat and electricity, high melting point (1580°C), high density (7.87 g/cm³), ferromagnetic.

Chemical Properties of Iron

- **Reactivity**: Iron reacts slowly with air and moisture to form rust (hydrated iron(III) oxide). The reaction is:
  - $4Fe+3O_2+6H_2O \rightarrow 2Fe_2O_3 \cdot xH_2O$
- **Acid Reactions**: Iron reacts with dilute acids to form iron(II) salts and release hydrogen gas:
  - $Fe+2HCl \rightarrow FeCl_2+H_2$
  - $Fe+H_2SO_4 \rightarrow FeSO_4+H_2$
- **Oxidation States**: Iron commonly exists as Fe^{2+} (ferrous) and Fe^{3+} (ferric) ions.

Uses of Iron

- **Construction**: Buildings, bridges, railings.
- **Domestic**: Boilers, radiators.
- **Manufacturing**: Machinery, tools.

Activity 5.7

1. **What common items are made of copper?**
   - Coins, electrical wires, plumbing pipes.
2. **Copper is used in electrical appliances. Give two reasons based on its physical properties.**
   - Copper is an excellent conductor of electricity and has good malleability for wiring.
3. **A solution of copper sulfate cannot be stored in a vessel made of iron. Give a reason and justify it by a balanced ionic equation.**
   - Iron reacts with copper sulfate, displacing copper:
     - $Fe+CuSO_4 \rightarrow FeSO_4+Cu$
   - Iron is more reactive than copper and will replace it in the solution.
4. **Why is copper so important in our technological society?**
   - Copper's high electrical conductivity and malleability make it crucial for electrical wiring and electronic components.

Occurrence and Extraction of Copper

- **Occurrence**: Found in ores like chalcopyrite, chalcocite, and malachite.
- **Extraction**:
  1. **Concentration**: Froth flotation to increase copper content.
  2. **Roasting**: Converts sulfide ores to copper(I) sulfide and removes iron and sulfur.
  3. **Smelting**: Further purification to obtain blister copper.

4. **Electrolytic Refining**: Pure copper is extracted from blister copper.

Physical Properties of Copper

- **Appearance**: Soft, ductile, malleable, reddish-brown.
- **Characteristics**: High electrical conductivity, melts at 1086°C, boils at 2310°C.

Chemical Properties of Copper

- **Reactivity**: Less reactive; does not react with dilute acids but reacts with oxidizing acids. Forms verdigris with moisture and air.

Uses of Copper

- **Alloys**: Bronze (copper and tin), brass (copper and zinc).
- **Electrical**: Wiring, cables.
- **Compounds**: Pesticides, pigments.

5.3 Production of Some Important Nonmetals

Nonmetals are elements that have properties opposite to those of metals. They include elements like nitrogen, phosphorus, oxygen, and sulfur. Here is a detailed look at their properties and production methods:

A. Physical Properties of Nonmetals

1. **State**: Nonmetals can be solids, liquids, or gases at room temperature.
2. **Appearance**: They are non-lustrous (do not shine) and do not exhibit metallic luster.
3. **Malleability and Ductility**: Nonmetals are neither malleable nor ductile.
4. **Hardness and Density**: They vary in hardness, but generally have low density compared to metals.
5. **Melting and Boiling Points**: Nonmetals have low melting and boiling points.
6. **Conductivity**: They are poor conductors of heat and electricity.
7. **Texture**: Nonmetals are generally softer compared to metals.
8. **Sonority**: They are non-sonorous, meaning they do not produce a ringing sound when struck.

B. Chemical Properties of Nonmetals

1. **Reaction with Oxygen**: Nonmetals react with oxygen when heated or burned to form oxides.
2. **Reaction with Acids**: They do not displace hydrogen from dilute acids.
3. **Acidic Oxides**: They form acidic or neutral oxides when reacting with oxygen.
4. **Hydrides**: They combine with hydrogen to form stable hydrides.
5. **Water Reaction**: Nonmetals generally do not react with water.

6. **Electronegativity**: They are electronegative, meaning they gain electrons to form negative ions.
7. **Oxidizing Agents**: Many nonmetals act as oxidizing agents.

Nitrogen

Occurrence and Production

- **Occurrence**: Nitrogen exists as a diatomic molecule, N_2, and makes up about 80% of the Earth's atmosphere. It also occurs in compounds like sodium nitrate and potassium nitrate, and is an essential element in DNA and proteins.
- **Industrial Production**: Nitrogen is obtained by:
    1. **Removing Impurities**: Air is purified to remove dust and particles.
    2. **Compression and Cooling**: The air is compressed and cooled to remove carbon dioxide and water vapor. As the temperature decreases, nitrogen condenses into a pale-blue liquid.
    3. **Fractional Distillation**: Liquid air is distilled to separate nitrogen, which is then collected and stored in steel cylinders.

Physical Properties

- **Characteristics**: Nitrogen is a colorless, odorless, and tasteless gas. It is inert under normal conditions due to the strong triple bond in N_2, which requires high energy to break.

Chemical Properties

- **Reactivity**: Nitrogen reacts with metals like lithium, calcium, and magnesium at high temperatures to form nitrides. It also reacts with oxygen to form oxides such as nitric oxide (NO) and nitrogen dioxide (NO_2).
- **Haber Process**: Nitrogen combines with hydrogen in the Haber process to produce ammonia (NH_3), used primarily in fertilizers.

Uses

- **Applications**: Nitrogen is used in food packaging to prevent oxidation, in semiconductor production, and as a refrigerant (liquid nitrogen). It is also crucial in the manufacture of ammonia.

Phosphorus

Occurrence and Extraction

- **Occurrence**: Phosphorus is found in nature only in combined forms, such as rock phosphate and in biological molecules like DNA. It does not exist in its elemental form in nature.

- **Extraction**: Phosphorus is extracted from rock phosphate using the Frasch process. This involves heating a mixture of rock phosphate, silica, and coke in an electric furnace.

Allotropic Forms

- **White Phosphorus**: This is a white, waxy substance that is poisonous and melts at 44.1°C. It consists of P_4 molecules and is highly reactive.
- **Red Phosphorus**: It is less reactive and denser than white phosphorus, forming a polymer structure.

Chemical Properties

- **Reactions**: Phosphorus reacts with oxygen to form P_4O_6 (tetraphosphorus hexoxide) and P_4O_{10} (tetraphosphorus decoxide). These oxides dissolve in water to form phosphorous and phosphoric acids.
- **Chlorine Reactions**: Phosphorus reacts with chlorine to form phosphorus trichloride (PCl_3) and phosphorus pentachloride (PCl_5).

Uses

- **Applications**: Red phosphorus is used in matches, while white phosphorus is used to produce phosphoric acid and other phosphorus compounds. Phosphorus is also essential for fertilizers and in various chemical industries.

Oxygen

Occurrence and Production

- **Occurrence**: Oxygen is abundant on Earth, making up about 46.6% of the Earth's crust and 20% of the atmosphere. It is found in compounds like oxides and silicates.
- **Production**: Oxygen is produced by fractional distillation of liquid air. It can also be produced naturally through the photochemical reaction forming ozone (O_3) in the stratosphere.

Physical Properties

- **Characteristics**: Oxygen is a colorless, odorless, and tasteless gas with a density of 1.429 g/L. It turns into a liquid at -182.96°C and solidifies at -218.4°C.

Chemical Properties

- **Reactivity**: Oxygen forms oxides with metals (basic oxides) and non-metals (acidic oxides). It supports combustion and is essential for burning fuels.

Sulphur

Occurrence and Extraction

- **Occurrence**: Sulphur is found in minerals like galena and pyrites and as hydrogen sulfide in natural gas. It is extracted using the Frasch process, involving superheated water and air to melt and bring sulphur to the surface.

Allotropic Forms

- **Rhombic Sulphur**: This is the most stable form, consisting of S_8 molecules and melting at 385.8K.
- **Monoclinic Sulphur**: It is less stable and only exists above 95.3°C.

Chemical Properties

- **Reactions**: Sulphur reacts with metals to form sulphides and burns in oxygen to produce sulfur dioxide (SO_2). Sulphur is also used to make sulphuric acid (H_2SO_4) via the Contact Process.

Uses

- **Applications**: Sulphur is used in fertilizers, fireworks, and as a raw material in producing sulfuric acid.

Chlorine

Occurrence and Extraction

- **Occurrence**: Chlorine is found in nature mainly as chlorides (e.g., sodium chloride) and is obtained through the electrolysis of brine (saltwater).
- **Extraction**: Chlorine is produced by electrolyzing concentrated sodium chloride solutions, where chlorine gas is formed at the anode and hydrogen gas at the cathode.

Uses

- **Applications**: Chlorine is used in disinfecting drinking water and in various chemical processes. It helps to maintain hygiene and prevent the spread of waterborne diseases.