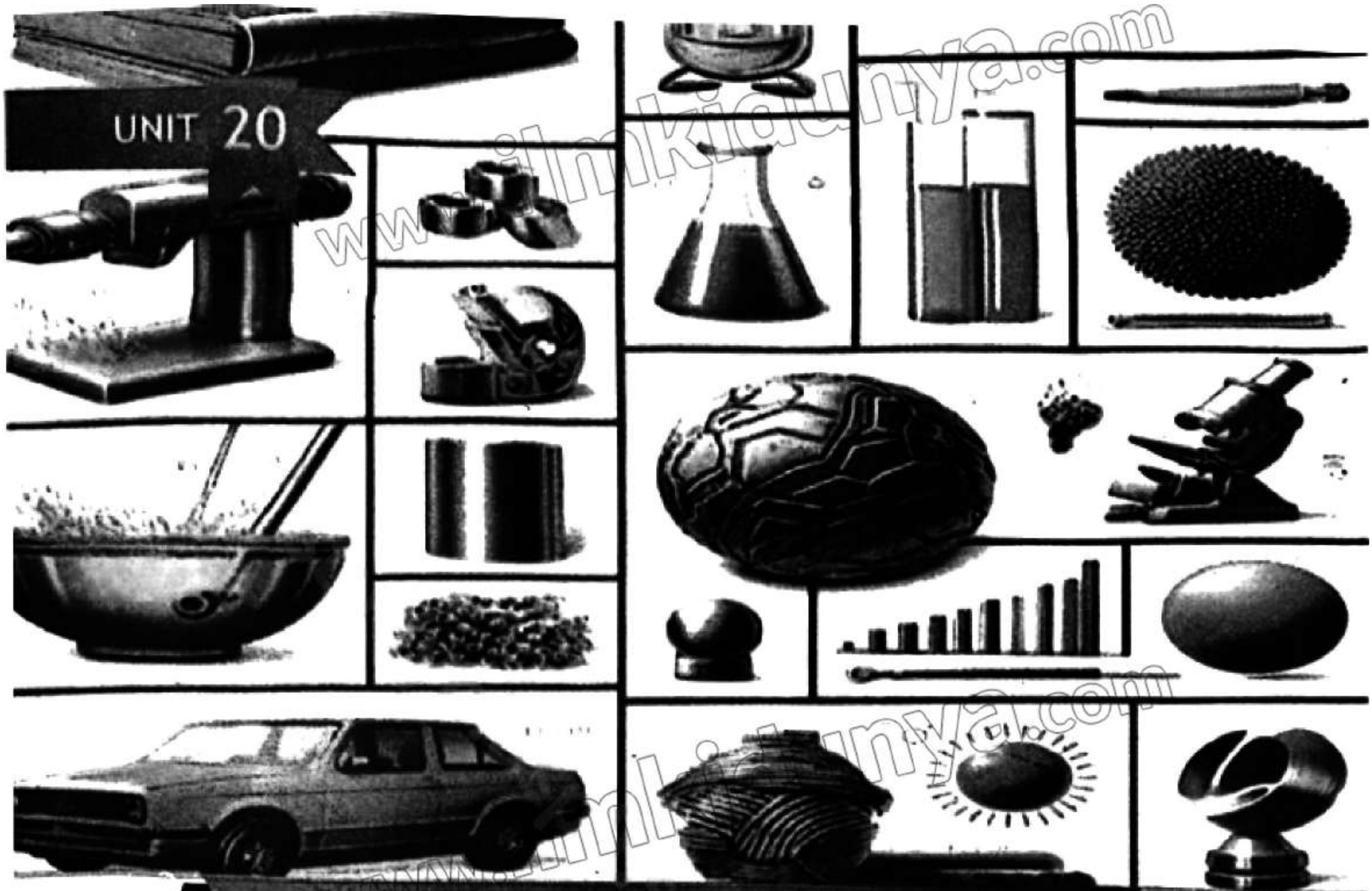
UNIT 20



MATERIALS

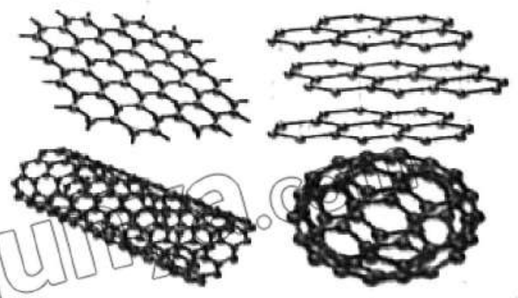
Student Learning Outcomes (SLOs)

- Explain the properties of different materials and how they can be applied to desired structures.
- Explain the process of extracting material from ores and alloying them to achieve desired characteristics.
- Explain the mechanism of catalysts and how they increase the rate of a reaction while remaining unchanged at the end.
- Explain the challenges associated with recycling and toxicity of some materials produced through materials science.
- Explain the use of X-rays crystallography in analyzing structures.

20.1 Material

A material is a substance or mixture that makes up an object. Everything around us is made from materials, each with unique properties. The materials can be soft or hard, flexible or stiff, and delicate or strong. Material can be used to describe something that is made of matter and exists in the physical world. There are many different types of materials. Some common examples of everyday materials are plastics, metals, fabric and glass.

> **Interesting Fact**
> Graphene is one of the strongest materials known. It conducts heat better than diamond,
>
> and may conduct electricity better than silver. As it's two-dimensional, it could be used to detect single molecules of a gas - if a gas molecule were to stick to a sheet of graphene there would be a local change in the electrical resistance.



20.1.1 Properties of material

The properties of materials such as strength, flexibility, heat and electrical conductivity and melting and boiling points are key factors that determine how materials can be used. These properties are influenced by the material's chemical composition and internal structure. For example, metal, paper, wood and plastic come in a variety of shapes, sizes, colors, and compositions. Each item made from these materials has unique properties due to the specific materials used. When different substances are mixed they create a new material with its own set of characteristics.

Processing methods, such as mixing, heating and cooling can alter a material's properties by changing its internal structure.

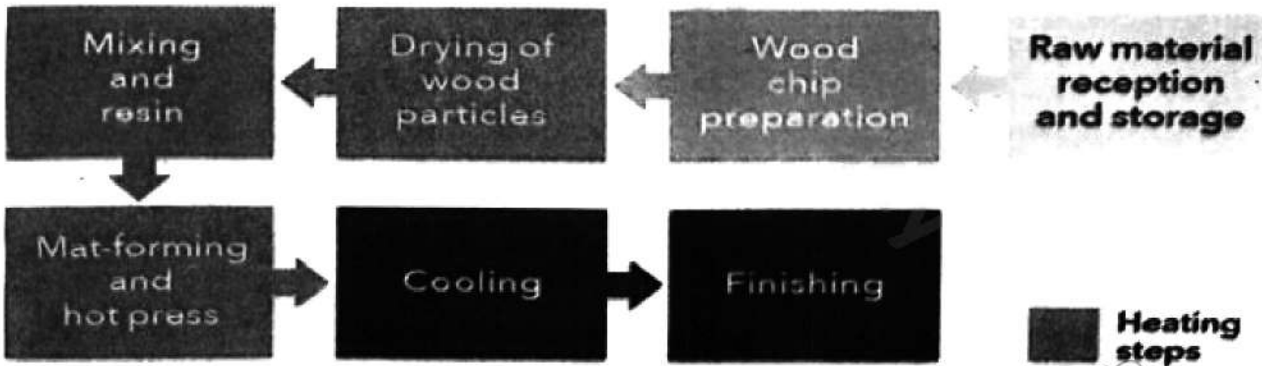


Fig 20.1 Processing Methods of Material

For instance, heating can increase the flexibility of some materials or change their conductivity. Cooling can make a material harder or more brittle.

Cost, color and texture are also important factors in determining how a material is used. For example, a material that is strong and lightweight might be chosen for applications where both strength and low weight are important such as in aerospace engineering.

Thus, the combination of material properties, processing techniques, and other factors like cost and appearance determines how materials are selected and used in different applications.

Some of the material and their structure and properties are as follows:

20.1.2 Alloys and metal compounds

Properties like shape and mass may be different for different objects even when they are made of the same material. Density is a useful property for making comparisons between different materials. Mixtures of metals called alloy is common example. By alloying some of the important properties of metals can be improved. Metals can be produced (smelted) from their ores by a variety of methods.

Fig 20.2 Metal Alloys

Fun Facts

Many alloys that contain **silver** in their name usually do not contain silver as one of their constituent elements. They are called 'silver' only because of their color. Examples of this are Tibetan silver and German silver.

Stainless steel is formed by mixing iron, small quantities of carbon and chromium is called 'stainless' because chromium gives it resistance from any kind of stain or iron rust.

Iron is the most used metal globally but it cannot be used in its pure form as it is soft and stretchable when heat is applied. At the same time if you add a very small amount of carbon to iron it becomes hard.

Copper is a good conductor of electricity and hence is used in wires to transmit electricity but the same copper when mixed with zinc or tin, we get alloys brass and bronze are not good conductors of electricity.

20.1.3 Properties of alloys

1. Alloys are stronger than the metals from which they are made.
2. Alloys are harder than the constituents' metals.
3. Alloys ere more resistant to corrosion.
4. Alloys have lower melting points than the constituent metals.
5. Alloys have lower electrical conductivity than pure metals.
6. They are characteristically shiny, and most are malleable (ability of a material to deform when compressed for example gold is very malleable and can be beaten to an extremely thin sheet) and ductile (can be drawn in the form of wires)

Plastic

All plastics are made from elements like hydrogen, carbon, oxygen, nitrogen, and other nonmetals. These elements are converted into long chains of molecules called polymers.

The word "poly" means many, and Polymers include plastics and rubber materials like polyethylene, nylon, polystyrene, and PVC. Most of the hydrocarbons used to make plastics come from oil and natural gas. During processing, other additives are mixed to give the plastics special characteristics.

Fig 20.3 Plastics

Properties

1. They have low density.
2. Chemically inert or unreactive.
3. Good insulators and low thermal conductivity.
4. They can easily moulded into different shapes and size
5. They are light in weight and are chemically stable.
6. Plastic polymers are low cost easy to manufacture.
7. Plastics are used in electronic devices and house hold gadgets as insulators.

Ceramics

Ceramics include materials like cement, glass, and clay minerals such as porcelain. Tiles are made from silica, glass, and porcelain. Ceramics are compounds made from metallic and non-metallic elements. They are lightweight and provide excellent thermal insulation. The thickness of tiles can vary. Some ceramic materials can also be magnetic. A common type of ceramic magnet is made from strontium and iron oxides.

Fig 20.4 Ceramics

Properties

1. They are very hard.
2. Ceramics are brittle.
3. Stiffness and strengths are comparable to those of metals.
4. Poor conductors of heat and electricity.
5. Could be transparent, translucent or opaque.

Concrete

Concrete is one of the most commonly used building materials and is widely used today. Concrete is made from two main ingredients:

1. A mixture of water and cement (a binding agent).

2. Filler materials like sand, crushed stone, and gravel. To make concrete, a mix of Portland cement (10-15%) and water (15-20%) forms a paste. This paste is combined with the aggregates to create the final material.

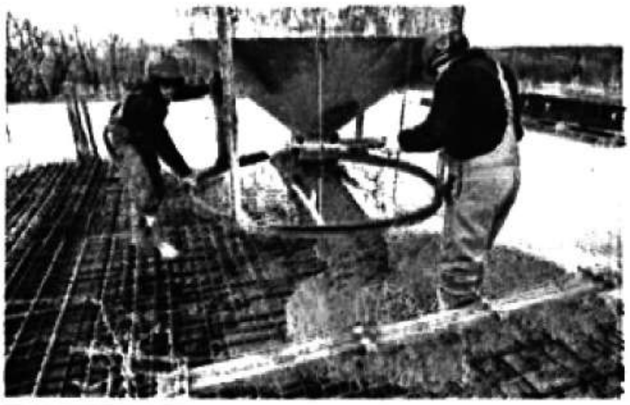


Fig 20.5 Concrete

Properties

1. It's affordable, durable, and can be molded into nearly any shape.
2. Concrete is a mixture of cement, water, sand and gravel that hardens over time to create a solid, strong substance.

Steel

Steel is another popular construction material. It is an alloy made mainly of iron with a small amount of carbon and sometimes other elements. The carbon makes steel strong and durable. Other elements like chromium, nickel, molybdenum, and silicon can be added to create different types of steel with various properties.

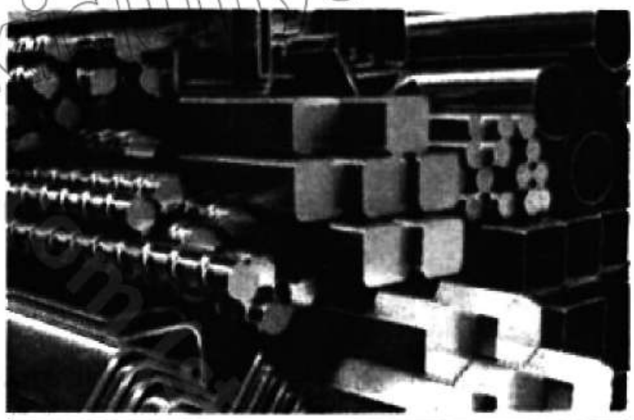


Fig 20.6 steel

Properties

1. Steel is a high-strength material and can be used for structural loads.
2. Steel is highly durable and rigid.
3. Steel is versatile material.
4. Most of steel are easily weldable.
6. Steel generally has lower thermal and electrical conductivity compared to other metals.
7. Steel can be completely recycled.
8. Steel can be alloyed with other elements such as chromium, nickel and molybdenum to resist corrosion.

20.2 Extracting Material from Ores and Alloying

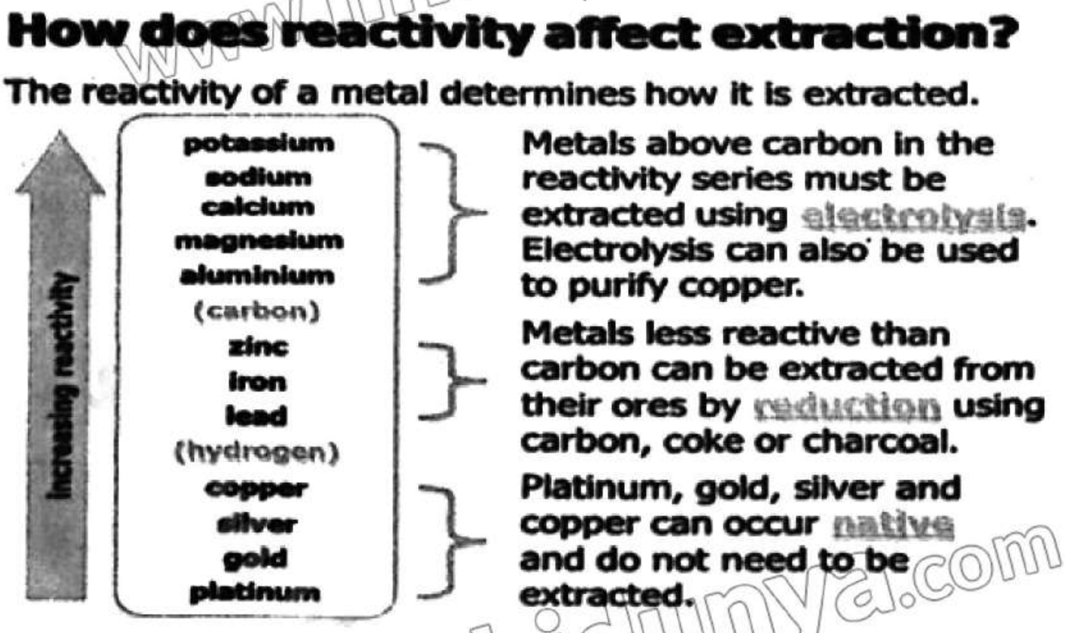


Fig 20.7 How reactivity affects extraction

1. Extraction:

- **Crushing and Grinding:**

  The extracted ore is broken into smaller fragments and subsequently reduced to a fine powder.

- **Concentration:**

  Frequently employed techniques include flotation process, magnetic separation, and gravitational separation.

2. Roasting:

The concentrated ore is heated in air below its melting point and converted into oxide. This process is called roasting. For example;

The roasting for zinc blende (ZnS) , cinnabar (HgS) and copper pyrite ore.

$$2ZnS_{(s)} + 3O_{2(g)} \rightarrow 2ZnO + 2SO_{2(g)}$$
$$HgS_{(s)} + O_{2(g)} \rightarrow Hg_{(l)} + SO_{2(g)}$$
$$2CuFeS_{2(s)} + O_{2(g)}\ ) \rightarrow Cu_2S_{(s)} + 2FeS_{(s)} + SO_{2(g)}$$

3. Smelting:

The method to reduce metal ions to free metal is called smelting. This is done by heating ore with a reducing agent. The most common reducing agents are coke, carbon monoxide and hydrogen. Some examples are:

$$Fe_2O_{3(s)} + 3CO_{(g)} \longrightarrow 2Fe_{(l)} + 3CO_{2(g)}$$

$$WO_{3(s)} + 3H_{2(g)} \longrightarrow W_{(s)} + 3H_2O_{(l)}$$

$$ZnO_{(s)} + C_{(s)} \longrightarrow Zn_{(s)} + CO_{(g)}$$

However, smelting of copper ore is done in two steps.

i) The roasted copper ore is heated: with coke and sand at about 1100°C. The materials melt and separate into two layers. The bottom layer that contains mixture of Cu_2S and FeS is called matte. While the upper layer is a silicate slag formed by the reaction of FeO and sand

$$2FeS_{(s)} + O_{2(g)} \longrightarrow 2FeO_{(s)} + 2SO_{2(g)}$$

$$FeO_{(s)} + SiO_{2(s)} \longrightarrow FeSiO_{3(s)}$$

ii) Bessemerization

In this process air is blown through the molten copper matte in a Bessemer converter (Figure 20.8). Any remaining iron sulplide (FeS) is oxidized and removed as slag($FeSiO_3$). In the final smelting step cuprous sulphide (Cu_2S)is oxidized to form cuprous oxide, which reacts with remaining cuprous sulphide to form metallic copper.

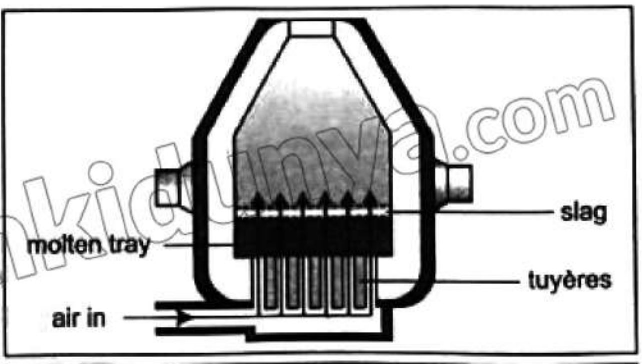


Fig 20.8 Bessemer converter

$$2Cu_2S_{(l)} + 3O_{2(g)} \longrightarrow 2Cu_2O_{(l)} + 2SO_{2(g)}$$

$$Cu_2S_{(l)} + 2Cu_2O_{(l)} \longrightarrow 6Cu_{(l)} + SO_{2(g)}$$

The product, called blister copper is about 97 to 99% pure Cu, with entrapped bubbles of SO_2 gas. Bessemerization is also used to convert pure iron into steel.

4. Refining or purification of metals

The metal obtained as a result of smelting contains some impurities. So, it must be refined. Following methods may be used.

i) Electrolytic refining:

An electrolytic cell is used in electro-refining, in which impure metal acts as the anode and a sample of pure metal acts as the cathode. For example, electrolytic refining of copper is carried out in an electrolytic tank containing acidified copper sulphate solution as electrolyte (Figure20.9). Impure slabs of copper act as anode and pure copper sheets as cathode.

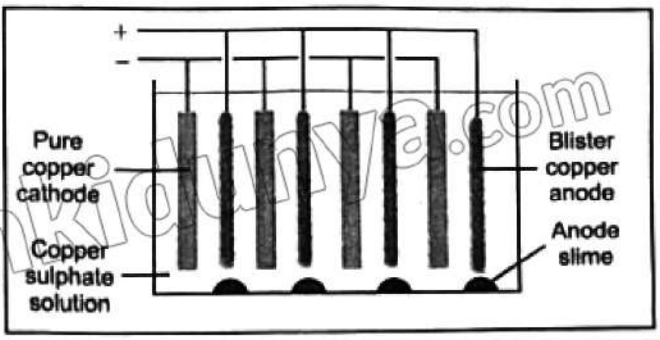


Fig 20.9 Electrolytic refining of copper

On passing an electric current through the solution, impure copper dissolves forming Cu^{+2} ions. These Cu^{+2} ions gain electrons at the cathode and form Cu atoms, which are deposited on the cathode. In this way, pure copper is collected at the cathode. The impurities like Au and Ag fall off the anode as anode mud.

Reaction at anode:

$$Cu_{(s)} \longrightarrow Cu^{2+}{}_{(aq)} + 2e^-$$

Reaction at the cathode:

$$Cu^{2+}{}_{(aq)} + 2e^- \longrightarrow Cu_{(s)}$$

ii) Distillation:

Metals with relatively low melting points such as As, and Hg are refined by distillation.

5. Alloying:

Alloying is the process of combining a metal with one or more other elements to enhance its properties such as strength, ductility, corrosion resistance, and hardness.

Methods:

- **Melting and Mixing:** The base metal is melted, and the alloying elements are added to the molten metal. The mixture is thoroughly stirred to ensure uniform distribution of the elements.

  For example, steel is made by adding carbon and other elements like chromium, nickel, and manganese to iron.
- **Powder Metallurgy:** This involves mixing fine powdered metals and pressing them into a desired shape before heating them to bond the particles. This method is useful for creating alloys with specific properties.
- **Mechanical Alloying:** This involves repeatedly fracturing and welding a mixture of powder particles to produce an alloy. This method is used for creating advanced materials with unique properties.

6. Shaping

- **Casting:** The molten alloy is poured into moulds to achieve the desired shape.
- **Forging:** The metal or alloy is hammed or pressed while it is hot.
- **Rolling:** The metal or alloy is passed through rollers to produce sheets or other shapes.
- **Machining:** Cutting and shaping the metal or alloy using tools.

7. Heat Treatment:

- **Annealing:** Heating the metal or alloy to a specific temperature and then cooling it slowly to remove internal stresses and improve ductility.
- **Quenching:** Heating the metal or alloy and then cooling it rapidly in water or oil to increase hardness.
- **Tempering:** Heating the quenched metal or alloy to a lower temperature and then cooling it to achieve a balance between hardness and ductility.

Examples of alloys

- **Steel**: Iron alloyed with carbon
- **Bronze**: Copper alloyed with tin
- **Brass**: Copper alloyed with zinc

> **Interesting fact**
>
> **Main purpose of making Alloy to decrease the intensity of corrosion of metals for example bronze is alloy of 90% copper and 10% tin. Bronze statues do not get affected by sun and rain. Stainless steel does not get stain with air or water and also does not rust. It is an alloy made from 74% iron ,18 %chromium and 8 % carbon.**

20.2.1 Importance of Alloy making

1. Alloys help to increase the metal hardness.
2. The melting point of pure metals is very high and alloying helps to reduce the melting point range.
3. By alloying the resistance increases and cannot be influenced by chemicals or weather conditions.
4. The process of alloying changes the metal color when mixed together, two different metals or one metal and another non-metal.
5. Alloying helps in the good casting of metals, as pure metals tend to solidify when melted and contract as well. After they are alloyed, they tend to expand and result in a good casting.

20.3 Mechanism of Catalysts

20.3.1 What is Catalysis?

Catalysis is process when the speed of a chemical reaction is altered by a substance called a catalyst. This catalyst is not used up in the reaction and can be used over and over again. Usually, even a small amount of catalyst is enough to speed up the reaction. In these reactions, the catalyst often forms a temporary unstable substance before returning to its original form, allowing it to keep working in a cycle.

In the presence of catalyst less energy is needed to start a chemical reaction but the overall energy doesn't change. A catalyst can help with multiple reactions. Other substances can affect how well a catalyst works: inhibitors make it less effective, and promoters make it more effective and can also change the reaction temperature.

Catalyzed reactions have less activation energy (the energy needed to start the reaction) than uncatalyzed ones, so they happen faster at the same temperature and with the same number of reactants. The reaction speed depends on how often reactants meet during the slowest step, which usually involves the catalyst. The amount of catalyst affects the reaction rate. Even though catalysts aren't used up in the reaction, they can be stopped, weakened, or destroyed by other processes.

20.3.2. Mechanism of Catalysis

Transition metals make excellent catalysts as they have incompletely filled d-orbitals that allow them to both donate and accept electrons easily from other molecules.

A catalyst increases the rate of reaction by lowering the activation energy by providing an alternate pathway with lower activation energy.

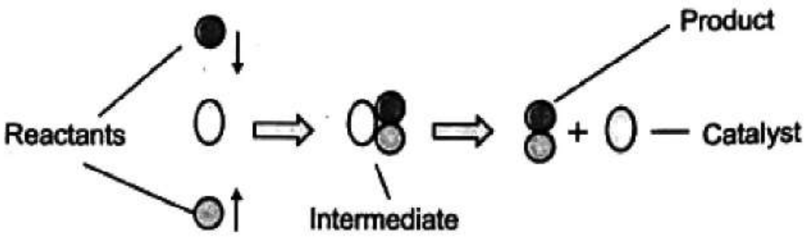


Fig 20.10 Mechanism of Catalysis

If the activation energy is reduced, more reactants can cross the energy barrier easily. Activation energy is the energy needed by reactants to start a reaction. The catalyst brings the reactants together by temporarily bonding with them. This makes it easier and quicker for the reactants to react together.

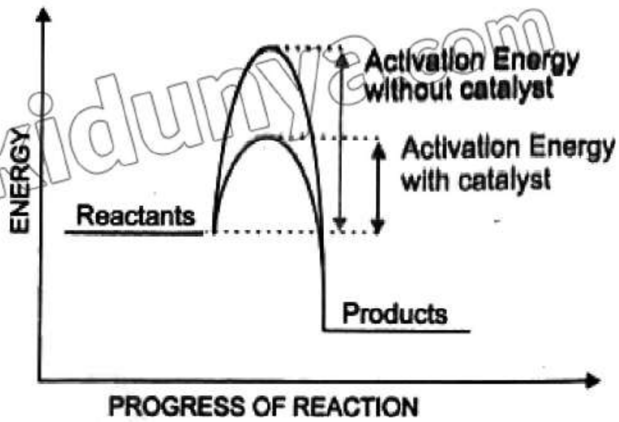


Fig 20.11 Catalytic Decomposition of H_2O_2

Example 1

Catalytic Decomposition of Hydrogen Peroxide

Reaction: $2H_2O_2 \rightarrow 2H_2O + O_2$

Catalyst: Manganese dioxide (MnO_2)

- Hydrogen peroxide molecules adsorb on the surface of MnO_2.
- MnO_2 provides a surface that facilitates the breakdown of hydrogen peroxide into water and oxygen, involving a lower activation energy pathway compared to the uncatalyzed reaction.
- The decomposition proceeds via the formation of intermediate species involving the MnO_2 surface.
- Water and oxygen molecules desorb from the MnO_2 surface.
- MnO_2 remains unchanged and can catalyse further decomposition of hydrogen peroxide.

Example 2

V_2O_5 is used as catalyst in the contact process for the preparation of sulfur trioxide from sulfur dioxide by oxidation.

$$2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)}$$

V_2O_5 is used as catalyst

Amazing Fact:

Recycling helps to save energy. If you recycle one glass bottle, it saves enough energy to light a 100-watt bulb for four hours, power a computer for 30 minutes, or a television for 20 minutes. Recycling one aluminum can saves enough energy to run a 55-inch HDTV to watch your favorite movie.

Fun fact about recycling:

Each ton (2,000 pounds) of recycled paper can save 17 trees, 380 gallons of oil, three cubic yards of landfill space, 4,000 kilowatts of energy, and 7,000 gallons of water. This represents a 64% energy savings, a 58% water savings, and 60 pounds less of air pollution.

20.4 Challenges Associated with Recycling

The recycling problem involves challenges in collecting, sorting, managing, and processing recyclable materials. These problems arise due to factors like poor waste management systems, improper waste disposal, lack of education and lack of awareness about recycling, and difficulty in separating recyclable from non-recyclable waste. Ensuring safe recycling practices and thorough testing of recycled materials is essential to minimize potential toxicological impacts.

Pollution occurs when non-recyclable materials mix with recyclables. If recycling costs more than the benefits, it might not be worth doing. Issues include knowing if we are recycling thermosetting plastics or thermoplastics. Some items, like chip bags and juice pouches, are hard to recycle because they are made of multiple layers of different materials.

Recycling and managing the toxicity of materials produced through materials science involve several challenges. Main challenges are as follows:

1. Complex Material Composition

- Modern materials often consist of multiple layers or composites, each made from different substances. Separating these components for recycling is technically challenging. It is often expensive.
- **Alloys** are designed for specific properties, but their mixed composition complicates recycling processes.

2. Contaminants and Purity Issues

- Materials are generally contaminated with substances like oils, adhesives, or other residues. These materials require additional processing steps to remove before recycling.
- Recycled materials must have the required purity levels for reuse which is difficult, especially for high-tech applications.

3. Economic Viability

- The processes required to recycle advanced materials are often more expensive than producing new materials. This makes recycling less attractive.

4. Environmental and Health Risks

- Some materials, such as certain plastics, batteries, and electronic components, contain toxic substances (e.g., lead, mercury, cadmium). They pose health and environmental risks if not properly managed.
- Recycling processes can generate hazardous emissions or by-products that pose serious health issues.

5. Technological Limitations

- Recycling technologies may not yet be advanced enough to efficiently process certain materials.
- **Lifecycle Analysis:** Comprehensive lifecycle analyses are needed to fully understand the environmental impacts of materials from production to disposal, which can guide better design and recycling practices.

20.5 X-Ray Crystallographic Analysis

X-ray crystallography is a method that uses X-rays to find out the detailed structure of a crystal, including the arrangement of its atom sand molecules. This helps us understand how these atoms and molecules are bonded and any irregularities in the crystal.

This technique can be used on various substances like salts, minerals, metals, semiconductors and biological compounds (such as proteins, DNA, and vitamins).

X-ray crystallography is valuable in many fields, including biology, chemistry, and geology.

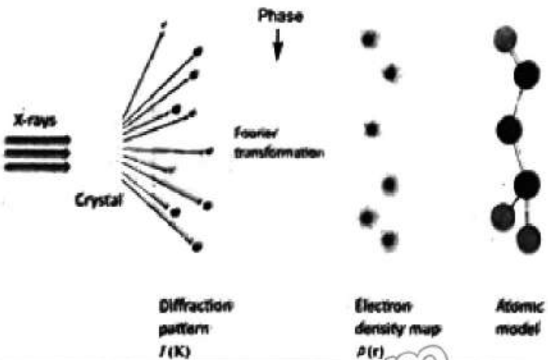


Fig 20.11 X-ray Crystallography

Barium tests are used to examine the digestive tract using a white powder Barium Sulphate. It is a chalky substance that you drink before they give you the X-ray which enables your doctor to make an accurate diagnosis.

20.5.1 Applications of X-ray Crystallography

X-ray crystallography is used to study many different molecules. It has been vital in many famous projects in chemistry. Early examples include determining the structures of simple crystals like quartz and salt. A notable achievement was discovering the double-helix structure of DNA by Franklin, Watson, and Crick in 1953. Other important molecules analyzed include Vitamin B12, insulin, and penicillin.

Some important applications of crystallography are as follows:

- X-ray crystallography helps in understanding the 3D structures of proteins and other biomolecules
- Determining the structures of DNA and RNA helps in understanding genetic information storage and transmission.
- By revealing the structure of target proteins, X-ray crystallography helps in identifying potential binding sites for new drugs.
- This technique helps in understanding the atomic structure of various materials, such as metals, ceramics, and polymers, leading to the development of new materials with desirable properties.
- It helps in structural determination of nanoparticles and the development of nanotechnology applications.
- Determining the structure of complex organic and inorganic compounds is fundamental for understanding their reactivity and properties.
- X-ray crystallography can help to explain the intermediates and transition states in chemical reactions.
- Determining the structures of minerals helps in understanding geological processes and the formation of natural resources.
- Studying how minerals change under different temperature and pressure conditions.
- Understanding the arrangement of atoms in solids can explain various physical properties such as conductivity, magnetism, and optical properties.
- Understanding the crystalline structures of pollutants can help in developing methods for their removal or neutralization.

KEY POINTS

1. Each item is made up of various materials and when one substance is mixed with another, it creates a unique material with specific qualities.
2. Homogeneous mixture formed by mixing metal with other metal or nonmetals in a certain proportion is called an alloy.
3. By making alloys some of the important properties of metals can be improved.
4. Recycling is the process of collecting, processing of materials that would otherwise be discarded as waste, converting them into new products.
5. The toxicity of materials produced through recycling can vary significantly depending on the type of material and the recycling process used.

6. A catalyst provides an alternate pathway for the reaction that has a lower activation energy. When activation energy is lower, more reactant particles have enough energy to react, so the reaction occurs faster.
7. X-ray crystallography uses electromagnetic radiation (specifically, X-rays) to determine the molecular and atomic structure of a crystal. The structure of the crystal causes the X-rays to diffract in specific directions.
10. X-ray crystallography is a technique used to determine the atomic and molecular structure of a crystal by measuring the angles and intensities of X-rays diffracted through the crystal lattice.
11. X-ray crystallography provides detailed information about the arrangement of atoms within the crystal, crucial for understanding the structure and function of various materials, including biological molecules like proteins.

EXERCISE

1. Multiple Choice Questions (MCQs)

i. Which process is used to purify metals to the desired purity?
   a) Smelting　b) Refining　c) Grinding　d) concentration

ii. How do catalysts speed up chemical reactions?
   a) By increasing the activation energy
   b) By providing an alternative pathway with lower activation energy
   c) By being consumed in the reaction
   d) By increasing the temperature of the reaction

iii. X-ray crystallography is primarily used to:
   a) Measure the density of materials　b) Determine atomic structures
   c) Conduct chemical reactions　d) Separate metal ores

iv. Which material is known for its high thermal resistance and brittleness?
   a) Metal　b) Polymer　c) Ceramic　d) Composite

v. Heating the metal to a specific temperature and then cooling it slowly to remove internal stresses and improve ductility is called?
   a) Annealing　b) Quenching　c) machining　d) Forging

vi. Tiles are made from
   a) silica　b) glass　c) porcelain　d) all of these

vii. The concentrated ore is heated in air below its melting point and converted into oxide. This process is called?
   a) Concentration　b) Smelting　c) Roasting　d) Bessemerization

viii. Which of the following materials is NOT considered a ceramic?
   a) Cement　b) Nylon　c) Glass　d) Porcelain

ix. What is the primary function of additives mixed with plastics during processing?

a) To reduce the cost of production
b) To enhance the colour of plastics
c) To give plastics special characteristics
d) To make plastics biodegradable

x. Which property is common to both plastics and ceramics?

a) High electrical conductivity
b) High density
c) Lightweight
d) High thermal conductivity

2. Short Answer Questions

i. Compare and contrast the properties of plastics and ceramics?
ii. Comment on the environmental impact of using steel and plastics in construction?
iii. Describe the properties and uses of ceramics?
iv. What is the process of smelting in metal extraction?
v. Explain the role of a catalyst in a chemical reaction?
vi. Give an example of an alloy and its components.
vii. What is concentration in the context of ore processing?
viii. How does refining improve the quality of metals?
ix. List four applications of x-ray crystallography?

3. Long Answer Questions

i. Explain the entire process of extracting a metal from its ore, including the steps of concentration, smelting, and refining.
ii. Describe the mechanism of catalysts in detail and give examples of their applications in both industrial contexts.
iii. Analyse the environmental and economic challenges associated with recycling materials.
iv. Elaborate on the principles and applications of X-ray crystallography. How does it contribute to our understanding of both biological molecules and synthetic materials?

Activity

Poster Design on Recycling

Objective:

To educate students about the importance of recycling and to encourage them to creatively express their knowledge and ideas through poster design.

Groups:

Divide the class into small groups of 3-4 students. Assign each group a specific aspect of recycling to focus on (e.g., plastic recycling, electronic waste, composting etc).