

## 31

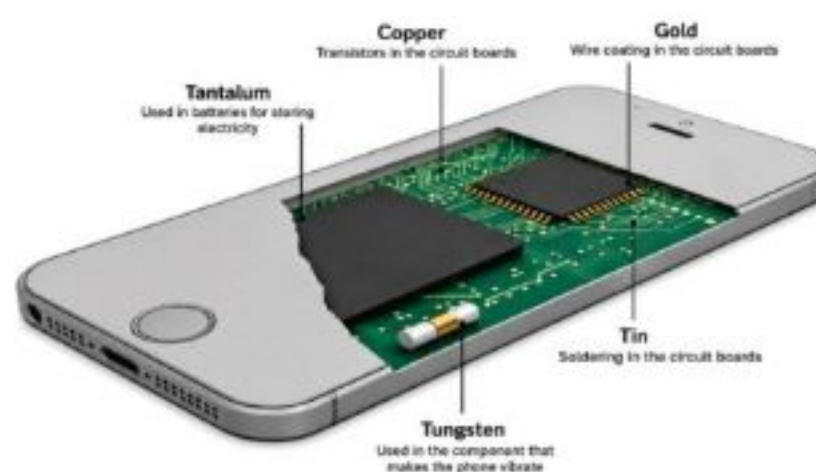
# MATERIALS AND ENERGY

## Student Learning Outcomes

[C-12-E-34 to C-12-E-49]

- ⊙ Explain the properties of different materials and how they can be applied to desired structures.
- ⊙ Explain the process of extracting metals from ores and alloying them to achieve desired characteristics.
- ⊙ Explain the mechanism of catalysts and how they increase the rate of 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-ray crystallography in analyzing structures.
- ⊙ Differentiate between petrochemicals and chemicals derived from them.
- ⊙ Identify the various raw materials for the petrochemical industry.
- ⊙ Explain the process of fractional distillation and refining of petroleum.
- ⊙ Describe the major chemical processes involved in the petrochemical industry.
- ⊙ Identify major petrochemicals and their applications.
- ⊙ Differentiate between energy density and specific energy.
- ⊙ Describe the nature, uses, and impact of fossil fuels.
- ⊙ Describe the processes of nuclear fission and fusion and their energy significance.
- ⊙ Explain the working and significance of solar panels as a source of energy.
- ⊙ Explain the environmental impact of energy consumption, particularly in relation to global warming and its relation to the importance of reducing carbon footprint and moving towards sustainable energy sources.
- ⊙ Evaluate different energy sources based on cost, efficiency, impact, and sustainability.

Humans have long benefited from natural resources for their daily needs. The most ancient materials are wood, metals, and those obtained from animals, such as clothes. With an enormous increase in the human population and limited natural resources, new materials and machines were needed to fulfill the human needs. It resulted in the invention of a large number of materials from metal alloys to nanomaterial, from large electric cells to very efficient miniature batteries, etc. The presently used machines such as computers, mobiles, construction machinery, aircrafts, etc., all involve a combination of modern materials and energy devices.



**Figure 31.1** This mobile contains a variety of metals, plastic, their composites, and a small but efficient energy device, i.e., Li-ion battery



This chapter gives an introduction to the role of chemistry in modern materials and energy sources.

It discusses the preparation, properties, and uses of a variety of materials, such as metals, alloys, polymers and ceramics, as well as the analytical techniques used for their analysis, such as X-ray crystallography. The chapter also looks at the important definitions including energy density, specific energy, and efficiency of the source, e.g., fossil fuel, nuclear and solar energy. It also highlights the environmental effects of the energy consumption. Finally, a discussion on the sustainable energy sources, such as photochemical energy devices, is given.

## 31.1 MATERIALS

A material is any substance or mixture of substances that makes up a physical object of daily-life or industrial importance, for example, plastics, metals, ceramics, building material, etc. Materials have superior thermal, mechanical (e.g., hardness, elasticity, etc.) and chemical properties. They are understood by their composition, the nature of chemical bonds, and the microstructure. The selection of a material for a certain application is made depending on its physical, chemical, mechanical, electrical and thermal characteristics. Different materials and their properties are being discussed in the following sections.

### 31.1.1 Metals and Alloys

Metals are hard, rigid substances that are good conductors of heat and electricity. They are malleable and ductile and thus can be easily rolled into sheets or easily drawn into wires without fracture. These characteristics allow the use of metals in indoor construction and industries. Steel is utilized in bridges and can be found in several buildings due to its strength. Aluminum is utilized in the bodies of aircrafts, because it is light-weight, and copper is normally used into electric wires since it has amazing conductivity.

Metals are mostly found in the earth crust. Less reactive metals, such as gold and platinum can be found in the free state, i.e. they exist in the metallic state in nature and do not form compounds with other elements frequently. On the other hand, more reactive metals, e.g., sodium, aluminium, iron, copper, etc., exist in the combined state in the form of ores. For example, hematite ( $\text{Fe}_2\text{O}_3$ ) is an ore of iron and it is found in certain parts of the world. Metal ores are distributed in the earth's crust in different quantities. Ores are not pure compounds, rather mixtures of the desired metal compound impurities, and earthly materials, which are called gangue. Such metals are extracted from their ores through a series of physical and chemical processes..

### Extraction of Metals (Metallurgy)

Metallurgy is the science of extracting metals out of their ores and making them pure for better use.

The reactivity and the nature of the metal defines the extraction procedure.

Metallurgy involves a series of processes to finally obtain the purest form of a metal.

- i. **Mining** is the process of acquiring the metal ores that are buried deep in the earth. For example, iron ores.



Figure 31.2 Left; A view of the iron ore (haematite) mining, right; A lump of haematite



ii. **Ore Concentration** is the process in which the ore of a metal is made free from impurities as much as possible.

iii. **Conversion of concentrated ore to metal oxide.**

This can be done in two ways, mostly. The first method is roasting which involves heating a sulphide ore of a metal with excess supply of air.

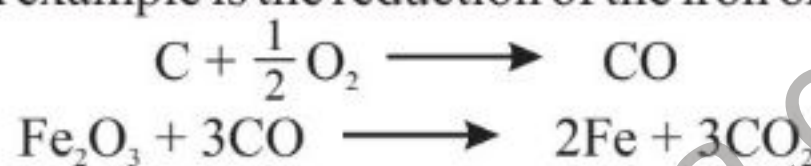


Another method is calcination in which a metal carbonate ore is heated in a limited or no air environment to convert it into its oxide.



iv. **Reduction of metal oxides to metal**

The reduction of metal oxides is the most important step of metal extraction. Different techniques are used for different metals depending on their reactivity. For less reactive metals (below carbon in the reactivity series), carbon is used as a reducing agent. Carbon is first converted into CO which then reacts with the metal oxide. Carbon monoxide displaces the oxygen from the metal oxide to form a free metal. An example is the reduction of the iron ore as follows:



However, the above method cannot be used for metals that are more reactive than carbon as carbon is not able to reduce their oxides. For such metals, an electrolytic method is used, which requires significant energy to melt the metal compounds and pass an electric current through them. This method is crucial for extracting highly reactive metals (e.g. Na, K, Al as they are not easily reduced with carbon), or for achieving very high purity in less reactive metals (e.g. Cu). The positive metal ions move to the negative electrode (cathode), where they gain electrons to form the metal.

v. **Refining the metal**

Most of metals have high percentages in the samples obtained after reduction. However, some metals need very high purity for special applications. For example, copper needs to be 99.99% pure in the electrical wiring. The final step is the purification to get the pure metal, which is then used for practical purposes. A metal can be refined by thermal, chemical or electrochemical methods.

vi. **Alloying of Metals**

Alloying involves the mixing of any two or more metals to give a homogeneous solution or mixing of a metal with a non-metal. This is done to alter the microstructure of the metal to enhance the properties, such as strength, corrosion resistance, and electrical or magnetic properties. Common alloys and their uses are provided in **Table 31.1**.

**Table 31.1** Properties and uses of common alloys

Alloy	Constituent Elements	Properties	Common Uses
Brass	Copper (60-90%) + Zinc (10-40%)	Strong, corrosion-resistant	Electrical fittings



<b>Bronze</b>	Copper (88%) + Tin (12%)	Hard, wear-resistant	Medals, statues
<b>Steel</b>	Iron (98-99%) + Carbon (0.1-2%) (and other elements: Cr, Ni, Mn, Si, S)	Tough, durable, strong	Buildings, tools
<b>Duralumin</b>	Aluminium (93-95%) + Copper(3.5-4.5%) + Magnesium (0.4-0.7%) + Manganese (0.4-0.7%)	Lightweight, strong, corrosion-resistant	Aircraft body

### 31.1.2 Ceramics

Ceramics are hard but brittle materials that have high melting temperatures and very good insulating capabilities, which make them fit in high temperature and electrical applications. Chemically, they contain a blend of silicates and oxides of alkali and alkaline earth metals, and aluminium, such as  $K_2O$ ,  $Na_2O$ ,  $CaO$ ,  $Al_2SiO_3$ , etc. The strong bonds and fixed structures give ceramics unique and highly desirable properties such as strength, durability, and resistance to corrosion and heat. Due to these characteristics, they are useful in pottery, furnaces, tiles and sanitary ware (porcelain), windows and optical fibres (glass), spark plugs (alumina), etc. A summary of various properties of ceramics and their applications is provided in **Table 31.2**.

**Table 31.2 Properties of ceramics and their applications**

Property	Description	Application Example
<b>High Melting Point</b>	Remain solid at very high temperatures.	Refractory bricks lining steel furnaces.
<b>Hardness and Wear Resistance</b>	Extremely difficult to scratch or abrade.	Abrasives (e.g., silicon carbide in sandpaper) and cutting tools.
<b>Electrical Insulator</b>	Do not conduct electricity (most).	Porcelain insulators on power lines.
<b>Chemical Inertness</b>	Highly resistant to corrosion and chemical attack.	Ceramic coatings on chemical processing equipment.

### 31.1.3 Polymers

Polymers are large inorganic or organic molecules having unique properties. Although, organic polymers are much more common, inorganic polymers are essentially more significant in certain applications than organic polymers. Polymers are prepared from a variety of small molecules of choice. A detailed discussion on polymers is given in **Chapter 26**.

### 31.1.4 Composites

Composites are very efficient and useful modern day materials. A composite is a combination of two or more materials to form a product which has better properties.



One component is called the matrix, while the others, which are caged in the matrix, are called reinforcement agents. Some composites may have more than one reinforcement agent. An example is fibreglass, which is composed of a polymer as the matrix, and the reinforcement agent may be the fibres of a fabric, glass, or carbon-based materials. The matrix holds the reinforcement, whereas the reinforcement provides high strength to the material. Composites possess good strength to weight ratio and strong resistance to corrosion and are, therefore, suitable in demanding applications. As an example, boat hulls and car bodies are made of fibreglass, whereas carbon fibre is widely used in the aircraft and sports gear industry because of its lightness and strong durability.



Figure 31.3 Fibreglass is used for insulating walls and ceiling from heat and cold

### 31.1.5 Semiconductors

Semiconductors are substances conducting electricity only in special conditions and are light, heat, and voltage sensitive. Due to these characteristics, they are important in modern electronic applications. The difference between conductors and semiconductors is that the current passing through a semiconductor can be controlled as demanded in an application. The most common semiconductor is silicon, which is used in microchips and solar panels since it is highly effective and abundant. A mobile SIM card is composed of a silicon chip with some other minor components, such as copper connectors. Silicon can be used to conduct, store and process data in a device. Another major semiconductor is gallium arsenide (GaAs), which is used in wireless communication, e.g. 5G internet devices. Gallium nitride (GaN) is used in electric cars for fast charging due to its advanced conductivity.



#### Quick Check 31.1



- Why ceramics are used as insulators on power lines.
- Why is silicon preferred for use in microchips and solar panels?
- What do reinforcement agents provide in composite materials?

## 31.2 TOXICITY AND RECYCLING IN MATERIAL SCIENCE

### 31.2.1 Toxicity of Materials

Toxicity is the extent to which a substance can harm an organism or the environment. A material may be toxic during its production, use, and final disposal. The toxicity is measured by the extent and type of hazard that a material may cause. Hazards posed by a material are of many types. At first place are **health hazards**, i.e., a substance can cause damage to health upon exposure. For example, metals like chromium are carcinogens (cause cancer), mutagens (change DNA and genes), and cause respiratory issues. Another example is some additives in plastics, which can cause hormonal problems in the body.

Some materials can cause **physical hazards** due to their physical or chemical properties.



The physical cause may happen to buildings, humans, ecosystems, and the environment. For example, a flammable or an explosive material can harm humans, forests, or damage a building. **Environmental hazards** are by the substances that can cause long-term harm to aquatic life or the environment. **Heavy metals** like lead, mercury, and cadmium can leach into soil and groundwater. Heavy metals are dangerous to plants, animals on ground, as well as fish and other aquatic organisms.

### 31.2.2 Major Toxic Materials

Although, there are a number of toxic materials that are becoming the part of the environment. Plastics and heavy metals are two major concerns that are being discussed here as examples. These materials are commonly used due to their superior properties. However, their long-term effects are lethal.

**Heavy Metals:** Lead (Pb), mercury (Hg) and cadmium (Cd) are the common metals found in electronics, batteries, and fluorescent lights. They can get into the ground water from where they can transfer to the living organisms.

**Plastics:** A lot of plastics have toxic additives such as phthalates or bisphenol A (BPA), which can interfere with the hormones. Microplastics can now be found in oceans, soil, and even in food which has a long-term effect on the human lives and the ecosystems. In humans, microplastics are found to be carcinogenic (cancer-causing)

### 31.2.3 Recycling

Recycling is an important aspect of waste management, conservation of resources and energy saving. Yet, in materials science, modern materials are experiencing severe technical, economic, and environmental limitations to recycling and reuse. With more complex synthetic products, toxicity and sustainable disposal have become a rising concern.

Recycling minimizes the solid wastes in the landfills and preserves the limited natural resources such as metals, oil and timber. One of its other advantages is energy saving e.g., the recycling of aluminium consumes 95 percent less energy as compared to the recovery of aluminum by using the raw ore.

#### Challenges Associated with Recycling

The first challenge is material separation challenge. Most of the present day products (e.g., mobile phones, laptops) are assembled using mixed materials which are not easily separated, such as plastic coating on metals or multi layered packaging films.

The second major challenge to recycling is expensive reprocessing. Reprocessing waste involves sorting, cleaning, and other methods, therefore, it is usually expensive. Reprocessing of plastic, electronics, and other materials requires a lot of energy. Excessive use of energy is uneconomical, especially when these materials are available elsewhere at a lower price.

Most often, reprocessing results in the contamination of the product material, posing the contamination challenges. The recycled metals and plastics can be contaminated by dye, chemicals, or biological materials that decrease their quality and safety for reuse. In food-grade use, recycling of contaminated plastic is not possible.



**Table 31.3** Principles and methods of recycling of some important materials

Material	Recycling Method	Chemical Principles/Focus
Plastics	<b>Mechanical Recycling</b> (Reprocessing)	Sorting, cleaning, melting, and reforming the plastic. Limited by contamination and degradation of polymer chains.
	<b>Chemical Recycling</b> (Depolymerization)	Breaking down the polymer chains into the original <b>monomers</b> or simpler chemicals using heat, solvents, or catalysts. This produces purer reactants.
Metals (Steel, Aluminum)	<b>Thermal and Chemical Refining</b> (Metallurgy)	Melting and refining processes to remove impurities. Requires significant energy, but much less than primary production.
Paper	<b>Pulping and De-inking</b>	Chemical and mechanical separation of fibres. Pulp is treated with chemicals (like NaOH or Na <sub>2</sub> CO <sub>3</sub> ) to remove inks and dyes.
Glass	<b>Cullet Preparation and Melting</b>	Cleaning, crushing, and melting the scrap glass ( <b>cullet</b> ) to form new glass. Chemically simpler as glass is a non-crystalline solid.

**Quick Check 31.2**

- Name two types of hazards caused by toxic materials.
- Which methods will you use for the recycling
  - empty metal food cans
  - empty beverage glass bottles
  - shopping bags and toys
- How do heavy metals enter the food chain?
- How does recycling help conserve natural resources?

### 31.3 X-RAY CRYSTALLOGRAPHY AND STRUCTURE ANALYSIS

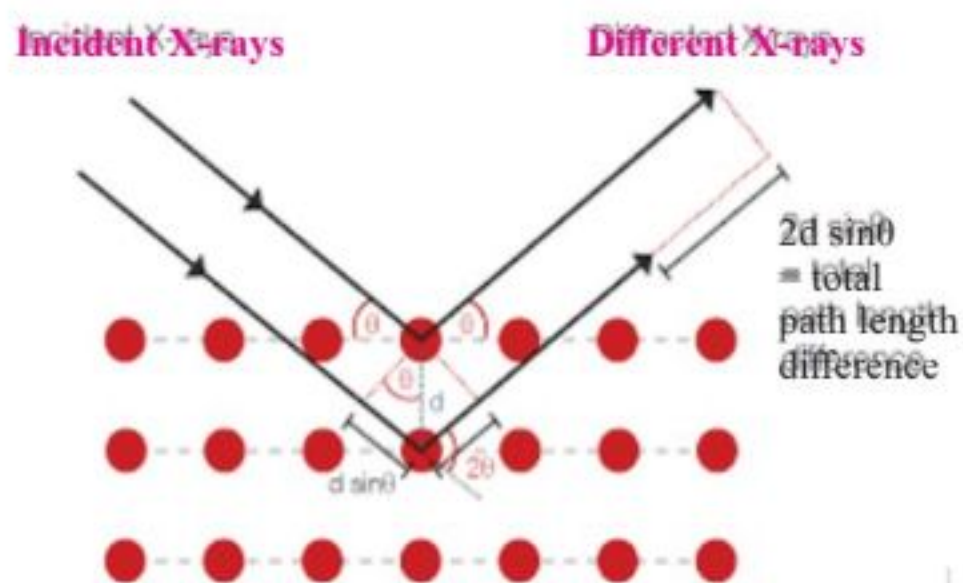
X-ray crystallography is a very strong analytical tool used to identify three dimensional positions of atoms in a crystalline solid. It is important in material science, biochemistry, and pharmaceutical chemistry as it enables scientists to visualize material structures.

X-rays have very small wavelength. Therefore, this electromagnetic radiation can be used to find the position of electrons and atoms in a molecule or an ionic compound. The solid materials consist of layers or strands of atoms.

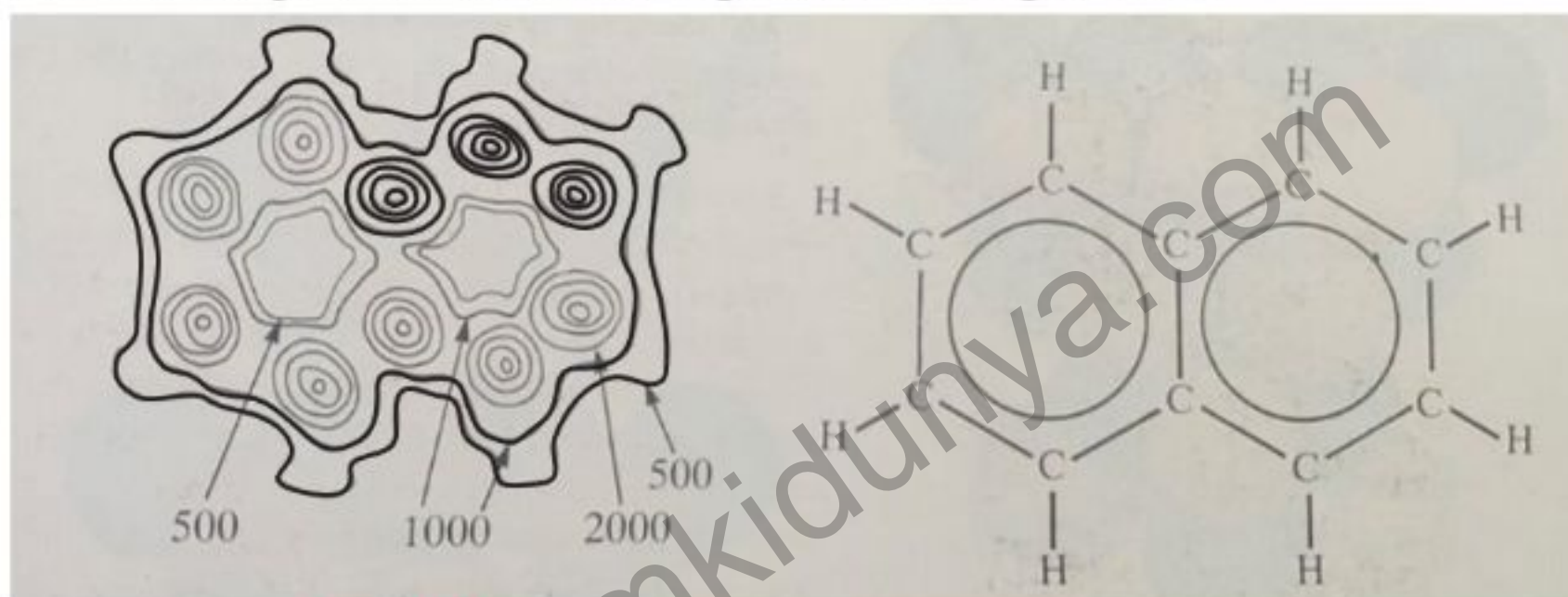


When the X-rays from the source fall on a crystal, they are diffracted after hitting the atoms at specific angles as shown in **Figure 31.4**.

These diffracted rays make patterns on a screen called the diffraction patterns. A diffraction pattern spots the location of atoms and electrons in a molecule. It also draws maps and determines the distance between atoms. With the help of mathematical models and the analysis of this pattern, scientists are able to draw a detailed map of atomic position and bond angles in the crystal. Thus, a complete pattern of atoms and their electron density can be mapped to determine the overall structure of the molecule or the crystal. The structure of the naphthalene molecule is presented in **Figure 31.5**.



**Figure 31.4** X-ray diffraction



**Figure 31.5** The diffraction pattern of the naphthalene molecule

The most well-known use of XRD is the determination of the double helix structure of DNA. The method of X-ray crystallography is still applicable in analyzing complex biomolecules like enzymes and proteins. It can also be used for pharmaceutical drug development. During the drug development designers employ this method to realize how a drug molecule attaches to its target. Another application is the analyses of materials and minerals. Here, it is used to analyze the minerals, synthetic crystals and nanomaterial. This is helpful to enhance material performance in the fields of electronics, optics and constructions.

## 31.4 FOSSIL FUELS

**Petroleum (crude oil), coal, and natural gas are collectively called fossil fuels.** Crude oil is mined at the underground reservoirs and refined in large size plants through fractional distillation. Major products from petroleum are naphtha, gasoline, kerosene and diesel.

Methane ( $\text{CH}_4$ ) is the major component of natural gas, in mixtures with ethane, propane, and butane. Methane is mainly employed in the production of ammonia (used in fertilizers) and methanol (utilized in solvents and fuel). Coal is not as useful as it was before, but it still represents a petrochemical raw material, especially in areas where reserves are high. The primary use is to obtain benzene, toluene, and xylene that are vital in the manufacture of dyes, resins, and explosives.



Table 31.4 Forms and uses of fossil fuels

Fossil Fuel	Main Uses
Petroleum	Transportation fuels (petrol, diesel), lubricants
Natural Gas	Cooking, heating, electricity, and fertilizer production
Coal	Electricity generation, cement, and steel industries

### Keep in Mind



Despite the fact that fossil fuels are highly efficient sources of energy, combustion of these products produces greenhouse gases such as carbon dioxide ( $\text{CO}_2$ ) and others. This leads to air pollution, global warming, and climate change.

## 31.5 FRACTIONAL DISTILLATION AND REFINING OF PETROLEUM

Crude oil is a complicated mixture of hydrocarbons and it needs separation into simpler and useful hydrocarbons. This separation process is done physically by a method known as fractional distillation which depends on the difference in boiling points of different hydrocarbons. During this process, the crude oil is heated inside a furnace until it is vaporized. The vapor is then passed to a fractionating column, a tall tower through which the temperature drops slowly going up.

Since the vapor travels upwards, various hydrocarbon constituents condense at various points in the column based on their boiling points. Hydrocarbons that are heavier have higher boiling point are condensed closer to the bottom, whereas lighter hydrocarbons with low boiling point rises further. The process enables the extraction of useful fractions of crude oil which are given below with their uses in **Figure 31.6**.

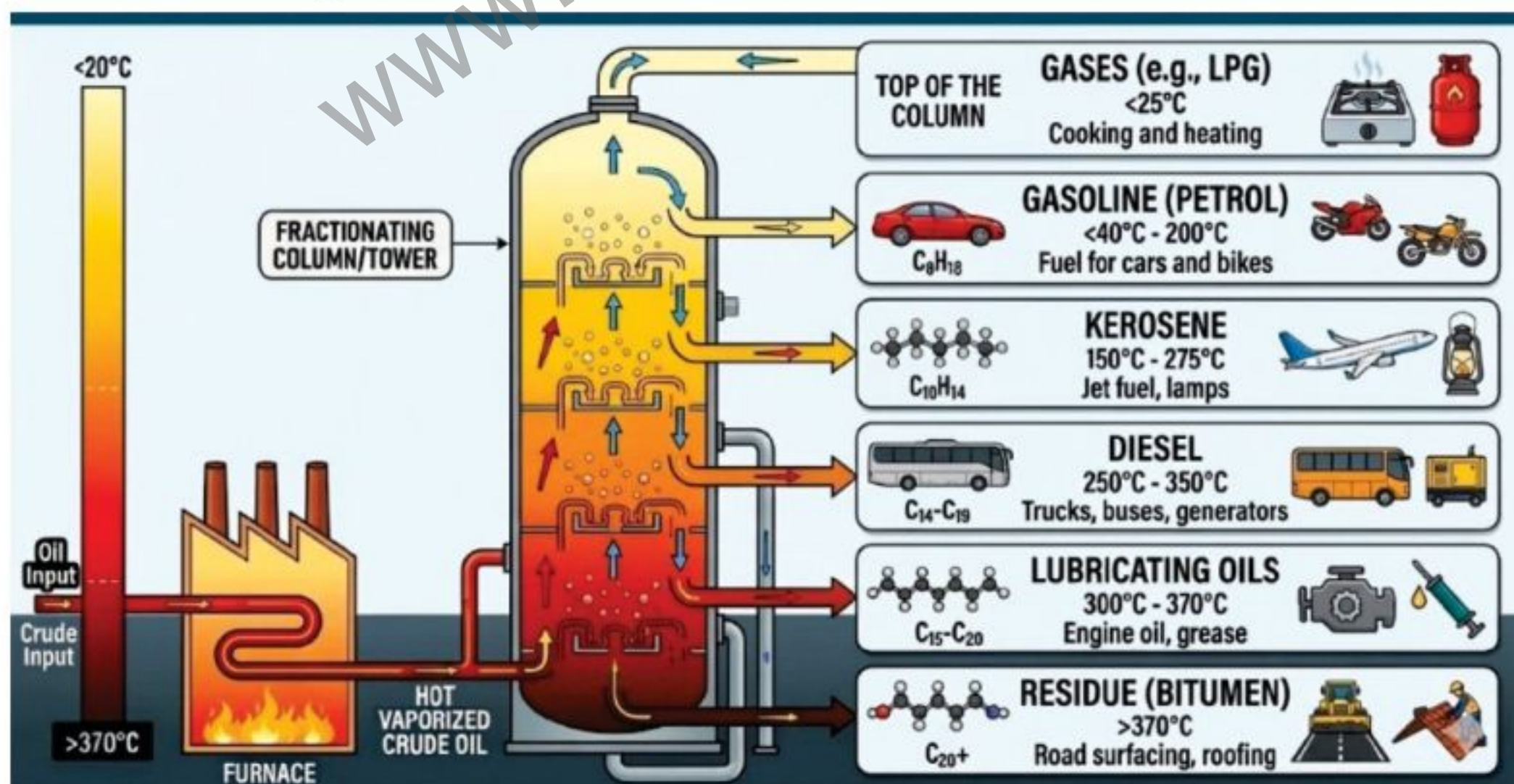


Figure 31.6 Fractional distillation of crude oil into useful hydrocarbons



Fractional distillation is an important process as it provides petrochemicals having applications in industries, domestic, and transportation purposes.



### Quick Check 31.3



- If fossil fuels are non-renewable resources, why are they still heavily used worldwide?
- Can XRD be used to find the structure of liquid?

## 31.6 PETROCHEMICALS

Petrochemicals are compounds (chemicals) obtained primarily by means of crude oil and natural gas by refining and transformation. They are used to make diverse daily items found in several industries including packaging, construction, textile, electronics, and medical sectors.

Synthetic chemicals or substances manufactured from petrochemicals represent derivatives of petrochemicals and these are very important industrial products. The derivatives of petrochemicals are subjected to chemical transformation, such as polymerization, oxidation, or substitution to obtain materials of immense daily-life significance. Some petrochemicals, their derivatives, and their uses are tabulated in **Table 31.5**.

**Table 31.5** Derivatives of petrochemicals and their uses

Petrochemical	Derived Chemical/Product	Uses
Ethene	Poly(ethene) (Plastic)	Bags, bottles, packaging
Propene	Poly(propene)	Containers, automotive parts
Benzene	Styrene → Polystyrene / Poly(phenylethene)	Disposable cups, insulation
Toluene	TNT (Trinitrotoluene)	Explosives
Xylene	Polyester Fibres	Textiles, clothing (fleece, jerseys), and upholstery.
Butadiene	Synthetic Rubber (e.g., Styrene Butadiene Rubber)	Tires, footwear

### 31.6.1 Petrochemical Process Technology

#### (a) Cracking

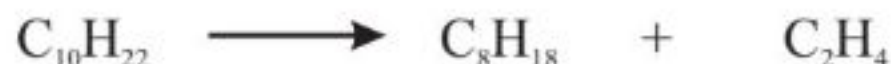
A chemical process involving the thermal dissociation of large hydrocarbons (typically a naphtha or heavy oils) molecules into smaller, more useful molecules, such as alkenes, is cracking. The process is necessary since ethene and propene, which are smaller in weight, are the major raw materials used in the production of plastics and artificial rubber. There are two primary methods used to achieve this: **Thermal Cracking** and **Catalytic Cracking**.

#### Thermal Cracking

This process is based on very high temperatures (usually between 450 °C and 750 °C) and high pressure to physically open the carbon-carbon bonds. Since no catalyst is involved, the process



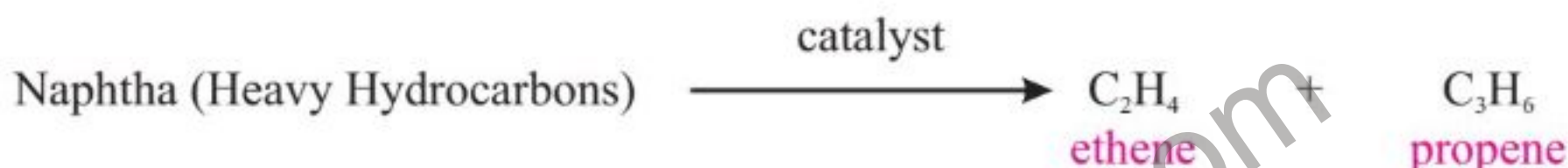
needs high energy input. It normally generates a high percentage of alkenes, which is important in the plastic industry. For example, a long-chain alkane, such as decane ( $C_{10}H_{22}$ ) can be thermally cracked to produce octane and ethene:



### Catalytic Cracking

Catalytic Cracking on the other hand is more efficient, and is more commonly used in modern refineries. This is done by adding a catalyst (usually zeolites (aluminosilicates) or silica-alumina), which reduces the activation energy of the reaction significantly. This enables the process to occur at reduced temperatures (approximately  $500^\circ C$ ) and pressures, saving energy and better control over the final products.

One example is the cracking of a heavy fraction naphtha in the presence of a catalyst to produce high-demand petrochemicals. The reaction normally gives a blend of short chain alkenes:



### b) Reforming

Reforming is a refining process that rearranges the molecular structure of hydrocarbons. In contrast to cracking (where the molecules are broken down), reforming rearranges straight-chain alkanes into a branched or cyclic (aromatic) structure.

The main purpose of reforming is to enhance the quality of fuel by converting low octane straight chains to high-octane branched or aromatic fuels to avoid engine knocking.

Reactions during reforming are given below:

#### 1. Isomerisation (formation of branched hydrocarbons)

The straight chain hydrocarbons are converted into branched-chain isomers of higher-octane numbers e.g.



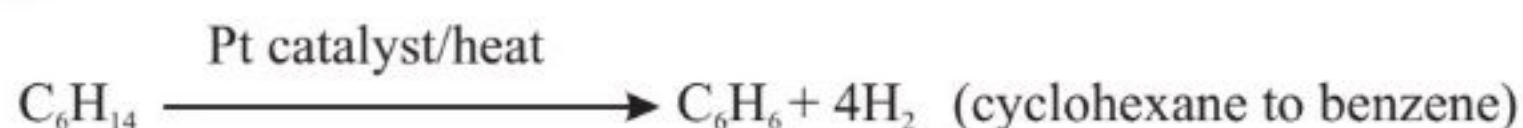
#### 2. Cyclization (cyclic hydrocarbons formation)

Cyclic compounds are prepared by the conversion of straight-chain hydrocarbons e.g.



#### 3. Dehydrocoupling (generation of aromatic hydrocarbons)

Hydrogen is lost by cycloalkanes to produce aromatic compounds. It is used to generate important chemical base materials e.g., BTX (benzene, toluene and xylene) that are the building blocks of plastics, dyes and synthetic fibres. For example, hexane, a straight 6-carbon chain is transformed into a stable aromatic ring, releasing hydrogen gas as a valuable byproduct.



**Quick Check 31.4**

- Why is catalytic cracking more commonly used in modern petroleum refineries?
- If more alkenes such as ethene and propene are desired to be produced from higher hydrocarbons, such as diesel or kerosine, which cracking method should be preferred and why?
- During reforming, hexane is converted into benzene and hydrogen. Explain why hydrogen can be considered a valuable by-product.

**31.7 ENERGY DENSITY AND SPECIFIC ENERGY**

When considering for different applications, there are two key aspects used to evaluate a fuel and must be kept under consideration; energy density and specific energy.

**Energy density is the energy capacity of a substance, generally expressed by the quantity of energy that can be stored per unit volume of a fuel, typically in megajoules per liter (MJ/L).** High-energy density fuels allow the use of a relatively small volume to store with large energy potential. These are useful in stationary applications and storage, e.g., in power plants, generators, etc. For example, diesel is more energy dense (~35.8 MJ/L) in comparison to gasoline (~34.2 MJ/L), i.e., it contains more energy per liter.

**Specific energy can be defined as the amount of energy contained in a mass. It is typically measured in megajoules per kilogram (MJ/kg).** It is an important measure in cases where weight is critical such as aviation or spacecraft mobile applications. A high-specific energy fuel will give significant amounts of energy, without contributing much mass. For example, hydrogen gas has extremely high specific energy (120 MJ/kg) that makes it potentially interesting in aerospace applications, although its energy density is low.



MORE INFO

**Interesting Information**

Compressed Natural Gas (CNG) used in the transportation sector in Pakistan is very economical. It has, however, lower energy density, which implies that vehicles need to carry more storage volume to carry enough fuel when compared to petrol. That is why CNG is suitable as a means of local commuting, and it is not perfect as a long traveling means

**31.8 NUCLEAR ENERGY – FISSION AND FUSION**

While studying fossil fuels and their harmful effects on the environment, it is also important to learn about **nuclear energy**. Nuclear energy is a potential and promising source of power that can help meet the world's growing energy needs. Nuclear energy is the energy that is released by nuclei of an atom, either when heavy nuclei are split (fission) or when light nuclei are combined (fusion). These reactions liberate extremely high quantities of energy as compared to chemical reactions.





## Did You Know?

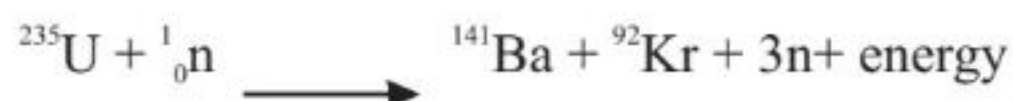
There was a great earthquake and tsunami in Japan, which triggered reactor accidents at Fukushima in (2011). More than 150,000 citizens were evacuated as a result of radioactive leaks, and the world became concerned about the safety of nuclear plants in disaster-prone regions.



## Nuclear Fission

Fission is the process in which a heavy atomic nuclei like uranium-235 or plutonium-239 is split into two lighter atomic nuclei with energy production, generation of neutrons and radiations. Neutrons produced can also lead to additional fission in a chain reaction.

The nuclear reaction between uranium-235 and a neutron is as follows.



Nuclear power plants extensively use nuclear fission to produce electricity. It has a very high energy production using small quantities as input; however, it has serious drawbacks, too. It produces radioactive waste which should be handled with care over a long duration. There is also the danger of nuclear accidents, the consequences of which have been observed in history, such as the Chernobyl catastrophe (1986) and the Fukushima accident (2011). These accidents seriously affected the environment and human health negatively.

## Solar Energy and Photovoltaic Cells

Solar PV (photovoltaic) system is a clean energy system where the solar panels that are typically composed of silicon semiconducting materials convert the energy of sunlight into electricity via photovoltaic effect. The exposure of the solar panel activates electrons in the material that produces the direct current (DC) electricity. This DC electricity is then converted to alternating current (AC) by an inverter and can be used to power homes, schools, offices and in industries. The system also has batteries to store electricity to use at night or cloudy days, and also assist in stabilizing voltage, and producing surge current. Other elements like electrical accessories, wires, appliances, and mounting structures make the entire solar energy system effective and safe.

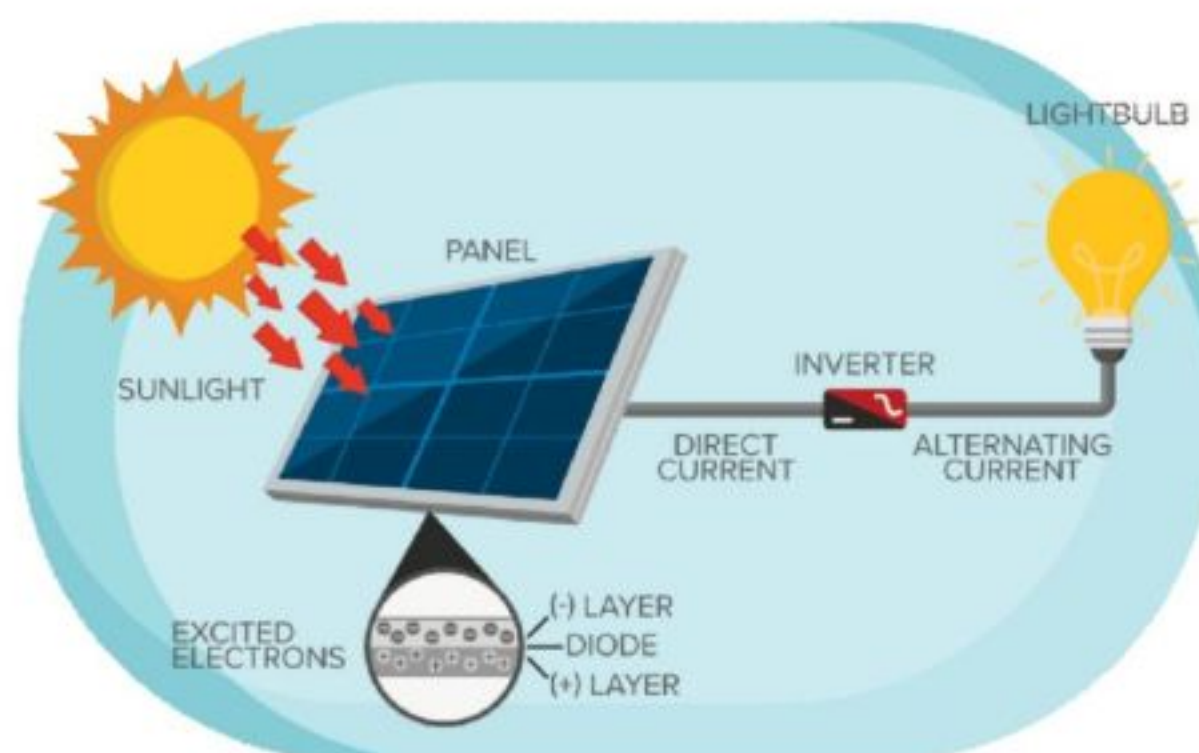


Figure 31.7 Working of solar panels



Solar energy has many key advantages over the traditional sources of energy. It is an environmentally friendly and renewable energy source. Therefore, it contributes to the fight against climate change and environmental pollution. Solar panels are also cost-effective in the long run, since they have limited maintenance requirements once installed.

Energy shortages, high fuel prices, and climate problems show that we need to switch to renewable energy sources like solar, hydro, and wind energy.



### Quick Check 31.5



- Why are **batteries included** in many solar energy systems?
- Besides power generation, where else is nuclear fission used?
- Identify the missing component in the reaction:  

$${}^{235}\text{U} + \text{n} \rightarrow \underline{\hspace{2cm}} + \underline{\hspace{2cm}} + 3\text{n} + \text{energy}$$
- Why do nuclear reactions release much more energy than chemical reactions?

## Exercise



### Q1. MULTIPLE CHOICE QUESTIONS

**I) A mining engineer discovers a new deposit of a metal that occurs primarily as a carbonate. Which sequence is most efficient for the extraction of metals?**

- Mining, Concentration, Roasting, Reduction with Carbon
- Mining, Concentration, Calcination, Reduction
- Mining, Concentration, Electrolysis
- Mining, Roasting, Refining

**II) The extraction of aluminium from its oxide is done by electrolysis and not by calcination because:**

- |   |                      |
|---|----------------------|
| a) Carbon forms alloy                     | b) Low melting point |
| c) Aluminium is more reactive than carbon | d) Removes gangue    |

**III) Which property makes ceramics suitable for furnace bricks?**

- |                       |                |
|-----------------------|----------------|
| a) Conductivity       | b) Low density |
| c) High melting point | d) Flexibility |

**IV) In fiberglass, the matrix mainly:**

- |                        |                         |
|------------------------|-------------------------|
| a) Provides strength   | b) Conducts electricity |
| c) Holds reinforcement | d) Increases weight     |

**V) Major limitation of mechanical recycling is:**

- |                      |                                    |
|----------------------|------------------------------------|
| a) High energy use   | b) Polymer degradation             |
| c) Monomer formation | d) use of $\text{Na}_2\text{CO}_3$ |

**VI) The mobile phone recycling is difficult because of:**

- |                                     |                       |
|-------------------------------------|-----------------------|
| a) Non-recyclable material          | b) Mixed materials    |
| c) No heat sensitivity of materials | d) High melting glass |



**VII) Chemicals from coal used in dyes are:**

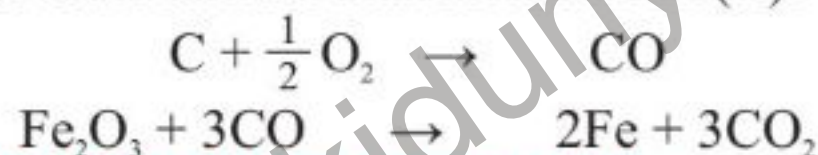
- |                   |                                       |
|-------------------|---------------------------------------|
| a) Methane series | b) Benzene, toluene, xylene           |
| c) Alkenes        | d) CO <sub>2</sub> and H <sub>2</sub> |

**VIII) Nuclear fission involves:**

- |                     |                     |
|---------------------|---------------------|
| a) Combining nuclei | b) Splitting nuclei |
| c) Breaking bonds   | d) Molecules        |

**Q2. SHORT ANSWER QUESTIONS**

- What is a chain reaction in nuclear fission?
- State the economic challenge associated with reprocessing waste materials.
- Keeping in view the concept of microstructure, explain why adding zinc to copper (to form Brass) results in a material that is stronger than pure copper.
- Define energy density and give one example.
- Name two specific semiconductors mentioned in the text and their modern applications.
- State two applications of X-ray crystallography in science or industry.
- State two advantages and one disadvantage of nuclear fission.
- In the reduction of Hematite (Fe<sub>2</sub>O<sub>3</sub>), carbon is added, but carbon monoxide (CO) is the actual species that displaces the oxygen. Explain why the gas (CO) is a more efficient reducing agent in a large-scale furnace than solid carbon (C).

**Q3. CONSTRUCTED RESPONSE QUESTIONS**

- Explain environmental problem, caused by fossil fuels.
- Based on the chemical equations provided, explain why roasting sulphide ores poses a greater environmental challenge compared to the calcination of carbonate ores.
- If a sample of copper is 98% pure after reduction, why is the final "refining" step still considered crucial for the manufacturing of electrical wiring?
- Explain, why chemical recycling (depolymerization) is often superior to mechanical recycling?
- Gold is often found in its free state, while sodium is only found in the combined states. Use the concept of the reactivity series to justify why the extraction process for sodium is significantly more energy-intensive than for gold.

**DESCRIPTIVE QUESTIONS**

- Explain composite materials by describing and differentiating the roles of the matrix and the reinforcement in them.
- Explain how X-rays interact with crystals to produce diffraction patterns and how these patterns help determine atomic positions.
- Describe the main steps involved in the extraction of metals from their ores.

