5. For each of the following pairs of solutions (of equal concentration) predict which solution has the higher concentration of H^+ ions:
   (a) HCl and CH_3COOH
   (b) H_2SO_4 and HNO_3

6. Magnesium sulphate ($MgSO_4$) is the chemical name for Epsom salt. It can be made in the laboratory by neutralising the base magnesium oxide (MgO).
   (a) Which acid should be used to make Epsom salt?
   (b) Write a balanced chemical equation for the reaction.
   (c) The acid is completely dissociated in water. Write an ionic equation. Which ion causes the solution acidic?

7. Aluminium hydroxide and calcium carbonate are often used as antacid. Write the balanced chemical equations for the reactions between these two bases and dilute hydrochloric acid.

8. Study the following diagram:

$$\left.\begin{array}{l}\text{potassium hydroxide} \xrightarrow{\text{dil. } H_2SO_4} \text{solution } \mathbf{A} \\ \text{barium hydroxide} \xrightarrow{\text{dil. HCl}} \text{solution } \mathbf{B}\end{array}\right\} \xrightarrow{\text{mixed}} \text{white ppt.} \mathbf{C} + \text{solution } \mathbf{D}$$

   (a) Give the names and formulae of substances **A** to **D**.
   (b) Write balanced chemical equations for the reactions taking place in the diagram.

9. You are provided three pairs of substances to produce their corresponding salts.
   (a) copper(II) oxide + dilute sulphuric acid
   (b) calcium chloride + sodium carbonate
   (c) potassium hydroxide + dilute nitric acid

   Answer the following questions.
   (i) Give the formula of each salt and predict whether the salt is soluble or insoluble.
   (ii) Which salt can be obtained by crystallisation?
   (iii) Which salt can be obtained by precipitation?
   (iv) Write a balanced chemical equation for each reaction.

10. Which two substances react to give a salt and water only? Explain.
   (a) copper(II) oxide and ethanoic acid
   (b) magnesium and dilute sulphuric acid
   (c) sodium oxide and water
   (d) zinc carbonate and dilute hydrochloric acid

11. How would you prepare the following salts? Describe their uses.
   (a) sodium sulphate
   (b) ammonium nitrate
   (c) magnesium sulphate

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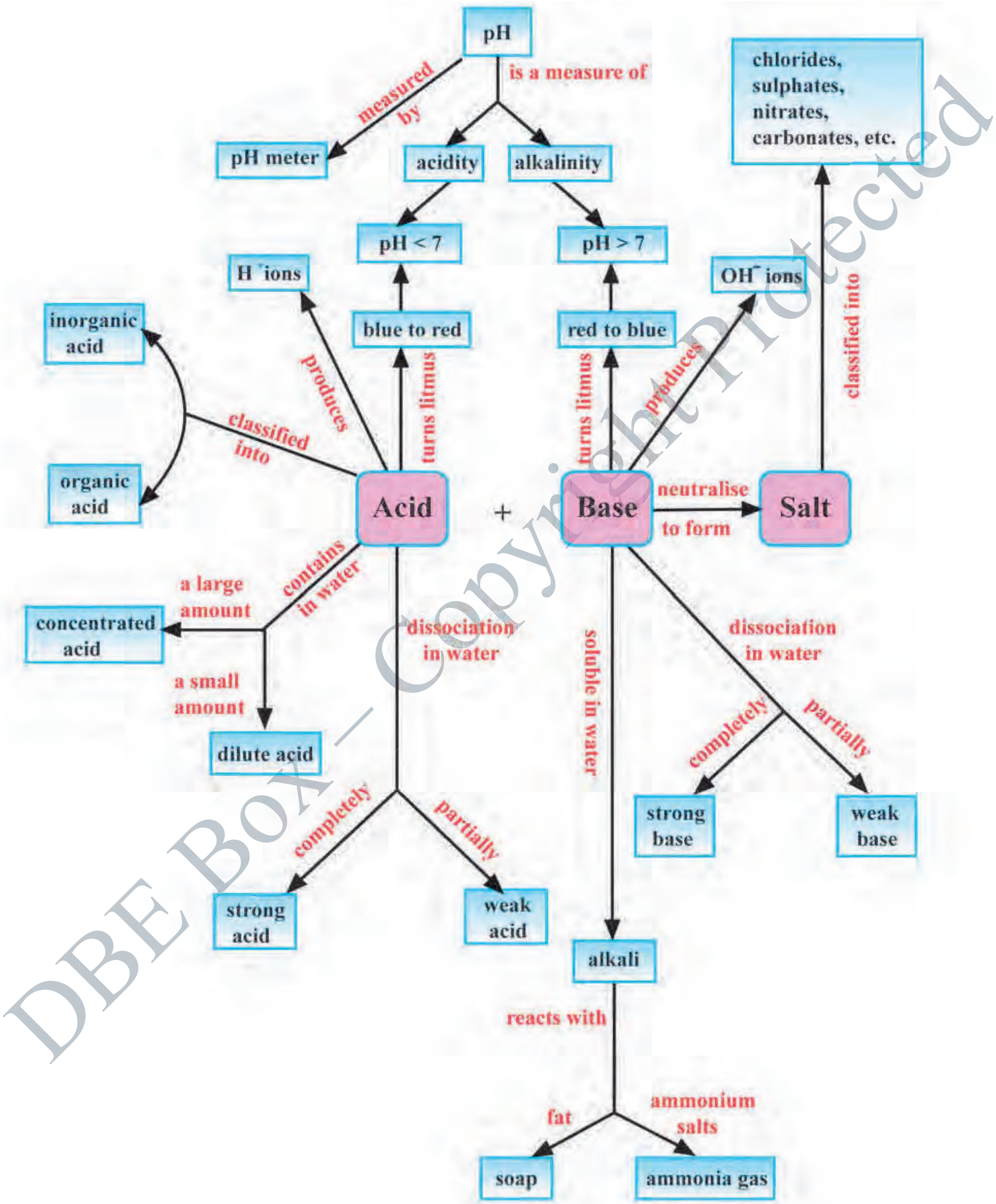
CHAPTER REVIEW
(Concept Map)



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CHAPTER 7 AIR, WATER AND SOIL

Air, water and soil are three natural resources that we cannot live without. On the other hand, air, water and soil are the three major kinds of pollution causing harm to both living creatures and the environment. To protect our air, water and soil, one should have the knowledge related to the renewable resources such as fresh air, fresh and clean water, and fertile soil.

Learning Outcomes

After completing this chapter, students will be able to:

- recognise the air around us including the composition and the various forms of air pollution and the sources of these pollutants;
- discuss the role of various pollutants on global warming and the greenhouse effect;
- describe the Earth's surface water, both salt and fresh, including the composition, hardness and various forms of water pollution;
- explain the purification of water in terms of distillation, ion exchange and the Permutit method;
- describe the various types of soil found on the surface of the Earth, including the composition and the various forms of waste and pollutants found in the soil;
- recognise soil information including: layers, texture, composition and pH.

7.1 AIR

Without food, we could live about a month. Without water, we could live a few days. But, without air, we would die within minutes. Due to industrialisation and transportation the air is polluted with some harmful gases. Simply, we are facing today is the growing problems of acid rain, some harmful gases, global warming and ozone depletion. Polluted air is linked to a variety of health concerns, ranging from short term irritation to serious diseases. Cultural heritage sites have also suffered from enormous damage due to acid rain.

(a) The Structure of the Atmosphere

The earth is surrounded by a layer of air about 8 ~ 10 km thick called the atmosphere. The atmosphere is the blanket of gas around the Earth about 700 km. It is divided into four layers: **troposphere, stratosphere, mesosphere** and **thermosphere** (Figure 7.1). The gases in the atmosphere are held in an envelope

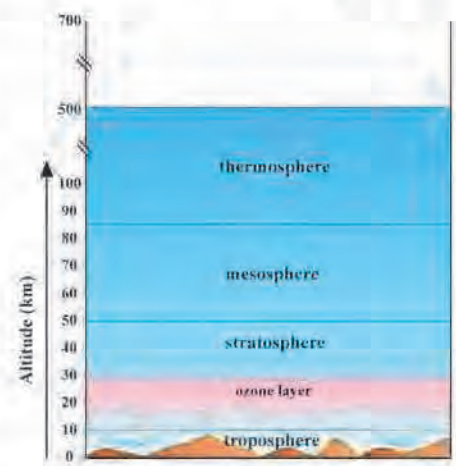

Figure 7.1 The Earth's Atmosphere

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around the Earth by its gravity. About 75 % of the mass of the atmosphere is found in the layer nearest the Earth called the **troposphere**, in which nearly all living things and nearly all human activity occur. The next region, **stratosphere**, is where we find the **ozone layer** that shields living creatures from deadly ultraviolet radiation. Beyond this layer, the atmosphere reaches into space but it becomes extremely thin beyond the **mesosphere**. The **thermosphere** is the layer in the Earth's atmosphere directly above the mesosphere.

(b) Composition of Air

Air is a mixture of several gases. The two main gases in air are nitrogen and oxygen. Other gases present in smaller amounts are carbon dioxide and the noble gases (mostly argon). As air is a mixture, its composition varies from time to time and from place to place.

Dry air contains (by volume) 78 % nitrogen (N_2), 21 % oxygen (O_2), 0.03 % carbon dioxide (CO_2) and 0.97 % noble gases. The concentration of carbon dioxide in the atmosphere has increased from 0.03 % to its present value 0.04 %. It is likely to rise as we burn more and more fossil fuels (coal, oil and gas). The amount of water vapour in air can vary widely around the world, from almost 0 % in a desert to about 5 % in a tropical forest. Figure 7.2 shows approximate composition of dry air.

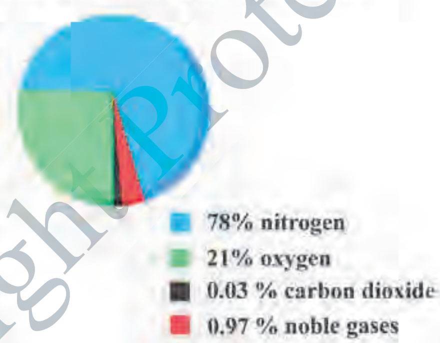

Figure 7.2 The Approximate Composition of Dry Air (by Volume)

Most of the gases in air are colourless and odourless. Some of the gases in air are essential. For example, we depend on oxygen but plants depend on carbon dioxide. And without nitrogen in air, fuels would burn too fast.

Oxygen is the reactive part of the air. It is slightly soluble in water and reacts with many other substances. The three important reactions involving oxygen are combustion, respiration and rusting. The process for respiration goes on in all our cells, by taking oxygen and releasing carbon dioxide and water.

$$\text{glucose} + \text{oxygen} \longrightarrow \text{carbon dioxide} + \text{water} + \text{energy}$$

$$C_6H_{12}O_6(aq) + 6O_2(g) \longrightarrow 6CO_2(g) + 6H_2O(l) + \text{energy}$$

The energy from respiration keeps us warm, allows us to move, and enables hundreds of different reactions to go on in our bodies.

There are only small amounts of carbon dioxide in the air, but it is important to all living things. Green plants need carbon dioxide for photosynthesis to produce glucose (carbohydrate) and oxygen. In this process, plants use carbon dioxide from the air and release oxygen into the air.

$$\text{carbon dioxide} + \text{water} \xrightarrow{\text{light, chlorophyll}} \text{glucose} + \text{oxygen}$$

$$6CO_2(g) + 6H_2O(l) \xrightarrow{\text{light, chlorophyll}} C_6H_{12}O_6(aq) + 6O_2(g)$$

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(c) Separating Gases from the Air by Fractional Distillation

Air is a mixture of gases. These gases can be separated from each other by fractional distillation. There are five steps in the separation process (Figure 7.3).

(1) Air is pumped into the plant, and filtered to remove dust particles.

(2) Carbon dioxide, water vapour and pollutants are removed since these would freeze late and block the pipes. In this step, the air is cooled until the water vapour condenses to water, followed by passing over beds of adsorbent beads to trap carbon dioxide and any pollutants in it.

(3) The air is then forced into a small space, or compressed. That makes it hot. It is cooled down again by recycling cold air, as the diagram shows.

(4) The cold, compressed air is passed through a jet, into a larger space. It expands rapidly, and this makes it very cold.

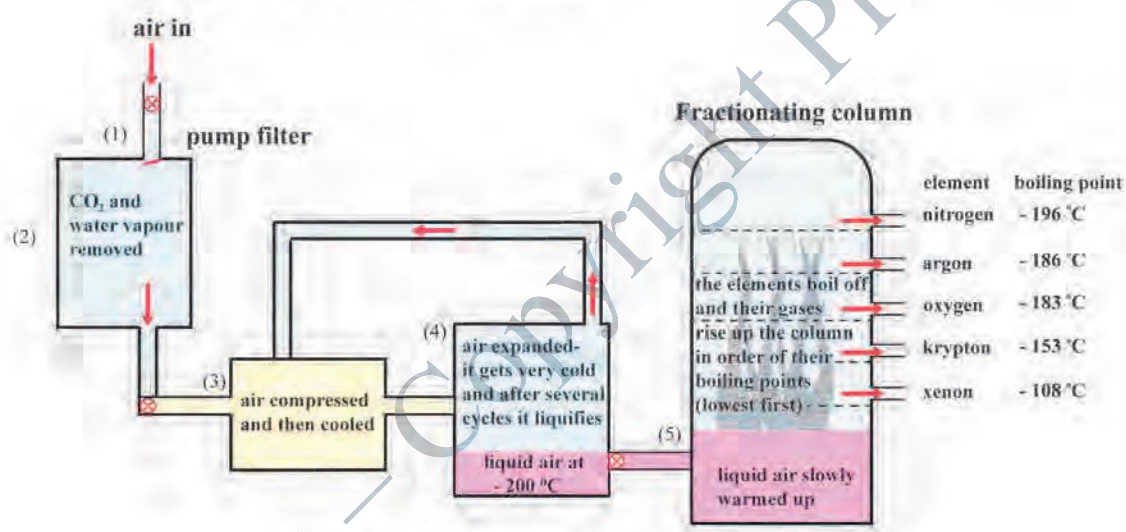

Figure 7.3 Fractional Distillation of Liquid Air

Steps 3 and 4 are repeated several times. The air gets colder each time. At -200 °C, it becomes liquid (liquefaction), except neon and helium. (These gases are separated from each other by adsorption on charcoal.)

(5) The liquid air is pumped into the fractionating column and it is slowly warmed up. The gases boil off, and are collected in tanks or cylinders. Nitrogen with the lowest boiling point boils off first.

(d) Air Pollution and Common Air Pollutants

The presence of substances in the atmosphere that are harmful to living things and to the environment contributes to air pollution. **Air pollution** is caused by solid particles (called particulates) and poisonous gases in the air. These substances are called **air pollutants**.

There are six main air pollutants: carbon monoxide, sulphur dioxide, nitrogen dioxide, methane, unburnt hydrocarbons and ozone, and their harmful effects are shown in Table 7.1.

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Table 7.1 Main Air Pollutants and Their Harmful Effects

Air pollutant	Source	Harmful effects
carbon monoxide, CO a colourless gas, insoluble in water, no smell	• incomplete combustion of carbon-containing substances, e.g., charcoal, wood and petrol	• poisonous even in low concentrations • reacts with the haemoglobin in blood and prevents it from carrying oxygen around the body and will cause death
sulphur dioxide, SO_2 an acidic gas with a pungent smell	• combustion of fossil fuels in motor vehicles, power stations and factories • volcanic eruptions	• irritates the eyes and throat, and causes respiratory (breathing) problems • can form **acid rain**
nitrogen dioxide, NO_2 an acidic gas	• vehicle exhaust fumes • chemical plants • lightning activity	• causes respiratory problems • gives **acid rain**
methane, CH_4 a colourless gas, no smell	• bacterial decay of vegetable matter • cows and other farm animals when digesting food • anaerobic decomposition in natural wetlands and rice fields	• causes **global warming** because of a **greenhouse gas**
unburnt hydrocarbons	• vehicle exhaust fumes • chemical plants	• cause cancer (carcinogenic) • react with nitrogen oxides to form ozone
ozone, O_3 a colourless gas	• reaction of nitrogen oxides and unburnt hydrocarbons in the presence of sunlight	• forms **photochemical smog** which irritates the eyes and lungs and causes breathing difficulties • damages plants

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(e) Global Warming and Greenhouse Effect

The Earth's surface is warmed by radiation from the sun.

Sunlight absorbed by the Earth's surface warms it up, and the surface releases heat in the form of infrared radiation. Carbon dioxide and other gases (water vapour, methane, nitrous oxide and ozone) in the air trap this radiation and prevent much of it escaping into space. The greater the amount of carbon dioxide and other heat-trapping gases, the larger is the amount of heat trapped and the warmer the Earth becomes. The average temperature of the Earth increases leading to **global warming** (Figure 7.4).

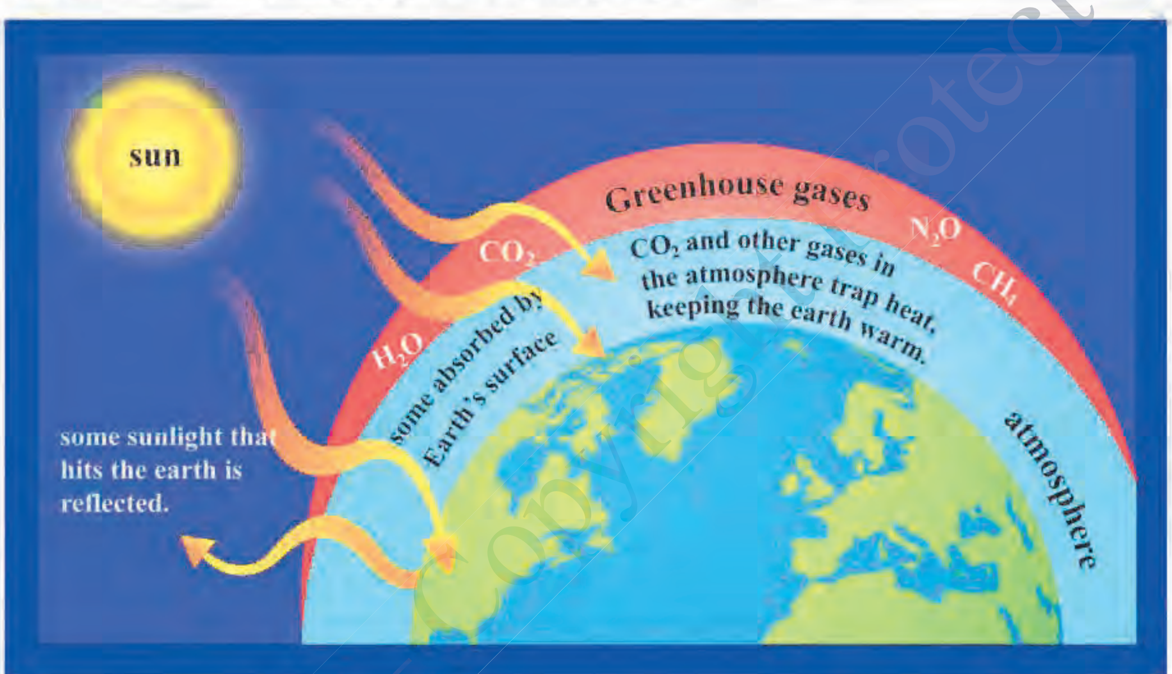

Figure 7.4 Global Warming and the Greenhouse Effect

We need greenhouse gases. Without them we would freeze to death at night, when the sun is not shining. But the level of greenhouse gases is now so high that it is causing global warming.

The gases occurred naturally in the atmosphere that trap heat are called **greenhouse gases** (GHGs) such as water vapour, carbon dioxide, methane, nitrous oxide and ozone. Besides, man-made chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), as well as sulphur hexafluoride (SF_6) are also GHGs.

Human activities, such as burning fossil fuels and farm-lands, and excessive use of fertilisers increase the amount of greenhouse gases. This greenhouse effect is gradually increasing the Earth's surface temperature, resulting in more extreme weather, such as flooding, drought, cyclone, forest fire, landslide, heat wave, etc. Another growing concern is the melting of glaciers and Artic ice which will increase sea levels resulting in many coastal communities being flooded and no longer habitable.

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(f) How Acid Rain is Produced

One major environmental effect of air pollutants is the formation of **acid rain** (Figure 7.5). Rain water is naturally slightly acidic (pH of about 5.7) because carbon dioxide in the air dissolves in rain water to form carbonic acid. Sometimes, oxides of sulphur and nitrogen are released into atmosphere as industrial waste. When these dissolve in water, water becomes more acidic.

Coal-burning power plants and engines fuelled by oil or petrol release gases that can form acid rain which often falls far from its source.

sulphur dioxide + oxygen + water ⟶ sulphuric acid

$$2SO_2(g) + O_2(g) + 2H_2O(l) \longrightarrow 2H_2SO_4(aq)$$

nitrogen dioxide + oxygen + water ⟶ nitric acid

$$4NO_2(g) + O_2(g) + 2H_2O(l) \longrightarrow 4HNO_3(aq)$$

Rain water with a pH less than 5 is called acid rain.

It has many negative effects, including killing animals and plant life, and damaging metal bridges and stone buildings (Figure 7.5).

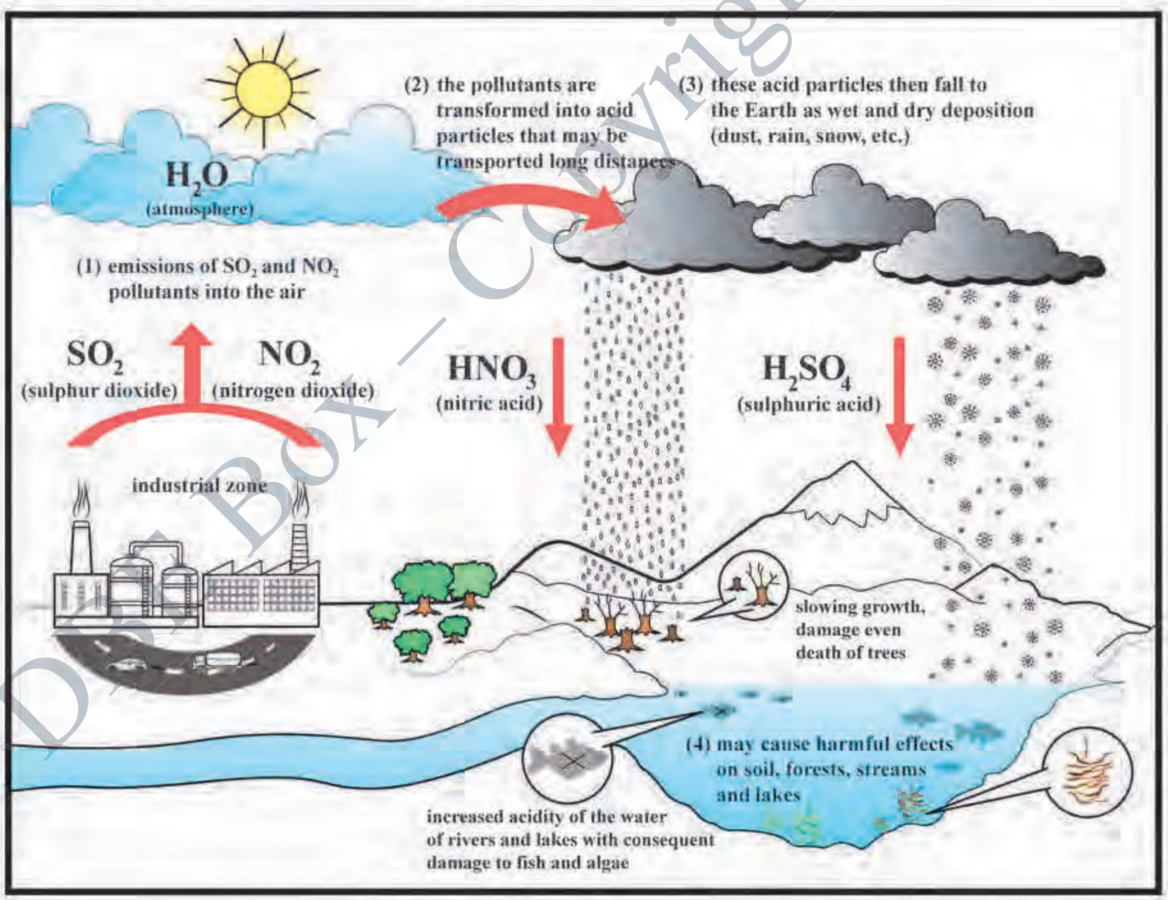

Figure 7.5 Formation of Acid Rain and its Effect on the Environment

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Chemistry in Daily Life

- The useful atmospheric gases for our society include O_2, N_2, He, Ar, Ne, CO_2, etc.
- **Oxygen** is used for planes, divers, astronauts and patients with breathing problems. It is used in steel works to remove impurities (C, Si, P and Mn). Oxyacetylene flame is used as fuel for cutting and welding metals.
- **Nitrogen** is unreactive. So it is flushed through food packaging to remove oxygen and keep the food fresh. **Liquid nitrogen** (bpt. -196 °C) is used to quick-freeze food in food factories and used in hospitals to store tissue samples. Nitrogen is used with argon to fill electric bulbs because these gases do not react with tungsten filament. Nitrogen is offered as an alternative to air for tyre inflation.
- **Carbon dioxide** is important in photosynthesis. Carbon dioxide is also used widely as a coolant, a refrigerant and ingredient in the manufacture of frozen foods, and used as fire extinguisher.
- The **noble gases** are unreactive or inert. This leads to many uses.
  - Argon provides the inert atmosphere in ordinary tungsten light bulbs.
  - Neon is used in advertising signs because it glows red when a current is passed through it.
  - Helium is used to fill balloons, since it is very light, and safe.

Review Questions

(1) In the fractional distillation of liquid air, which gas is distilled over first? Why?
(2) Name two greenhouse gases. State how greenhouse gases can cause global warming.
(3) What are two pollutants that cause acid rain? Explain, using appropriate equations, how these substances are involved in the formation of acid rain.
(4) How is carbon monoxide as an air pollutant formed in the environment?

Key Terms

- **Air pollution** is the condition in which air contains a high concentration of air pollutants that may harm living things and also damage non-living things.
- The **six common air pollutants** are carbon monoxide, sulphur dioxide, nitrogen dioxide, methane, unburnt hydrocarbons and ozone, and these are harmful to health and damage the environment.
- **Global warming** is the increase in the Earth's average temperature due to the built-up of greenhouse gases in the atmosphere. Global warming may lead to melting of the polar ice caps, rise in sea levels, floods, droughts and food shortages.
- **Acid rain** is formed when acidic air pollutants mainly sulphur dioxide and nitrogen dioxide react with water in the air (atmosphere). Acid rain corrodes buildings and metal structures, damages vegetation, and kills fish in freshwater lakes and streams.

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7.2 WATER

Water is the commonest compound on this planet. More than 70 % of the Earth's surface is covered with sea water, and the land masses are dotted with rivers and lakes. It is vital to our existence and survival because it is one of the main constituents in all living organisms. For example, human bones contain 31 % water, kidneys are about 82 % water and blood is about 90 % water. Those properties of water that make it uniquely suited for the support of life also make it easy to pollute. Many chemical substances are soluble in water. Removing these pollutants from our water supplies often requires enormous expenditures. You should be aware of the importance of good, safe drinking water as well as the prevention for water pollution.

(a) Occurrence of Water

Water is the most abundant substance on the Earth's surface. Out of 100 % of water that cover the Earth's surface, 97.5 % are sea water; only 2.5 % make up fresh water. Out of 2.5 % fresh water, 1.97 % make up ice caps and glaciers, 0.5 % make up ground water, only 0.02 % make up lakes and rivers, and the remaining 0.01 % are soil moisture.


Khakaborazi ice cap

Pure water cannot be found in nature. All natural waters contain impurities in varying amounts. Hence, **natural water** does not exist in a neutral state.

Rain water is the purest form of natural water. However, it may contain dissolved gases (such as oxygen and carbon dioxide) and dust from the atmosphere. Dissolved carbon dioxide makes rain water slightly acidic.


Natural water in Inlay lake

River water contains some dissolved gases and also some dissolved solids depending upon the soil over which it passes. River water is unfit to drink. The Ayeyawady River is the lifeline of Myanmar and majority of the country's population is dependent on the river for their livings. The river water finally flows into the sea carrying contaminants with it. **Sea water** contains various soluble salts (about 3.5 %).


Ayeyawady River


Sea water near Gaw Yan Gyi Island

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(b) The Unique Properties of Water

(i) Pure water is a clear, transparent and colourless liquid in thin layers. Thick layers of water have bluish colour.

(ii) The freezing point of water is 0 °C (32 °F) and the boiling point of water at 1 atmosphere is 100 °C (212 °F).

(iii) Water has a greater specific heat capacity than almost any other liquid.

(iv) Water decreases in density when it freezes.

(v) With decrease in temperature, most substances diminish in volume, and hence increase in density. However, water has the very unusual property of having a temperature at which its density is a maximum. This temperature is 3.98 °C or 4 °C to the nearest degree.

(vi) Water is regarded as the most universal solvent because it dissolves almost all substances to a greater or lesser extent.

(c) Hardness of Water

The water you drink contains some dissolved solids and gases. These dissolved materials usually are not harmful and can, in fact, be good for you. Where do they come from? Rain water dissolves carbon dioxide as it falls through the atmosphere. A small fraction of this dissolved carbon dioxide reacts with the water to produce carbonic acid, which is a weak acid.

$$\text{water} + \text{carbon dioxide} \rightleftharpoons \text{carbonic acid}$$
$$H_2O(l) + CO_2(g) \rightleftharpoons H_2CO_3(aq)$$

As this solution passes over and through rocks containing limestone (calcium carbonate, $CaCO_3$) and dolomite (calcium magnesium carbonate, $CaMg(CO_3)_2$), the weak acid in the rain attacks these rocks, and very slowly dissolves them to form calcium and magnesium hydrogen carbonates.

$$\text{calcium carbonate} + \text{carbonic acid} \longrightarrow \text{calcium hydrogen carbonate}$$
$$CaCO_3(s) + H_2CO_3(aq) \longrightarrow Ca(HCO_3)_2(aq)$$

Some of the rocks may contain gypsum (calcium sulphate, $CaSO_4.2H_2O$), anhydrite (anhydrous $CaSO_4$) or kieserite ($MgSO_4.H_2O$), which are very sparingly soluble in water. The presence of any of these dissolved sulphates or hydrogen carbonates causes the water to become 'hard'.

(i) Soap and detergent

Soap is the sodium salt of organic fatty acid. The most common one is sodium stearate which is the sodium salt of stearic acid, $C_{17}H_{35}COOH$. The formula of sodium stearate is $C_{17}H_{35}COONa$.

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sodium hydroxide	+	stearic acid (fatty acid)	$\longrightarrow$	sodium stearate	+	water
$NaOH(aq)$	+	$C_{17}H_{35}COOH(s)$	$\longrightarrow$	$C_{17}H_{35}COONa(s)$ soap	+	$H_2O(l)$

Detergents (soapless soaps) contain molecules with a salt-like group attached to a long chain of hydrocarbon. For example, sodium alkyl benzene sulphonates are synthetic soapless detergents. The structure of sodium 4-dodecyl benzene sulphonate, $C_{18}H_{29}SO_3Na$, is given below.

sodium 4-dodecyl benzene sulphonate

(ii) Effect of hard water on soap

In hard water areas all over the world, it is difficult to make the soap lather. Instead, the water becomes cloudy. This cloudiness is caused by the presence of a solid material formed by the reaction of the dissolved substances in the water with soap (basically sodium stearate) and it is a real problem. This white solid material is known as **scum**.

sodium stearate (soap)	+	calcium hydrogen carbonate	$\longrightarrow$	calcium stearate (scum)	+	sodium hydrogen carbonate
$2C_{17}H_{35}COONa(s)$	+	$Ca(HCO_3)_2(aq)$	$\longrightarrow$	$(C_{17}H_{35}COO)_2Ca(s)$	+	$2NaHCO_3(aq)$

The amount of soap required to just produce a lather with water can be used to estimate the hardness of the water. To overcome the problem of scum formation, soapless detergents have been developed. The advantage of these detergents is that their salts of calcium and magnesium are soluble in water. Therefore, detergents do not form curdy or greasy scum in hard water.

sodium 4-dodecyl benzene sulphonate	+	calcium hydrogen carbonate	$\longrightarrow$	calcium 4-dodecyl benzene sulphonate	+	sodium hydrogen carbonate
$2C_{18}H_{29}SO_3Na(aq)$	+	$Ca(HCO_3)_2(aq)$	$\longrightarrow$	$(C_{18}H_{29}SO_3)_2Ca(aq)$	+	$2NaHCO_3(aq)$

(iii) Degree of hardness

Degree of hardness of water is defined as number of parts of mass of $CaCO_3$ (calcium carbonate), equivalent to various calcium and magnesium salts present in one million parts by mass of water. It is expressed in ppm (parts per million).

Based on the degree of hardness, the water can be determined to be soft or hard. As the degree of water hardness increases, the water becomes to be hard.

Table 7.2 shows the classification of water based on degree of water hardness.

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Table 7.2 Classification of Water Based on Degree of Hardness of Water

Degree of hardness of water (mg / L or ppm)	Classification
< 17.1	soft
17.1 ~ 60	slightly hard
60 ~ 120	moderately hard
120 ~ 180	hard
> 180	very hard
17.1 mg / L = 17.1 ppm	

(d) Types of Hardness

Depending upon the types of salts dissolved in water, hardness in water can be divided into two types – temporary hardness and permanent hardness.

Temporary hardness is caused by the presence of dissolved calcium or magnesium hydrogen carbonates. Temporary hardness is so called because it is easily removed by boiling.

Permanent hardness is caused by the presence of dissolved calcium or magnesium chlorides and sulphates. Permanent hardness is much more difficult to remove and certainly cannot be removed by boiling.

Effect of hardness

When water containing any of these substances is evaporated, a white solid deposit of calcium or magnesium sulphate and / or calcium carbonate (limescale) is left behind.

Calcium carbonate is formed from the decomposition of calcium hydrogen carbonate by heating. This calcium carbonate causes the '**furring**' in kettles that occurs in hard water areas. This furring may be removed by the addition of dilute acid.

$$\text{calcium hydrogen carbonate} \xrightarrow{\Delta} \text{calcium carbonate} + \text{water} + \text{carbon dioxide}$$

$$Ca(HCO_3)_2(aq) \xrightarrow{\Delta} CaCO_3(s) + H_2O(l) + CO_2(g)$$

$$\text{hydrochloric acid} + \text{calcium carbonate} \longrightarrow \text{calcium chloride} + \text{water} + \text{carbon dioxide}$$

$$2HCl(aq) + CaCO_3(s) \longrightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

Blockages in hot water pipes are caused by a similar process to the furring of kettles. A thick deposit of limescale builds up.

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(e) Removal of Hardness

(i) By boiling method

Temporary hardness from water is easily removed by boiling. When heated, the calcium hydrogen carbonate decomposes, producing insoluble calcium carbonate.

$$\text{calcium hydrogen carbonate} \xrightarrow{\Delta} \text{calcium carbonate} + \text{water} + \text{carbon dioxide}$$

$$Ca(HCO_3)_2(aq) \xrightarrow{\Delta} CaCO_3(s) + H_2O(l) + CO_2(g)$$

The substances in permanent hard water are not decomposed when heated and therefore cannot be removed by boiling. Both types of hardness can be removed by the following method.

(ii) By addition of washing soda ($Na_2CO_3.10H_2O$ crystals)

The calcium or magnesium ion, which actually causes the hardness, is removed as a precipitate by adding washing soda. Therefore, it can no longer cause hardness.

$$\underset{\text{(from hard water)}}{\text{calcium ion}} + \underset{\text{(from washing soda)}}{\text{carbonate ion}} \longrightarrow \text{calcium carbonate}$$

$$Ca^{2+}(aq) + CO_3^{2-}(aq) \longrightarrow CaCO_3(s)$$

(f) Water Pollution and Water Purification

The main causes of water pollution are sewage, fertilisers, pesticides, industrial wastes, oil and detergents. Pollution makes rivers and lakes smell. It kills aquatic plants and animals and other living things. It makes the water unfit for human consumption. Table 7.3 shows some sources of water pollutants and the effects.

Table 7.3 Some Sources of Water Pollutants and the Effects

Pollutants	Source	Effect
industrial waste (containing heavy metals such as Pb, Cu, Cd, Hg, Cr, etc.), dyes	industries	harmful effects (chronic health problem)
pesticides	agriculture fields	poisonous (from respiratory problem to cancer)
fertilisers	agriculture fields	waterway pollution, chemicals burn to crops, increased in air pollution, mineral depletion of the soil
oil spill	oil tanker	seriously affect the marine environment

Water pollution can be prevented by the proper disposal of sewage and industrial wastes. These pollutants should be treated and rendered harmless before they are discharged into the rivers or seas. The polluted water can be purified by several methods such as filtration, chlorination, distillation and deionisation (ion exchange), etc.

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Ordinary water is more or less impure; it usually contains dissolved salts and dissolved gases and sometimes organic matter. The water is distilled away from the dissolved substances; however, it is far too expensive to be used on a large scale.

Ionic impurities can be effectively and cheaply removed from water by passing through substances like zeolite having giant structure. A zeolite is an aluminosilicate (or sodium aluminium silicate, $NaAl_2Si_4O_{12}$). It consists of a rigid framework formed by the aluminium, silicon and oxygen atoms. But sodium ions are loosely held and may be replaced by ions of calcium, magnesium and iron present in hard water. The removal of calcium, magnesium and iron results the removal of hardness according to the **Permutit method**.

sodium zeolite + calcium chloride ⟶ calcium zeolite + sodium chloride

$$2NaZ(s) + CaCl_2(aq) \longrightarrow CaZ_2(s) + 2NaCl(aq)$$

In order to get pure drinking water from rain water and river water, the process of water treatment used is illustrated in Figure 7.6.

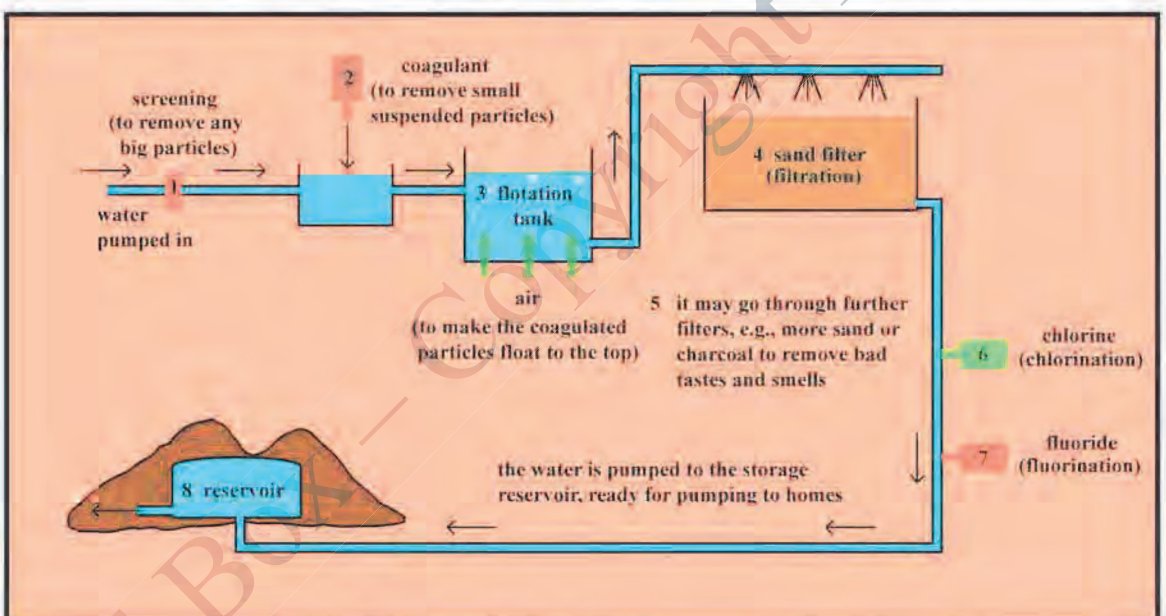

Figure 7.6 Modern Water Treatment Plant

Chemistry in Daily Life

- Water has many other important uses besides sustaining life. Water is used for cooking, cleaning, drinking, gardening and waste disposal (toilet flushing) **in home**. It is applied as a solvent as well as cleansing agent, a coolant, a major ingredient in the manufactured product and generating electricity **in industry**, and is also used for irrigation **in agriculture**.

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Review Questions

(1) How will you test for hardness in water?
(2) Name two compounds in each case which can cause:
 (a) temporary hardness (b) permanent hardness.
(3) Write chemical equations, how temporary hard water reacts with soap.
(4) How do you soften temporary hard water?
(5) Explain how you will distinguish between temporary and permanent hardness in water.
(6) What are the effects of temporary and permanent hardness of water?

Key Terms

- **Hard water** is water which will not readily form a permanent lather with soap. **Soft water** is water which readily gives a permanent lather with soap.
- **Water hardness** is the amount of dissolved calcium ions, magnesium ions or both in the water. **Temporary hardness** is caused by dissolved calcium hydrogen carbonate which is removed by boiling. **Permanent hardness** is caused by dissolved calcium or magnesium chloride and sulphate which cannot be removed by boiling.
- **Degree of hardness of water** is the number of parts of mass of $CaCO_3$ (calcium carbonate), equivalent to various calcium and magnesium salts present in one million parts by mass of water (ppm).
- **Permutit method** is a process in which hard water containing calcium or magnesium salt is passed through a layer of sodium zeolite. The calcium or magnesium is removed and the corresponding sodium salt passes in solution.
- **Water pollution** is caused by the pollutants such as sewage, industrial wastes, chemical fertilisers and detergents. The treatment needed to make water fit to drink depends on the source of the water. The process of **water treatment** involves both filtration and chlorination.

7.3 SOIL

Like air and water, soil plays an essential role in our **ecosystems**. Earth's body of soil, called the **pedosphere**, has four important functions: as a medium for plant growth, as a means of water storage, supply and purification, as a modifier of Earth's atmosphere and as a habitat for organisms.

Soil is upper layer of the Earth in which plants grow, a black or dark brown material typically consisting of a mixture of organic remains, clay and rock particles. Soil plays a very important role as it produces food for human beings and animals. Good soil and a congenial climate for productivity are valuable assets for any nation. **Erosion** and a continuous cropping have taken terrific toll of the soil in many parts of the world. Excessive use of fertilisers may also cause the soil pollution. We should have the basic knowledge of soil types and general soil information since agriculture is one of the backbones of the Myanmar economy.

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(a) Soil Profile

Figure 7.7 shows three main layers (top soil, subsoil, bedrock) of the soil with increasing depth. The sequence of these layers is the soil profile. Each layer has its own characteristics.

- The top layer is known as the **top soil** or the **humus layer**, which is rich in organic materials. As this layer consists of decomposed material and organic matter, it has a dark brown colour.

  The humus makes the top soil soft, porous to hold enough air and water. In this layer, the seeds germinate and roots of the plants grow. Many living organisms like earthworms, bacteria and fungi are found in this layer of soil.

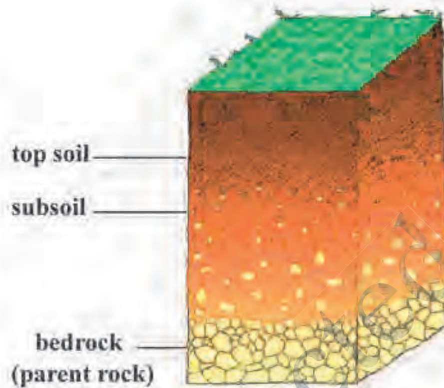

Figure 7.7 Typical Layers Found in a Soil Profile

- Just below the top soil lies another layer called **subsoil**.
  It is comparatively harder and more compact than top soil. It is lighter in colour than the top soil because there is less humus in this layer. This layer is less organic but is rich in minerals brought down from the top soil. It contains metal salts, especially iron oxide in a large proportion. Farmers often mix top soil and subsoil when ploughing their fields.
- The next layer is **bedrock** or **parent rock**, which lies just below the subsoil. Bedrock contains no organic matter and is made up of stones and rocks, so it is very hard.

(b) Composition of Soil

The mineral component of soil originates from the parent rocks by weathering processes, while the organic component is due to plant biomass in various types of decay as well as high populations of bacteria, fungi and animals such as earthworms.

The basic components of soil are mineral matter (45 %), organic matter (5 %), air (20 ~ 30 %) and water (20 ~ 30 %) (Figure 7.8).

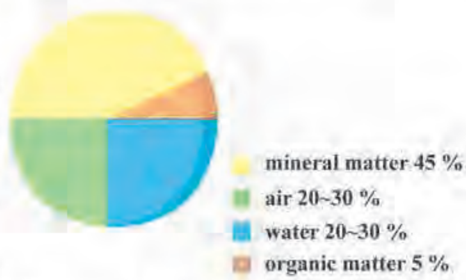

Figure 7.8 Composition of Soil

Air and water occupy the pore spaces in soils. Pore spaces are the voids between the soil particles. Fine-textured soils have more total pore space than coarse-textured soils. As soils absorb water, the air space decreases. Except for gravel and rocks that occur occasionally in soils, there are three fractions; sand, silt and clay. The organic matter of soils is made up of undecomposed and partially decomposed residues of plants and animals and the tissue of living and dead microorganisms.

(c) Soil Texture

Soil texture is simply characterised by the relative proportion of sand, silt and clay separates (particles) found in the soil.

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Soil texture is affected by the constituent materials found within it, specifically sand, silt and clay particles. A coarse sand will feel gritty but a wet clay will feel heavy and sticky.

Soil is made up of different-sized particles. Sand particles tend to be the biggest. Clay particles are very small. If the proportion of the sand in the soil is increased, the average size or soil particles increases and the resultant soil becomes coarser in texture.

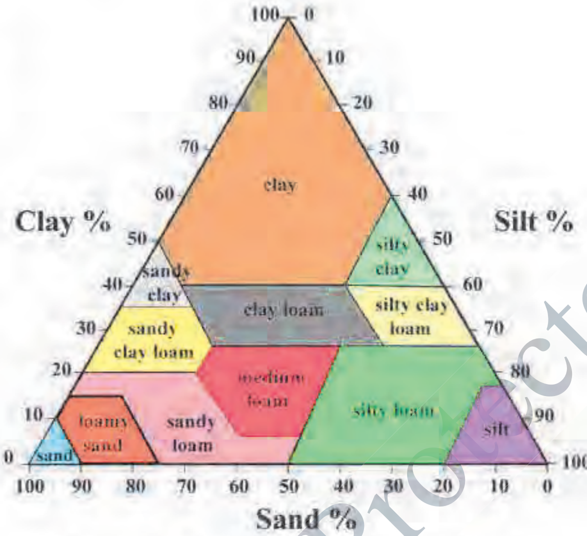

Figure 7.9 Soil Textural Triangle

If the proportion of clay in the soil is increased, the average size of the soil particle decreases and the resultant soil becomes finer in texture.

Soil textural triangle is a classification system used to determine soil classes based on their physical texture. There are twelve classes as shown in Figure 7.9.

The term **loam** refers to a **soil** with a combination of **sand**, **silt** and **clay** sized particles. For example, a **soil** with **30 % clay**, **50 % sand** and **20 % silt** is called a **sandy clay loam**.

(d) Plant Nutrients in Soil

One of the most important functions of soil in supporting plant growth is to provide essential plant nutrients – **macro-nutrients** and **micro-nutrients**. Macro-nutrients are those elements that occur in substantial levels in plant materials or in fluids in the plant. Micro-nutrients are elements that are essential only at very low levels and generally are required for the functioning of enzymes.

Essential macro-nutrients	**Essential micro-nutrients**
carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur	boron, chlorine, copper, iron, manganese, molybdenum, zinc, sodium, vanadium

Nitrogen, phosphorus and potassium (**NPK**) are plant nutrients that are obtained from soil. They are so important for crop productivity that they are commonly added to soil as fertilisers.

Nitrogen has the most dramatic effect on the leaf growth, especially in grass and cereal plants. It is used to make protein in plants. Nitrogen bound to soil humus is especially important in maintaining soil fertility.

Nitrogen pathways in soil are shown in Figure 7.10.

Phosphorus is essential in the nucleus of every cell, so growth cannot continue in its

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complete absence. It is particularly associated with the development of a strong root system and floral development.

Potassium is required at high levels for growing plants. Potassium activates some enzymes and plays a key role in the water balance in plants and for some carbohydrate transformations.

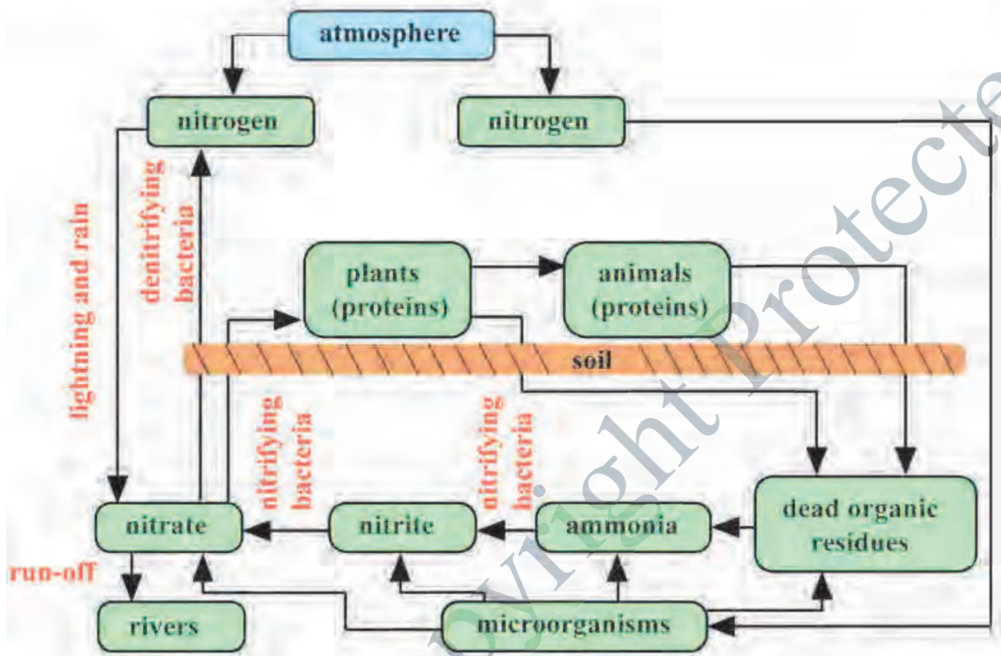

Figure 7.10 Nitrogen Pathways in Soil

(e) Soil pH

Soil pH is a fundamental property that affects a surprisingly large range of chemical, physical and biological processes in soils. Soil pH is a measure of the acidity and alkalinity in soils. pH of the soil can be measured by means of a pH meter or pH paper. The optimal pH range for most plants is **between 5.5 and 7.0**; however, many plants have adapted to thrive at pH values outside this range.

Soil pH is important because of its effect on the availability of essential elements, or nutrients, in soils. For example, many elements can be taken up by plants more easily if the soil pH is near neutral to marginally acidic. Outside this pH range, plants may be deficient in some elements, or some elements may become toxic. If the soil is more acidic than the required pH, it can be treated by adding lime. **Lime** is alkaline and it will **neutralise** the **acidity of the soil** and make it more neutral. **Alkali** or **alkaline soils** are **clay soils** with **high pH (> 8.5)**. **Gypsum** helps in the treatment of **alkaline soils**.

(f) Waste and Pollutants in Soil

Soil is the receptor of large quantities of waste products: domestic, human, animal, industrial and agricultural products.

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Combustion of sulphur-containing fuels smelting process emits SO_2, and finally leaves sulphate on the soil. Nitrates from the atmosphere are deposited on the soil. Lead particulate from automobile exhausts also settles on soil along both sides of highways with heavy automobile traffic. High levels of Pb, Zn, etc. are observed on soils near lead and zinc mines, etc.

Fertilisers and pesticides applied to crops are largely retained by the soil. They become part of environmental cycles due to sorption by the soil, leaching into water, etc. Pesticides undergo degradation in soil, through the processes of biodegradation, chemical degradation, or photochemical reactions. In this respect, insects, earthworms, plants and microorganisms play important roles in biodegradation of pesticides.

Pesticide residues on crops and food products cause long-term health hazards. It may be concluded that the quality of soil has an impact on public health standards through the human food chain. The environmental health aspects of soil deserve serious attention in the near future.

(g) Sources of Soil Pollution

The main sources which pollute the soil are acid rains, repeated use or excess use of the same fertiliser, inadequate drainage system in agricultural fields, spraying the vegetable and fruit plants with insecticides and herbicides, etc.

Chemistry in Daily Life

- Soil is the foundation of basic **ecosystem** function.
- Soil filters our water, provides essential nutrients to our forest and crops, and helps regulate the Earth's temperature.

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Review Questions

(1) Illustrate the typical layers found in a soil profile.
(2) What do you understand by the terms 'macro-nutrients' and 'micro-nutrients'?
(3) Why is the sandy soil not good for growing crops?
(4) By using the soil textural triangle, classify the type of soil with 10 % clay, 30 % sand and 60 % silt.

Key Terms

- **Organic matter** in soil is made up of undecomposed and partially decomposed residue of plant and animal tissues of living and dead microorganisms.
- **Soil texture** is a measure of the relative propotion of sand, silt and clay separates (particles) found in the soil.
- According to the **soil textural triangle**, the soil can be classified into twelve classes by the relative proportion of sand, silt and clay separates (particles) found in the soil.

EXERCISES

1. Write TRUE or FALSE for each of the following statements. If FALSE, correct it.
   (a) Carbon dioxide and argon are the major gases in air.
   (b) Green plants require oxygen for photosynthesis to produce glucose.
   (c) Nitrogen content in soil humus is especially important in maintaining soil fertility.
   (d) As the proportion of the sand in the soil is increased, the average size of soil particles decreases.
   (e) Most plants grow best when the soil is neutral or slightly acidic.
   (f) Nitrates from the atmosphere are deposited on the soil.

2. Tick the correct word(s), term(s), notation(s), etc., given in the brackets.
   (a) An air pollutant that can cause breathing problems is (methane; carbon monoxide; carbon dioxide; water vapour).
   (b) The approximate pH of acid rain is (less than 5; greater than 10; equal to 7; greater than 7).
   (c) What layer is called the humus layer and is made up of plant remains like leaves and twigs? (organic; top soil; subsoil; bedrock)
   (d) The important soil measurement determines how much water it can hold is (temperature; texture; colour; consistency).
   (e) Temporary hardness is easily removed by (filtration; chlorination; boiling; neutralisation).
   (f) Essential macro-nutrients for plants are (carbon; chlorine; copper; iron).

3. Fill in the blanks with suitable word(s) or phrase(s).
   (a) The two gases that cause acid rain are _____.
   (b) Nitrogen and oxygen in the air can be obtained by _____ of liquid air.
   (c) The furring of kettles or boilers is as a result of the decomposition of $Ca(HCO_3)_2$ in hard water into _____ .
   (d) Insects, earthworms, plants and microorganisms play important roles in _____ of pesticides.
   (e) Temporary hardness is so called because it is easily removed by_____ .
   (f) The layer of soil which is located at the very bottom is known as _____ .

4. Oxygen and nitrogen, the two main gases in air, are both slightly soluble in water. A sample of water was boiled, and the gases collected. The water vapour was allowed to condense and the remaining gases were measured. In a 50 cm^3 sample of these gases, 18 cm^3 were oxygen.
   (a) (i) What percentage of oxygen is present in the sample of air?
   (ii) How does this compare to the percentage of oxygen in the atmosphere?
   (b) About what percentage of atmospheric air is nitrogen?
   (c) Which gas, nitrogen or oxygen, is more soluble in water?

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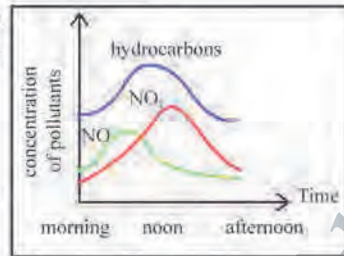
5. The diagram shows how the concentration of air pollutants in a busy city varies with time. How do you account for these variations with the hour of the day?



6. Discuss the following:
   (a) Industry normally requires water which has been softened.
   (b) Hard water causes kettles to fur. This 'fur' can be removed by using a dilute acid.
   (c) Hard water wastes soap.
   (d) Hard water can coat lead pipes and reduce the possibility of lead poisoning.

7. In recent years pollution of rivers and lakes has become a serious problem.
   (a) State two main sources of river pollution.
   (b) State four major water pollutants.
   (c) Suggest how to prevent these pollution.

8. Some of our drinking water is obtained by purifying river water.
   (a) Would distillation or filtration produce the purer water from river water? Give a reason for your answer.
   (b) Which process, distillation or filtration, is actually used to produce drinking water from river water?

9. Sketch the pathway of conversion of nitrogen in air to animal proteins.

10. In the treatment of water for public use, state the purpose of the addition of :
   (a) aluminium sulphate
   (b) chlorine
   (c) sodium hydroxide
   (d) sulphur dioxide

11. The soil pH is important in agriculture. Explain why.

12. Explain what is meant by the term 'pollution' with reference to air and water.

13. (a) Name an air pollutant produced by the burning of coal.
   (b) Name the air pollutant produced by the combustion of petrol in a car engine.

14. How can you treat the acidic soil? Explain briefly.

15. Make a list of four major water pollutants and explain where they come from. What damage can these pollutants do?

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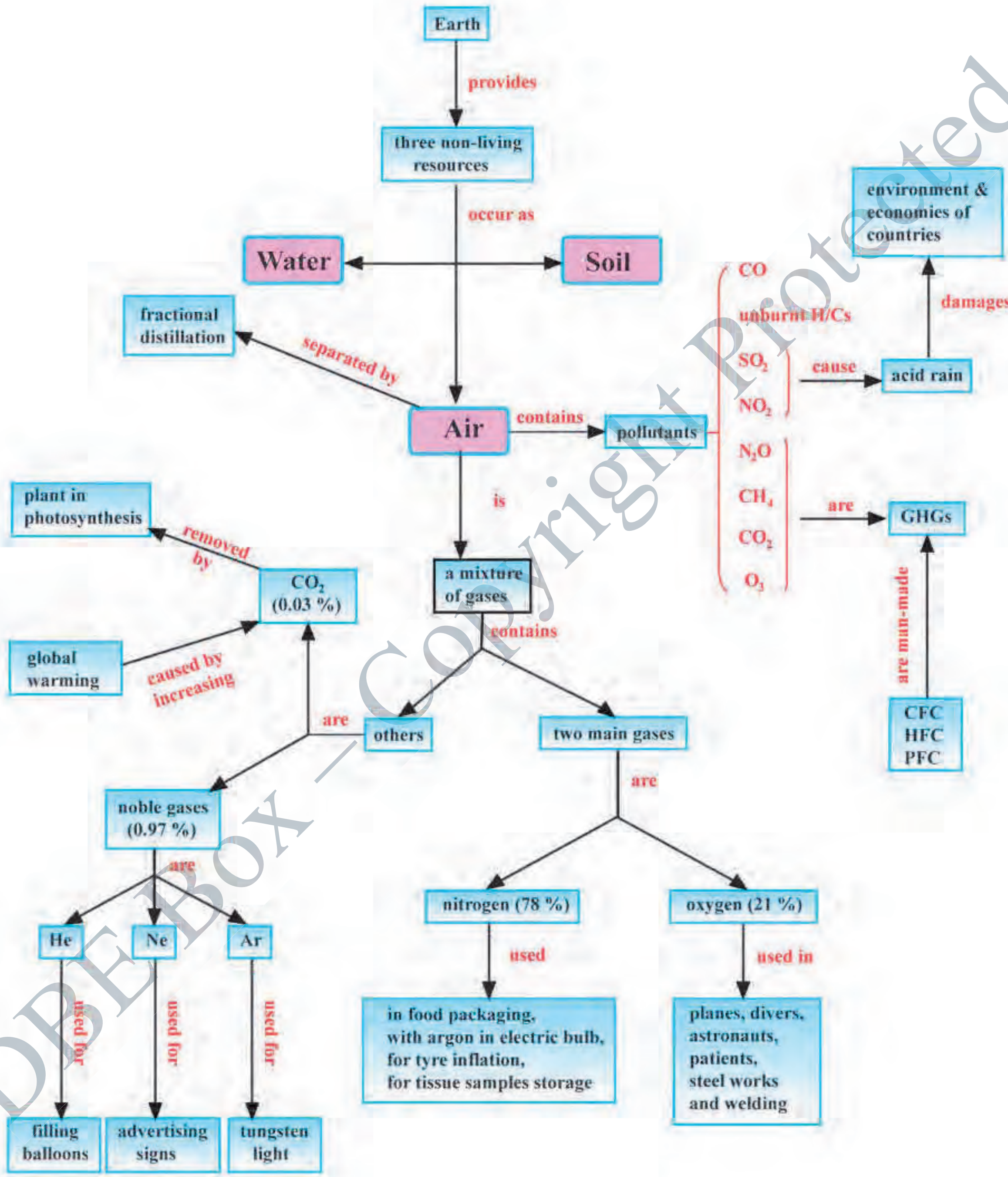
CHAPTER REVIEW
(Concept Map)



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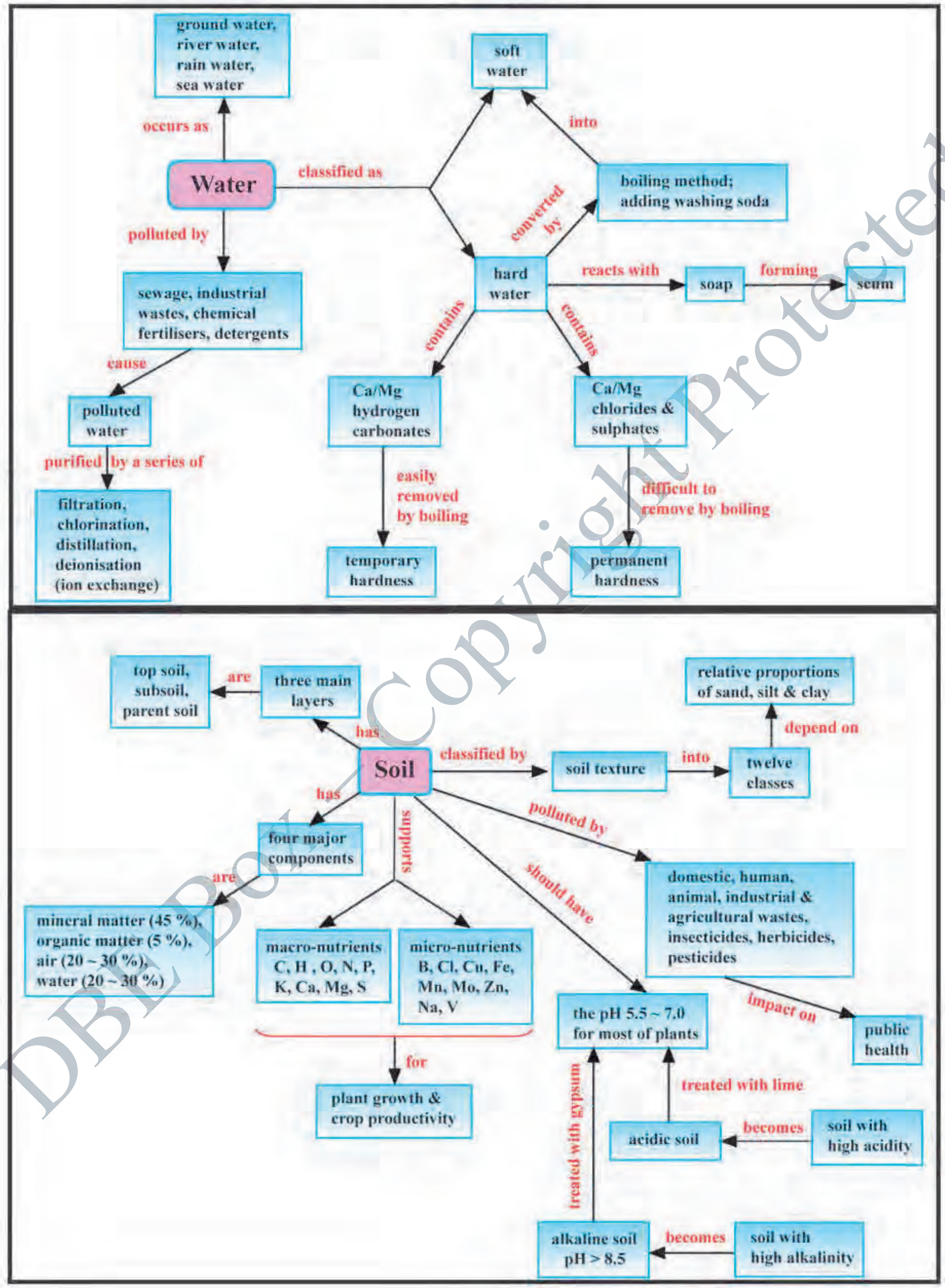
Continued from CHAPTER REVIEW (Concept Map)



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CHAPTER 8 FUELS AND CRUDE OIL

In the twenty first century society, the main energy source which is used to operate the machines, power cars and buses, daily cooking our food and lighting our homes is obtained from fossil fuels.

A fuel is a substance that releases sufficient energy to do work as it undergoes a chemical change. The heat energy produced in combustion is converted into more useful forms of energy such as light energy, mechanical energy and electrical energy (electricity). Throughout history, wood and even natural gas were used thousands of years ago. They were used mainly for warmth and for cooking food. From the earlier times, wood and coal were the most common fuels. At present, fossil fuels are the main energy source used in the world.

Crude oil (petroleum), coal and natural gas are called fossil fuels because they are formed from the remains of plants and animals that lived millions of years ago. These fuels are classified as non-renewable and are finite (limited) resources because they take a very long time (millions of years) to form. Modern society is still using up fossil fuels reserved for heavy and soft industries, for non-stop transportation, generating electricity in power stations, and also for cooking.

Oil and gas production

Learning Outcomes

After completing this chapter, students will be able to:

- identify the sources, properties and behaviours of fossil fuels;
- explain the process of fractional distillation as applied to crude oil;
- describe the catalytic cracking process used to split long chain hydrocarbon molecules into shorter ones;
- recognise the sources, compositions and uses of alternative fuels, and describe the preparation methods of biodiesel and hydrogen fuel.

8.1 FOSSIL FUELS

There are three major fossil fuels. They are (a) coal (b) crude oil and (c) natural gas. Coal comes from fossil plant materials. Crude oil and natural gas are formed from the bodies of marine microorganisms. The formation of these fuels took place over many millions of years. That is why they are not only classified as non-renewable, but of finite (limited) reserved resources.

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(a) Coal

Coal is fossilised plant material containing mainly carbon together with hydrogen, nitrogen and sulphur. Most coal was formed during the Carboniferous period (286-360 million years ago). The action of pressure and heat through geological forces converted the plant material in stages from peat to lignite to bituminous soft coal to hard coal (anthracite). At each stage the percentage of carbon increases. Coal contains between 80 to 90 % carbon by mass. Coal is found in many countries. The United States, Russia, China and some European countries have large coal deposits. MYANMAR also has coal deposits in Shan State, Kachin State, Taninthayi Region and Sagaing Region.

Coal is a black solid. It is mainly carbon, with small amounts of hydrogen, oxygen, nitrogen and sulphur. Coal is used in many countries to produce electricity. At a coal burning power station, coal is burnt in air to heat the water in a boiler. The steam produced turns the steam turbines to generate electricity (Figure 8.1). When coal is burnt, the main products are carbon dioxide and water. Quantities of soot, oxides of sulphur and nitrogen, and a solid residue called ash are also produced. Various kinds of pollutants are produced when coal is burnt.

Coal is also used to produce coke. When coal is strongly heated in the absence of air, a solid called **coke** is produced. Coke is almost pure carbon. It burns more cleanly than coal and it does not produce as much smoke. The main use of coke is as a reducing agent in the blast furnace for making iron.

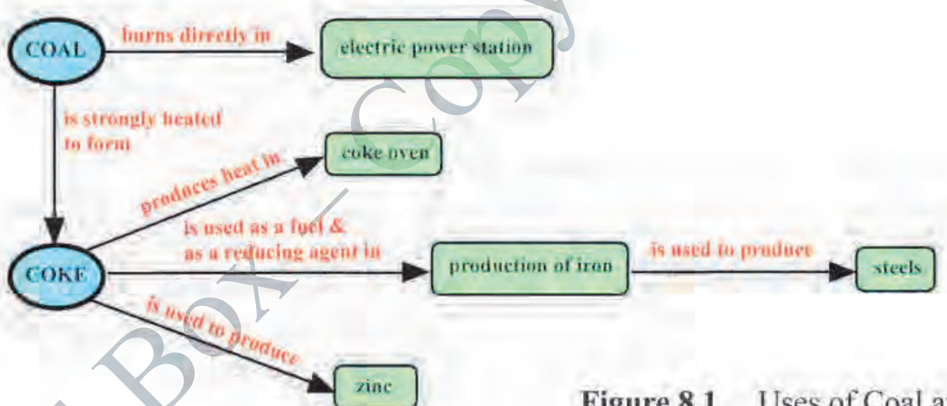

Figure 8.1 Uses of Coal and Coke

(b) Crude Oil

Crude oil (also called petroleum) is a thick black liquid. It is found together with natural gas in the Earth. Today, about 40 % of the world's energy comes from petroleum while 20 % comes from natural gas. Large amounts of petroleum are produced in the Middle East, the United States and Russia.

Myanmar is one of the world's oldest oil producers. British Burma exported its first barrel of crude oil in 1853. The London-based Burma Oil Company (BOC) was established in 1871 and began production in the Yenangyaung oil field in 1887 and the Chauk oil field in 1902.

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The formation of crude oil and natural gas

The crude oil and natural gas were formed from dead animals and plants that lived in the seas a long time ago. The dead materials settled at the bottom of the sea, where it was covered with sand and other sediment. Rock then formed on top of the animal and plant remains. High pressure and temperature changed it into petroleum over millions of years. Some of it was changed into a gas - called natural gas.

Crude oil and **natural gas** are found together, held in between layers of non-porous rock in the ground (Figure 8.2). These fuels are extracted by a drilling pipe through the rock. These fuels are hydrocarbons. Hydrocarbons are made up of hydrogen and carbon only.

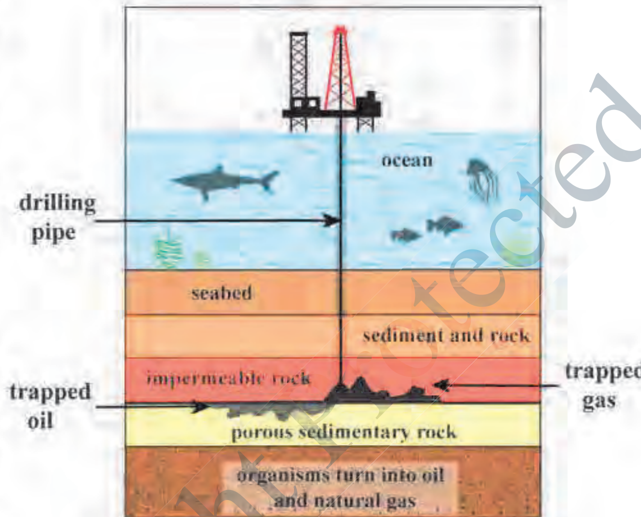

Figure 8.2 Extraction of Natural Gas and Oil from Seabed

(c) Natural Gas

Natural gas was formed at the same time as crude oil and the two are often found together, although it may occur on its own or with coal. It consists mainly of methane (85-95 %) with varying amounts of ethane, propane, butane and other gases such as carbon dioxide, nitrogen, hydrogen sulphide, etc.

Chemistry in Society

- The fuels that are derived from petroleum support more than half of the world's total energy production.
- Crude oil, coal and natural gas are non-renewable fossil fuels and contain stored energy from photosynthesis trapped millions of years ago.
- Fuel oil and natural gas are used to generate electricity. Petroleum products are used for the manufacture of synthetic fibers for clothing and in plastics, paints, chemicals, fertilisers, insecticides, soaps and synthetic rubber.
- Myanmar is today primarily a natural gas producer. As of 2015, Myanmar exports gas to Thailand and China.

Review Questions

(1) Why is petroleum called a fossil fuel?
(2) Describe the uses of coal.

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Key Terms

- A **fuel** is a substance that releases sufficient energy to do work as it undergoes a chemical change.
- **Fossil fuels** consist of coal, petroleum and natural gas. **Natural gas** consists mainly of methane, CH_4. **Crude oil** (petroleum) is a mixture of many different hydrocarbon molecules.
- **Non-renewable fuels** are fuels which take millions of years to form and which are used up at a rapid rate.
- **Renewable fuels** are fuels produced from renewable resources. (e.g., vegetable oils, animal oils, etc.)
- **Combustion of coal** releases nitrogen oxides, sulphur dioxide, particulate matter (PM), mercury and dozens of other substances known to be hazardous to human health.

8.2 FRACTIONAL DISTILLATION OF CRUDE OIL

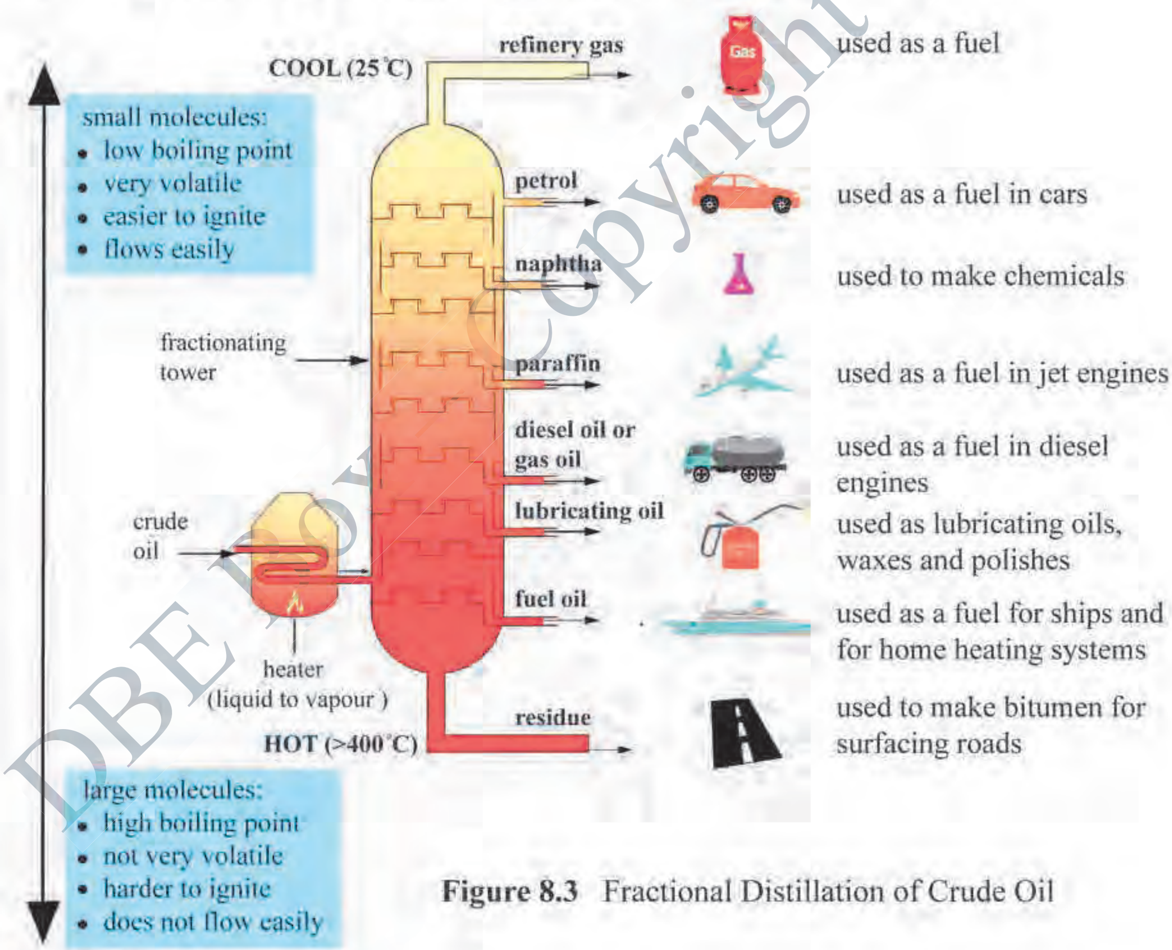

Figure 8.3 Fractional Distillation of Crude Oil

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Crude oil is a mixture of many different **hydrocarbon** molecules. These molecules have different sizes and number of carbon atoms. The small molecules have few carbon atoms and low boiling points, while the large molecules have many carbon atoms and high boiling points. Therefore, it is necessary to refine the crude oil into useful fuels and chemicals.

Separation of the crude oil takes place in a fractional distillation column, or fractionating tower into different fractions (parts) in an oil refinery (Figure 8.3).

Crude oil is heated in a furnace. Many fractions could be collected, each having a different boiling point range. The oil vaporises and passes up the fractionating column. The fractions condense and come out of the column at different heights depending on their boiling points. The petroleum gas fraction comes out first at the top of the column as its molecules have the lowest boiling points. Then, a series of fractions such as petrol, naphtha, kerosene and diesel comes out in order of increasing boiling points, number of carbon atoms and viscosity. The lubricating oil fraction comes out at the bottom because its molecules have higher boiling points, followed by fuel oil. Bitumen is the residue at the bottom of the column.

All the fractions are insoluble in water and burn in air. The properties and uses of some of the main fractions from the distillation of crude oil are given in Table 8.1.

Table 8.1 Some Important Crude Oil Fractions

Fraction	Approximate boiling point range / °C	Approximate number of carbon atoms per molecule		Important uses
refinery gas (petroleum gases)	below room temperature < 40	1 ~ 4	Increasing boiling point and viscosity ↓	bottled gas for gas cookers and motor cars
petrol (gasoline)	35 ~ 75	5 ~ 10		petrol for motor cars
naphtha	70 ~ 170	8 ~ 12		petrochemicals
paraffin (kerosene)	170 ~ 250	10 ~ 14		fuel for jet aircraft; kerosene lamps for light and kerosene stoves for cooking
diesel oil	250 ~ 340	15 ~ 25		fuel for diesel engines of buses, lorries, trucks, steamers and trains
lubricating oil	350 ~ 500	19 ~ 35		lubricant in engines to reduce friction; also for making waxes and polishes
fuel oil	500 ~ 600	30 ~ 40		fuel for ships, factories and central heating
bitumen (residue)	> 600	> 70		a black substance used to make surface roads and roofing

Note: 'Crude oil' (UK) is the same as 'petroleum' (USA); 'petrol' (UK) is the same as 'gasoline' (USA); and 'paraffin' (UK) is the same as 'kerosene' (USA).

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There is a greater demand for petrol and kerosene than other fractions. Consequently, cracking method is used to produce smaller molecules from larger hydrocarbon molecules.

Chemistry in Society

- Gasoline, kerosene and diesel oil provide fuel for automobiles, tractors, trucks, aircraft and ships.
- Lubricating oil is used as lubricant in engines to reduce friction; also for making waxes and polishes.
- Bitumen is used for surfacing roads.

Review Questions

(1) Name a crude oil fraction that: (a) is used for jet aircraft (b) has the smallest molecules (c) is the most viscous (d) has molecules with 19-35 carbon atoms.

(2) Consider the following petroleum fractions:
naphtha, paraffin, bitumen, diesel oil, lubricating oil
Which of the above fractions:
(a) has the lowest boiling point; (b) has the highest boiling point;
(c) is used to make waxes; (d) is used as a fuel for jet engines;
(e) contains 15 – 25 carbon atoms per molecule?

(3) In an oil refinery, the mixture of hydrocarbons in petroleum is separated into fractions. Petroleum fraction **X** has the boiling point range of 35-70 °C. Petroleum fraction **Y** has the boiling point range of 170-250 °C. List three facts in which petroleum fraction **X** differs from petroleum fraction **Y**. Give reasons for your answer.

(4) There is a limited quantity of petroleum on Earth. Describe two ways of conserving petroleum.

Key Terms

- **Hydrocarbon** is any of a class of organic chemical compounds composed only of the elements carbon (C) and hydrogen (H).

8.3 CATALYTIC CRACKING

Fuels made from oil mixtures contain large hydrocarbon molecules and are not efficient. They do not flow easily and are difficult to ignite. Crude oil often contains too many large hydrocarbon molecules and not enough small hydrocarbon molecules to meet demand. Consequently, cracking is important to convert the larger hydrocarbon molecules to smaller ones.

Larger molecules from the heavier fractions (paraffin (kerosene) and diesel) can be broken into smaller, more valuable, molecules. When a catalyst is used, this process is called **catalytic cracking** ('cat cracking').

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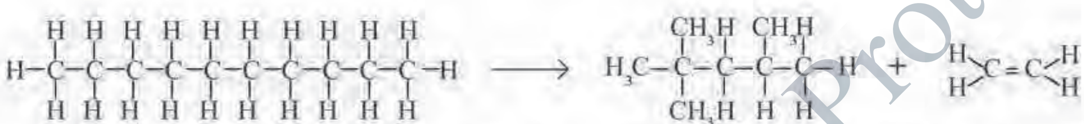
Cracking is a **thermal** decomposition process in which large alkane hydrocarbon molecules are broken down by passing them over a heated catalyst under pressure. The products are smaller alkanes used for fuels (e.g., petrol or diesel) and alkenes which are used to make polymers: plastics and other important compounds.

Cracking takes place in huge reactor. In this reactor, particles of catalyst (made of powdered minerals such as silica, alumina and zeolites) are mixed with the hydrocarbon fraction at a temperature around 500 °C and moderately low pressure. The cracked vapours containing smaller molecules are produced by the following types of reactions:

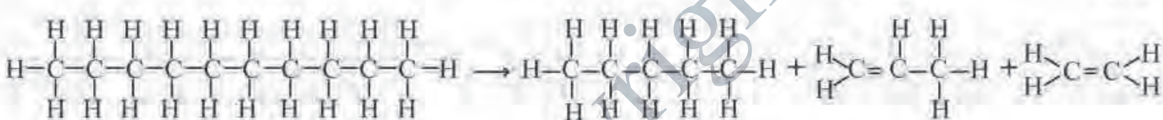
$$\text{Decane} \xrightarrow[\text{moderately low pressure}]{\text{heat, catalyst}} \text{2, 2, 4-trimethyl pentane} + \text{ethene}$$

$$C_{10}H_{22} \longrightarrow C_8H_{18} + C_2H_4$$



$$\text{Decane} \longrightarrow \text{pentane} + \text{propene} + \text{ethene}$$

$$C_{10}H_{22} \longrightarrow C_5H_{12} + C_3H_6 + C_2H_4$$



Cracking reactions generally give two main types of products:

(i) an alkane with a shorter chain than the original and
(ii) a short-chain alkene molecule.

Both these products are useful. The shortened alkanes can be blended with the gasoline fraction to enrich the petrol. The alkenes are useful as raw materials for making several important products. Figure 8.4 shows the various uses for the ethene produced; preparation of ethanol and plastics such as polyethene, polychloroethene and polystyrene. Here in, ethene polymerises to polyethene, i.e., many ethene molecules combine to form larger molecule polyethene that contains repeating structural units. Propene polymerises to polypropene (trade name 'polypropylene'), while butene polymerises to produce synthetic rubber.

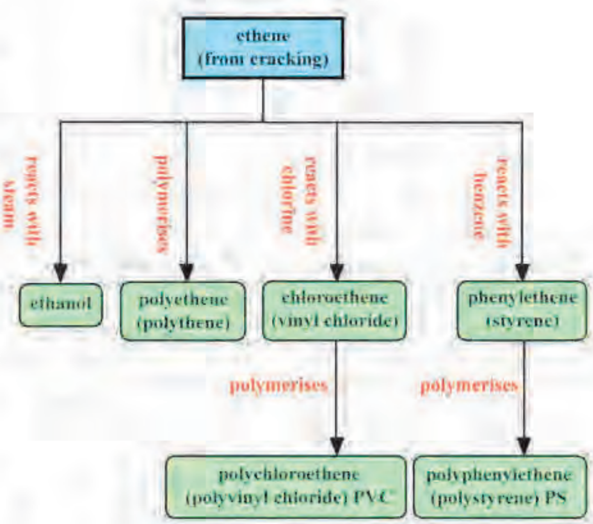


Figure 8.4 Important Products from Ethene

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The alkane produced from cracking may be straight chain alkanes which turn to branched isomer on heating with the catalyst. Therefore, they have higher octane ratings (octane number) than unbranched alkanes. The higher the **octane number**, the greater the fuel's resistance to knocking in an internal combustion engine.

The octane number of a given fuel is determined by comparing the amount of knocking that fuel causes when combusted with the amount of knocking caused by two standard reference fuels; *iso*-octane which resists knocking **(antiknocking)** and has an octane number of 100 and heptane which causes knocking and has an octane number of 0. For example, if a gasoline sample has the same antiknock quality as that of a mixture containing 90 % *iso*-octane and 10 % heptane, then the octane number for that sample is defined as 90.

Chemistry in Society

- The short chain alkenes such as ethene are always produced in cracking. They are important for use in chemical industry and in the production of plastics.
- The branched-chain alkanes produced by cracking are useful components of high octane petrol.
- Antiknocking agent (e.g., tetraethyl lead) is a gasoline additive used to reduce engine knocking and increase the fuels octane rating by raising the temperature and pressure at which auto-ignition occurs.

Review Questions

(1) What happens during cracking? Discuss briefly.
(2) Cracking is a thermal decomposition. Explain why.
(3) Describe the usual conditions needed for cracking a hydrocarbon in the petroleum refinery.
(4) Explain why cracking is so important.

Key Terms

- **Catalytic cracking** is a process used to split long chain alkanes into shorter alkanes and alkenes in the presence of catalyst under pressure and high temperature.
- **Catalyst** is a substance that speeds up the chemical reaction without getting consumed.
- **Zeolites** are microporous, aluminosilicate minerals commonly used as commercial adsorbents and catalysts.
- **Thermal decomposition** is the breaking down of a chemical compound, caused by heat.
- **Octane rating (octane number)** is a measure of a fuel's ability to resist 'knock'.
- **Engine knocking** refers to the sharp sounds caused by combustion of some of the compressed air-fuel mixture in the cylinder.

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8.4 ALTERNATIVE FUELS

Fossil fuels take millions of years to form. There are limited amounts in the Earth. At the present rate of consumption, petroleum and natural gas may run out within 50 years and coal will only last for a further 250 years. Therefore, scientists have tried to overcome the problem of limited crude oil supply by looking for alternative fuels to replace crude oil.

An **alternative fuel** is an internal combustion engine fuel other than gasoline or diesel oil. Alternative fuels include natural gas (methane, compressed natural gas - CNG), propane (liquefied petroleum gas - LPG), hydrogen fuel, biomass-derived fuels, biodiesel, bio-alcohols (including ethanol and methanol), alcohol mixtures with gasoline or other fuels (gasohol) and electricity.

Hydrogen fuel, biomass-derived fuels, biodiesel, bio-alcohols (including ethanol and methanol) are renewable fuels, and also known as alternative transport fuels.

Some alternative fuels and their uses are described in Table 8.2.

Table 8.2 Some Alternative Fuels and Their Uses

Fuels	Source	Composition	Uses
LPG (Liquefied Petroleum Gas)	petroleum gas	propane and butane	used as fuels in vehicles, cars, trucks and stationary power generation, for cooking and other heating systems
CNG (Compressed Natural Gas)	natural gas	90 % methane	used as fuels in vehicles, cars, trucks and stationary power generation
biodiesel	plant oils, animal oils	long chain esters	used in power tractor engines, petro-diesel engines and electricity generation engines
biogas	waste organic matter	methane	used for heating and cooking, and the solid residue is used as a fertiliser
hydrogen fuel	water, petrol and natural gas	hydrogen	used as fuels for cars, in space shuttles and other big rockets
gasohol	petrol and ethanol	90 % petrol + 10 % ethanol, 15 % petrol + 85 % ethanol (US)	used as fuels in vehicles

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Preparation of biodiesel

The plant or animal oils have to be converted to biodiesel by **'Transesterification'**. The conversion involves four stages :

(1) the preparation of nearly **100 % pure methanol or ethanol,**
(2) the addition of **potassium hydroxide or sodium hydroxide basic catalyst** to the prepared pure methanol or ethanol,
(3) the treatment of the seed oil with the prepared basic catalytic solution and the solution heated to 60 °C which is the **transesterification** process producing methyl or ethyl ester as **the product (biodiesel)** of the reaction and
(4) the removal of glycerine and sodium or potassium salt of fatty acids (soap) from the reaction mixture by washing with water, and pure biodiesel is separated out by using the **biodiesel processor**.

The transesterification reaction can be generally presented as below.

$$\text{triglyceride} + \text{alcohol} \xrightleftharpoons{\text{catalyst}} \text{esters} + \text{glycerol}$$

$$\begin{array}{l} CH_2\text{-O-CO-}R_1 \\ | \\ CH\text{ -O-CO-}R_2 \\ | \\ CH_2\text{-O-CO-}R_3 \end{array} + 3\ R\text{-}OH \xrightleftharpoons{\text{catalyst}} \begin{array}{l} R\text{-O-CO-}R_1 \\ R\text{-O-CO-}R_2 \\ R\text{-O-CO-}R_3 \end{array} + \begin{array}{l} CH_2\text{ - }OH \\ | \\ CH\text{ - }OH \\ | \\ CH_2\text{ - }OH \end{array}$$

Biodiesel can be used to power tractor engines, petro-diesel engines and electricity generation engines. It is the potential substitute for petro-diesel since the source of the biodiesel is renewable and cost effective.

Hydrogen fuel

Most hydrogen is manufactured on a **large scale** in industry from petrol and natural gas. For example, a mixture of methane (from natural gas) and steam is passed over a nickel catalyst.

$$\text{methane} + \text{steam} \xrightarrow{Ni} \text{carbon monoxide} + \text{hydrogen}$$
$$CH_4(g) + H_2O(g) \xrightarrow{Ni} CO(g) + 3H_2(g)$$

The carbon monoxide gas is then reacted with more steam.

$$\text{carbon monoxide} + \text{steam} \longrightarrow \text{carbon dioxide} + \text{hydrogen}$$
$$CO(g) + H_2O(g) \longrightarrow CO_2(g) + H_2(g)$$

The hydrogen is separated from the carbon dioxide by passing the gases through an alkali to absorb the acidic carbon dioxide.

Smaller quantities of hydrogen are produced by the electrolysis of water containing sulphuric acid, though it is more expensive.

$$\text{water} \longrightarrow \text{hydrogen} + \text{oxygen}$$
$$2H_2O(l) \longrightarrow 2H_2(g) + O_2(g)$$

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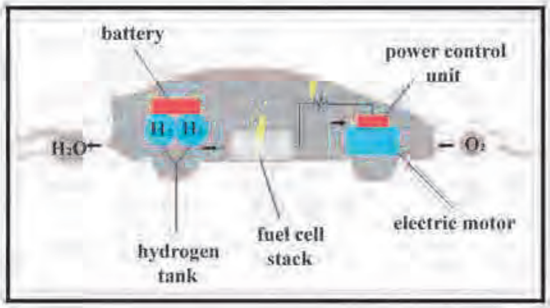
Hydrogen burns cleanly in air. The product is steam, which is a non-pollutant.

$$\text{hydrogen} + \text{oxygen} \longrightarrow \text{steam}$$

$$2H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$$

However, hydrocarbon fuels, such as petrol and diesel, produce polluting oxides of carbon in combustion.

Hydrogen produces at least twice as much heat energy per gram when burnt, than any other common fuel. This is why it is used as a fuel in space shuttles and other big rockets. Hydrogen has great possibilities as a fuel for cars, replacing petrol. Experimental hydrogen-powered cars are already being used.



Hydrogen fuel cell car

Hydrogen fuel cell in space shuttle

Biogas (Methane or Marsh gas)

Methane gas is formed naturally under a number of different circumstances. Anaerobic bacteria help decomposition of organic matter under geological conditions to produce natural gas. Methane accumulates in coal-mines, where it can cause explosions. Marsh gas, which bubbles up through the stagnant water of marshes, swamps and paddy fields, is also methane. Methane produced in this way contributes to the **'greenhouse effect'**.

Methane is produced from organic waste (biomass) when it decays in the absence of air. This can be exploited as a source of energy. In India and China, biomass digesters are important sources of fuel for villages. Industrialized countries produce large amounts of waste, which is deposited in landfill sites. Biogas forms as the rubbish decays.

Chemistry in Society

- The order for the main energy sources currently used in the world in terms of producing energy is:
  crude oil > coal > natural gas > hydroelectric > nuclear fission > wind > biofuels > solar > geothermal.
- Plant oil, hydroelectric, wind, biofuels, solar and geothermal are all renewable energy sources.
- Natural gas offshore projects in Myanmar are Yadana project, Yetagon project, Shwe Platform project and Zawtika project.

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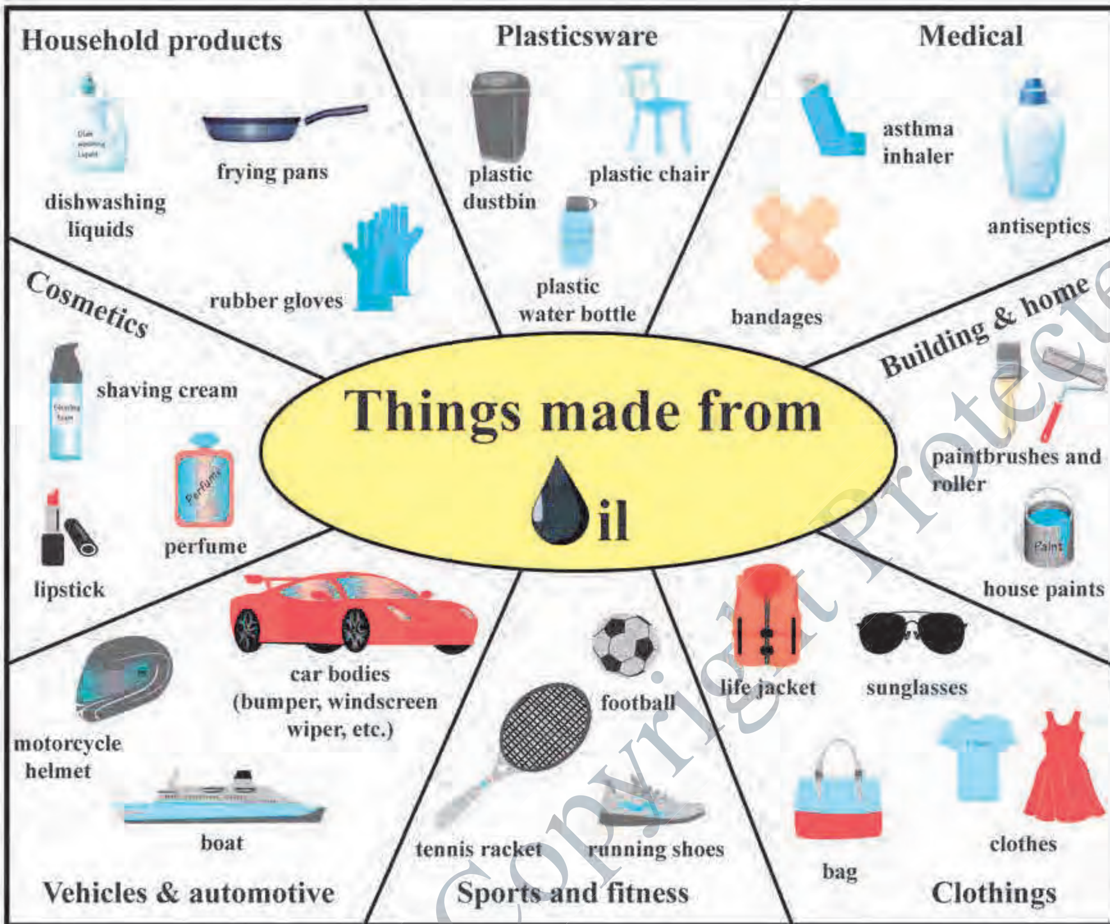

Petroleum products

Natural gas offshore projects in Myanmar

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Review Questions

(1) Name each alternative fuel that: (a) is used for cooking and heating systems (b) has the composition of long chain ester (c) is the source of waste organic matter (d) has molecules with 15-20 carbon atoms.

(2) What are the differences between diesel and gasohol?

Key Terms

- **CNG** refers to compressed natural gas (90 % methane) and **LPG** refers to liquefied petroleum gas which is composed of propane and butane.
- **Biodiesel** refers to a vegetable oil- or animal fat-based diesel fuel consisting of long-chain alkyl (methyl, ethyl, or propyl) esters.
- **Transesterification** is the process of exchanging the alkoxy group of an ester compound by another alcohol. These reactions are often catalysed by the addition of an acid or a base catalyst.
- **Biogas** is the mixture of gases produced by the breakdown of organic matter in the absence of oxygen.

EXERCISES

1. Write TRUE or FALSE for each of the following statements. If FALSE, correct it.
   (a) Nowadays, all fossil fuels are not used up rapidly.
   (b) There is a gradual change in the physical properties of the petroleum fractions.
   (c) Hydrogen is a good fuel because it is non-polluting when it burns.
   (d) At present, there is no alternative fuel to fossil fuels.
   (e) Catalytic cracking results in more branched-chain alkanes.

2. Match each of the items given in List A with the appropriate correct item shown in List B.

List A	List B
(a) coke	(i) produced from plant oil
(b) methane	(ii) formed from waste organic matter
(c) biodiesel	(iii) blended fuel from petrol and ethanol
(d) biogas	(iv) a reducing agent
(e) gasohol	(v) main constituent of natural gas

3. Complete the following sentences by using the words given.
   (a) boiling points, bitumen, fractional distillation, hydrocarbons, crude oil, number of carbon atoms, natural gas, coal, fuel oil
   Fossil fuels are classified into ____, _____ and _____. Petroleum is a mixture of _____. It is separated into different fractions by _____. As the _____ of the fractions increase, the _____ of the fractions increase. The last fraction is _____ and the residue is _____.
   (b) alcohol, ester, transport, petrol-diesel, transesterification, sodium hydroxide, biodiesel
   Plant oils can be converted to _____ by using _____. The plant oils are treated with _____ catalyst, in the presence of 100 % pure ____ at 60 °C. The resultant product is ____. It is a potential substitute for _____ and so it is an alternative _____ fuel.

4. Petroleum is considered as a non-renewable fuel while oil from palm trees is considered as a renewable fuel. Explain this statement.

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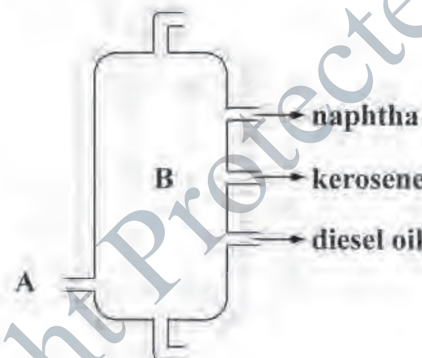
5. (a) Hydrogen is used as a rocket fuel. Why?
   (b) How can you produce hydrogen fuel from (i) natural gas and (ii) water? Write down the chemical equations in words and symbols.

6. Explain the term 'transesterification' in your own words. Describe the application of this reaction.

7. What is meant by the term 'octane number'? Why is it significant?

8. The diagram shows how petroleum can be refined.



   (a) What does 'refining petroleum' mean?
   (b) Name the process used to refine petroleum.
   (c) What change of state occurs at A?
   (d) Explain how petroleum is separated at B.
   (e) State (i) two similarities; (ii) two differences between naphtha and diesel oil.
   (f) Name two fuels, suitable for cars, which are not obtained from petroleum.
   (g) Among three fractions, which fraction has the lowest boiling point and which one has the highest boiling point?
   (h) Among three fractions, which fraction contains the smallest molecules and which one contains the biggest molecules?

9. Petroleum is a mixture of hydrocarbons. The different hydrocarbons have different boiling points and petroleum has to be separated into its various components before the individual components can be used.
   (a) How would you explain the term 'hydrocarbon'?
   (b) Name the separation method used to separate petroleum in oil refineries. What physical property of liquids makes separation by this method?
   (c) Suggest the name of a petroleum fraction that would be suitable for each of the following purposes:
      (i) seal cracks in the concrete tanks
      (ii) boil a beaker of water in the laboratory
      (iii) protect a wooden furniture
      (iv) oil the sewing machine to reduce friction

10. Cracking is a process that split larger hydrocarbons into smaller ones.
   (a) Give two reasons why an oil company might want to crack a hydrocarbon.
   (b) Give the conditions under which cracking is carried out.
   (c) A molecule of the hydrocarbon $C_{11}H_{24}$ was cracked to give two molecules of ethene (C_2H_4) and one other molecule. Write a balanced chemical equation for the reaction which took place.
   (d) Write a chemical equation for an alternative cracking reaction involving the same hydrocarbon $C_{11}H_{24}$.

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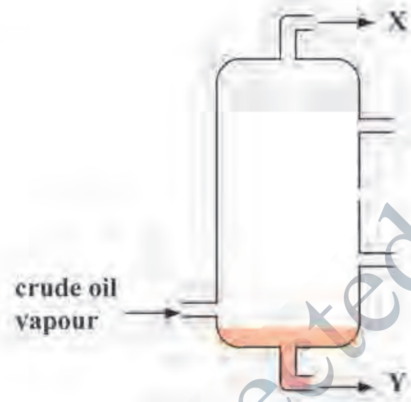
11. The diagram given represents the process of fractional distillation of crude oil. Which of the following statements about fractions **X** and **Y** is correct? Give reason for your answer.
    (a) **X** burns more easily than **Y**.
    (b) **X** has a higher boiling point than **Y**.
    (c) **X** is used for making road surfaces.
    (d) **Y** is the lighter fraction compared with **X**.



12. Consider the following petroleum fractions: diesel oil, kerosene, naphtha, petroleum gas, bitumen.
    (a) Place the above fractions in order of decreasing volatility from most volatile to least volatile.
    (b) Of the fractions given above,
        (i) which contains hydrocarbon with more than 20 carbon atoms per molecule?
        (ii) which contains propane (C_3H_8)?
        (iii) which is used as a starting material for making plastics?

13. A hydrocarbon, **Q**, was found to contain 82.8 % carbon by mass.
    (a) What is the empirical formula of **Q**?
    (b) The molecular formula of **Q** is C_xH_{10}. In which petroleum fraction would **Q** be found? Explain your answer.

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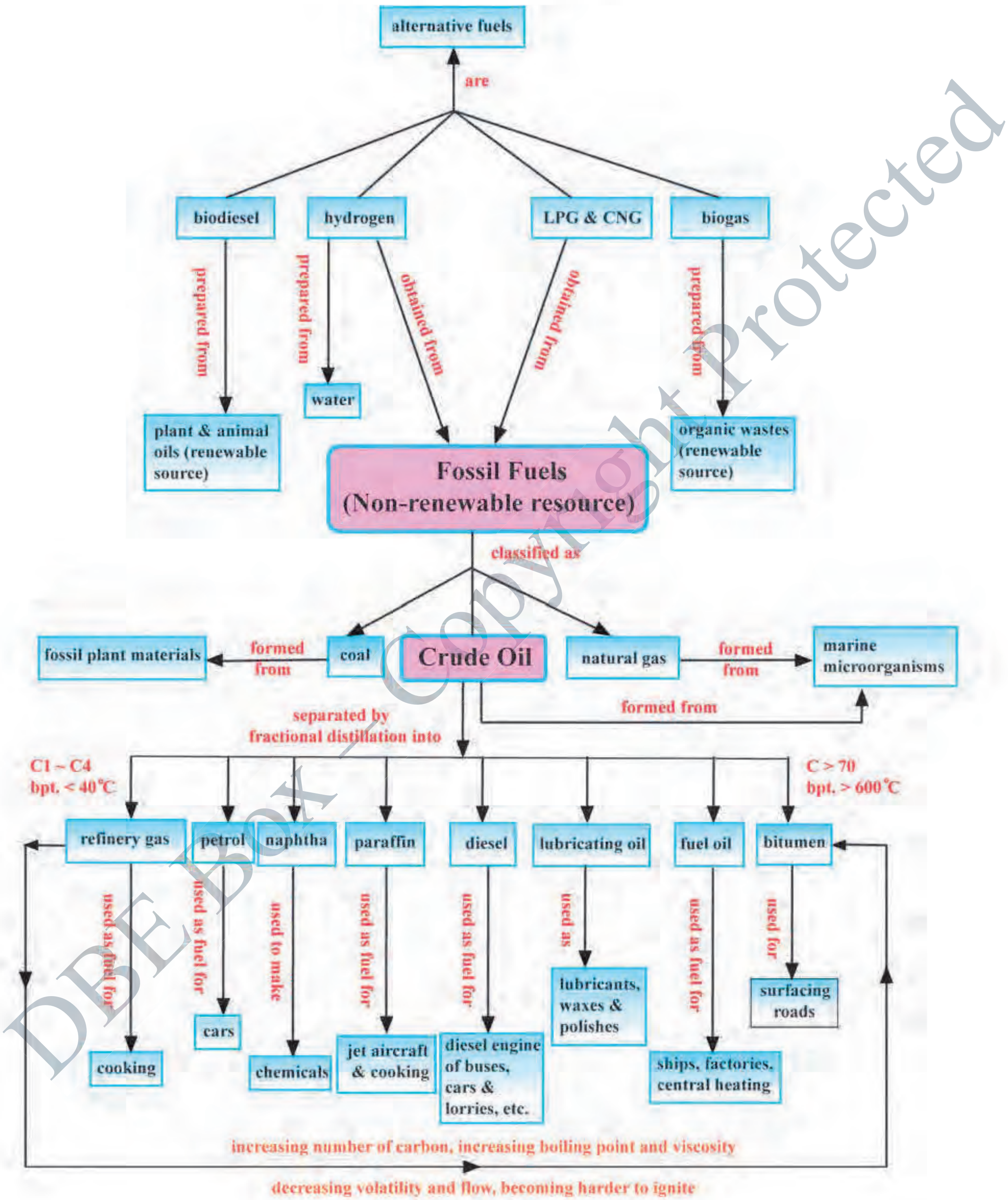
CHAPTER REVIEW
(Concept Map)



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GLOSSARY

Acid a compound that dissolves in water to produce hydrogen ions, H^+

Acidic oxide a non-metallic oxide which reacts with basic oxide to produce salt

Acid rain the rain formed when acidic air pollutants mainly sulphur dioxide and nitrogen dioxide react with water in the air (atmosphere)

Air pollution the condition in which air contains a high concentration of air pollutants that may harm living things and also damage non-living things

Alkali a base which is soluble in water producing OH^- ions

Allotropes Two or more forms of an element that occur in the same physical state but different in properties

Alloy a substance made by combining two or more metallic elements, especially to give greater strength or resistance to corrosion

Amphoteric oxide a metallic oxide which possesses both basic and acidic properties

Anion a negatively charged ion

Atom the smallest particles into which an element can be divided

Atomic number (Z) the number of protons in the nucleus of an atom of an element

Avogadro's constant the number (6.02×10^{23}) of entities or a stated type of particles (atoms, ions or molecules) in a mole of those substances

Base a chemical compound that combines with an acid to form a salt and water

Basic oxide a metallic oxide which reacts with acid to form salt and water

Binary compounds compounds formed by the combination of two elements

Biodiesel a vegetable oil- or animal fat-based diesel fuel consisting of long-chain alkyl (methyl, ethyl, or propyl) esters

Biogas the mixture of gases produced by the breakdown of organic matter in the absence of oxygen

Boiling point the temperature at which the vapour pressure of the liquid is equal to the atmospheric pressure of the surrounding

Brownian motion the continuous random movement of small particles suspended in a gas or liquid, which arises from collisions with the gas or liquid particles, e.g., the motion of pollen grains on still water, movement of invisible dust in a room

Catalyst a substance that speeds up the chemical reaction without getting consumed

Catalytic cracking a process used to split long chain alkanes into shorter alkanes and alkenes in the presence of catalyst under pressure and high temperature

Cation a positively charged ion

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Centrifugation a technique used for the separation of particles from a solution according to their size, shape, density, viscosity of the medium and rotor speed

Chemical change a change in which one or more new substances are formed

Chromatography a separation method of mixed substances that depends on the speed at which they move through special media, or chemical substances

CNG Compressed Natural Gas (90 % methane)

Complete electronic structure the arrangement of all the electrons of an atom of the element in appropriate sub-shells

Compound a substance containing two or more different elements chemically joined together in a fixed ratio

Compound oxide the combination of two different oxides of the same element

Concentrated acid an acid solution which contains the pure acid or predominantly large proportion of the acid

Condensation the change from a gaseous state to its liquid state

Covalent bond a bond formed by sharing of electrons between two atoms by weak intermolecular force of attraction

Crude oil a mixture of many different hydrocarbon molecules

Crystallisation a process by which a chemical is converted from a liquid solution into a solid crystalline state

Decantation a process to separate mixtures of solid and liquid or two immiscible liquids to settle and separate by gravity

Degree of hardness of water the number of parts of mass of $CaCO_3$ (calcium carbonate), equivalent to various calcium and magnesium salts present in one million parts by mass of water (ppm)

Deposition the direct solidification of a vapour by cooling; the reverse of sublimation

Diatomic molecules molecules composed of only two atoms of same or different elements

Dilute acid an acid solution which contains a relatively small amount of the acid

Dissociation reaction a chemical reaction in which a compound breaks apart into two or more parts

Electron affinity the energy released when an electron is added to a gaseous atom to form a gaseous ion

Electronegative elements non-metals which tend to gain electrons and form negative ions

Electronic structure the distribution of electrons in an atom of an element

Electropositive elements metals which tend to lose electrons and form positive ions

Element a substance that cannot be broken down into other simpler substances through chemical means

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Empirical formula formula which shows the simplest whole number ratio of atoms in a compound

Engine knocking the sharp sounds caused by combustion of some of the compressed air-fuel mixture in the cylinder.

Essential electronic structure the representation of the arrangement of valence electrons of an atom of the element in appropriate sub-shells

Evaporation the process of a substance in a liquid state changing to a gaseous state due to an increase in temperature and / or pressure

Filtration a method for separating an insoluble solid from a liquid

Fossil fuels the fuels consisting of coal, petroleum (crude oil) and natural gas

Fractional distillation a method for separation of a liquid mixture into fractions with different boiling points (and hence chemical composition) by means of distillation, typically using a fractionating column

Freezing the process in which a liquid becomes sufficiently cold to change into a solid

Freezing point the temperature at which a liquid becomes a solid

Fuel a substance that releases sufficient energy to do work as it undergoes a chemical change

Global warming the increase in the Earth's average temperature due to the built-up of greenhouse gases in the atmosphere

Hard water water which will not readily form a permanent lather with soap

Heterogeneous mixture one that is non-uniform, and where the different components of the mixture can be seen (The components separate, and the composition varies.)

Homogeneous mixture one in which the composition of its components are uniformly mixed throughout (The components cannot be seen separately on visual or microscopic examination.)

Hydrocarbon any of a class of organic chemical compounds composed only of the elements carbon (C) and hydrogen (H)

Indicator a substance that has different colours in acidic and alkaline solutions

Ion a charged particle

Ionic bond a bond formed by the complete transfer of an electron or electrons from one atom to another resulting in the formation of cations and anions. These oppositely charged ions are held together by a force of electrostatic attraction

Ionisation energy the amount of energy required to remove an electron from a gaseous atom to form a gaseous ion

Isobars the atoms with same mass number but different atomic numbers

Isotopes atoms of the same element that have the same number of protons but different number of neutrons (or) the atoms of the same element with different masses

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Law of conservation of mass the law that states that the total mass of the reactant(s) equals to the total mass of the product(s)

LPG Liquefied Petroleum Gas which is composed of propane and butane

Magnetic separation a method used to separate the components of a mixture when at least one of them is magnetic in nature

Matter a substance made up of tiny particles, and has mass and takes up space. Three common states of matter are solid, liquid and gas.

Mass number (A) the sum of the number of protons and neutrons or the total number of nucleons in the nucleus of an atom of an element

Melting point the temperature at which a solid changes to a liquid state at one atmospheric pressure

Metalloids the elements that have the properties of both metals and non-metals

Mixture a combination of more than one substance, where these substances are not bonded to each other (It consists of two or more substances which may be present in any proportion by weight. The constituents of the mixture do not combine chemically.)

Molar mass the mass of one mole of a substance

Molar volume of a gas a volume of 24 dm^3 or 24,000 cm^3 at room temperature and pressure (r.t.p.) for one mole of gas

Molecular formula formula that shows the total number of atoms of each element present in one molecule or one formula unit of the compound

Molecule the simplest unit of a chemical substance, usually a group of two or more atoms

Neutral oxide an oxide that does not react with either acids or bases

Neutralisation the reaction between an acid and a base to form a salt and water only

Non-renewable fuels fuels which take millions of years to form and which are used up at a rapid rate

Nucleon number the total number of protons and neutrons in the nucleus of its atom

Octane rating (octane number) a measure of a fuel's ability to resist 'knock'

Octet rule a rule which states that in forming a chemical bond, atoms gain, lose or share electrons in such a way to attain the stable electronic structures of the noble gases, i.e., to have eight electrons in the outermost shell

One mole of a substance the amount of substance that has the same number of particles (atoms, molecules, etc.) as there are atoms in exactly 12 g of ^{12}C

Organic matter a substance that is made up of undecomposed and partially decomposed residue of plant and animal tissues of living and dead microorganisms

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Oxidation number the combining capacity of the element and also indicates the positive and negative nature of its atoms in the compounds

Periodic Table a list of chemical elements arranged in order of atomic number in rows, so that elements with similar electronic structures (and hence, similar chemical properties) appear in vertical columns

Permanent hardness of water hardness of water caused by dissolved calcium or magnesium chloride and sulphate which cannot be removed by boiling

Permutit method a process in which hard water containing calcium or magnesium salt is passed through a layer of sodium zeolite, the calcium is abstracted and the corresponding sodium salt passes in solution.

Peroxide an oxide that reacts with an acid to produce salt and hydrogen peroxide

pH a measure of the acidity or alkalinity of a solution

Physical change a change in which no new substances are formed (There may be a temporary change in colour, temperature and state of the substances but no new substances are formed.)

Polyatomic molecules molecules composed of three or more atoms of same or different elements

Product the substance that is produced in the reaction

Reactant the substance that takes part in the reaction

Relative atomic mass the average mass of one atom of that element compared to one twelfth the mass of one atom of carbon-12

Relative formula mass the sum of the relative atomic masses of all the atoms in the formula

Relative molecular mass the mass of one molecule of a substance compared to one twelfth the mass of one atom of carbon-12

Renewable fuels fuels produced from renewable resources

Salt a substance produced from the reaction between an acid and a base or a metal

Saturated solution a solution in which no more solute will dissolve at the given temperature, in the presence of excess solute

Simple distillation a procedure by which two liquids with different boiling points can be separated

Soft water water which readily gives a permanent lather with soap

Soil texture a measure of the relative propotion of sand, silt and clay separates (particles) found in the soil

Solubility the mass in grams of the substance which will saturate 100 g of water, at given temperature

Solute a substance which dissolves in a solvent to give a solution

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Solution a clear homogeneous mixture obtained when a substance dissolves in a solvent (In a solution the solute is uniformly distributed throughout the solution.)

Solvent a substance, mostly liquid, in which another substance dissolves to give a homogeneous mixture

STP standard temperature, 0 °C or 273 K and standard pressure, 760 mmHg or 1 atmosphere

Strong acid an acid that completely dissociates in water and gives H^+ ions

Strong base a base that completely dissociates in water producing OH^- ions

Sublimation the change of solid state directly into gaseous state without melting

Supersaturated solution a solution that retains more solute than that required to saturate the solution at room temperature

Temporary hardness of water hardness of water caused by dissolved calcium hydrogen carbonate which is removed by boiling

Ternary compounds the compounds formed by the combination of three elements

Thermal decomposition the breaking down of a chemical compound, caused by heat

Transesterification the process of exchanging the alkoxy group of an ester compound by another alcohol

Triatomic molecules molecules composed of only three atoms of same or different elements

Unsaturated solution a solution in which more of the solute can dissolve at the given temperature

Valence the number of electrons in the outermost shell when the number of electrons in the outermost shell is 4 or less, or equals to 8 minus number of electrons in the outermost shell when the number of electrons in the outermost shell is greater than 4.

Vaporisation the process that occurs when a chemical or element is converted from a liquid to a vapour

Water hardness the amount of dissolved calcium ions, magnesium ions or both in the water

Weak acid an acid that partially dissociates in aqueous solution and gives H^+ ions

Weak base a base that partially dissociates in water producing OH^- ions

Zeolites microporous, aluminosilicate minerals commonly used as commercial adsorbents and catalysts

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