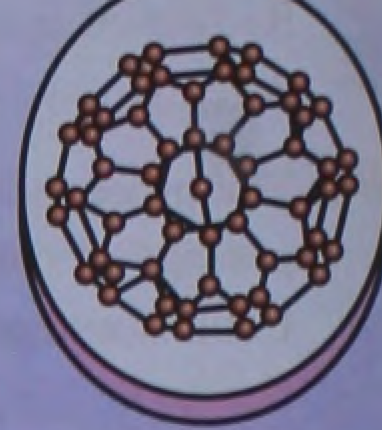
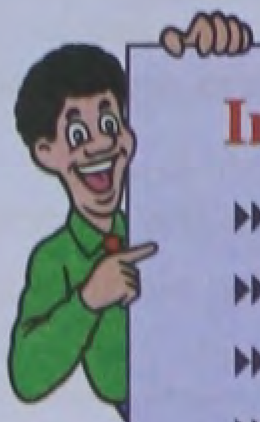
4 CARBON AND ITS COMPOUNDS





In This Chapter You Will Learn :

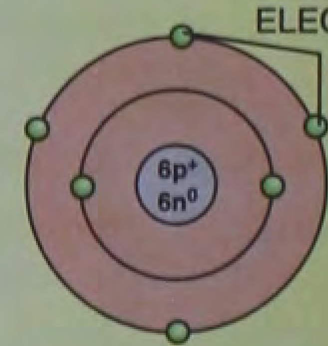
- *Introduction and occurrence*
- *Allotropy and allotropes of carbon*
- *A crystalline form of carbon*
- *Diamond*
- *Graphite*
- *Amorphous form of carbon*
- *Fuels : as source of energy*
- *Types of fuels and characteristics of good fuels*
- *Fossil fuels : coal, petroleum and its products, natural gas*
- *Combustion*
- *Flame : parts of a candle flame*
- *Fire and fire extinguishers*
- *Carbon monoxide : a poisonous gas and a reducing agent*

Symbol of carbon **:** C, ***Atomic number*** **:** 6, ***Mass number*** **:** 12, ***Valency*** **:** 4

INTRODUCTION

Carbon is the very basis of life, since matter constituting all living things, whether plants or animals, contains carbon. Therefore it is not surprising that it is one of the most widely distributed elements on the earth. In fact it is the third most important element, *i.e.* after oxygen and hydrogen, for the existence of life on the earth.

The name *carbon* is derived from the Latin word *carbo* (meaning *coal*).



Orbital structure of carbon has four electrons in its valence shell, i.e. the valency of carbon is 4

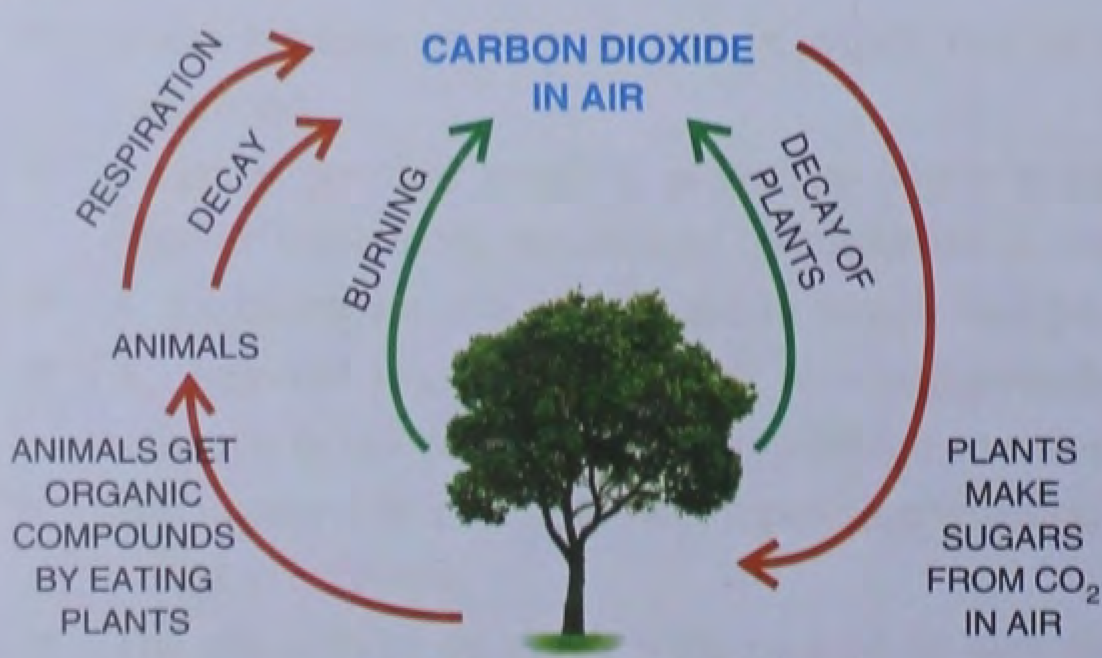


Fig. 4.1 Carbon Cycle

4.1 OCCURRENCE

Carbon occurs in the earth's crust in the free as well as in the combined state.

In the *free state,* it occurs as coal, diamond and graphite.

In the *combined state,* carbon occurs in :

(i) the atmosphere (as carbon dioxide gas).

(ii) natural water as dissolved carbon dioxide

(iii) natural gas and petroleum.

(iv) food nutrients like starch, sugar, fats, proteins, vitamins, *etc*.

(v) carbonates and bicarbonates such as chalk, limestone, marble ($CaCO_3$)*, calamine ($ZnCO_3$), washing soda ($Na_2CO_3 \cdot 10H_2O$) and baking soda ($NaHCO_3$).

(vi) Clothing materials like cotton, silk, terylene, rayon etc.

Note : Carbon is unique non-metal having widely differing forms and properties. Mankind has known carbon in the form of charcoal and soot ever since the discovery of fire.

Although carbon constitutes only 0·03% of the earth's crust, it forms an enormously large number of compounds. The number is so large that an entire branch of chemistry, called **organic chemistry**, is devoted to the study of carbon and its compounds.

In fact, for the convenience of study, all compounds are classified into two classes:

(i) organic compounds

(ii) inorganic compounds.

All organic compounds essentially contain carbon as a constituent.

A few examples of useful organic compounds are starch, wax, vinegar, alcohol, dyes, detergents, soaps, plastics, clothing materials like nylon, silk, wool and cotton, as well as paper, polythene, perfumes, disinfectants and medicines.

* *$CaCO_3$ is the chemical formula for all the three substances, chalk, marble and limestone.*

NAMES OF SOME COMPOUNDS CONTAINING CARBON

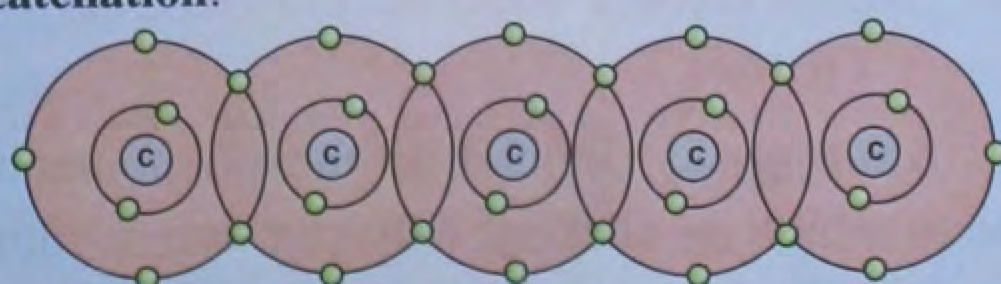
Organic Compounds

Class	Name	Chemical Formulae
Hydrocarbons	Methane	CH_4
	Butane	C_4H_{10}
	Ethene	C_2H_4
	Ethyne	C_2H_2
	Benzene	C_6H_6
	Naphthalene	$C_{10}H_8$
Alcohols	Methyl alcohol	CH_3OH
	Ethyl alcohol	C_2H_5OH
Acids	Acetic acid (vinegar)	CH_3COOH
	Formic acid	$HCOOH$
	Oxalic acid	$(COOH)_2$
Sugars	Glucose	$C_6H_{12}O_6$
	Sucrose	$C_{12}H_{22}O_{11}$

Inorganic Compounds

Name	Chemical Formulae
Carbon dioxide	CO_2
Carbon monoxide	CO
Calcium carbonate	$CaCO_3$
Sodium carbonate	Na_2CO_3
Copper carbonate	$CuCO_3$
Zinc carbonate	$ZnCO_3$
Sodium bicarbonate	$NaHCO_3$
Calcium bicarbonate	$Ca(HCO_3)_2$

Note : The large number of organic compounds is due to the ability of carbon atom to form long chains with other carbon atoms through sharing of electrons. This is a unique property of carbon known as **catenation**.



Carbon atoms can form long chains by sharing their valence electrons with other carbon atoms.

In addition, petroleum is a mixture of carbon compounds found in a liquid state. Also, vegetable oils are the liquid forms of carbon compounds.

Oxides of carbon (CO_2, CO), carbonates and bicarbonates belong to inorganic compounds.

Activity 1

To show the presence of carbon in sugar.

Take some sugar in a test tube. Heat it for some time. You will observe that sugar first melts, then turns brown, and finally gets charred and turns black. This black substance is carbon. This experiment proves that sugar contains carbon.

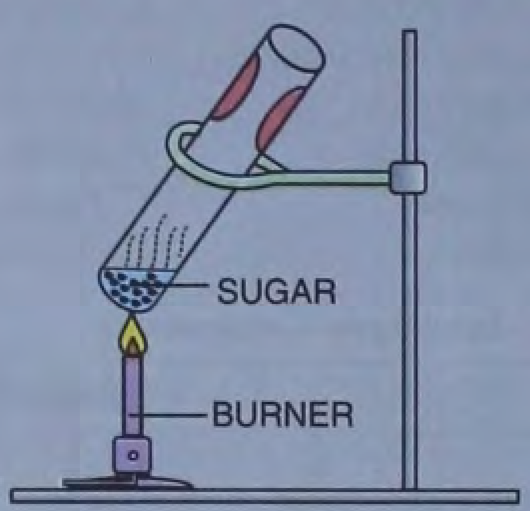


Fig. 4.2 Sugar turns black on heating

Some useful carbon products

1. **PVC :** The full form is polyvinyl chloride. It is used for making pipes.
2. **Bakelite :** It is tough, resistant plastic that can be moulded into different shapes. It is used to make cameras, telephones, plugs *etc*.
3. **Polyethene :** This is another important compound of carbon with various uses. All of you must be familiar with this word polyethene, often used to make carry bags.
4. **Carbon fibre :** Organic textile fibres are heated to make silky threads of pure carbon. These fibres are combined with other materials such as plastic to make very strong and light composite materials, which are useful for objects where tightness and strength are important, from tennis ball to small aeroplanes.

Do you know that these carbon fibres are much thinner than human hair, but are eight times stronger than steel?

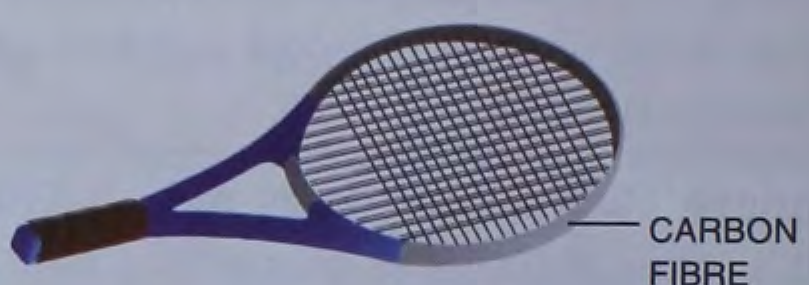


Fig. 4.3 Carbon Fibre

Tennis rackets made with a carbon fibre frame are much lighter and stronger than wooden ones.

A. Crystalline Forms of Carbon

4.2 ALLOTROPY AND ALLOTROPES OF CARBON

Allotropy is defined as the phenomenon due to which an element exists in two or more forms in the same physical state with identical chemical properties but with different physical properties. Such forms of an element are known as its allotropic forms or *allotropes*.

Some elements exhibiting allotropy are carbon, phosphorus and sulphur.

Note : Allotropes of :

(i) Phosphorus : Yellow Phosphorus
Red Phosphorus
White Phosphorus

(ii) Sulphur : Rhombic, Monoclinic, Plastic, Colloidal and flower of sulphur.

The chart given on this page outlines the different allotropes of carbon. The allotropes of carbon are divided into two types:

(i) crystalline allotropes

(ii) amorphous or non-crystalline allotropes

These two broad types are sub-divided into a number of specific allotropes.

All these forms of carbon differ in their physical properties, but when burnt in the presence of oxygen, they all produce carbon dioxide, with the release of heat.

$$\text{Diamond/graphite/coal/coke} + \text{Oxygen} \xrightarrow{\Delta} \text{Carbon dioxide} + \text{Heat}$$

$$C + O_2 \xrightarrow{\Delta} CO_2 + \text{Heat}$$

WHAT ARE CRYSTALS ?

A crystal is a solid whose particles [atoms, molecules or ions] are arranged in a definite pattern and outwardly expressed by a geometrical form (with plane faces).

For example : Sodium chloride and sugar are crystalline in nature, *i.e.* their molecules have a definite cubical shape.

4.3 CRYSTALLINE ALLOTROPES OF CARBON

4.3.1 Graphite

Graphite is a crystalline form of carbon. Natural graphite is extensively found as the mineral *plumbago* in both Sri Lanka and Siberia. In India, graphite is found in Jammu and Kashmir, Bihar, Orissa, Rajasthan and West Bengal.

Preparation of graphite : Pure graphite is prepared artificially by heating powdered coke mixed with a little sand and Iron (III) oxide in an electric furnace to a temperature of about 3000°C.

$$\underset{\text{(Sand)}}{SiO_2} + 3C \xrightarrow[\text{ferricoxide}]{3000°C} 2CO + \underset{\text{(Silicon carbide)}}{SiC}$$

$$SiC \xrightarrow{\Delta} Si + C \text{ (graphite)}$$

Structure of graphite : In a graphite molecule each carbon atom is linked with three neighbouring carbon atoms, thus forming a *hexagonal arrangement of atoms.* These hexagonal groupings of carbon atoms are arranged as layers or sheets piled one on top of the other. The layers are held together by weak forces such that they can slide over one another. This is why graphite is soft and slippery and can be used as a lubricant in machines and in pencil leads. Also, in a

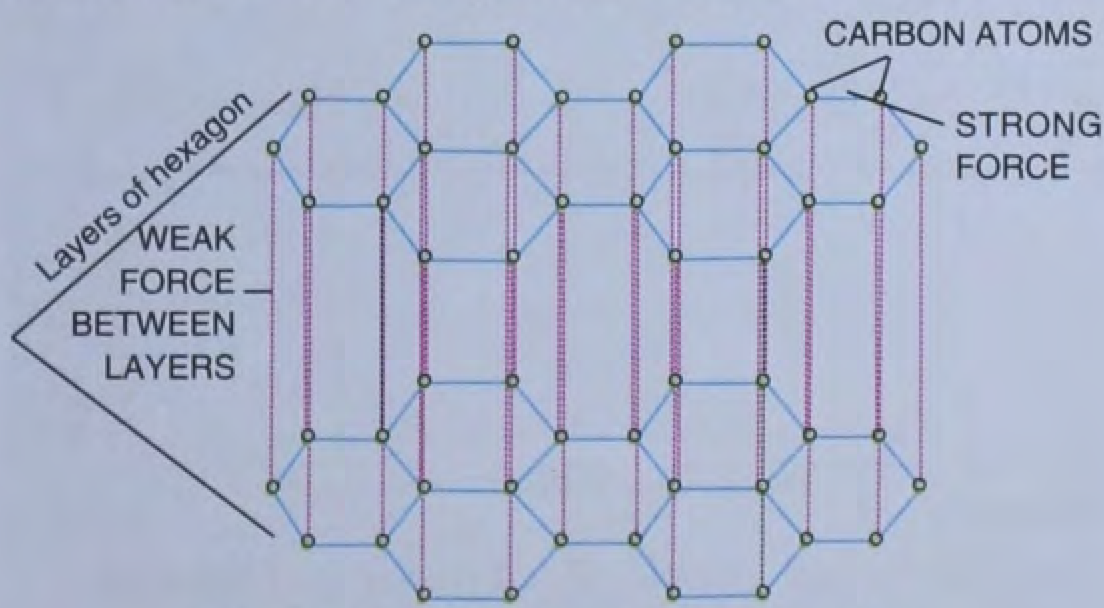
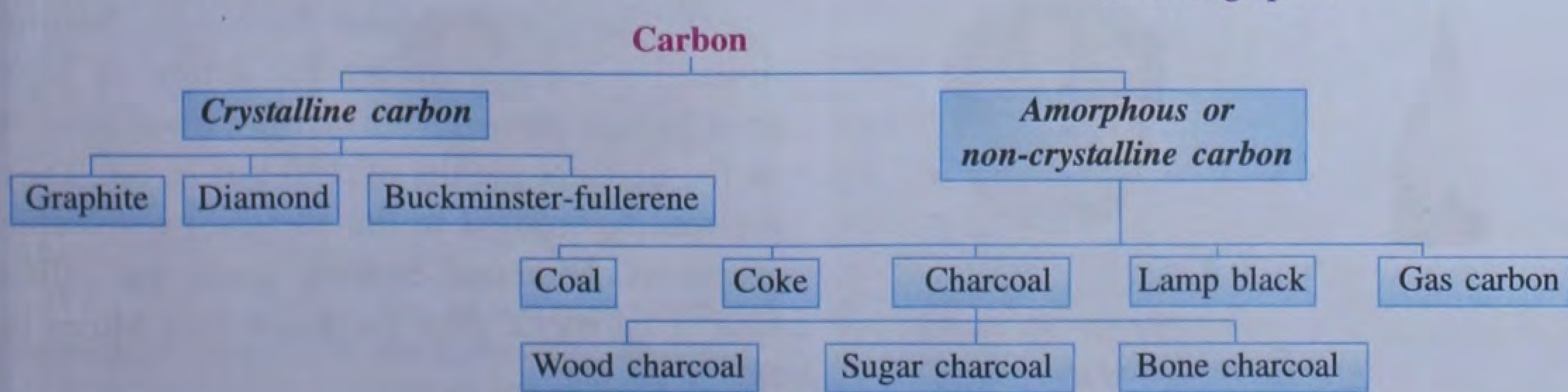


Fig. 4.4 Hexagonal network of carbon atoms in graphite



graphite molecule, one valence electron of each carbon atom remains free, thus making graphite a good conductor of electricity.

Carbon – Carbon binding force is strong in the hexagon itself so the melting point and boiling point are high.

Properties of graphite :

1. Graphite is a greyish black, opaque substance, with a metallic lustre.

Activity 2

TO SHOW THAT GRAPHITE IS A GOOD CONDUCTOR OF ELECTRICITY

Take a graphite rod. Connect it to a battery, a bulb and a switch with the help of connecting wires. Now close the circuit with the help of the switch.

What do you observe?

The bulb starts glowing.

This is because graphite conducts electricity.

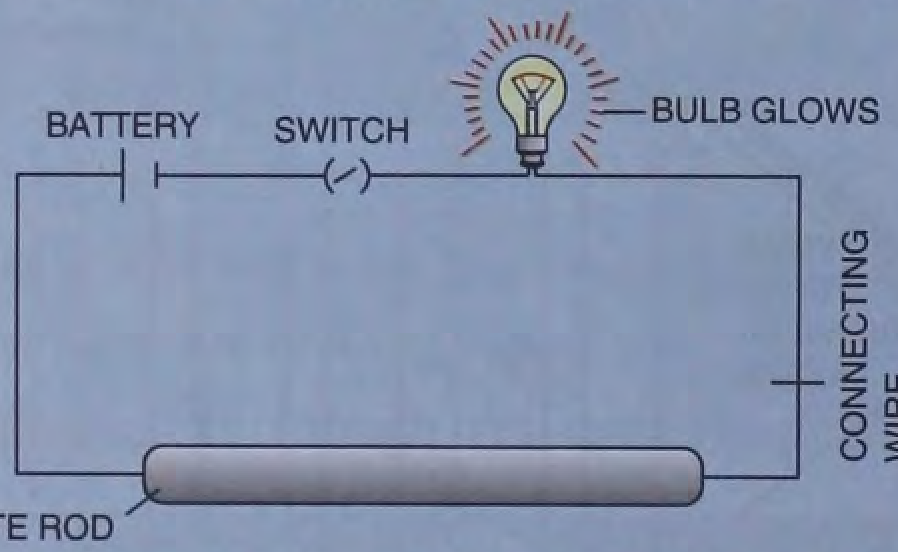


Fig. 4.5(a) An electric circuit (using graphite rod)

Graphite is used in many other ways too.

Fig. 4.5(b) Different uses of graphite

2. Its density is 2·39 g/cm^3.
3. It is stable to heat and has a very high melting point of 3700°C.
4. It is soft and greasy to touch.
5. It marks a black stain on paper.
6. It is a good conductor of heat and electricity.

Uses of graphite :

1. With petroleum jelly to form **graphite grease** (a lubricant).
2. For making the electrodes of electric furnaces.
3. For making crucibles for melting metals due to its high melting point.
4. For making carbon brushes for electric motors.
5. For making pencil leads because it can mark black on paper (pencil leads are made by mixing graphite with variable quantities of clay).
6. It is used in nuclear reactors as moderator to slow down the speed of neutrons.

4.3.2 Diamond

Diamond is perhaps the purest form of carbon. It occurs in all shapes and sizes. Diamonds are found in South Africa, Brazil, Namibia, Russia, Australia, U.S.A. and India. In India, diamonds are found at *Goleconda* in Karnataka and at *Panna* in M.P.

Formation of natural diamonds : Natural diamonds are formed by the action of high pressure and temperature on the carbon present in the earth at depths of 150 km or so. They are mostly brought to the surface by volcanic eruptions. Diamond bearing rocks are called *kimberlite rocks,* after the Kimberley Mines in South Africa.

Preparation of artificial diamonds : Synthetic or artificial diamonds are made from graphite. Graphite is subjected to very high temperature (about 3000°C) and pressure. The diamonds produced under such conditions are rather small.

Value of diamonds : The value of a diamond as a gem depends upon :

(i) its weight

(ii) the impurities present in it.

The weight of a diamond is expressed in terms of carats [1 carat = 0·2 g].

Some famous natural diamonds are :

(i) KOHINOOR
(ii) PITT DIAMOND] mined in India

(iii) CULLINAN (the biggest diamond ever found, mined in South Africa).

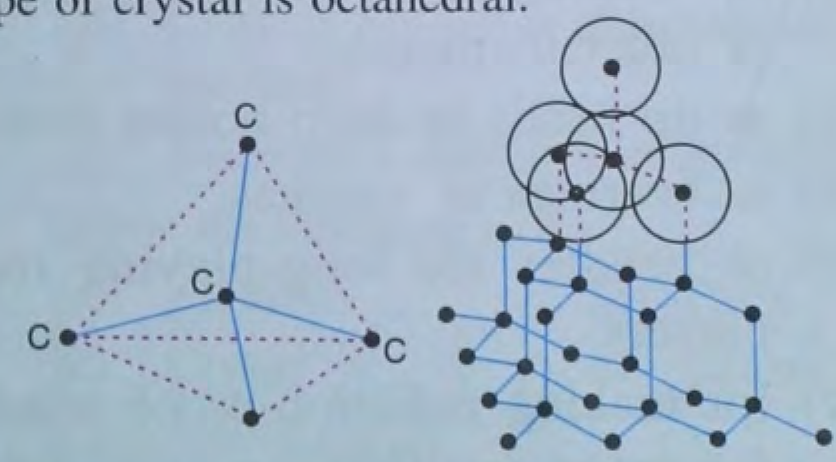
Colourless, transparent diamonds are the costliest because they have negligible impurity. The value of a diamond decreases with an increase in the impurities present in it.

It is the presence of small traces of metallic oxide and salt that imparts distinct colours to diamonds. *These coloured diamonds are called gems.* Diamond gems of the darker colours, *i.e.* red, pink and blue, are extremely rare and therefore very valuable. Diamonds can also be grey, yellow, brown, green and orange, and even black. Black diamonds have copper oxide present in them as impurity. They are not used as gems, but they have important industrial uses.

Fig. 4.6 A diamond sparkles due to the reflection of light from its several cut surfaces.

THE STRUCTURE OF A DIAMOND

A diamond is a giant molecule. The number of valence electrons in a carbon atom is four. As such each carbon atom is linked with four neighbouring carbon atoms, thus forming a rigid tetrahedral structure. It is this strong bonding that makes diamond the hardest naturally occurring substance. Since they have no free or mobile electrons, diamonds do not conduct electricity. The basic tetrahedral unit of a diamond crystal is repeated infinitely forming three dimensional molecule. The shape of crystal is octahedral.



For details about valence electrons refer to Chapter 3.

Properties of a diamond :

1. Pure diamond is transparent and colourless. Impurities impart colours to diamonds.
2. It is the hardest naturally occurring substance. Black diamonds are the hardest of all.
3. It is of a brittle nature.
4. It has a refractive index of 2·5, which is a very high value. Therefore diamonds sparkle.
5. It has a density of 3·5 g/cm^3.
6. It is insoluble in any solvent.
7. It is a bad conductor of heat and electricity.
8. Though it is stable to heat, prolonged heating can change a diamond into graphite.

Fig. 4.7 Diamond Jewellery

Uses of diamonds :

1. Because of its brilliant shine, pure diamond is used in jewellery as a gem.
2. Impure diamond (black diamond) is used:
   (i) for cutting and drilling rocks, glass or other diamonds.
   (ii) as tip heads in deep boring drills.
   (iii) as bearings in watches.
   (iv) as needles for long-playing record players.
   (v) for making radiation-proof windows for space satellites (so as to prevent the entry of harmful radiation).

Differences between diamond and graphite

Diamond	*Graphite*
1. Pure diamond is colourless and transparent.	1. Graphite is greyish black, opaque and shiny.
2. It is the hardest naturally occurring substance.	2. It is soft and greasy to touch.
3. It has high density, *i.e.* 3·5 g/cm^3.	3. It has a comparatively low density, *i.e.* 2·39 g/cm^3.
4. It is a bad conductor of electricity.	4. It is a good conductor of electricity.
5. It burns in air at 900°C to form carbon dioxide.	5. It burns in air at 700°C to form carbon dioxide.

4.3.3 Fullerenes

Fullerenes are the third crystalline form of carbon. Though they were discovered only recently, they have been found to exist in interstellar dust as well as in the geological formations of the earth.

In fullerenes, many carbon atoms are held together in a cage-like structure. (The number of carbon atoms vary between 30-900) In the most common fullerene, called *buckminster fullerene* or *buckyball,* 60 carbon atoms are arranged in a spherical structure. Buckminster fullerene is denoted as C_{60}. It is named after **Richard Buckminster Fuller**, an American architect. There are larger and smaller fullerenes, made of 32, 50, 70 and 76 carbon atoms respectively. However, in fullerenes, the cluster of carbon atoms exists as unlinked particles, unlike as it is in diamond and graphite, where the carbon atoms are held together in a crystalline pattern.

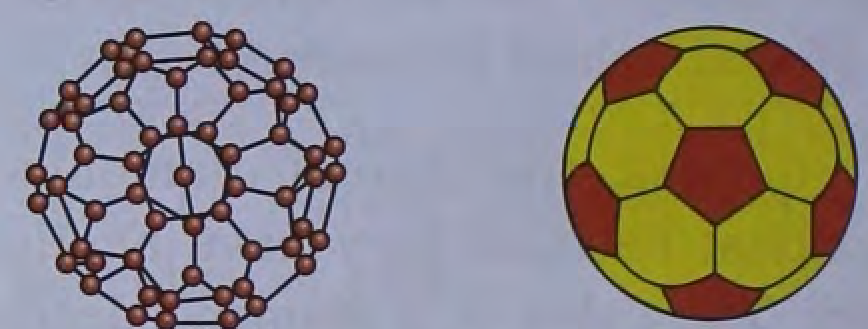


Fig. 4.8 The structure of buckminster fullerene. The structure has hexagons and pentagons, just as there are in a football.

Properties of Fullerene :

1. The colour of fullerenes varies according to the number of carbon atoms present in them.
2. They are soluble in organic solvents.
3. They have specific gravity ranging from 1·8 to 2.1.
4. Chemical fullerenes are more active than diamond and graphite. On heating upto ±1000°C their cage like structure breaks.

Uses :

1. They act as insulators.
2. Some of the compounds of fullerens are used as **superconductors**.

EXERCISE – I

1. Fill in the blanks :
   (a) .... is present in both living and non-living things.
   (b) The tendency of an element to exist in two or more forms but in the same physical state is called ....
   (c) .... and .... are the two major allotropes of carbon.
   (d) .... is the hardest substance that occurs naturally.
   (e) The name 'carbon' is derived from the Latin word ....

2. Choose the correct alternative :
   (a) In combined state, carbon occurs as
      (i) coal (ii) diamond
      (iii) graphite (iv) petroleum
   (b) A crystalline form of carbon is
      (i) lamp black (ii) gas carbon
      (iii) sugar (iv) fullerene
   (c) Graphite is not found in
      (i) Bihar (ii) Maharashtra
      (iii) Orissa (iv) Rajasthan
   (d) Diamond is used for
      (i) making the electrodes of electric furnaces.
      (ii) making crucible for melting metals.
      (iii) cutting and drilling rocks and glass.
      (iv) making carbon brushes for electric motors.
   (e) Carbon forms innumerable compounds because
      (i) it has four electrons in its outermost shell.
      (ii) it behaves as a metal as well as a non-metal.
      (iii) carbon atoms can form long chains.
      (iv) it combines with other elements to form covalent compounds.

3. Write *'true'* or *'false'* against the following statements :
   (a) Carbon constitutes 0·03% of the earth's crust.
   (b) Graphite is the purest form of carbon.
   (c) Coloured diamonds are costlier than colourless and transparent diamonds.
   (d) Graphite has layers of hexagonal carbon bondings.
   (e) Diamond is insoluble in all solvents.

4. Define the following terms :
   (a) Allotropy (b) Carat
   (c) Crystal (d) Catenation

5. Name the following :
   (a) Substances whose atoms or molecules are arranged in a definite pattern.
   (b) Different forms of an element found in the same physical state.
   (c) The hardest naturally occurring substance.
   (d) A greyish black non-metal that is a good conductor of electricity.
   (e) The third crystalline form of carbon.

6. Answer the following questions :
   (a) Why is graphite a good conductor of electricity but not diamond ?
   (b) Why is diamond very hard ?
   (c) What are fullerenes ? Name the most common fullerenes.
   (d) What impurity is present in black diamond ?

7. Explain the softness of graphite with reference to its structure.

8. Give *two* uses of :
   (a) graphite (b) diamond

9. Differentiate between graphite and diamond.

B. Amorphous Forms of Carbon

INTRODUCTION

The word *amorphous* means *lacking in form or shape*. Accordingly, amorphous substances have no particular shape or structure. Their atoms or molecules are not arranged in any regular geometrical pattern. Some common amorphous substances are anhydrous copper sulphate, sulphur powder and talcum powder.

The amorphous forms of carbon include coal, coke, charcoal, lampblack (soot) and gas carbon. They are derived from different sources. The amorphous forms of carbon are usually not pure (except sugar charcoal). Coal occurs in nature while the other forms are obtained as the black residue of compounds rich in carbon when they are heated in the absence of air.

Note : The amorphous forms of carbon contain nitrogen, hydrogen, oxygen and sulphur as impurities.

4.4 COAL

Coal is one of the cheapest fossil fuels. It is a hard black solid. Rich deposits of coal are found in Russia, China, USA, Germany, South Africa and Australia. In India large deposits of coal are found in Jharkhand, West Bengal, Orissa and Madhya Pradesh.

Formation of coal : The formation of coal took millions of years. Coal was formed by the bacterial decomposition of ancient vegetable matter buried under successive layers of the earth. Under the action of high temperature and pressure, and in the absence of air, the decayed vegetable matter converted into coal through a series of steps as shown in the chart given on the next page. With each successive layer of formed coal, the amount of carbon present in the deposit increased and the level of impurities decreased. **This process is known as carbonization** and the most active episode of carbonization took place in the carboniferous era, *i.e.* 270 million years ago.

4.4.1 Types of coal

Carbonization of vegetable matter over millions of years results in four varieties of coal, which vary with respect to their carbon content.

(i) **Peat :** Peat is the first stage in the formation of coal. Therefore it is light brown in colour and contains only about 50 to 60% carbon. So peat is the most inferior form of coal.

(ii) **Lignite :** It is the second stage in the formation of coal. It contains more than 60% carbon. It is also brown in colour, but it is harder than peat.

(iii) **Bituminous :** Bituminous coal is the third stage in the formation of coal. There are high, medium and low varieties of bituminous coal, with carbon content being 90%, 80% and 70–75% respectively.

PLANTS $\xrightarrow[\text{pressure}]{\text{heat}}$ PEAT [light brown; 50– 60 % carbon] $\xrightarrow[\text{pressure}]{\text{heat}}$ LIGNITE [brown, 60–70% C] $\xrightarrow[\text{pressure}]{\text{heat}}$ BITUMINOUS (black, 80–90%C) $\xrightarrow[\text{pressure}]{\text{heat}}$ ANTHRACITE (black, 90–98%C)

Bituminous coal is the most common variety of coal and is also known as household coal. It is black and hard. On heating it, both volatile and non-volatile materials are given out.

(iv) Anthracite : It is the purest variety of coal. It is the oldest stage in the formation of coal. Its carbon content varies between 92-98%. It is hard, dense and black. It is difficult to ignite, but once ignited it burns with a lot of heat and for a very long time. It is found at only a few places in the world.

4.4.2 Uses of coal

1. Coal is used as both a domestic and an industrial fuel, *i.e.* in homes, thermal power stations, steam engines and furnaces.
2. It is used to prepare coke, coal gas and coal tar.
3. It is used in the manufacture of synthetic petrol.
4. Coal is also an important requirement for the manufacture of some fertilizers, drugs, synthetic textiles and perfumes.
5. It is used as a source of organic compounds such as benzene, naphthalene, aniline, *etc*.

4.4.3 Destructive distillation of coal

Destructive distillation of coal produces coke, coal tar, coal gas and ammonia solution.

$$\text{Coal} \xrightarrow[\text{distillation}]{\text{destructive}} \text{Coke} + \text{Coal-tar} + \text{Coal-gas} + \text{Ammonia solution}$$

Important definitions

1. ***Carbonization :*** The process of the slow conversion of vegetable matter into carbon-rich substances is called carbonization.
2. ***Destructive distillation :*** When a substance is heated in the absence of air, the process is called destructive distillation. It results in the decomposition of the substance, bearing a carbon-rich residue.

Activity 3

Experiment : *To study the products obtained by destructive distillation of coal.*

Procedure : Place some powdered coal in a hard-glass test tube. Heat it strongly till it changes into coke that lies in the test tube as a grey porous residue.

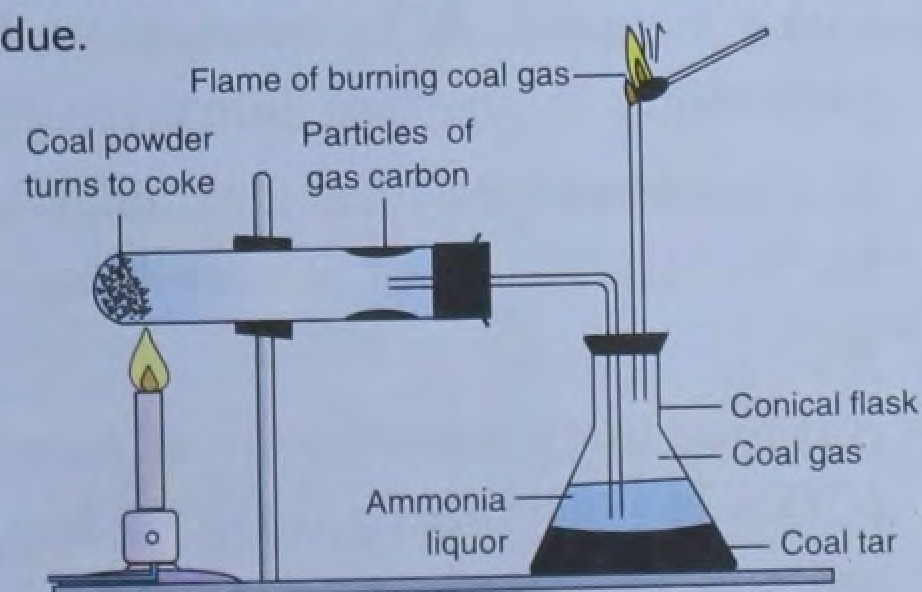


Fig. 4.9 Destructive distillation of coal.

Observation : Dark brownish black vapours are given out. Some carbon present in the vapours solidifies near the mouth of hard-glass test tube and is called *gas carbon*.

When the above vapours are passed through water contained in a conical flask, a large proportion of the vapours condenses to form two distinct layers.

The lower layer consists of a black, thick liquid, which is called *coal tar.* The upper layer contains *ammonia liquor.* A colourless gas bubbles out of flask and it is commonly called *coal gas*. It burns with a yellowish flame when it is ignited.

Coke : Coke is an amorphous form of carbon. It is a black, porous, solid substance that burns without smoke. It contains about 98% carbon. It is a good reducing agent and a bad conductor of heat and electricity. Coke is prepared by the destructive distillation of coal.

Coke is of two types :

Hard coke : It is light lustrous substance used in industrial furnaces.

Soft coke : It is black and porous. It ignites with difficulty and is used in house hold furnaces.

Uses of coke :

1. Coke is used as a smokeless fuel, particularly in smelting furnaces.
2. It is used extensively as a reducing agent for the extraction of metals from their ores.
3. It is used in the manufacture of water gas ($CO + H_2$) producer gas ($CO + N_2$) and artificial graphite.
4. It is also used to prepare metallic carbides, *viz.* calcium carbide.

Coal tar : Coal tar is a foul smelling, dark brown liquid. On fractional distillation it furnishes a number of useful organic compounds that are used for making dyes, drugs and explosives.

Coal gas : Purified coal gas is used as an industrial and a household fuel.

Ammonia solution : It is used in the preparation of artificial fertilizers.

4.5 CHARCOAL

When a solid organic substance is subjected to destructive distillation, a grey black porous solid is produced, which is named as charcoal. Charcoal is obtained from a variety of sources of plant and animal origin. Each type is named after the source from which it is obtained. The three main types of charcoal are wood charcoal, bone charcoal and sugar charcoal.

4.5.1 Wood charcoal

Wood charcoal is prepared when wood is heated in a limited supply of air. It is a black, porous, brittle solid. Locally wood charcoal is prepared by piling logs of wood one above the other with a gap in the centre of the pile. The pile is covered with wet clay to prevent the entry of air. A few holes are left at the bottom of the pile. The wood is set on fire. When the fire dies out, a greyish black, brittle, porous solid is left behind, which is wood charcoal.

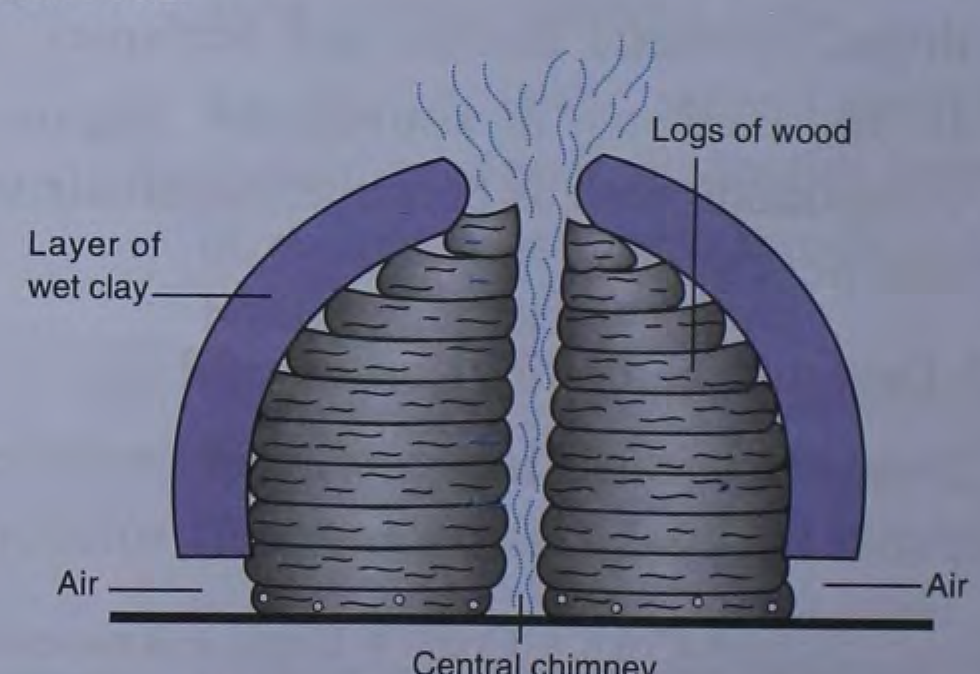


Fig. 4.10 Local preparation of wood charcoal.

Activity 4

To show how to prepare wood charcoal in the laboratory.

Procedure : Take some sawdust in a hard glass test tube. Then fit a right-angled delivery tube to it with the help of a one-holed cork. Dip the other end of the delivery tube in another test tube held in a trough of cold water with the help of a clamp (see Fig. 4.7 below). Fix another delivery tube into the second test tube. Heat the sawdust strongly. Bring a burning match stick near the end of the second delivery tube. The gas that is liberated burns with a blue flame. Keep heating the sawdust till it chars to a black mass.

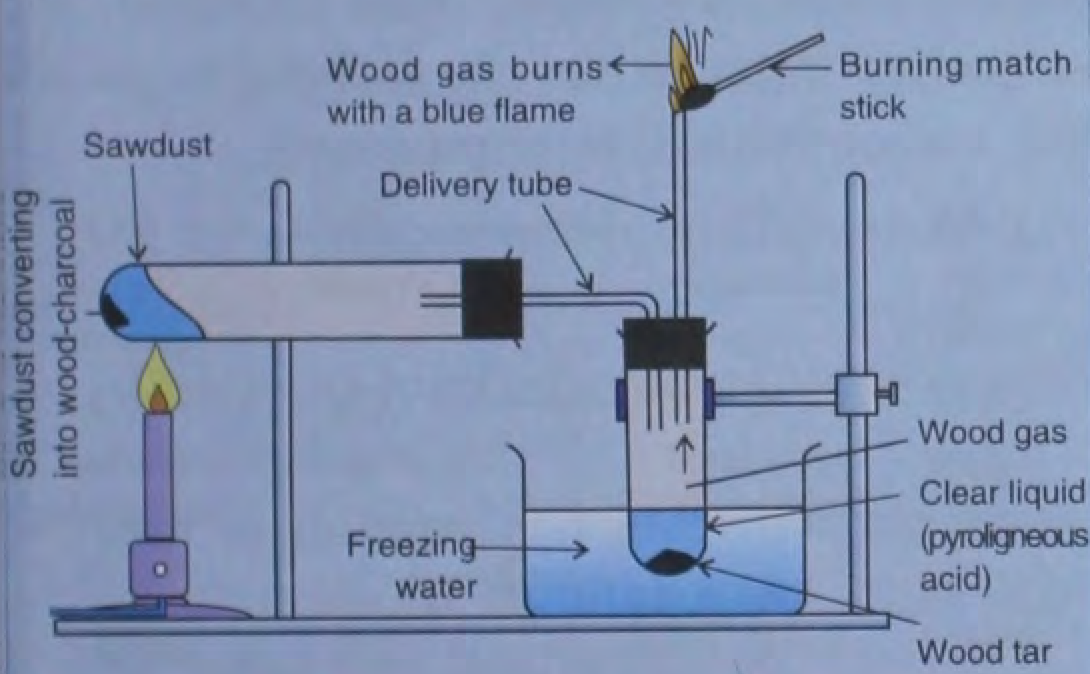


Fig. 4.11 Preparation of wood charcoal

Now the second test tube contains a liquid. *The lower layer of the liquid is dark coloured and is known as* ***wood tar****. The upper, colourless layer of liquid, is known as* ***pyroligneous acid****. The black residue left in the first test tube is* ***wood charcoal****.*

$$\text{Wood} \xrightarrow[\text{distillation}]{\text{destructive}} \underset{\text{charcoal}}{\text{Wood}} + \underset{\text{tar}}{\text{Wood}} + \underset{\text{acid}}{\text{Pyroligneous}} + \text{Wood gas.}$$

Physical properties of wood charcoal :

1. Wood charcoal is a soft, black, porous solid.
2. It is brittle and tasteless.
3. Though it is heavier than water but floats on it, since it is porous and has the capacity to hold air in its pores. When the air is removed from the pores of the wood charcoal by boiling water, the charcoal gradually settles down.
4. It is a bad conductor of heat and electricity.
5. It is a good adsorbent of gases, liquids and solids.

Adsorption is the property due to which a substance absorbs gases, liquids and solids on its surface.

Activity 5

To show that wood charcoal is a good adsorbent.

Procedure : Take a gas jar and fill it with hydrogen sulphide gas. It smells like rotten eggs. Put some charcoal pieces in the jar and close the lid. Now shake the jar and leave it still for a few minutes. Then remove the lid. You will notice that there is no smell in the jar. This proves that char-coal is a good adsorbent.

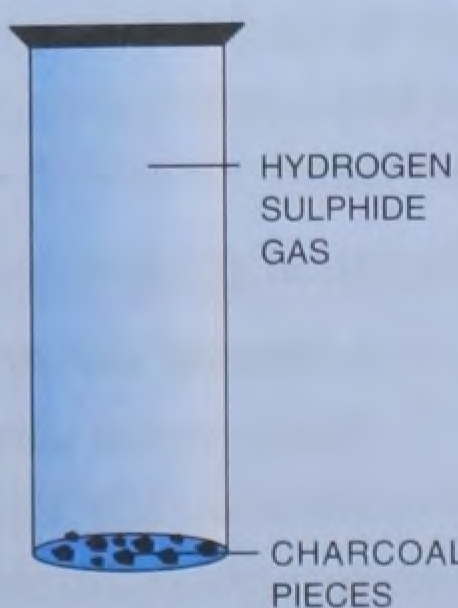


Fig. 4.12
A jar containing a gas with a foul smell

Activity 6

To show that wood charcoal adsorbs colouring matter.

Procedure : Take a glass tumbler, fill it half with water and pour in a few drops of ink. Colourless water turns blue, meaning that an ink solution has been formed. Now add a small quantity of charcoal powder to the ink solution and stir well.

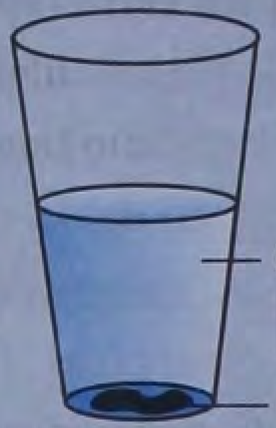


Fig. 4.13 Wood charcoal adsorbs colouring matter from its solution.

After a while you will observe that the blue colour of the ink solution fades away. This proves that wood charcoal adsorbs ink from the ink solution, *i.e.* coloured matter from its solution.

Activated Charcoal : The adsorption capacity of wood charcoal is increased by heating it upto 900°C by steam, because it opens up the pores and increases its capacity to hold more gas. This charcoal is called **activated charcoal.**

Chemical properties of wood charcoal

1. *Action of air or oxygen on charcoal:*

When wood charcoal is heated in air or in oxygen to 100°C, it burns without a flame to form carbon dioxide gas. A large amount of heat energy is liberated in the process. However, in limited supply of air, carbon monoxide is formed.

$$\underset{\text{(carbon)}}{C} + \underset{\text{(oxygen)}}{O_2} \rightarrow \underset{\text{(carbon dioxide)}}{CO_2} + \text{Heat}$$

$$2C + \underset{\text{(limited oxygen)}}{O_2} \rightarrow 2CO$$

2. *Action of nonmetals other than oxygen:*

Wood charcoal reacts with nonmetals like hydrogen, sulphur etc. to give the respective compounds.

(i) $C + 2H_2 \xrightarrow[\text{spark}]{\text{Electric}} CH_4$ (Methane)

(ii) $C + 2S \xrightarrow{\Delta} CS_2$ (Carbondisulphide)

3. *Action of metals :*

Charcoal reacts with metal like calcium at high temperature to give calcium carbide.

$$Ca + 2C \xrightarrow{\Delta} CaC_2$$

4. *Reducing action of charcoal:*

(a) On metallic oxides : Charcoal has strong affinity for oxygen. Therefore when metallic oxides like zinc oxide, lead oxide and copper oxide are heated with charcoal, the respective metal oxides are reduced to metals and carbon monoxide is produced.

$$\underset{\text{(zinc oxide)}}{ZnO} + \underset{\text{(charcoal)}}{C} \longrightarrow \underset{\text{(zinc)}}{Zn} + \underset{\text{(carbon monoxide)}}{CO}$$

$$\underset{\text{(copper oxide)}}{CuO} + \underset{\text{(powdered charcoal)}}{C} \longrightarrow \underset{\text{(copper)}}{Cu} + \underset{\text{(carbon monoxide)}}{CO}$$

$$\underset{\text{(lead monoxide)}}{PbO} + \underset{\text{(powdered charcoal)}}{C} \xrightarrow{\text{strong heat}} \underset{\text{(lead)}}{Pb} + \underset{\text{(carbon monoxide)}}{CO}$$

(b) On steam : When superheated steam is passed through white hot charcoal, steam gets reduced to hydrogen and a mixture of carbon monoxide and hydrogen is produced. This mixture is called **water gas**.

$$\underset{\text{(white hot charcoal)}}{C} + \underset{\text{(superheated steam)}}{H_2O} \xrightarrow{\text{strong heat}} \underbrace{CO + H_2}_{\text{(water gas)}}$$

(c) On concentrated acids : Wood charcoal reduce concentrated sulphuric acid to sulphur dioxide and conc. nitric acid to nitrogen dioxide.

$$\underset{(conc)}{C + 2H_2SO_4} \rightarrow CO_2 + 2SO_2 + 2H_2O$$

$$\underset{(conc)}{C + 4HNO_3} \rightarrow CO_2 + 4NO_2 + 2H_2O$$

(d) On Sand (silicon dioxide) : Wood charcoal reduces silicon dioxide into silicon carbide when heated strongly in presence of electric spark.

$$\underset{(Sand)}{SiO_2} + 3C \xrightarrow{\Delta} \underset{(silicon\text{-}carbide)}{SiC} + 2CO_2$$

Uses of wood charcoal :

1. Wood charcoal is used as a fuel because it burns at low temperatures and produces no smoke.
2. It is used extensively as a reducing agent in the extraction of metals from their respective metallic oxides.
3. It is an important constituent of gun powder.
4. Due to its high adsorbing capacity, wood charcoal is used :
   (a) in military and industrial gas masks to adsorb harmful gases (poisonous and foul smelling).
   (b) in the form of tablets by persons suffering from indigestion and gastric problems. The tablets adsorb the stomach gases and thus relieve gas pressure.
   (c) to decolourise sugar syrup and refine fats and oils.
   (d) in making filters and sieves.

4.5.2 Sugar charcoal

Sugar charcoal is the purest form of amorphous carbon. It is prepared by heating cane-sugar or glucose in the absence of air.

$$\text{cane-sugar} \xrightarrow{heat} \text{sugar charcoal} + \text{water}$$

$$C_{12}H_{22}O_{11} \xrightarrow{heat} 12C + 11H_2O$$

Sugar charcoal can also be prepared by the dehydration of cane-sugar or glucose in the presence of concentrated sulphuric acid. The acid absorbs the water, leaving behind carbon.

Uses : Sugar charcoal is used mostly as a reducing agent to extract metals from their respective oxides. It is also used to decolourise coloured solutions. It is used to prepare artificial diamonds.

$$\text{Sugar charcoal} \xrightarrow{3000° - 3500°C} \text{Artificial diamond}$$

4.5.3 Bone charcoal

Destructive distillation of bones produces bone charcoal alongwith bone oil and organic compound pyridine. Bone charcoal contains mainly calcium phosphate, *i.e.* its carbon content is rather limited (10-12%). The carbon content of bone charcoal is separated by treating the latter with hydrochloric acid, which dissolves the calcium phosphate. Carbon is then filtered out of the solution and in this form it is called **bone black** or **ivory black**.

Uses of bone charcoal :

1. Bone charcoal is extensively used to decolourise cane-sugar in the process of manufacturing sugar.
2. It is also used in the manufacture of a large number of phosphorus compounds.
3. Ivory black is used as a black pigment in artistic painting because it is the deepest black.
4. It is used to filter aquarium water.
5. It is used to remove excess fluoride from water which causes tooth decay.

4.6 LAMP BLACK (SOOT)

Lamp black is one of the amorphous forms of carbon. It contains 98-99% carbon. It is prepared by heating carbon-rich substances like turpentine oil or kerosene oil in a limited supply of air. The oil burns with a smoky flame that contains large amounts of free carbon. The black smoke is collected in the form of black powder over damp blankets kept inside the chambers. The collected powder is called **lamp black** or **soot**. It is a light, black powder that is used in our country as **kajal** or **surma**.

Uses :

1. Lamp black is used in making black shoe polish, carbon paper, printing ink, black paint, *etc*.
2. It is also used in the manufacture of tyres and gun powder.

Activity 7

Preparation of kajal (lamp black) from vegetable oil.

Take some mustard oil or ghee in an earthen lamp or a bowl. Put a cotton wick in it. Light the wick and hold a metal plate over the flame.

Black powder gets deposited on the surface of the plate. This is *kajal*, a commonly used cosmetic for the eye lashes.

Fig. 4.14 Preparing kajal at home.

4.7 GAS CARBON

Gas carbon is prepared by destructive distillation of coal or when petroleum products are heated at high temperatures in a closed container.

Carbon particles are deposited on the walls of the container which is **gas carbon**.

It is a grey solid. It is also a good conductor of electricity.

Uses : It is used for making electrodes of dry cells and carbon rods for arc lamps.

EXERCISE – II

1. Fill in the blanks :
   (a) .... is formed when charcoal is burnt in a limited supply of air.
   (b) Coal is a .... form of carbon.
   (c) .... is the most inferior form of coal.
   (d) Wood charcoal is a .... conductor of heat and electricity.
   (e) .... is used in making black shoe polish.
2. Choose the correct alternative :
   (a) Anthracite is
      (i) an inferior type of coal
      (ii) a superior type of coal
      (iii) a cheapest form of coal
      (iv) none of above

(b) Destructive distillation of coal yields
   (i) coal tar
   (ii) coal gas
   (iii) coke
   (iv) all of the above

(c) Lamp black is
   (i) an amorphous form of carbon
   (ii) a crystalline form of carbon
   (iii) a pure form of carbon
   (iv) a cluster of carbon atoms

(d) The process by which decayed plants slowly convert into coal is called
   (i) petrification
   (ii) carbonisation
   (iii) carbonification
   (iv) fermentation

(e) The purest form of the amorphous carbon is
   (i) wood charcoal
   (ii) sugar charcoal
   (iii) bone charcoal
   (iv) lamp black

3. Write *'true'* or *'false'* against the following statements :

(a) Charcoal is a good adsorbent.

(b) Coke is obtained by destructive distillation of sugar.

(c) Activated charcoal is a good conductor of electricity.

(d) Wood charcoal is an important constituent of gun powder.

(e) Coal gas is used in the preparation of artificial fertilizers.

4. Define the following :

(a) Carbonization (b) Adsorption

(c) Bone black

5. Name the following :

(a) Substances whose atoms or molecules are not arranged in a geometrical pattern.

(b) The best variety of coal.

(c) The purest form of amorphous carbon.

(d) An amorphous form of carbon that contains about 98% carbon.

(e) Mixture of carbon monoxide and hydrogen.

6. Answer the following questions :

(a) What is destructive distillation ? What are the products formed due to the destructive distillation of coal ?

(b) Why is wood charcoal used in water filters and gas masks ?

(c) How is wood charcoal made ? What other substances are formed in the process.

(d) How many carbon atoms are there in Buck minster-fullerenes ?

7. (a) Describe the formation of coal.

(b) Name four types of coal with percentage of carbon present in each.

8. Name the products formed when :

(a) wood is burnt in the absence of air.

(b) bone is heated in the absence of air.

(c) steam is passed over red hot wood charcoal.

9. Give *two* uses for each of the following :

(a) coal (b) coke

(c) wood charcoal (d) sugar charcoal

(e) bone charcoal (f) lamp black

10. Give balanced equations for the following chemical reactions :

(a) wood charcoal and conc. nitric acid

(b) coke and steam

(c) wood charcoal and lead monoxide.

C. Fuels and Combustion

4.8 FUELS

A fuel is a substance that is used to produce energy, mostly usable heat. Most of the fuels produce heat and light energy when they burn in air. The other product is an oxide. Fuels are used for cooking, transportation, industry, power generation, *etc*. Some common fuels are coal, wood, natural gas, CNG (*Compressed Natural Gas*), LPG (*Liquefied Petroleum Gas*), petrol, kerosene, diesel, *etc*.

4.8.1 Characteristics of a good fuel

Though a large number of substances burn to produce energy, all of them are not used as fuel. The characteristics of a good fuel are :

1. It should have a high calorific value.

Calorific value : The usefulness of a fuel is often measured in terms of its calorific value. The amount of heat energy liberated when 1g of fuel is completely burnt is called the calorific value of that fuel. It is expressed in calories/gram or kilojoules/kilogram.

Table showing calorific value of some fuels

Fuel	*Calorific value* (Cal/g)
Wood	4000
Coal	7000
Coke	8000
Water gas	3000 – 6000
Petrol	11500
Natural gas	8000 – 12000

2. It should be environment-friendly and it should burn completely, *i.e.* without leaving any solid or gaseous residue (ash or soot or smoke).
3. It should be cheap and readily available.
4. It should be easy to store, transport and handle.
5. It should have a *moderate* ignition temperature.

Ignition temperature : The temperature at which a substance begins to burn is called its ignition temperature.

A fuel with low ignition temperature catches fire quickly and is difficult to control. On the other hand a fuel with high ignition temperature will be difficult to ignite.

4.8.2 Types of fuel

(A) Based on the sources fuels are classified as :

Primary fuel (Natural) : The fuels which are obtained directly from nature are called primary fuels *e.g.* coal, wood, natural gas etc.

Secondary fuel (Derived) : The fuels which are derived from natural fuels are called secondary fuels *e.g.* coke, kerosene, water gas etc.

(B) Based on its physical state, a fuel is classified as a solid, a liquid or a gaseous fuel :

Solid fuels : Coal, wood, coke, charcoal and tallow are common solid fuels. Wood was perhaps the first solid fuel used by man. But solid fuels require much space for storage. They have a high ignition point and leave behind smoke and ash on burning.

Liquid fuels : Petrol, kerosene, diesel and methanol (spirit) are common liquid fuels. Most of them are obtained from crude petroleum (also called crude oil). They leave no residue on burning and they can be stored easily too.

Gaseous fuels : Natural gas, producer gas, coal gas, water gas, LPG and biogas are common gaseous fuels. They have low ignition temperature and they leave no residue on burning.

Fuels like natural gas, LPG, petrol, kerosene, diesel, *etc*. are organic compounds belonging to their simplest class known as **"hydrocarbons"**.

FUELS

Primary			Secondary (Derived)		
Solid	*Liquid*	*Gaseous*	*Solid*	*Liquid*	*Gaseous*
e.g. : coal wood	*e.g. :* crude petroleum	*e.g. :* natural gas	*e.g. :* coke charcoal	*e.g. :* petrol diesel	*e.g. :* water gas bio gas

4.9 HYDROCARBONS

Hydrocarbons are the compounds made up of carbon and hydrogen only.

- Hydrocarbons having one to five carbon atoms are *gases* at room temperature *e.g.* methane.
- Hydrocarbons having six to twenty carbon atoms are *liquids*, *e.g.*, petrol, kerosene, etc.
- Hydrocarbons with more than 20 carbon atoms are *solids*, *e.g.* wax, paraffin, etc.

4.9.1 Methane

Methane is the simplest hydrocarbon. Its molecular formula is CH_4, *i.e.* it contains one atom of carbon linked separately with four atoms of hydrogen, as shown in Fig. 4.15.

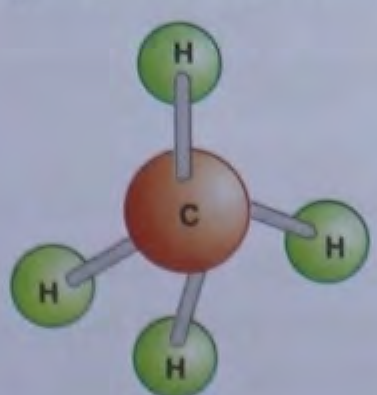


Fig. 4.15 Structural formula of methane.

Natural sources of methane

1. Methane is found in coal mines. Coal gas contains about 30 per cent methane. In coal mines, methane poses a danger since it forms an explosive mixture with air.
2. It is formed in marshy areas by the slow decomposition of vegetable organic matter. Therefore methane is also called **marsh gas.**
3. It is the main constituent of the natural gas that is found alongwith petroleum. Natural gas contains 80–98 per cent methane.

Methane burns in air with a *bluish non-sooty flame* to form carbon dioxide and water vapour, large amount of heat is also given out. **Thus, it is a good gaseous fuel.**

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

When methane burns in an *insufficient supply of air* (oxygen), it forms carbon monoxide and water.

$$2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$$

$$CH_4 + O_2 \rightarrow C + 2H_2O$$ **(with still less oxygen)**

4.10 BIOGAS (GOBAR GAS)

Biogas is a mixture of gases obtained by the degradation and the decomposition of animal and plant matter. It is chiefly composed of methane. The other gases present in biogas are carbon dioxide, hydrogen, traces of hydrogen sulphide and water vapour.

Formation of biogas : Animal dung and plant wastes contain fats, carbohydrates, proteins and anaerobic bacteria. The waste material is mixed with water and allowed to ferment in the absence of air for 30–40 hours.

The anaerobic bacteria slowly decompose the complex organic compounds to form biogas. The residue contains all the necessary plant nutrients and is, therefore, used as manure.

Advantages of biogas :

1. Biogas is a fuel with a high calorific value. It does not produce any smoke on burning.
2. It can be easily ignited. It undergoes complete combustion.
3. It can be directly supplied through pipes to our homes.
4. It is a cheap fuel and generates manure as a byproduct.

4.11 PETROLEUM

The word 'petroleum' is derived from the Latin words *petra* meaning *rock* and *oleum* meaning *oil.*

Petroleum is a dark coloured, viscous, sticky mixture, with a foul smell. It is found trapped between layers of impervious rock (non-porous rock). The *Crude oil* is a mixture of solid, liquid and gaseous hydrocarbons, alongwith salt, water and earthly impurities.

Petroleum is a versatile form of energy. In fact, the economy of a modern nation depends critically on its petroleum wealth. Hence the term 'black gold' is used for petroleum.

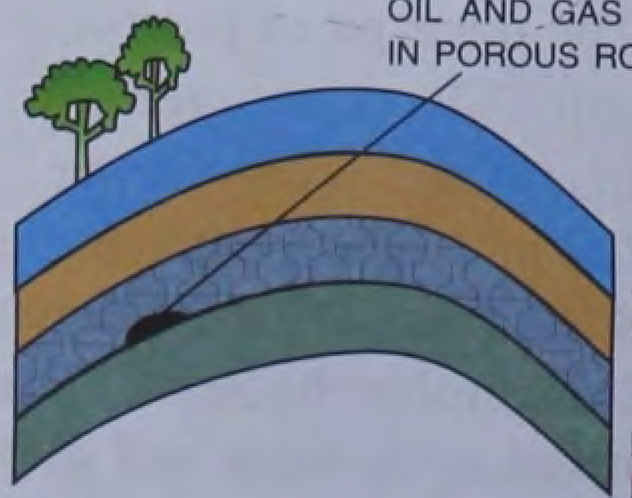


Fig. 4.16 Crude oil under the earth's surface.

The major oil producing countries are Saudi Arabia, Iran, Iraq, Kuwait, USA and Russia. In India crude oil is obtained mainly from Gujarat, Assam and Bombay High.

4.11.1 Formation of petroleum

Petroleum is formed by the action of pressure and heat on animal and plant matter, most of which was buried under the earth millions of years ago. Petroleum (or rock oil) occurs at moderate depths, *i.e.* 500 m – 2000 m below the earth's surface, usually between layers of non-porous rock. Oil deposits are also found under shallow ocean beds. Often there is a layer of natural gas resting under high pressure over the layer of crude oil.

4.11.2 Extraction and refining of petroleum

Petroleum is obtained by drilling holes into the earth's crust at places where oil deposits are known to be located. At first, natural gas comes out through the rocks with great pressure . Then petroleum comes out by itself. After the pressure subsides petroleum has to be pumped out of the wells. The crude oil so obtained is a mixture of kerosene, petrol, diesel, lubricants and various other substances, each with its own density and boiling point. The crude oil is then subjected to "refining". The method used for refining crude petroleum oil is called **"fractional distillation"**.

Refining : The process by which different pure substances are obtained from a crude substance is called refining.

Fractional distillation : The process by which pure fractions of a crude liquid mixture are separated due to the difference in their respective boiling points is known as fractional distillation. In other words, fractional distillation is a particular type of refining.

The process of refining is carried out in a *furnace* with a *long fractionating column.* It is done by :

(i) heating the crude oil up to 400°C in the furnace and

(ii) condensing the vapours of the various fractions of the crude oil inside the fractionating column according to their different boiling points.

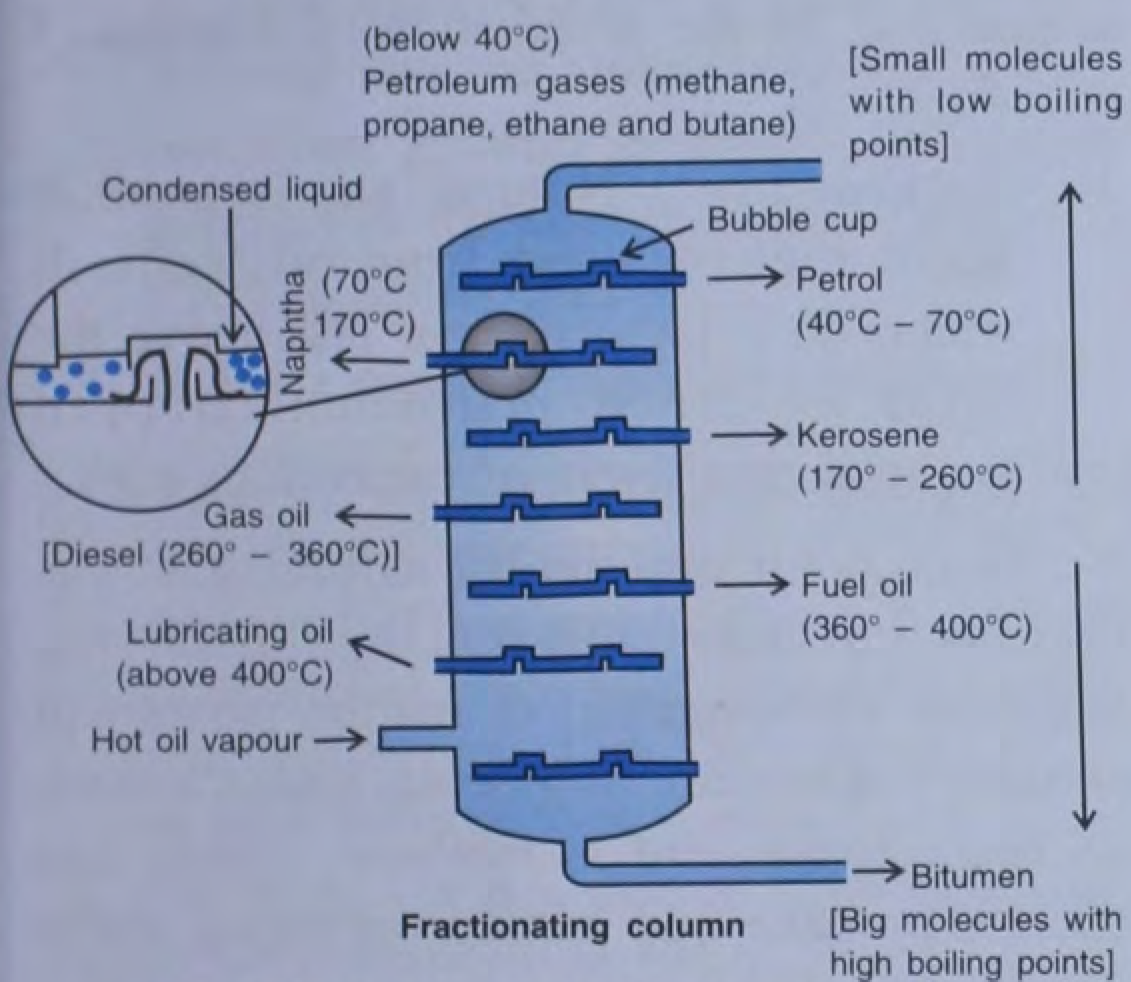


Fig. 4.17 Fractional distillation of petroleum

At 400°C most of the hydrocarbons present in the crude oil get vaporised. The hot vapours rise from the bottom of the fractionating column where the temperature is the highest. The hydrocarbon with the highest boiling point condenses first while those with lower boiling points successively rise to the top and accordingly condense. The process is continued to the point when the crude oil is separated into all its different fractions.

4.12 PRODUCTS OF PETROLEUM AND THEIR USES

1. ***Petroleum gas :*** It is the gaseous fraction of petroleum and consists of hydrocarbons. The boiling point of petroleum gas is below 20°C.

2. ***Liquefied petroleum gas (LPG) :*** Petroleum gas gets liquefied when it is subjected to high pressure at room temperature. This is liquefied petroleum gas, commonly known as LPG. Its main content is *butane* and *isobutane.* It is highly volatile in nature and changes back into a gas as soon as the pressure is relieved. *LPG is used as a household fuel.*

Advantages of LPG :

1. It has a high calorific value and a low ignition temperature.
2. It burns with a blue flame and produces no smoke.
3. It is easy to handle and convenient to store.

Note : *LPG is stored and marketed in steel cylinders, each containing about 14·2 kg of gas. The liquefied gas is mixed with a small amount of a strong smelling substance, called ethyl mercaptan* (C_2H_5SH), *which helps to detect any leakage of the gas.*

3. ***Petrol or gasoline :*** It is a mixture of hydrocarbons, with the molecular formulae ranging from C_5H_{12} to C_9H_{20}. The boiling point also varies from 40°C to 70°C.

Uses :

(i) As a motor fuel.

(ii) As a drycleaning fluid.

4. ***Naphtha :*** It is a mixture of hydrocarbon with the molecular formulae ranging from $C_{10}H_{22}$ – $C_{12}H_{26}$. The boiling point varies from 70°C – 170°C.

Uses : To make motor fuel, plastics, drugs, pesticides, fertilizers etc.

5. ***Kerosene oil :*** It is a mixture of hydrocarbons, with the molecular formulae ranging from $C_{10}H_{22}$ to $C_{12}H_{26}$. The boiling point thus varies from 180°C to 260°C.

Uses :

(i) As a fuel for house stoves.
(ii) In lanterns, petromaxes and lamps.
(iii) Very pure kerosene is used as an aviation fuel as well. It is a kin to gasoline.

6. ***Diesel oil :*** The boiling points of the hydrocarbons that constitute diesel oil vary from 260°C to 340°C.

Uses : It is used as a motor fuel for heavy machines such as trucks, buses, lorries, tractors, generators and trains, especially in the form of HSD*.

7. ***Fuel oil :*** The boiling points of the hydrocarbons forming fuel oil vary from 340°C to 400°C. Fuel oil is used as a fuel in thermal power stations and in ships.

8. ***Lubricating oil :*** It is a thick, viscous liquid that is used for lubricating bearings, valves, chains and many other machine parts as well.

9. ***Paraffin wax :*** It is a white semi-solid with its boiling point above 400°C. It contains grease, vaseline and wax, which have multiple uses.

Uses :

(i) Paraffin wax is used for making vaselines and ointments.
(ii) It is used also for making candles, wax paper, matchsticks, face creams, etc.
(iii) It is used as grease for lubrication purposes as well.

10. ***Asphalt (Bitumen) :*** It is a black, sticky, non-volatile semi-solid. Asphalt is an important ingredient of road pavement material.

Uses : It is used as coating material to prevent rusting and for the preparation of waterproof materials.

11. ***Natural gas :*** Natural gas is another fossil fuel obtained from oil wells. It occurs in a layer reserve just above the layer of crude petroleum, trapped between two layers of impervious rock.

Alongwith petroleum, natural gas was formed millions of years ago from the anaerobic carbonization of marine plants and animals*. A mixture of gaseous hydrocarbons, its main constituent is *methane.* Gases like ethane, propane and butane constitute about 5% of natural gas.

Uses :

1. Natural gas is the cheapest gaseous fuel and it has wide ranging uses as domestic and industrial fuel.
2. It is used as a source of hydrogen and carbon because, when it is heated strongly, it breaks up into carbon and hydrogen, which can be collected.

$$CH_4 \xrightarrow{\Delta} C + 2H_2$$

$$\underset{\text{(natural gas)}}{\text{Methane}} \xrightarrow[\text{heating}]{\text{strong}} \text{Carbon} + \text{Hydrogen}$$

* *High speed diesel*

* *Natural gas is a product of animal remains unlike coal and petroleum which are formed from mainly vegetable matter.*

12. *CNG :* Nowadays *compressed natural gas* has become a popular fuel for three wheelers, cars and buses. It does not cause much pollution and is a relatively cheap fuel.

Advantages of CNG :

1. It is lead free and its use reduces harmful emission into the air.
2. In case of a leakage it rises and gets diffused into the atmosphere, *i.e.* it does not form ground hugging puddles as happens in the case of petrol. Obviously CNG is lighter than air.
3. It has a moderate ignition temperature.

1. **Wood :** It is a primary fuel obtained from the trunks and branches of trees. It is used as a domestic fuel from ancient times. But it has low calorific value, produces lots of smoke and leaves residue in the form of ash. Therefore now a days its use is restricted to rural areas.
2. **Water gas :** It is a mixture of hydrogen and carbon monoxide ($CO + H_2$).
3. **Producer gas :** It is a mixture of carbon-monoxide and nitrogen ($CO + N_2$). Both the gases are important industrial fuels. *(Details of coal given in part 2B).*
4. **Coal gas :** It is a mixture of methane, hydrogen and carbon monoxide which is obtained by destructive distillation of coal.

4.13 COMBUSTION OR BURNING

Combustion or *burning* is a chemical process in which substances combine with oxygen in the air to produce a large amount of energy in the form of heat and light.

Combustion involves :

(i) formation of oxides

(ii) release of heat energy

(iii) release of light energy (in some cases)

For example

(i) Charcoal burns in oxygen (present in air) to produce carbon dioxide and heat.

$$C + O_2 \xrightarrow{\text{burning}} CO_2 + \text{heat energy}$$

(ii) Magnesium burns in oxygen with a dazzling light to produce its oxide alongwith heat and light.

$$2Mg + O_2 \xrightarrow{\text{burning}} 2MgO + \text{heat} + \text{light}$$

(iii) Methane burns in oxygen to produce carbon dioxide, water and heat.

$$CH_4 + 2O_2 \xrightarrow{\text{burning}} CO_2 + 2H_2O + \text{heat}$$

Table listing some products obtained by the fractional distillation of petroleum as well as their uses

Products	*Boiling point range*	*Uses*
1. Petroleum gas (natural gas)	upto 40°C	as fuel
2. Petrol	40° – 70°C	automobile engines
3. Naphtha	70° – 170°C	petrochemicals, plastics and insecticides
4. Kerosene	170° – 260°C	as fuel for jet engines and domestic stoves
5. Diesel	260° – 340°C	as fuel for heavy engines
6. Lubricating oils	above 340°C	for polishes and waxes and for oil for machinery
7. Fuel oil	above 340°C	as fuel for ships and power stations
8. Paraffin waxes	above 400°C	for making candles, vaseline, waterproofing materials and grease
9. Asphalt (bitumen)	obtained as solid	for surfacing of roads and waterproofing of materials.

Table showing the nature of certain gases with respect to combustion

Nature of gas	*Example*
Itself non-combustible but a supporter of combustion	Oxygen and chlorine
Itself combustible but a non-supporter of combustion	Hydrogen and carbon monoxide
Both non-combustible and a non-supporter of combustion	Carbon dioxide, nitrogen and hydrogen chloride

(iv) Cooking gas (LPG) [which is a hydrocarbon (butane)] burns to give carbon dioxide, heat and a small amount of light.

$$2C_4H_{10} + 13O_2 \xrightarrow{\text{burning}} 8CO_2 + 10H_2O + \text{heat} + \text{light}$$

From the above it is clear that combustion is a form of oxidation. All fuels undergo oxidation during their combustion.

4.14 IMPORTANT TERMS

1. **Combustible substances :** A substance that can burn easily in oxygen, with evolution of energy, is called a combustible substance.
   Examples : Coal, wood, phosphorus, hydrogen, petrol, *etc*.
2. **Inflammable substances :** Those combustible substances that burn with a flame and have a low ignition temperature are called inflammable substances. They are mostly volatile liquids or gases.
   Examples : Kerosene, petrol, LPG (cooking gas), etc.
3. **Non-combustible substances :** Substances that cannot burn in air or oxygen are called non-combustible substances.
   Examples : Glass, stone, sand, chlorine, copper sulphate, etc.
4. **Supporter of combustion :** The gaseous environment that supports combustion or burning but does not itself burn is called "supporter of combustion".
   Examples : Oxygen, chlorine, nitrous oxide, etc.
5. **Non-supporter of combustion :** The gaseous environment that does not allow combustion to take place is called "non-supporter of combustion".
   Examples : Hydrogen, nitrogen, carbon monoxide, carbon dioxide, etc.

CONDITIONS NECESSARY FOR COMBUSTION

For a combustion reaction to take place, the following conditions must be met.

(i) There should be a combustible substance.

(ii) There should be a medium or an environment in which combustion can take place.

(iii) The ignition temperature of the combustible substance should be attained.

Activity 8

To show that air [or oxygen] is necessary for burning (or combustion)

Take a candle and fix it on a table. Light the candle. It burns smoothly, with a bright flame. Now cover the candle with a glass tumbler. The flame gets extinguished. This

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is because the supply of air is cut off when the lighted candle is covered with the glass tumbler, proving that air is necessary for burning.

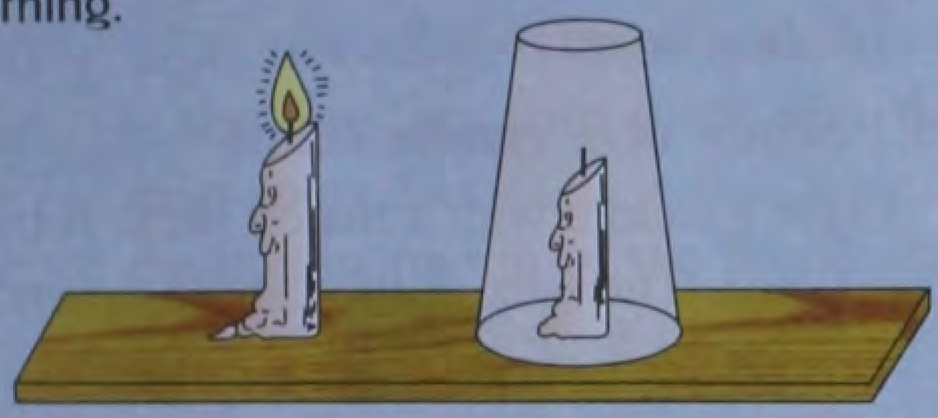


Fig. 4.18 Air or oxygen is necessary for burning.

Some other common experiences also show that air is essential for burning.

(i) A slow fire bursts into flames when air is blown into it as it gets more oxygen.

(ii) A flame gets extinguished if air is blown from the mouth as it gets more carbon dioxide.

(iii) Sand is often thrown on fire to put it out. This is because sand cuts off air supply to the fire.

Types of combustion :

The types of combustion reactions are :

- Rapid combustion
- Spontaneous combustion
- Slow combustion
- Explosion

- **Rapid combustion :** A combustion reaction in which large amounts of heat and light are produced in a short time is called rapid combustion.

  Example : When a smouldering match stick is brought near a candle, it starts burning immediately. Other examples are burning of cooking gas, kerosene oil, *etc.*

- **Spontaneous combustion :** A combustion reaction which once started does not require any external heat to proceed further is called spontaneous combustion. The heat is provided by the burning substance.

  Example : Burning of phosphorus.

- **Slow combustion :** A combustion reaction in which fuel burns at a moderate rate and a part of fuel remains unburnt is called slow combustion.

  Example : Coal, wood *etc.*

- **Explosion :** A reaction in which tremendous amounts of heat, light and sound are released in a short interval of time is called an explosion.

  Example : Burning of a fire cracker or of hydrogen (with a pop sound) when mixed with air.

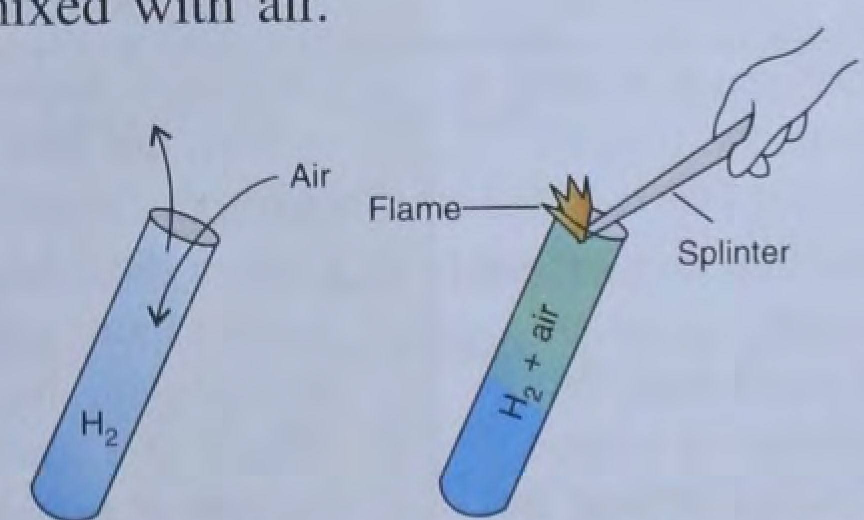


Fig. 4.19 Formation of an explosive mixture when hydrogen comes into contact with air.

Burning in absence of air

Some substances contain a high percentage of oxygen in their molecule. On heating, these compounds release some oxygen which helps them in burning even in the absence of air with the help of some combustible material. *Eg.* : – Potassium chlorate ($KClO_3$), Potassium nitrate (KNO_3), *etc.*

Respiration :

A process similar to burning or combustion is **respiration** which takes place inside living things. In this process also, the products are carbon dioxide and water vapour with the release of energy, but the amount of energy is less and is in the form of chemical and heat energy. Hence it is a slow oxidation process.

Respiration is defined as a chemical process in which the food is burnt (in living cells) by oxygen to produce carbon dioxide, water vapour and energy.

$$\underset{\text{(glucose)}}{C_6H_{12}O_6} + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Heat} + \text{ATP}$$

Note : ATP – Adenosine triphosphate in which chemical energy is stored.

Comparison of burning and respiration

Burning	Respiration
1. Oxygen is needed to burn the fuel.	1. Oxygen is needed to burn the food in our body.
2. Carbon dioxide and water vapour are formed with the release of a large amount of heat and light energy.	2. Carbon dioxide and water vapour are formed with the release of a small amount of energy in the form of chemical and heat energy.
3. It is a fast oxidation process.	3. It is a slow oxidation process.
4. It is man-made and needs initiation.	4. It is natural and takes place spontaneously.
5. It occurs at high temperature.	5. It takes place at body temperature.

4.15 FLAME

A flame is a zone of combustion of gaseous substances. Heat and light are given out by a flame. Some substances burn with a flame while some others do not do so. A flame is produced when a combustible substance changes into its vapour state on heating. Examples of substances that burn with a flame are camphor, wood, candle, *etc*.

4.15.1 Study of a candle flame

Light a candle with a match stick. It burns with a flame. The wax of the candle around its wick melts and molten wax changes into vapour. This vapour burns in air and produces a flame.

The unequally heated parts of a candle flame are as shown below :

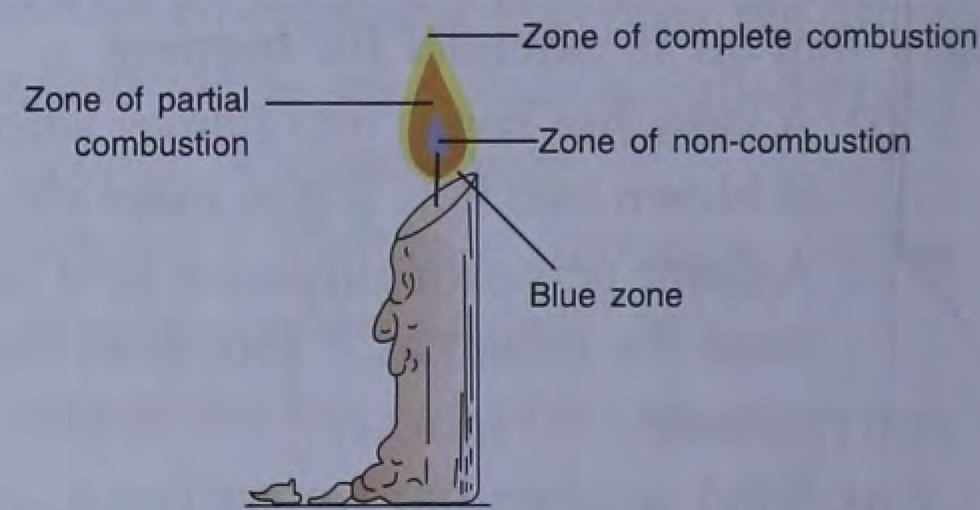


Fig. 4.20 Variously heated parts of a candle flame

(i) Blue zone : It lies at the bottom of the flame. The blue colour of the flame is due to the burning of carbon monoxide, which is produced by the incomplete combustion of carbon.

$$C + O_2 \rightarrow 2CO$$
$$2CO + O_2 \rightarrow 2CO_2$$

(ii) Zone of non-combustion : This is a dark zone that lies around the wick of the candle. It contains unburnt gas particles. No combustion takes place in this zone, since no oxygen is available there.

(iii) Zone of partial combustion : This zone is pale yellow in colour, and it surrounds the dark inner zone of non-combustion. This is the luminous part of the flame (sooty flame). The yellow colour is imparted due to the presence of unburnt carbon particles that are yet hot enough to emit a yellow light.

(iv) Zone of complete combustion : This is the non-luminous zone of a flame (non-sooty flame). It is the outermost, the hottest region of the flame, where the combustion of wax-vapour takes place completely, thus giving carbon dioxide and water vapour.

$$\underset{\text{(candle)}}{C_xH_y} + O_2 \xrightarrow{\text{heating}} CO_2\,(g) + H_2O\,(g)$$

4.16 FIRE AND FIRE EXTINGUISHERS

When a substance burns with a flame, the heat and the light, and often the smoke so produced, constitute "fire".

For a fire to occur, the presence of a combustible substance and a supporter of combustion are required as well as attainment of the required ignition temperature is necessary. If any of the above conditions is not satisfied, a fire will not be produced, *i.e.* even if there is a fire already it will die out. This is the principle that is exploited for "fire fighting" purposes.

4.16.1 Precautions to avoid fire accidents and fighting fire

(A) Taking care of combustible substances :

1. The premises of petrol pumps, LPG godowns, fire cracker shops should be out of bounds for all kinds of burning objects, fires and heat radiating hot articles. This is because the materials stored here are highly combustible, *i.e.* they have low ignition points.
2. At home we must see that combustible materials like furniture and synthetic textiles, do not come into contact with fire.

(B) Care to cut off the supply of air and lower temperature below ignition point

Once a fire has started it can be extinguished only by either cutting the supply of air or lowering the temperature below the ignition point. This can be done by :

(i) pouring water or sand over the fire.

(ii) applying carbon dioxide to the fire with the help of fire extinguishers.

(iii) putting off the main switch in case of an electrical fire.

4.16.2 First aid to victims of fire

We should give the following first aid to fire victims.

(i) If the clothes of the victim have caught fire he/she she should be wrapped immediately with a thick blanket so as to cut off the supply of air to the fire.

(ii) The victim should be taken into open space in order to reduce the effect of the smoke and/or any poisonous gases produced because of the fire.

(iii) Cold water should be poured over the victim's body to absorb excess heat and prevent the formation of boils. Ice packs can be applied as well.

(iv) The victim should be taken to the hospital for further medical treatment.

4.16.3 The use of carbon dioxide in fire extinguishers

Carbon dioxide helps to extinguish fire because :

(i) it neither burns nor does it help in burning.

(ii) it is heavier than air, and thus it insulates the burning substance by cutting off its supply of oxygen.

Fire extinguishers are devices in which carbon dioxide is produced in different forms for use as the extinguishing agent.

Some common types of fire extinguisher are :

(i) Soda-acid fire extinguisher
(ii) Foam-based fire extinguisher
(iii) Liquid carbon dioxide fire extinguisher

(i) Soda-acid fire extinguisher : It contains sulphuric acid and sodium bicarbonate, in separate chambers. When the apparatus has to be used, contact is made between the two chemicals and carbon dioxide is produced. The gas comes out in the form of a solution that extinguishes fire.

$$2NaHCO_3 + H_2SO_4 \rightarrow Na_2SO_4 + \overbrace{2H_2O + 2CO_2}^{\text{Extinguishing agent}}$$

(ii) Foam-based fire extinguisher : It contains aluminium sulphate and sodium bicarbonate, in separate chambers. The two chemicals mix and react to form carbon dioxide and aluminium hydroxide, which come out together through the nozzle of the apparatus as foam. This foam is used to extinguish oil-fed fires, because the foam covers the oil as well as cuts off air supply to the fire.

(iii) Liquid carbon dioxide fire extinguisher: It is the most modern type of fire extinguisher. Liquid carbon dioxide is stored in a steel cylinder under pressure. When the valve of the cylinder is opened, the pressure falls and liquid carbon dioxide solidifies into ***white snow*** (dry ice), which can be used to put out both oil-fed and electrical fires.

Why we cannot use the soda-acid and the foam-types of fire extinguisher to fight an electrical fire?

In these fire extinguishers the extinguishing solutions are prepared in water which, being impure, conducts electricity. As a result, an electric shock could result, which could then lead to short-circuiting and another fire.

Activity 9

You can make your own fire extinguisher

Take some sodium bicarbonate (baking soda) in a small bottle. Drill a hole through the cap of the bottle and pass a straw through it. Plug the hole properly with grease [or flour] to make the bottle leak proof. Now open the cap, quickly add some vinegar and close the bottle with the cap. A brisk effervescence is observed. Direct the open end of the straw towards a lit candle or a burning splinter. The gas coming out of the straw extinguishes the flame. This proves that carbon dioxide so produced helps to extinguish the flame.

$$\underset{\text{Sodium bicarbonate}}{NaHCO_3} + \underset{\text{Acetic acid (vinegar)}}{CH_3COOH} \rightarrow \underset{\text{Sodium acetate}}{CH_3COONa} + H_2O + CO_2$$

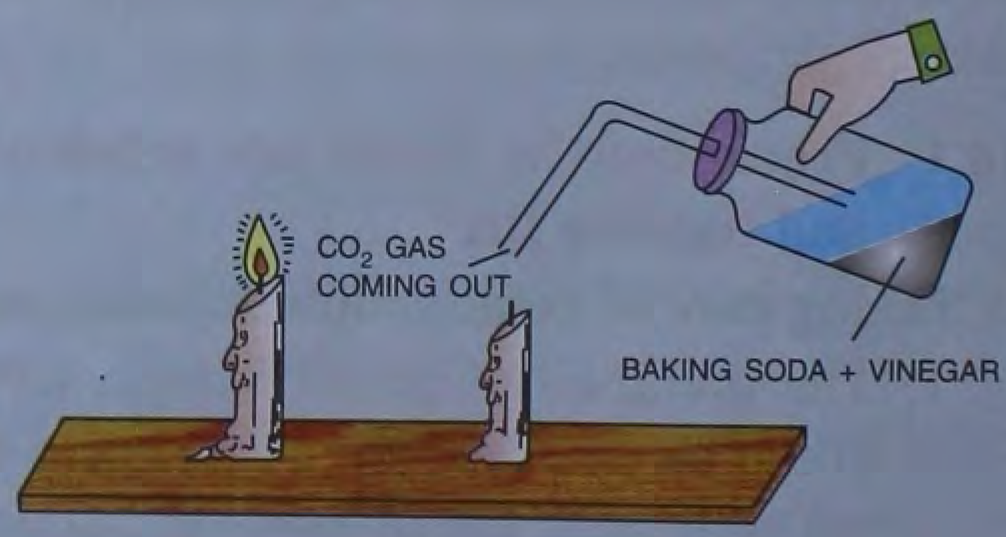
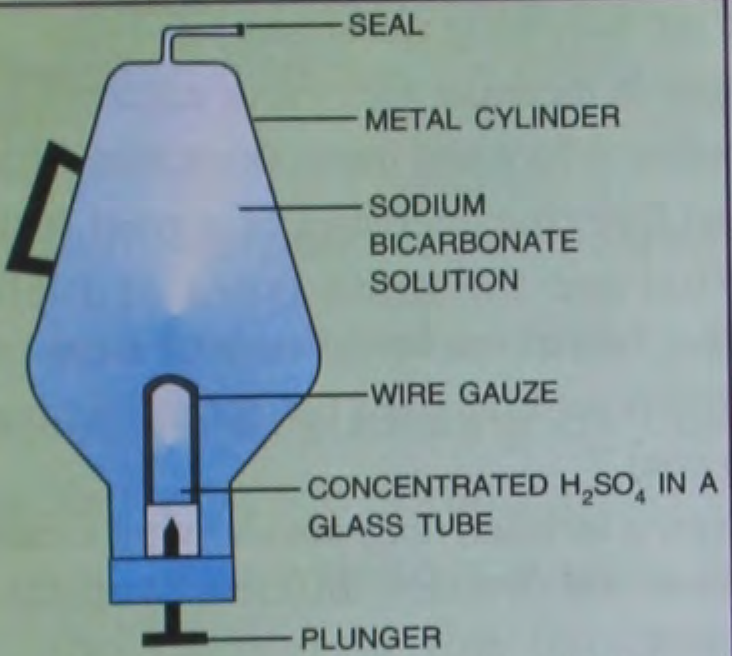


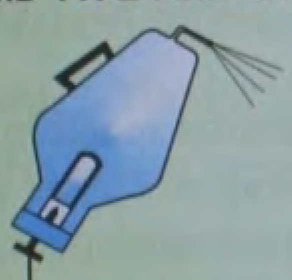
Fig. 4.21 Diagram showing preparation of CO_2 at home

Note : Acetic acid is commonly known as vinegar and is used in food substances.

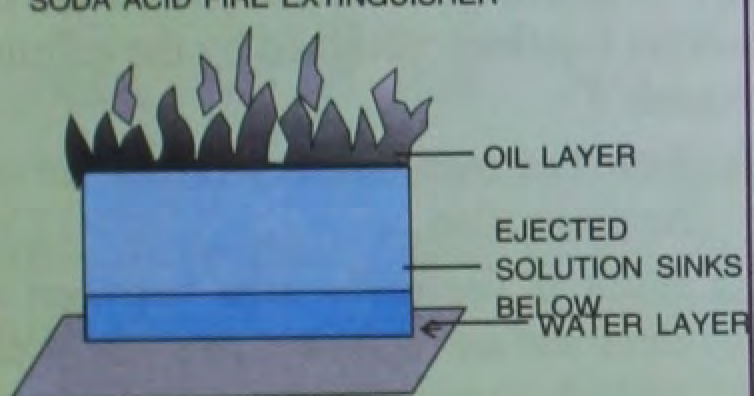
SODA-ACID FIRE EXTINGUISHER	LIQUID CARBON DIOXIDE FIRE EXTINGUISHER	FOAM TYPE FIRE EXTINGUISHER



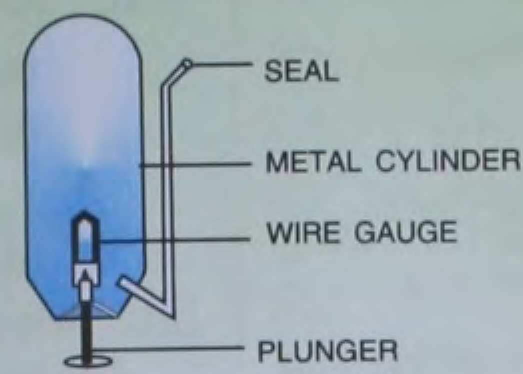
SODA-ACID TYPE FIRE EXTINGUISHER

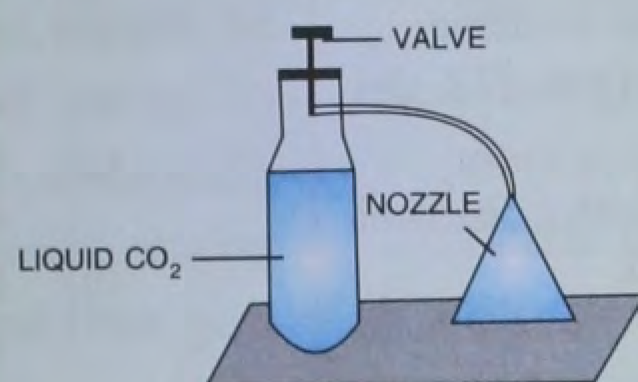


SODA ACID FIRE EXTINGUISHER

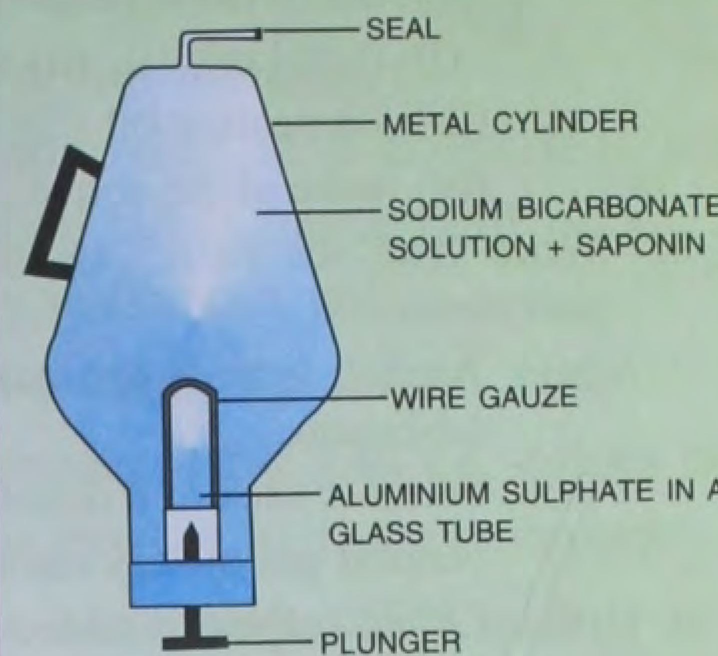


A SODA-ACID FIRE EXTINGUISHER CANNOT FIGHT AN OIL FIRE

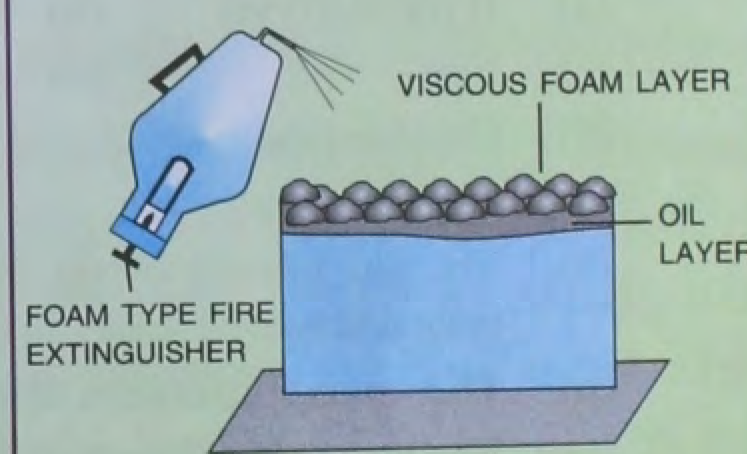




LIQUID CARBON DIOXIDE FIRE EXTINGUISHER



FOAM TYPE FIRE EXTINGUISHER



A FOAM TYPE FIRE EXTINGUISHER CAN FIGHT AN OIL FIRE

EXERCISE – III

1. Fill in the blanks :
   (a) Coal and petroleum are .... fuels.
   (b) The temperature at which a combustible substance catches fire is called its ....
   (c) .... is added to LPG to detect its leakage.
   (d) Combustion is an .... process.
   (e) .... is the simplest hydrocarbon.

2. Choose the correct alternative :
   (a) For combustion reactions
      (i) air is essential
      (ii) a combustible substance is essential
      (iii) both (i) and (ii) are essential
   (b) Petrol is
      (i) combustible
      (ii) a supporter of combustion
      (iii) non-combustible
      (iv) none of the above
   (c) Which of the following is a solid fuel ?
      (i) petrol (ii) kerosene
      (iii) coke (iv) methanol
   (d) Burning of phosphorus is an example of
      (i) rapid combustion
      (ii) spontaneous combustion
      (iii) explosion
      (iv) none of the above

(e) During the fractional distillation of petroleum, which of the following liquids is obtained in the range of 30°C to 120°C?
   (i) diesel oil (ii) petrol
   (iii) lubricating oil
   (iv) none of the above

3. Write *'true'* or *'false'* against the following statements :
   (a) Asphalt is used for making candles and lubricants.
   (b) Petrol is used as a domestic fuel.
   (c) Natural gas mainly contains methane.
   (d) Liquid sulphur is added to LPG to detect leakage.
   (e) Sleeping in a closed room with a charcoal fire burning can be harmful.

4. Define the following terms :
   (a) Hydrocarbons (b) Flame
   (c) Fire (d) Calorific value
   (e) Combustion

5. Name the following :
   (a) The gas formed by the decomposition of plant and animal wastes in the absence of air.
   (b) The main constituent of biogas.
   (c) The main constituent of LPG.
   (d) The process by which the various fractions of crude oil are separated.
   (e) The foul-smelling substance that is added to the cooking gas supplied in cylinders.
   (f) The zone that lies at the bottom of a flame.

6. Answer the following questions :
   (a) How is methane formed in nature ?
   (b) Define a fuel and name three fossil fuels.
   (c) List five characteristics of a good fuel.
   (d) What are the three types of fuels ? Give two examples of each of them.
   (e) Why is cooking gas a better fuel compared to coal ?
   (f) Draw a labelled diagram showing a candle flame and describe different temperature zones.
   (g) How is biogas prepared ? Give its two advantages.
   (h) Define a combustion reaction giving two examples. What are the conditions necessary for combustion ?
   (i) How is petroleum refined ? What are the various fractions obtained by the refining process ?
   (j) (i) State two methods by which a fire can be controlled.
   (ii) What is the difference between an electrical and an oilfed fire ? How can we fight them. Give a detailed answer.
   (iii) What first aid should be given to a victim of fire ?

D. Carbon Monoxide — A Compound of Carbon

INTRODUCTION

Molecular formula : CO, ***Relative molecular mass :*** 28

As the name suggests, carbon monoxide is an oxide of carbon containing one atom of carbon and one atom of oxygen in its molecules.

4.17 OCCURRENCE

Carbon monoxide occurs in coal gas, volcanic gases, tobacco fumes and chimney gases, and in the exhaust gases of automobiles (in trace).

4.18 FORMATION OF CARBON MONOXIDE AND ITS ADDITION TO THE ATMOSPHERE

Mostly carbon monoxide is formed when a large amount of carbon or its compounds is burnt in a limited supply of air or oxygen. In other words, *carbon monoxide is a product of incomplete burning.*

$$\underset{\text{(carbon)}}{2C} + \underset{\text{(oxygen)}}{O_2} \xrightarrow{\text{heat}} \underset{\text{(carbon monoxide)}}{2CO}$$

Incomplete burning of fuels : Domestic and industrial ovens running on coal or coke or charcoal produce some carbon monoxide. In an oven, where there is usually free supply of air, the carbon at the lower end burns to produce carbon dioxide. This carbon dioxide passes through the heated layers of coke placed above in the oven, reacts with it and thus gets reduced to carbon monoxide.

$$C + O_2 \rightarrow CO_2 + \text{heat}$$
$$CO_2 + C \rightarrow 2CO$$

The carbon monoxide so produced burns with a pale blue flame at the top of the oven again forming carbon dioxide.

$$2CO + O_2 \rightarrow 2CO_2$$

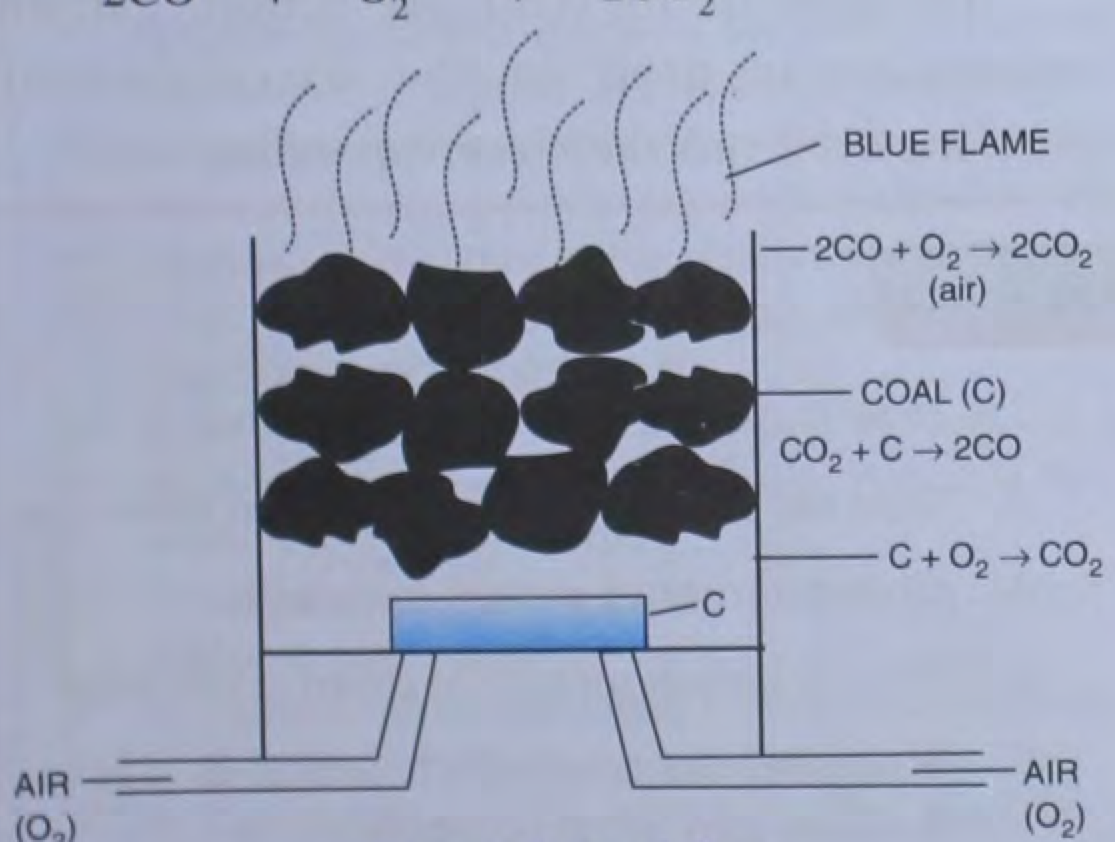


Fig. 4.22 Coal fire

Exhaust gases of automobiles :

In automobile engines mostly petrol or diesel is used as fuel. Both contain carbon and hydrogen. They burn within the engine in a limited supply of air thus forming a little bit of carbon monoxide too.

Properties of carbon monoxide :

1. Carbon monoxide is a colourless and tasteless gas, but it has a faint odour. It is a highly poisonous gas.
2. It is very sparingly soluble in water.
3. It is a thermally stable gas, *i.e.* it does not decompose even at high temperatures.
4. Though it is a combustible gas, it is a non-supporter of combustion. In air it burns with a blue flame to form carbon dioxide. (See Fig. 4.22)

4.19 CARBON MONOXIDE IS POISONOUS

Carbon monoxide is a highly poisonous gas. If air containing even 0·5% carbon monoxide by volume is inhaled, death can result. This is because carbon monoxide combines with the haemoglobin present in the red blood cells of our body to form a stable compound called *carboxyl-haemoglobin*. This stable compound does not allow haemoglobin to absorb or carry oxygen, thus depriving our body cells of oxygen. This causes paralysis of the respiratory organs and results in death due to suffocation (asphyxiation).

4.20 HARMFUL EFFECTS OF CARBON MONOXIDE, PRECAUTIONS AND REMEDIES FOR ITS POISONING

1. *Sleeping in a closed room with a coal fire burning*

It is very dangerous to sleep in a room where coal or wood is burning and the doors and the windows are closed. Owing to the limited supply of air in such a room, carbon monoxide is produced. Since the gas is colourless and has a barely detectable smell, people sleeping in the room do not feel its presence and run the risk of CO poisoning.

2. ***Starting a car engine inside a closed garage***

Carbon monoxide is almost always present in a small amount in the exhaust gases of automobiles, owing to incomplete combustion of motor fuels. Therefore it is not advisable to start a car engine inside a closed garage. More of carbon monoxide could thus be produced inside a closed area, increasing the risk of poisoning.

Remedies for carbon monoxide poisoning

(i) The victim should be immediately brought out into the open.

(ii) The victim should be given artificial respiration with *carbogen* (a mixture of 95% oxygen and 5% carbon dioxide) to restore normal breathing.

(iii) At places where carbon monoxide concentration is on the higher side, people should wear gas masks that absorb carbon monoxide and oxidise it to carbon dioxide. Such masks are made of *hopcolite* (a mixture of metallic oxides).

4.21 REDUCING ACTION OF CARBON MONOXIDE

Carbon monoxide is a strong reducing agent. It reduces the oxides of the less active metals to their respective metals and itself gets oxidised to carbon dioxide in the process.

e.g. (i) $\underset{\text{(black cupric oxide)}}{CuO} + CO \xrightarrow{\text{heat}} \underset{\text{red/brown}}{Cu} + CO_2$

(ii) $\underset{\text{(lead monoxide)}}{PbO} + CO \xrightarrow{\text{heat}} \underset{\text{(lead)}}{Pb} + CO_2$

(iii) $\underset{\text{(ferric oxide)}}{Fe_2O_3} + 3CO \xrightarrow{\text{heat}} \underset{\text{(iron)}}{2Fe} + 3CO_2$

Because of its reducing action, carbon monoxide is used in the extraction of pure metals from their corresponding ores.

EXERCISE – IV

1. Fill in the blanks :
   (a) .... is formed when carbon is burnt in a limited supply of air or oxygen.
   (b) Carbon monoxide burns in air with a .... flame to form carbon dioxide.
   (c) Carbon monoxide is a product of .... combustion.
   (d) A mixture of 95% oxygen and 5% carbon dioxide is called ....
   (e) Carbon monoxide is used as a .... in the extraction of pure metals from their corresponding ores.
2. How is carbon monoxide gas formed ?
3. State the poisonous nature of carbon monoxide.
4. Give *two* uses of carbon monoxide.
5. Why is carbon monoxide called silent killer ?
6. State *three* ways by which carbon dioxide gas is added into the atmosphere.
7. Explain the reducing action of carbon monoxide.
8. Write *two* remedies for carbon monoxide poisoning.

9. Match the following :

Column A	Column B
1. A product of incomplete burning	(a) Hopcolite
2. Nature of carbon monoxide	(b) Combustible gas
3. A compound formed by the combination of haemoglobin and carbon monoxide	(c) Carboxy-haemoglobin
4. A mixture of metallic oxides	(d) Carbon monoxide
5. Carbon monoxide	(e) Highly poisonous

RECAPITULATION

- Carbon occurs in all living matter, substances derived from living matter (food and fuels), in the earth's crust and in the atmosphere.
- Carbon forms so many compounds because carbon can form long chains. Most compounds of carbon are studied under organic chemistry.
- Graphite, diamond and fullerenes are allotropes of carbon. They are crystalline.
- Diamond is the hardest naturally occurring substance known.
- Fullerenes are discovered only recently.
- Amorphous carbon has different forms : coal, coke, charcoal, lamp black and gas carbon. All are not pure.
- Coal, coke and charcoal are used as fuels. Charcoal can be activated by heating it upto 900°C which increases its adsorbing capacity.
- Coke and charcoal are good reducing agents.
- Bituminous coal is the most common variety of coal.
- Gas carbon is a good conductor of electricity.
- A fuel is a substance which produces usable heat energy or other forms of energy.
- Most of the fuels produce energy when they burn in air.
- Methane is the simplest hydrocarbon. It is an important fuel.
- Coal, petroleum and natural gas are called fossil fuels because they are derived from the remains of plants and animals.
- Petrol, diesel, kerosene, paraffin wax, fuel oil, lubricants, asphalt all are obtained from petroleum.
- Biogas is the cheapest and easily available fuel for domestic use. It is formed by plant's and animal's waste materials (cow dung).
- Combustion is an oxidation process in which substances burn in air to produce oxides and evolve heat and light energy.
- A flame is produced when a combustible substance changes into its vapour state on heating.
- Flame, heat and light and smoke produce fire.
- A fire can be extinguished either by lowering the ignition temperature of combustible material or by cutting off the supply of air.
- Fire extinguisher is a device in which carbon dioxide gas is produced for extinguishing fire.
- Carbon monoxide gas is an oxide of carbon formed due to incomplete combustion of carbon and carbon derivatives.
- It is poisonous and becomes fatal if inhaled in sufficient quantity.
- It also acts as a reducing agent in the extraction of metal from their oxides.