13. Carbon : An Important Element

- **Carbon – occurrence, properties, allotropes**
- **Hydrocarbons**
- **Carbon dioxide and methane – occurrence, properties, uses**

Can you recall?

1. What is an element? What are the different types of elements?
2. What remains behind on complete combustion of any organic compound?
3. What type of element is carbon? Give some information about it.

You have learnt that carbon is a non-metallic element. You have also learnt about its occurrence in nature in the form of some compounds.

Try this

1. Take some milk in an evaporating dish. Heat the evaporating dish on a Bunsen burner. What remains behind at the bottom of an evaporating dish on complete evaporation of the milk?

2. Take small samples of sugar, wool, dry leaves, hair, seeds, split pulses and plastic in separate test tubes. Heat each test tube and observe the changes taking place in the substances.

What does the black substance remaining in each test tube indicate?

Carbon

The element carbon is available abundantly in the nature and occurs in free as well as in the combined state. In this chapter, let us study the properties of the non-metallic element carbon.

Make a list of all substances/objects that you use in daily life from morning till night and divide those substances into the columns in the following table.

1. Symbol of carbon – C
2. Atomic number – 6
3. Atomic mass – 12
4. Electron configuration – 2,4
5. Valency – 4
6. Non-metallic element

Metallic objects	Earthen/glass objects	Other objects/substances

Now look at the list of objects in the last column. It contains foodstuffs, clothes, medicines, fuels, wooden objects, etc. Carbon is the common and important constituent of all these substances.

Can you tell? What is a compound ? How are compounds formed ?

Compounds obtained directly or indirectly from plants and animals are called organic compounds and compounds obtained from minerals are called inorganic compounds. All the organic compounds contain carbon. Carbon is the main element even in cellular DNA and RNA that transfer hereditary characteristics from one generation to the next.

An introduction to scientists

The German chemist Wohler synthesized an organic compound urea from an inorganic compound ammonium cyanate. Ever since then, many organic compounds have been made from inorganic compounds. Carbon was found to be the main element in all these compounds. Hence, organic chemistry is also referred to as chemistry of carbon compounds.

$$NH_4^+CNO^- \xrightarrow{\text{Heat}} NH_2CONH_2$$

Occurrence of carbon

The name 'carbon' is derived from the Latin word 'carbo' meaning coal. Carbon is found in nature in free as well as compound state. Carbon in the free state is found as diamond and graphite, and in the combined state in the following compounds.

1. As carbon dioxide and in the form of carbonates such as calcium carbonate, marble, calamine ($ZnCO_3$)
2. Fossil fuel – coal, petroleum, natural gas
3. Carbonaceous nutrients – carbohydrates, proteins, fats
4. Natural fibres – cotton, wool, silk

Science capsule

In the earth's crust, carbon is present to the extent of approximately 0.27% in the form of carbonate, coal, petroleum. In atmosphere, the proportion of carbon in the form of carbon dioxide is approximately 0.03 %.

Some types of plants which grow on the ocean floor convert carbon in marine water into calcium carbonate.

Properties of carbon

Allotropic nature of Carbon

Allotropy – Some elements occur in nature in more than one form. The chemical properties of these different forms are the same but their physical properties are different. This property of elements is called allotropy. Like carbon, sulphur and phosphorus also exhibit allotropy.

Allotropes of carbon

A. Crystalline forms

1. A crystalline form has a regular and definite arrangement of atoms.
2. They have high melting points and boiling points.
3. A crystalline form has a definite geometrical shape, sharp edges and plane surfaces.

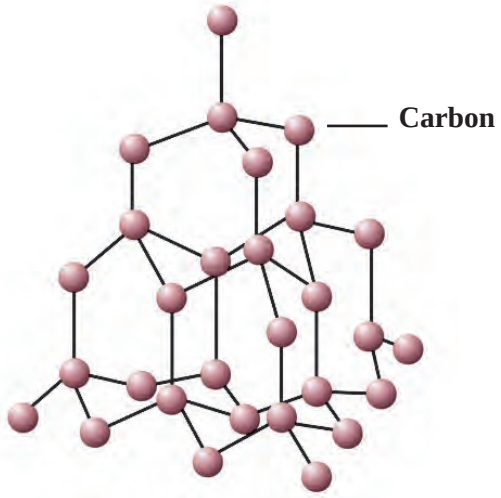
Carbon has three crystalline allotropes.

1. Diamond

Diamonds are found in India mainly in Golconda (Telangana) and Panna (Madhya Pradesh). Diamonds are also found in South Africa, Brazil, Belgium, Russia and America.

13.1 Diamond

Structure : In diamond, every carbon atom is bonded to four neighbouring atoms by covalent bonds. Due to this three dimensional structure, diamond become very hard.



13.2 Structure of carbon atoms in diamond

Properties

1. Brilliant and pure diamond is the hardest natural substance.
2. The density of diamond is 3.5 g/cm^3.
3. The melting point of diamond is 3500 ^{0}C
4. When diamond is heated at 800 ^{0}C in the presence of oxygen CO_2 is given away. In this process no other product besides CO_2 is formed.
5. Diamond does not dissolve in any solvent.
6. Acids/bases have no effect on diamond.
7. Diamond is a bad conductor of electricity as it does not have free electrons.

A peep into the past

Once upon a time, India was famous for the 'Kohinoor' diamond. This diamond was found in the 13th century in the mine at Guntur (Andhra Pradesh). Its weight was 186 carats.

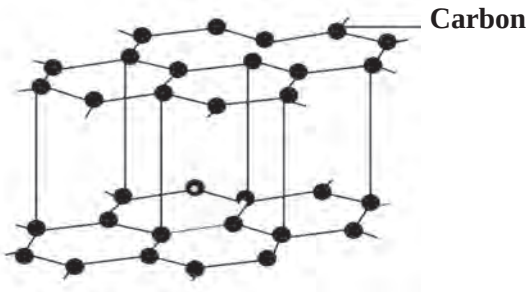
Uses

1. Diamonds are used in glass cutting and rock drilling machines.
2. Diamonds are used in ornaments.
3. Diamond knives are used in the eye surgery.
4. Diamond dust is used for polishing other diamonds.
5. Diamond is used to make windows giving protection from radiation in space and in artificial satellites.

2. Graphite

Graphite is found in the natural state in Russia, New Zealand, America and India. The lead used in pencil is made by mixing graphite with clay. This process was discovered by Nicholas Jacques Conte in 1795.

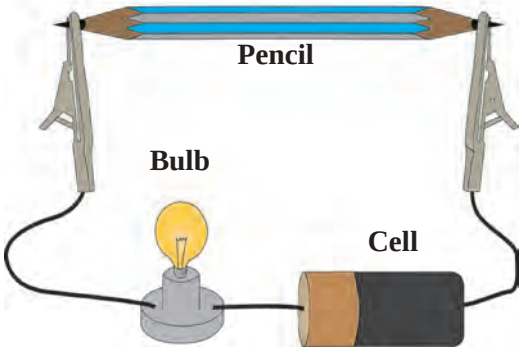
Structure : Every carbon atom in graphite is bonded to three other carbon atoms in such a way that a hexagonal layered structure is formed. A graphite crystal is made of many sheets or layers of carbon atoms. These layers slip over each other on applying pressure. One layer of graphite is called graphene.



13.3 Graphite and structure of carbon atoms in graphite

Try this

Apparatus : Pencil, electrical wires, battery/cell, small bulb, water, kerosene, test tubes, lead pencil, etc.



13.4 Flow of electric current through graphite

Procedure :

1. Remove the lead from a pencil, and feel it with your fingers. What colour is it? Try to break the lead with your hand.
2. Assemble the apparatus as shown in the diagram. Start the electric current in the circuit. Observe. What did you find?
3. Take some water in a test tube. Take some kerosene in another test tube. Put lead dust in both the test tubes. What did you find?

Properties of graphite

1. Graphite found in nature is black, soft, brittle and slippery.
2. Inside each layer of graphite, free electrons move continuously within the entire layer. That is why graphite is a good conductor of electricity.
3. Due to the layered structure graphite can be used for writing on paper.
4. The density of graphite is 1.9 to 2.3 g/cm^3.
5. Graphite does not dissolve in most solvents.

Uses of graphite

1. Graphite is used for making lubricants.
2. Graphite is used for making carbon electrodes.
3. Graphite is used in pencils for writing.
4. Graphite is used in paints and polish.
5. Graphite is used in arc lamps which give a very bright light.

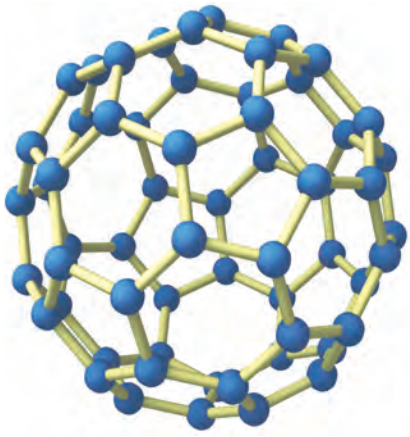
Buckytubes (Carbon nano-tube)

3. Fullerene

Fullerene, an allotrope of carbon, is rarely found in nature. It is found in soot and in interstellar space. The first example of fullerene is Buckminsterfullerene (C_{60}). This allotrope of carbon is named fullerene after the architect Richard Buckminster Fuller because the structure of C_{60} resembles the structure of the geodesic dome he designed.

Harold Kroto, Robert Curl and Richard Smalley were given the Nobel prize in chemistry 1996, for the discovery of this carbon allotrope, fullerene C_{60}.

C_{60}, C_{70}, C_{76}, C_{82} and C_{86} are other examples of fullerene. Their molecules occur in small numbers in soot.



Buckyball (C_{60})

13.5 Structure of fullerene

Properties

1. Molecules of fullerenes are found in the form of buckyballs and buckytubes.
2. There are 30 to 900 carbon atoms in one molecule of a fullerene.
3. Fullerenes are soluble in organic solvents such as carbon disulphide, chlorobenzene.

Uses

1. Fullerenes are used as insulators.
2. Fullerenes are used as a catalyst in water purification.
3. At a certain temperature fullerene exhibits superconductivity.

B. Non-crystalline / Amorphous forms

The arrangement of carbon atoms in this form is not regular. Coal, coke are the non-crystalline forms of carbon.

1. Coal : Coal is a fossil fuel. It contains carbon, hydrogen and oxygen. It also contains nitrogen, phosphorus and sulphur. It occurs in the solid state. It is of four types.

a. Peat : Formation of peat is the first step in the formation of coal. It contains a high proportion of water and less than 60% of carbon. Therefore, not much heat can be obtained from peat.

b. Lignite : Peat was transformed into Lignite due to increased pressure and temperature inside the earth. It contains 60 to 70% of carbon. Lignite is the second step of the formation of coal.

c. Bituminous coal : Bituminous coal was formed as the third step of formation of coal. It contains 70 to 90% of carbon.

d. Anthracite : Anthracite is known as the pure form of coal. This coal is hard and contains about 95% of carbon.

2. Charcoal : The charcoal that is made from animals is made from their bones, horns, etc. On the other hand, the charcoal made from plants is formed by combustion of wood in an insufficient supply of air.

Uses of coal :

1. Coal is used as fuel in factories and homes.
2. Coal is used to obtain coke, coal gas and coal tar.
3. Coal is used in thermal power plants for generation of electricity.
4. Charcoal is used in purification of water and organic material.

3. Coke : The pure coal that remains when coal gas has been taken away from coal, is called coke.

Uses of coke :

1. Used as domestic fuel.
2. Coke is used as a reducing agent.
3. Coke is used in production of aeriform fuel such as water gas ($CO + H_2$) and producer gas ($CO + H_2 + CO_2 + N_2$).

Peat

Lignite

Bituminous coal

Anthracite

Coke

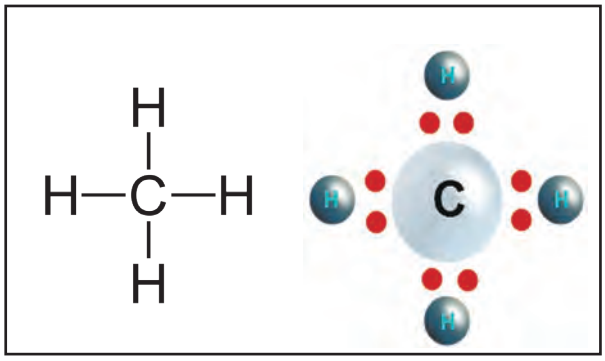
13.6 Non-crystalline forms of carbon

Hydrocarbons : basic organic compounds

Along with carbon, the element hydrogen is also included in most organic compounds. The compounds formed from only carbon and hydrogen are called basic organic compounds. These are also called hydrocarbons.

The electronic configuration of carbon is 2, 4. If four electrons are added to the second orbit of carbon, its octet becomes complete and its electronic configuration becomes stable like that of the nearest inert gas neon (2, 8). Therefore, the valency of carbon is 4. However, this occurs by sharing of electron rather than a give and take of electrons. In other words a carbon atom can form four covalent bonds with other carbon atoms or atoms of different elements.

When a carbon atom shares one electron each with four hydrogen atoms and forms four C-H bonds, a methane CH_4 molecule is formed.



13.7 Structural formula and electron dot model of methane

Properties of covalent compounds

1. Covalent compounds have low melting points and boiling points.
2. Generally they are insoluble in water and soluble in organic solvents.
3. They are poor conductors of heat and electricity.

Saturated and unsaturated hydrocarbons

A carbon atom exhibits a characteristic property. It can form a chain of carbon atoms by forming covalent bonds with other carbon atoms. The hydrocarbons having only single bonds between carbon atoms are called saturated hydrocarbons. For example ethane (C_2H_6) which is (CH_3—CH_3), propane (CH_3—CH_2—CH_3).

Some hydrocarbons have a multiple bond between two carbon atoms. A multiple bond can be a double bond or a triple bond. Hydrocarbons having at least one multiple bond are called unsaturated hydrocarbons. For example, ethene ($H_2C=CH_2$), ethyne ($HC\equiv CH$), propene (CH_3-$CH=CH_2$), propyne (CH_3-$C\equiv CH$).

Use your brain power !

Does an electric charge form on atoms when a covalent bond is formed between them? Why is a single bond between two carbon atoms strong and stable?

Solubility of carbon

Try this

Apparatus : 3 conical flasks, stirrer.

Chemicals : Water, kerosene, cooking oil, coal powder, etc.

Procedure : Take 3 conical flasks and take cooking oil, water and kerosene respectively in each. Add half a spoonful of coal powder in each of the conical flasks and stir with the help of stirrer. Observe the mixtures in the three conical flasks.

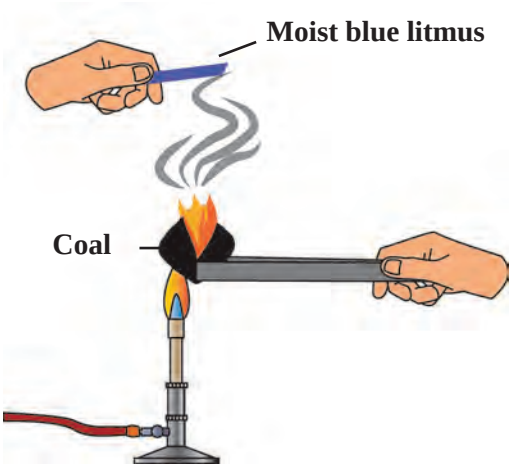
13.8 Solubility of coal in water

Use your brain power!

1. In which of the solvents- water, kerosene and cooking oil does the coal powder dissolve?
2. What inference will you draw about the solubility of carbon?

Reaction of carbon with oxygen

Try this



13.9 Reaction of carbon with oxygen

Apparatus : Coal, match box, moist litmus paper, etc.

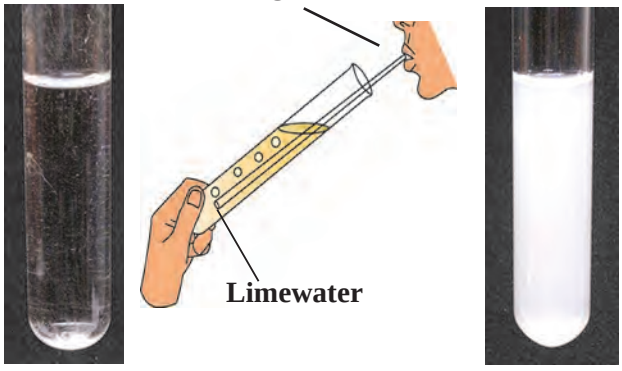
Procedure : Ignite the coal. Hold the moist blue litmus paper over the gas released on igniting the coal. Note the observation.

1. With which gas in the air does the coal react on igniting?
2. What is the substance formed?
3. What change takes place in the litmus paper?
4. Write down the chemical reaction taking place in the above procedure.

Apparatus : Test tube, straw, limewater, etc.

Procedure : Take freshly prepared limewater in a test tube. Blow for sometime into the limewater through the straw and observe the limewater. What did you see?

What might be the reason behind the change?



13.10 Reaction of limewater with CO_2

Carbon dioxide

Molecular formula: CO_2, molecular mass : 44, melting point : - 56.6 ^{0}C

Occurrence : Carbon dioxide occurs in the air in the free state to the extent of about 0.03%. Exhaled air contains about 4% of CO_2. CO_2 is present as a salt in chalk and Shahabad tiles/ marble/ limestone. CO_2 is given out in the combustion of wood and the fossil fuel coal.

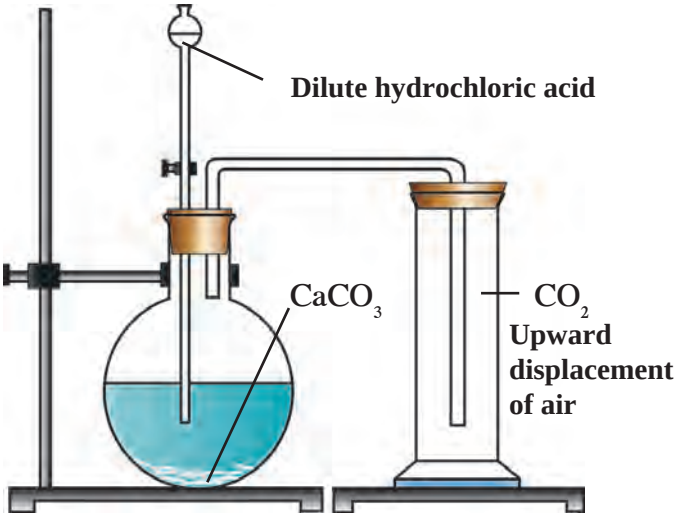
Try this

Apparatus : Retord stand, round bottom flask, thistle funnel, gas delivery tube, gas jars.

Chemicals : Calcium carbonate (Pieces of Shahabad tiles / marble pieces / limestone), dilute hydrochloric acid.

Procedure :

1. Assemble the apparatus as shown in the figure. While assembling place $CaCO_3$ in the round bottom flask.
2. Add dilute HCl in the flask through thistle funnel. See to it that the end of the funnel dips in the acid.
3. CO_2 is formed as a result of the reaction between $CaCO_3$ and HCl. Collect this gas in four to five gas jars. The chemical equation of the above reaction is as follows.



13.11 Preparation of carbon dioxide

$$CaCO_3 + 2\,HCl \rightarrow CaCl_2 + H_2O + CO_2 \uparrow$$

Physical and chemical properties of carbon dioxide

1. Observe the colour of the gas formed in the above experiment.
2. Smell the gas in the gas jar.

   Use separate gas jars for the activities 3 to 7 below:
3. Remove the lid of a gas jar and put some limewater in it.
4. Place a burning candle in a gas jar.
5. Drop a small amount of a solution of some universal indicator in one gas jar filled with CO_2 and shake it.
6. Pour some water in a gas jar and shake it.
7. Moisten a blue and a red litmus paper and drop them in a gas jar of CO_2.

   Enter your observations in all the above activities in the following table.

Physical properties of CO_2

Test	Observations
Odour	
Colour	

Chemical properties of CO_2

Test	Observations
Burning candle	
Universal indicator	
Limewater	
Water	
Litmus paper	

Use your brain power! Is the density of CO_2 more or less than that of air?

Some more chemical properties of carbon dioxide

1. Sodium carbonate is formed when carbon dioxide is passed through an aqueous solution of sodium hydroxide (Sodium carbonate = washing soda)

   Chemical equation of the reaction $2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$

2. Sodium bicarbonate is formed on passing CO_2 through an aqueous solution of sodium carbonate. (sodium bicarbonate = baking soda)

   Chemical equation of the reaction $Na_2CO_3 + H_2O + CO_2 \rightarrow 2NaHCO_3$

a. Write down the equation of the chemical reaction taking place between water and carbon dioxide in the above experiment.

b. Write down the equation of the chemical reaction taking place on putting limewater in the gas jar of CO_2.

Uses of carbon dioxide

1. CO_2 is used to make aerated drinks
2. Solid carbon dioxide is used in cold storage and also to keep milk and milk products and frozen substances cool during transport. It is also used for getting special effects of a mist in dramas and movies.
3. CO_2 obtained by chemical reaction or kept under pressure is used in fire extinguishers.
4. Liquified CO_2 is used to remove caffeine from coffee.
5. Liquid CO_2 is used as solvent in modern eco-friendly dry cleaning.
6. Plants use CO_2 in air for photosynthesis.

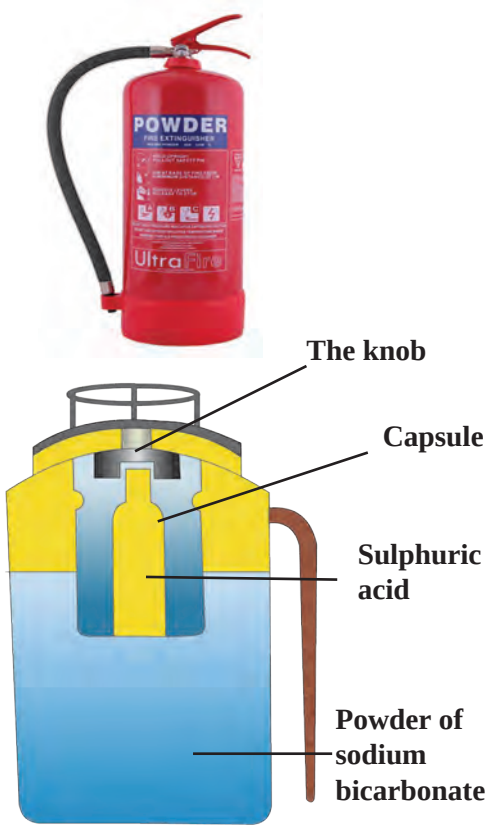
Regular fire extinguisher

A fire extinguisher contains sodium bicarbonate powder. There is also dilute sulphuric acid placed in a glass capsule. The capsule breaks on pressing the knob, the sulphuric acid comes in contact with the sodium bicarbonate and the two react chemically to release CO_2 which comes out.

CO_2 based fire extinguishers do not cause corrosion and are non conductors of electricity. Therefore these are used when electrical and electronic equipment catches fire.

CO_2 based fire extinguishers are used to extinguish small scale fire. It is beyond their capacity to extinguish a big fire.

In modern fire extinguishers liquid and solid CO_2 is filled under pressure. On reducing the pressure it becomes gaseous and comes out forcefully through the horn-like hose pipe.



13.12 Internal structure of fire extinguisher

Chemical reaction $2NaHCO_3 + H_2SO_4 \rightarrow Na_2SO_4 + 2\,H_2O + 2\,CO_2 \uparrow$

Nowadays, many types of fire extinguishers are used. Collect more information about the way CO_2 is used in them to extinguish a fire.

Methane – molecular formula CH_4, molecular mass – 16

Occurrence

1. Methane occurs in natural gas to the extent of 87%.
2. Decomposition of organic matter in the absence of air (anaerobic) produces methane.
3. Methane is present in biogas.
4. Methane is found in coal mines.
5. Methane is found at the surface of marshy places which is why it is also called marsh gas.
6. On heating a mixture of hydrogen and carbon monoxide gases at 300 ^{0}C in the presence of nickel (catalyst) methane gas is formed.
7. Fractional distillation of natural gas gives methane in pure form.

Physical properties of methane

1. Melting point of methane is (-182.5 ^{0}C).
2. Boiling point of methane is (-161.5 ^{0}C).
3. It is a colourless gas.
4. The density of liquid methane is less than that of water.
5. Methane is sparingly soluble in water. It is highly soluble in organic solvents like gasoline, ether and alcohol.
6. Methane is in gaseous state at room temperature.

Chemical properties of methane

1. Methane is highly inflammable. It burns by reacting with oxygen to give a bluish flame. In this reaction, 213 kcal/mol of heat is given out. Methane burns completely.

   Chemical reaction $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ + heat

2. Chlorination

Methane and chlorine gases react with each other at the temperature of 250 ^{0}C to 400 ^{0}C in presence of ultraviolet light and form mainly methyl chloride (chloromethane) and hydrogen chloride. This reaction is called chlorination of methane.

Chemical reaction $CH_4 + Cl_2 \xrightarrow{\text{Light}} CH_3Cl + HCl$

Uses of methane

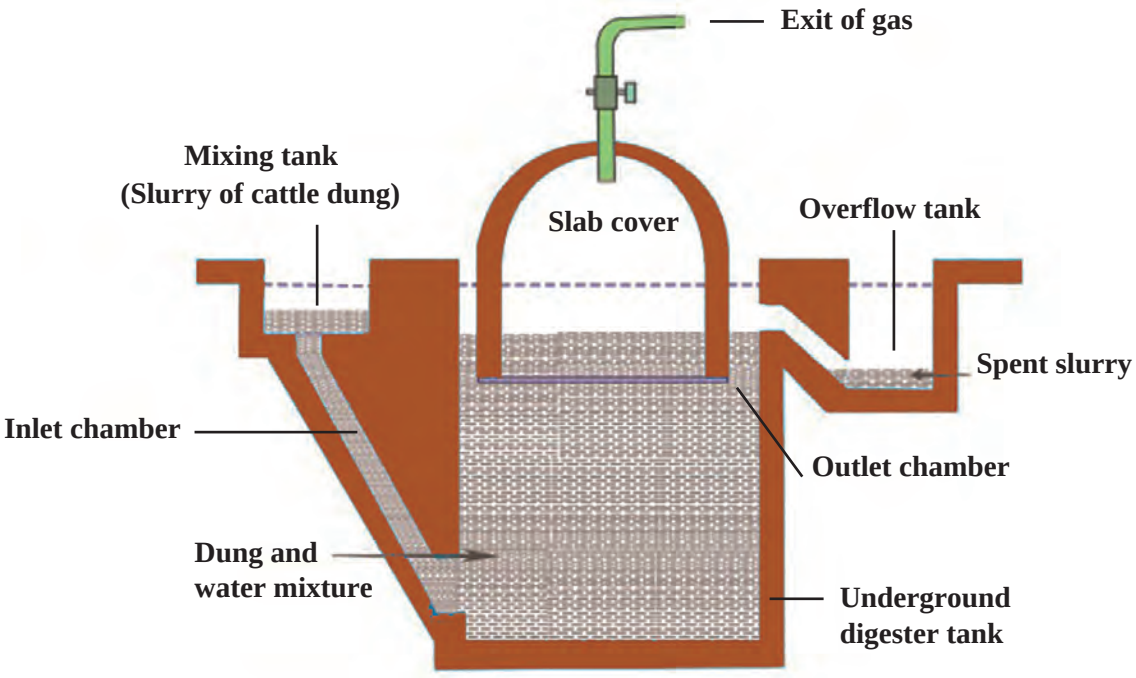
1. Methane in the form of natural gas is used in industries such as fabric mills, paper mills, food processing industry, petrol purification.
2. Being the smallest hydrocarbon, the proportion of CO_2 released in the combustion of methane is small and, therefore, it is used as a domestic fuel.
3. Methane is used for production of organic compounds such as ethanol, methyl chloride, methylene chloride and acetylene.

Methane gas was discovered by the Italian scientist Alessandro Volta between 1776 and 1778 while he was studying the gases found in marshy land.

Using ICT

Prepare a detailed report on carbon. Use computer applications such as Notepad, Word for this purpose and send the reports to others.
Websites -https://www.boundless.com/chemistry/,www.rsc.org/learn-chemistry

Biogas plant : Animal dung, dry leaves, wet garbage get decomposed by anaerobic microbes in a biogas plant. This produces methane gas also called biogas. Biogas is a very cheap fuel option which meets the demand for cooking gas. It is also used for production of an electricity. Biogas contains about 55% to 60% methane and the rest is carbon dioxide. Biogas is a fuel which is convenient to use and, in addition to this, a very good manure is also produced as a side product of the process.



13.13 Biogas plant

Biogas production process

Production of biogas is an anaerobic process. It takes place in two stages.

1. Production of acids

The microbes act on the biodegradable complex organic compound and produce organic acids.

2. Methane gas production

The methanogenic bacteria act on the organic acids to produce methane gas

$$CH_3COOH \rightarrow CH_4 + CO_2\uparrow$$

Find out

Visit a biogas plant and get to know the actual functioning of the plant. Find out which electrical instruments are run on that plant.

Exercises

1. Select the proper option and complete the statements

(single, all, double, ionic, carbon, give and take, hydrogen, multiple, share, most, covalent)

a. A carbon atom forms a …… bond with other atoms. In this bond the two atoms ….electrons.

b. All the carbon bonds in a saturated hydrocarbon .....…. electrons.

c. At least one carbon bond in an unsaturated hydrocarbon is ….

d. ….. is the essential element in all the organic compounds.

e. The element hydrogen is present in ….. organic compound.

2. Answer the following questions

a. Why are carbon and its compounds used as fuels?

b. In which compound forms does carbon occur?

c. Write the uses of diamond.

3. Explain the difference:

a. Diamond and graphite.

b. Crystalline and non-crystalline forms of carbon.

4. Write scientific reasons

a. Graphite is a conductor of electricity.

b. Graphite is not used in ornaments.

c. Limewater turns milky when CO_2 is passed through it.

d. Biogas is an eco-friendly fuel.

5. Explain the following.

a. Diamond, graphite and fullerenes are crystalline forms of carbon.

b. Methane is called marsh gas.

c. Petrol, diesel, coal are fossil fuels.

d. Uses of various allotropes of carbon.

e. Use of CO_2 in fire extinguisher.

f. Practical uses of CO_2.

6. Write two physical properties each.

a. Diamond

b. Charcoal

c. Fullerene

7. Complete the following Chemical reactions.

1. ……+…… $\rightarrow CO_2 + 2H_2O$ + Heat

2. ……+…… $\rightarrow CH_3Cl + HCl$

3. $2\,NaOH + CO_2 \rightarrow$ ……+……

8. Write answers to the following in detail.

a. What are the different types of coal? What are their uses?

b. How will you prove experimentally that graphite is good conductor of electricity?

c. Explain the properties of carbon.

d. Classify carbon.

9. How will you verify the properties of carbon dioxide?

Project

Make a model of a biogas plant and make a presentation in the class about the process of gas production.

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