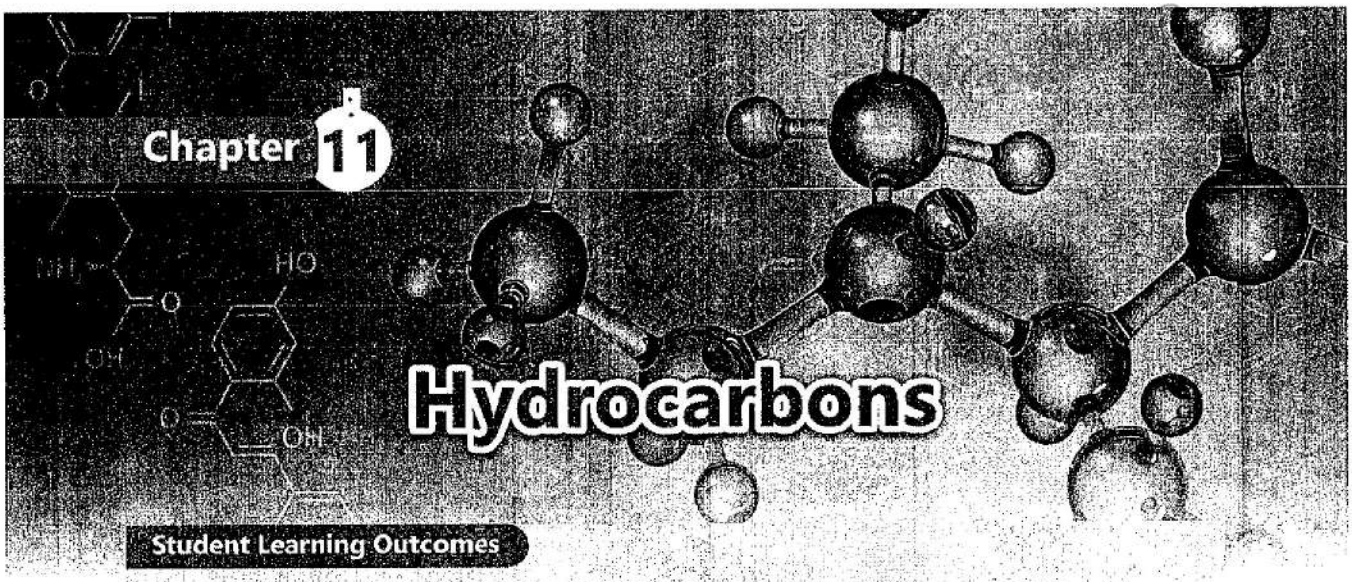


Chapter 11

Hydrocarbons

Student Learning Outcomes

After studying this chapter, students will be able to:

- Describe the properties of alkanes as being generally unreactive, except in terms of combustion and substitution by chlorine
- State that in a substitution reaction one atom or group of atoms is replaced by another atom or group of atoms
- Describe the substitution reaction of alkanes with chlorine as a photochemical reaction, and draw the structural or displayed formulae of the products, limited
- Describe, using symbol equations, preparation of alkanes from cracking of larger hydrocarbons, hydrogenation of alkenes and alkynes, and reduction of alkyl halides

Introduction

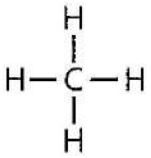
All the organic compounds are known to contain carbon as an essential element. This fact has led us to define organic chemistry as the chemistry of carbon compounds. The ionic compounds like carbonates, cyanides, carbides and cyanates, etc. and the oxides of carbon are, however, classified as inorganic compounds. Apart from carbon, most of the organic compounds contain hydrogen and oxygen as well.

Organic compounds are famous for their large number and diverse behaviour. Several million organic compounds are known to exist naturally or have been synthesized in the laboratory. Organic molecules are usually large and more complex in nature. They include life molecules like proteins, enzymes, carbohydrates, lipids, vitamins and nucleic acids, pharmaceuticals and synthetic fibres, etc.

The number of compounds formed by the element carbon is far more than the total number of compounds formed by all the rest of elements put together. This is due to some unique properties of carbon.

The element carbon is present at the center of the periodic table and it is energetically not possible for it to gain or lose electrons to form ionic bonds. Therefore, it forms four covalent bonds. Because of their small size, these covalent bonds are short and strong enabling carbon to give strong and stable bond with itself and with hydrogen, oxygen and nitrogen. The self-linking property of carbon is called catenation and due to this it forms long, straight and branched chains and rings.

Carbon atom mostly forms covalent bonds with carbon, hydrogen, oxygen, nitrogen and halogens. Compounds in which carbon forms single bond with other atoms are called saturated compounds. These compounds are generally represented by their structural formulas. Methane a saturated compound, is represented by the following structural formula.



or its condensed form is CH_4

A structural formula thus shows the symbols for the atoms present in the compounds connected by short lines which represent the bonds present in them. Other examples of saturated compounds are C_2H_6, CH_3Cl, CH_3OH, CH_3NH_2, etc.

Exercise

What do you understand by the term structural formula of an organic compound?

11.1 Hyrocarbons

The family of hydrocarbons constitutes a very large number of simple organic compounds containing carbon and hydrogen only. Most of the fuels which we use every day, for example, natural gas, LPG (Liquefied Petroleum Gas), CNG (Compressed Natural Gas), petrol, diesel and kerosene oil, are all simple hydrocarbons. These hydrocarbons also serve as a feedstock to prepare more complex and useful compounds like plastics, medicines, synthetic fibres, paints and varnishes.

Hydrocarbons are classified into several structural types called, alkanes, alkenes, alkynes and aromatic hydrocarbons. Only alkanes are discussed in this chapter.

Methane is the simplest alkane and it is mainly used as a fuel but it is also used to make hydrogen gas, carbon black, carbon disulphide, chloroform, hydrocyanic acid, etc.

11.2 Alkanes

Alkanes are the simplest family of hydrocarbons with only carbon – carbon and carbon – hydrogen single bond. Alkanes are also called saturated hydrocarbons because all the four valencies of carbon in them are fully utilized either by hydrogen atoms or by other carbon atoms. For example, in ethane (CH_3-CH_3) both the carbon atoms are fully saturated with single bonds.

Alkanes are represented by a general formula C_nH_{2n+2} (where n is an integer). Methane being the simplest hydrocarbon, is also called parent hydrocarbon.

As a result of the great complexity and large number of organic compounds, it is not possible to name each and every compound individually. The International Union of Pure & Applied Chemistry has devised a systematic way of naming organic compounds called IUPAC nomenclature.

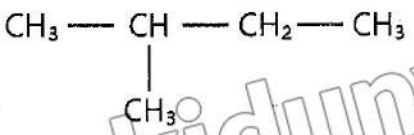
According to IUPAC system of nomenclature, the entire name of an organic compound has three parts:

1. Root: It tells us the number of carbon atoms in the longest continuous chain present in the molecule. The roots upto ten carbon atoms are shown in table 11.1.
2. Suffix: It is added after the root and tells us about the class of organic compounds.
3. Prefix: It is indicated before the root and tells us about the group or groups attached to the longest chain.

Table (11.1)

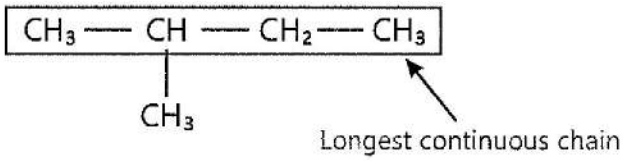
Root	No. of Carbon atoms
Meth-	1
Eth-	2
Prop-	3
But-	4
Pent-	5
Hex-	6
Hept-	7
Oct-	8
Non-	9
Dec-	10

To explain the above system, let us name the following compound.

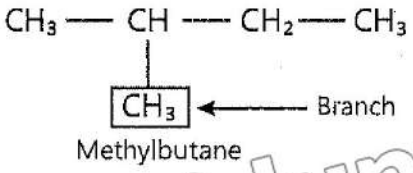


(a) Identify the longest continuous chain present in the compound.
(b) Identify the class of organic compounds.
(c) Identify the substituent or substituents if present.

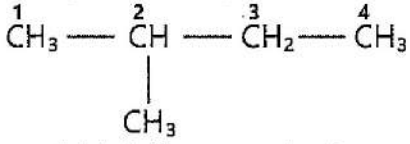
This organic compound contains four carbon atoms in the longest continuous chain and it belongs to the family of organic compounds called Alkanes. The root is therefore But- and the suffix –ane added to this. The organic compound will thus be given the name Butane.



The name of the only branch methyl- will be added to this name as prefix. So the name will become:



To specify where the branch occurs, the longest continuous chain is numbered starting from the end closest to the branch. This number is then attached to this prefix. The name of the above compound will then be:



If a compound has no branches, its name will contain only root and suffix.

Interesting Information!

The distinguishing feature of alkanes making them distinct from other compounds is their lack of reactivity towards usual chemical reagents.

Exercise

1. **Name the following compounds according to IUPAC system of nomenclature.**

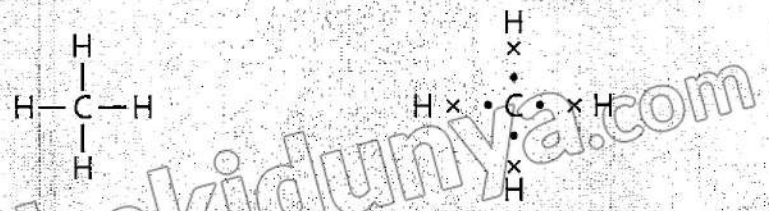
(i) $(CH_3)_2CH-\underset{\displaystyle CH_3}{\underset{|}{CH}}-CH_2-CH_3$ (ii) $(CH_3)_2CH-CH_2-CH_3$

2. **Draw the structural formulae of the following saturated compounds.**

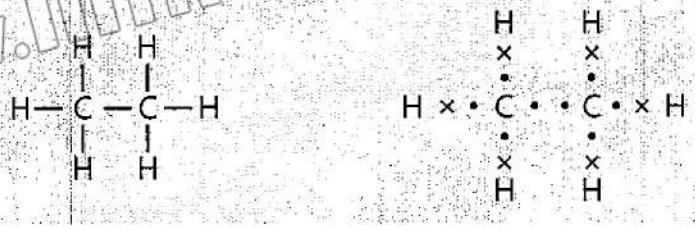
C_2H_5Br, CH_3NH_2, CH_3CH_2OH

Electron cross and dot structures of Alkanes

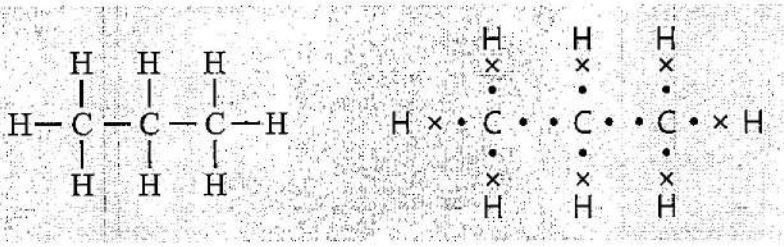
Methane



Ethane



Propane



Exercise

How many methyl and methylene, groups are present in each of the above compounds?

11.3 Preparation

Generally, any member of the alkane series can be prepared by the following methods.

1. Cracking of Higher Hyrocarbons

Cracking is the name of a process in which hydrocarbons with higher molecular masses are broken up into smaller hydrocarbons which are more useful. This is done by heating the hydrocarbons at high temperature in the presence of a catalyst.

Fractional distillation of petroleum gives naphtha which consists of a mixture of liquid hydrocarbons. It is then heated at around 500°C in the presence of catalyst called zeolite to give hydrocarbons which have five to ten carbon atoms.

$$\underset{\text{(Mixture of hydrocarbons)}}{\text{Naphtha}} \xrightarrow[\text{Zeolite}]{\text{Heat}} \text{Alkanes and alkenes containing 5 to 10 carbon atoms}$$

Interesting Information!

Cracking of hydrocarbons helps balance the availability of petroleum fractions with the demand for them. When cracking transforms bigger hydrocarbons into small hydrocarbons, the fuel supply is increased. That helps to balance demand with supply.

2. Reduction of Alkenes and Alkynes

Alkanes can be prepared by reducing alkenes and alkynes with hydrogen gas in the presence of nickel metal as a catalyst. Methane cannot be prepared by this method. The reaction is also called hydrogenation of alkenes and alkynes and is an example of addition reaction. An addition reaction occurs when hydrogen (H_2) is added to an unsaturated compound.

$$\underset{\text{Ethene}}{CH_2=CH_2} + H_2 \xrightarrow[200°C]{Ni} \underset{\text{Ethane}}{CH_3-CH_3}$$

$$\underset{\text{Ethyne}}{CH\equiv CH} + 2H_2 \xrightarrow[200°C]{Ni} \underset{\text{Ethane}}{CH_3-CH_3}$$

Interesting Information!

Reduction reaction of unsaturated compounds is used to prepare banaspati ghee and margarine.

5. Reduction of Alkyl Halides

Alkyl halides (R-X) can be reduced to alkanes with hydrogen generated by reaction of zinc metal with hydrochloric acid.

$$R — X + Zn/HCl \xrightarrow{[2H]} R — H + H — X$$

$$\underset{\text{Chloromethane}}{CH_3 — Cl} + Zn/HCl \xrightarrow{[2H]} \underset{\text{Methane}}{CH_3 — H} + H — Cl$$

11.4 Important Reactions

Alkanes are sometimes reffered to as paraffins which means "little affinity". This term describes their behaviour, for alkanes show little chemical affinity for other substances and are chemically inert to most laboratory reagents. However, alkanes do react with chlorine and oxygen under suitable conditions.
The unreactivity of alkanes may be explained on the basis of the non-polarity of the bonds present in them. The electronegativity values of carbon (2.6) and hydrogen (2.1) do not differ appreciably and the bonding electrons between C – H and C – C bond, are almost equally shared. This fact makes alkanes almost non-polar. In view of this, the reagents like acids, alkanes, oxidizing agents find no reaction site in alkane molecules to which they could be attached.

1. Halogenation

Alkanes give substitution reactions. The reactions which involve the replacement of hydrogen of alkanes by an atom or a group of atoms like halogen are called substitution reactions. Alkanes react with halogens especially chlorine to give alkyl halides. Since these substitution reactions are carried out in the presence of sunlight, these are called photochemical substitution reactions.

$$\underset{\text{Methane}}{CH_4} + Cl_2 \xrightarrow{h\nu} \underset{\text{Chloromethane}}{CH_3 — Cl} + H — Cl$$

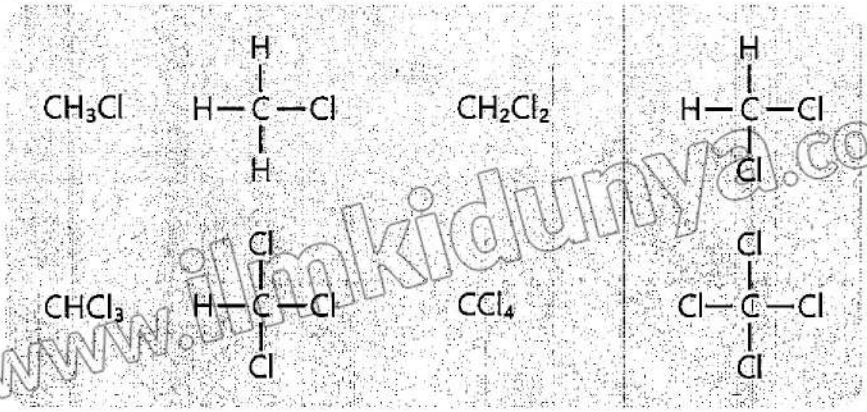
The reaction may proceed ahead and all the hydrogen atoms attached with carbon of the methane are successively replaced by chlorine atoms.

$$CH_3-Cl + Cl_2 \xrightarrow{h\nu} CH_2Cl_2 + HCl$$
Dichloromethane

$$CH_2Cl_2 + Cl_2 \xrightarrow{h\nu} CHCl_3 + HCl$$
Trichloromethane or chloroform

$$CHCl_3 + Cl_2 \xrightarrow{h\nu} CCl_4 + HCl$$
Tetrachloromethane or carbon tetrachloride

Structural Formulae of the Products.



2. Combustion

Alkanes burn in oxygen or air to form CO_2 and H_2O with the evolution of large amount of heat. The reaction is called combustion.

$$\underset{\text{Methane}}{CH_4\,(g)} + 2O_2\,(g) \longrightarrow CO_2 + 2H_2O\,(g) + \text{heat}$$

$$2CH_3-CH_3\,(g) + 7O_2\,(g) \longrightarrow 4CO_2 + 6H_2O\,(g) + \text{heat}$$
Ethane

Interesting Information!

A mixture of natural gas (methane) and air may explode when ignited. This is the main cause of explosion at homes where gas leakage occurs.

Exercise

(1) In the reduction of alkyl halides with Zn / HCl, alkyl halide is being reduced. Which species in this reaction is being oxidized?

(2) During the combustion reaction of ethane, which bonds are being broken and which are being formed?

(3) What products other than CH_3Cl are formed when methane reacts with chlorine gas?

Key Points

1. The compounds obtained from plants and animals were named as organic compounds. Fredrich Wohler was the first chemist to prepare an organic compound in the laboratory.
2. Organic chemistry is the chemistry of carbon compounds. The element carbon is unique in its behaviour.
3. Organic compounds are covalent in nature. Their melting point and boiling points are generally low.
4. Organic compounds containing carbon and hydrogen are called hydrocarbons. They are classified into saturated and unsaturated hydrocarbons.
5. Hydrocarbons containing a single bond between carbon and hydrogen are called saturated hydrocarbons or alkanes.
6. Alkanes can be named by a systematic way of nomenclature called IUPAC system of nomenclature.
7. Alkanes can be prepared by a number of different methods of preparation.
8. Although alkanes show least reactivity towards other compounds, they react with halogens and undergo combustion reactions.

Exercise

1. Tick (✓) the correct answer.

(i) Which other atom is almost always present along with carbon atom in all organic compounds?

(a) Oxygen (b) Nitrogen
(c) Hydrogen (d) Halogen

(ii) Which other metal can be used to reduce alkyl halides?

(a) Al (b) Mg (c) Ni (d) Co

(iii) If naphtha undergoes a combustion reaction what products do you expect to form?

(a) Alkanes (b) Alkenes
(c) CO_2 and H_2O (d) Both alkanes and alkenes

(iv) Why does a mixture of zinc and hydrochloric acid acts as a reducing agent?

(a) Because zinc acts as a reducing agent.
(b) Because atomic hydrogen is produced with Zn / HCl which acts as a reducing agent.
(c) Because molecular hydrogen is produced with Zn / HCl which acts as a reducing agent.
(d) Because chloride ions are produced with Zn / HCl which act as a reducing agent.

(v) Which alkane will evolve the most amount of heat when it is burnt with oxygen?

(a) Ethane (b) Propane
(c) Butane (d) iso-Butane

(vi) Indicate the most reactive hydrocarbon.

(a) $CH_3 — CH_3$ (b) $CH_2 = CH_2$
(c) $CH \equiv CH$ (d) CH_4

(vii) Which hydrocarbon is responsible for explosions in coal mines?

a) Butane b) Pentane c) Methane d) Ethene

(viii) Which product will be formed when ethyl bromide (C_2H_5Br) is treated with Zn/HCl

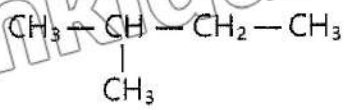
(a) CH_4 (b) $CH_3 - CH_3$
(c) $CH_3 - CH_2 - CH_2 - CH_3$ (d) $CH_3 - CH_2 - CH_3$

(ix) Which of the following is not a process of halogenation of alkanes?
(a) Cracking (b) Chlorination
(c) Bromination (d) Iodination

(x) How many moles of oxygen will be required to completely burn propane?
(a) 4 moles (b) 5 moles (c) 3 moles (d) 6 moles

2. Questions for Short Answers

i. Differentiate between an organic and an inorganic compound.
ii. Why are organic compounds found in large numbers?
iii. Name the products which are obtained when natural gas is oxidized under controlled conditions.
iv. How naphtha fraction is decomposed to give lower hydrocarbons?
v. Write down the molecular formula, structured formula and the condensed structural formula for iso-butane.
vi. How are organic compounds useful for us?
vii. Write down the names of five such organic compounds which exist naturally?
viii. Give IUPAC name to the following compound.



ix. How do the melting and boiling points of alkanes change when we move from lower members to higher members?

3. Constructed Response Questions

i. Why do alkanes show little reactivity towards the other reagents?
ii. Why does a mixture of natural gas and air explode?
iii. How do you compare the melting and boiling points of inorganic and organic compounds?
iv. Reactions of alkanes with chlorine takes place in the presence of sunlight. What is the role of sunlight in the reaction?
v. How do you compare the boiling point of n – butane with that of iso – butane?
vi. Why are organic compounds not generally soluble in water?

4. Descriptive Questions

i. Describe the importance of organic compounds in daily life.
ii. Why is carbon so important as an element that the whole branch of chemistry is based on it?
iii. A carbon–carbon single bond (C – C) does not behave as a functional group but a carbon carbon double bond (C = C) does. Explain.
iv. Explain IUPAC system of nomenclature for alkanes.
v. How combustion reaction of alkanes is useful for us?

5. Investigative Questions

i. When natural gas valve is kept open in the kitchen, the gas spreads through the whole kitchen. This may cause an explosion. What is the reason of this explosion and how can you avoid it?
ii. "Neem" is a common tree grown throughout our country. Comment on the medicinal benefits of this tree.
iii. Name a few popular medicines which are, in fact, organic compounds?