CHAPTER 15

Exploring the Building Blocks of Life

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Introduction

Chemistry is involved in everything we do; from growing and cooking of food to cleaning our homes and launching of rocket into space. According to the American Chemical Society (ACS), Chemistry is the study of matter (matter, in turn, is anything that has mass and takes up space) and the changes that matter can undergo when it is subjected to different environments and conditions (as cited in Lims & Biggs, 2021). Every material in existence is made up of matter–even our own bodies.

Chemistry can be classified into different branches; physical chemistry, environmental chemistry, inorganic chemistry, and organic chemistry are some of the branches of chemistry. Harvey (2023) posited that inorganic chemistry is interested in compounds not containing carbon, though there are some instances of overlap between the two fields (i.e. inorganic and organic chemistry). Finished products made from inorganic compounds and processes which we use in everyday life include jewellery made from diamond, gold, silver, batteries made from electrochemical processes and redox reactions, table salt, potassium used for cooking etc. Inorganic processes that occur around us include purification of water, evaporation of seawater to obtain salt, rusting and corrosion of metals etc. These processes take place without requiring organic reactants neither do they give rise to organic products.

Organic chemistry, on the other hand, specifically studies compounds that contain the element carbon. In chemistry, the word organic refers to carbon–containing compounds; therefore, organic chemistry is the branch of science that studies compounds that contain carbon (Emerson & Foist 2023). Carbon is undeniably the central element in organic chemistry. However, it is important to understand that not all carbon–containing compounds are organic compounds–there is an exception. Organic chemistry is the study of compounds of carbon occurring naturally–excluding the oxides of carbon and trioxocarbonate (IV) compounds, which are classified as inorganic compounds (Ojokuku, 2012). We can now see that compound such as carbon IV oxide (CO_2), Carbon (II) oxide (CO), sodium trioxocarbonate IV (Na_2CO_3) among others are not organic compounds even though they are carbon containing. According to Helminstine (2019), organic chemistry plays a part in the development of common household chemicals, foods, plastics, drugs, and fuels most of the chemicals are part of daily life hence; organic chemistry is defined as the study of carbon and the study of the chemistry of life.

Importance of Organic Chemistry

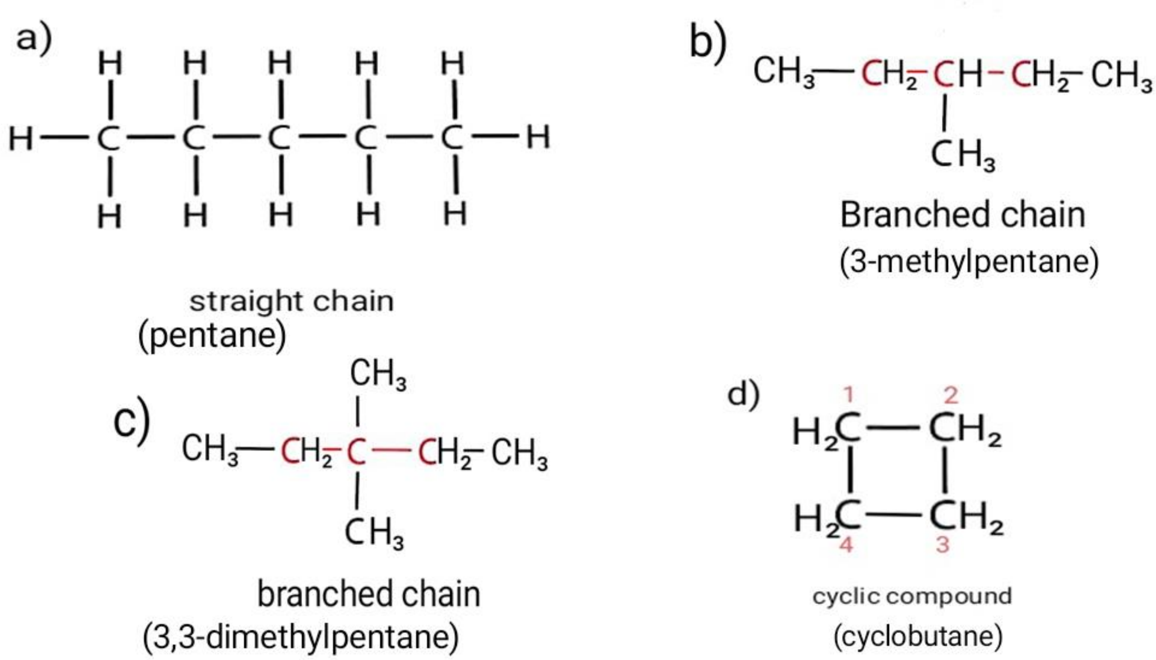
The study of organic chemistry gives us better understanding about organic compounds, organic processes that occur around and within us and also helps us appreciate the uniqueness of carbon over all other elements. Organic chemistry plays a part in the development of common household chemicals, foods, plastics, drugs, and fuels most of the chemicals are part of daily life (Helminstine, 2019). Organic compounds such as sugar, starch, soaps, detergents, kerosene, fuel, cooking gas, plastics, drugs such as panadol, paracetamol, aspirin etc. contribute to our daily life needs. Organic processes within and around us include: fermentation of glucose (this leads to production of alcohol), enzymatic catalysis of food substances we eat, local synthesis of herbs and leaves of plants for medicinal purpose, separation of crude oil into different organic fractions usually done in the refinery etc. also contribute to our daily personal and economic needs.

The uniqueness of carbon

Scholars have posited different definitions for organic chemistry; however, there is a common denominator which is the fact that carbon is the primary element of concern in organic chemistry. According to Carpenter (2021), out of 118 elements, only one has its own field of study: carbon. Why carbon? Why not nitrogen which is next to it on the periodic table or even silicon which is immediately below carbon in the same group? Higginbotham (2021) answered that no other element can quite do what carbon does.

In organic compounds, carbon exhibits the covalency of four (4). Carbon forms the maximum of four bonds. The four valence electrons in a carbon atom can do this by forming four single bonds, or by forming two single bonds and a double bond, by forming one single bonds and a triple bond, or by forming two double bonds (Higginbotham, 2021). In addition, carbon atoms have the unique ability to form bonds with themselves i.e. other carbon atoms (Teachoo, 2023). This is known as catenation. We can say that catenation is a property by which a carbon atom bonds with any number of other carbon atoms to form various sizes of organic compounds. These compounds can be straight chained, branched or cyclic. Examples of straight, branched and cyclic or ring chained organic compounds are given below.

Fig. 1: Example of straight, branched and cyclic organic compounds



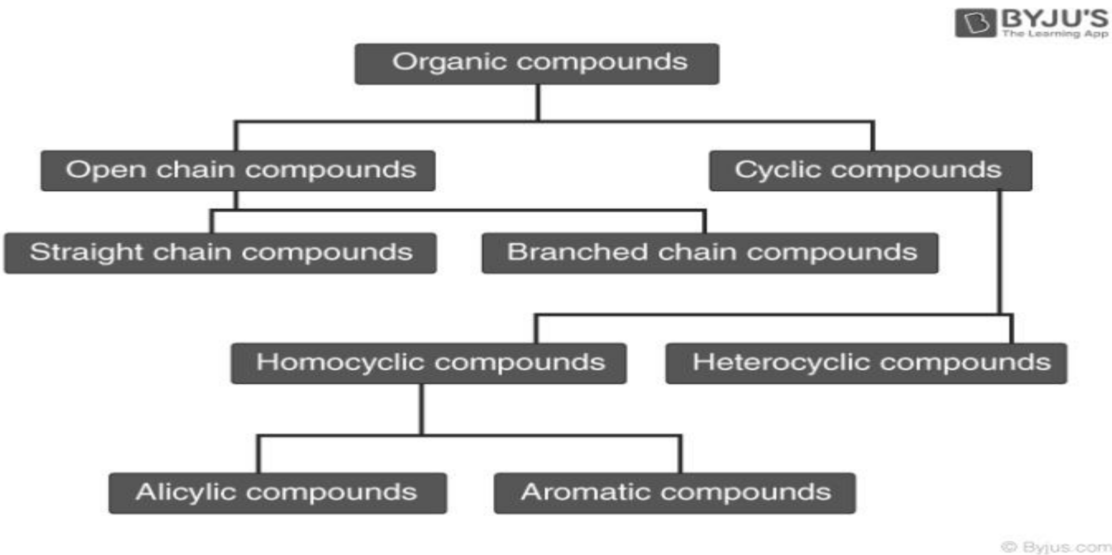
Atoms of other elements lack the ability to bond in such a way that carbon does. With every additional carbon to carbon bond, a new compound is formed giving rise to more organic compounds. With this phenomenon, Carpenter (2021) asserted that there are more types of carbon-based molecules in existence than all non-carbon ones put together. This illustrates the uniqueness of carbon. Due to the large number of organic compounds in existence, it is important that we classify them in order to have a better understanding of their relationships and differences.

Classes of organic compounds

There are different ways in organic compounds can be classified. Each classification has a rationale attached. It could be based on the nature of the structure of the organic compounds or based on the type of atom attached to the central carbon atoms and so on.

Based on the nature of the structure, organic compounds can be classified into: open chain compounds and cyclic compounds. There are further subdivisions after the major division as shown in the figure below:

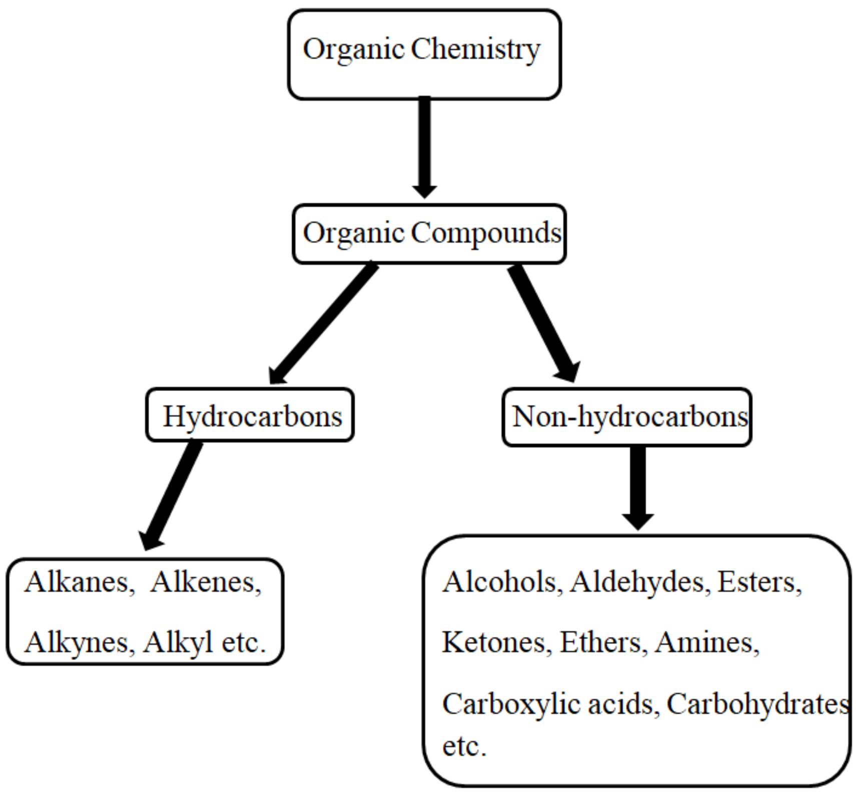
Figure 2: Classification of organic compounds according to their structure



Source: Byju’s (n.d.)

While, according to the atoms attached to the central carbon atom, organic compounds can be divided into two: hydrocarbons and non-hydrocarbons. Hydrocarbons are organic compounds that are made up carbon and hydrogen only. While non-hydrocarbons contain carbon, hydrogen and other atoms such as oxygen, chlorine, sulphur etc. This classification is illustrated in the figure below:

Figure 3: Classification of organic compounds according to the kinds of atoms attached to the central carbon atom



It is established that there are millions of organic compounds in the world. However, no two different organic compounds share the same name. Each of these compounds has a distinct name as a means of identification. This is made possible by the International Union of Pure and Applied Chemistry (IUPAC).

IUPAC Nomenclature of Organic Compounds

Have you ever heard of names of compounds like 1,1-dichloroethane, 2-methylpentanol, 2,2-difluorohexane and wondered how the names are arrived at? These names are arrived at using guiding rules from the International Union of Pure and Applied Chemistry (IUPAC). It is an international federation working for the advancement of the chemical sciences, especially by developing nomenclature and terminology. The IUPAC naming system was created in order to give each organic compound a unique and unambiguous name, and to correlate easily between the structure itself (Baxter & Reid 2023).

As earlier stated, there are millions of organic compounds in existence. These compounds are distinct and must have unique names in order to differentiate them. The IUPAC nomenclature system provides rules for naming compounds which when followed will circumvent the discrepancies that may arise from using the common nomenclature. The nomenclature process is guided by rules unique to each class of organic compounds. Organic compounds belonging to the same class tend to have similar properties and react in a similar way. What causes the similarity in functions and reactions is referred to as their functional group.

Functional Group

The possession of a complex brain in human beings gives us the advantage to behave differently from other animals–it is our functional group. The IUPAC Goldbook asserted that a functional group is an atom, or a group of atoms that has similar chemical properties whenever it occurs in different compounds (as cited in Salmina, Haider & Tetko, 2015). We can say that a functional group is a part of a material that makes it to function in a certain way which is different from another. It is responsible for the characteristic physical and chemical properties of classes of organic compounds. For instance, organic compounds like methanoic acid and ethanoic acid are acidic. This is because they have the carboxylic functional group in them (–COOH) that makes them acidic. The absence or removal of that functional group through synthesis will make the compound lose its acidity. Another example can be seen in the case of Alkanes. Alkanes are the simplest hydrocarbons and are widely regarded to be less reactive. This is because their functional group (single bond) is responsible for that. More examples are provided in the table below:

Table 1: Common classes of organic compounds and their functional groups

Class of compound	**Functional Group**	**Example**
Alkanes	–C–H/ –C–C–	$H_3C–CH_3$ (Ethane)
Alkenes	–C=C–	$H_2C=CH_2$ (Ethene)
Alkynes	–C≡C–	HC≡CH (Ethyne)
Alkanols	–OH	CH_3OH (Ethanol)
Alkanoic acids	–COOH	CH_3COOH (Ethanoic acid)
Alkanals	–CHO	CH_3CHO (Ethanal)
Alkanones	>C=O	CH_3COCH_3 (Propanone)
Alkanoates	–COO–	CH_3COOCH_3 (Methylethanoate)

A functional group is responsible for the physical and chemical properties of a class of organic compounds, especially in their homologous series.

Homologous Series

A homologous series contains homologues (members) that differ by one methylene (CH_2) group (Tatomir, Pierce & Cena, 2023). In homologous series, the compounds (members) have the same functional group and similar chemical properties and successive members of the series differ by molecular formula of CH_2 which translates into molecular mass of 14g. Homologous series can be used to study family of organic compounds. A member of a homologous series is called a homologue.

Homologous series in alkanes

Alkanes are the simplest hydrocarbons and have the functional group –C–H (carbon to hydrogen bond) which sometimes can be taken as –C–C– (carbon to carbon single bond)for clarity. Alkanes form a homologous series with the general formula C_nH_{2n+2}. Where n is any positive whole number from 1. The first ten members of this series and their molecular formulas are given below:

Table 2: The first ten members of the straight chain alkane homologous series and their molecular masses

Name	Molecular formula	Molar mass
Methane	CH_4	16 $gmol^{-1}$
Ethane	C_2H_6	30 $gmol^{-1}$
Propane	C_3H_8	44 $gmol^{-1}$
Butane	C_4H_{10}	58 $gmol^{-1}$
Pentane	C_5H_{12}	72 $gmol^{-1}$
Hexane	C_6H_{14}	86 $gmol^{-1}$
Heptane	C_7H_{16}	100 $gmol^{-1}$
Octane	C_8H_{18}	114 $gmol^{-1}$
Nonane	C_9H_{20}	128 $gmol^{-1}$
Decane	$C_{10}H_{22}$	142 $gmol^{-1}$

The series above shows that each successive member differs by CH_2 unit which translates into 14g. Other additional characteristics of the alkanes include:

1. They have carbon to carbon single bonds in their compounds.

2. They are saturated. This is because of the carbon to carbon single bond (–C–C–) and consequently, they do not undergo addition reaction.

3. They are sp^3 hybridised.

4. They have the general formula C_nH_{2n+2}.

5. They can be straight chained or cyclic.

6. They are also called paraffins

7. Their names end with the suffix –ane

Uses of Alkanes

Alkanes have many applications. Some of the applications of alkanes as mentioned in Dong (2021) include:

1) The first four members of the alkanes (from methane to butane) are used primarily for heating and cooking, and are also used for power generation in some countries.

2) Alkanes from pentane to octane are highly volatile liquids −they are used as fuel for internal combustion engines.

3) Alkanes above hexadecane ($C_{16}H_{34}$) are the most important components of fuel oil and lubricating oil.

4) Many solid alkanes can be used as paraffin waxes, as in candles.

Homologous Series in Alkenes

Alkenes are the second class of hydrocarbon characterized by the following:

1. They have at least one carbon to carbon double bond in their molecules (–C=C–)

2. They are unsaturated. The double bond enable them to undergo addition reaction, hence, they are unsaturated.

3. They are sp^2 hybridised

4. They have the general formula C_nH_{2n}

5. They can be straight chained or cyclic

6. They are also called olefins.

7. Their names end with the suffix –ene

8. The first member of the alkene homologous series is ethene.

The first nine members of the series are given below:

Table 3: The first nine (9) members of the alkene homologous series

Name	Molecular formula	Molar mass
Ethene	C_2H_4	28 $gmol^{-1}$
Propene	C_3H_6	42 $gmol^{-1}$
Butene	C_4H_8	56 $gmol^{-1}$
Pentene	C_5H_{10}	70 $gmol^{-1}$
Hexene	C_6H_{12}	84 $gmol^{-1}$
Heptene	C_7H_{14}	98 $gmol^{-1}$
Octene	C_8H_{16}	112 $gmol^{-1}$
Nonene	C_9H_{18}	126 $gmol^{-1}$
Decene	$C_{10}H_{20}$	140 $gmol^{-1}$

Uses of alkenes

Alkenes have many applications. Some of the applications of alkenes as mentioned in Sharma (2021) include:

1) Alkenes are used as the building block to prepare complex organic compounds. For instance, ethane acts as a starting material for preparation of ethanol.

2) Alkenes are used for the manufacture of polyethylene, which is used for making polythene pipes, buckets, and toys.

3) Ethene is used as the artificial ripening of fruits.

3) Oxy-ethylene derived from ethylene is used in the production of mustard gas, and its flame for metal cutting and welding

Homologous Series in Alkynes

1. Alkynes have one carbon to carbon triple bond bond in their molecules (–C≡C–)

2. They are unsaturated. The triple bond enable them to undergo addition reaction, hence, they are unsaturated.

3. They are sp^3 hybridised

4. They have the general formula C_nH_{2n-2}

5. They can be straight chained or cyclic

6. Their names end with the suffix –yne

7. The first member of the alkene homologous series is ethyne

Table 4: The first nine (9) members of the alkene homologous series and their molecular masses

Name	Molecular formula	Molar mass
Ethyne	C_2H_2	26 $gmol^{-1}$
Propyne	C_3H_4	40 $gmol^{-1}$
Butyne	C_4H_6	54 $gmol^{-1}$
Pentyne	C_5H_8	68 $gmol^{-1}$
Hexyne	C_6H_{10}	82 $gmol^{-1}$
Heptyne	C_7H_{12}	96 $gmol^{-1}$
Octyne	C_8H_{14}	110 $gmol^{-1}$

Nonyne	C_9H_{16}	124 $gmol^{-1}$
Decyne	$C_{10}H_{18}$	138 $gmol^{-1}$

Uses of alkynes

Oxyacetylene flame is used in gas welding

2) Acetylene is used as illuminant in lighthouses

3) Acetylene is used in preparation of acetaldehyde, ethyl alcohol, synthetic rubber etc.

Formulas in Organic Chemistry

Molecular formula

The molecular formula is a formula generated from molecules that represents the total number of individual atoms in a compound's molecule (Vendatu, 2023). It has a subscript which indicates the number of each type of atom in the molecule. The molecular formula tells us atom of what element is present in a compound and how many of it is present. It does not tell the connections between the atoms.

Table 5: Examples of organic compounds and their molecular formulas

Name	Molecular Formula
Glucose	$C_6H_{12}O_6$
Methane	CH_4
Trichloromethane	$CHCl_3$
Ethanoic acid	$C_2H_4O_2$
Ethanol	C_2H_6O
Benzene	C_6H_6

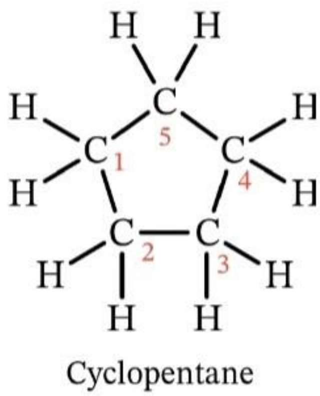
Methanal (Formaldehyde)	CH_2O
Glycerol (propane-1,2,3-triol)	$C_3H_8O_3$

Note that: in writing the molecular formula for an organic compound, carbon comes first; then hydrogen and then other atoms follow.

Structural formula

The skeletal formula is also called line bond formula. A line bond formula shows all the carbon and hydrogen atoms and the bonds attaching them. Thus, line bond formulas show the order of attachment of the various atoms (Roy, n.d.). The molecular formula tells us the atoms present in an organic compound but it does not tell us how the atoms are connected or bonded to each other. The structural formula however, provides the detail of the connections between the atoms in a given compound. Example is shown below with cyclopentane which has the molecular formula C_5H_{10}.

Figure 4: The structural formula for cyclopentane where the bonds and connections between the atoms are clearly illustrated.



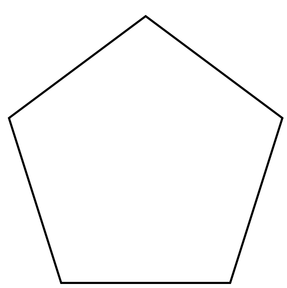
Condensed formula

The condensed formulas show hydrogen atoms right next to the carbon atoms to which they are attached (Roy, n.d.). In other words, it can be said to be the molecular formula of each carbon atom present in a compound. It can be easily obtained when the structural formula is drawn. For example, in the structural formula for cyclopentane above, the first carbon atom is bonded to two hydrogen atoms, then we first write CH2; the second carbon atom is connected to two hydrogen atoms as well, so we write CH2. In fact, each of the 5 carbon atoms is connected to two hydrogen atoms. The condensed structure becomes $CH_2CH_2CH_2CH_2CH_2$ which can be further simplified to $(CH_2)_5$, meaning there are five consecutive CH_2 units.

Skeletal or line formula

In skeletal structure, carbon atoms are implied at the corners and ends of lines, and each carbon atom is understood to be attached to enough hydrogen atoms to give each carbon atom four bonds (Roy, n.d.). Some organic compounds have giant molecules and structures. Drawing their structural formula becomes cumbersome; hence there is need for adoption of the skeletal or line formula. In line formula, lines such as zig-zag are used to represent organic compounds. The starting and finishing points represent carbon atoms and every angle in between these two phases designates the presence of a carbon atom. Hydrogen atoms that are directly connected to carbon atoms are ignored. However, non-hydrogen atoms or groups connected to the carbon atom must be indicated. The skeletal formula for cyclopetane is shown below

Figure 5: Skeletal formula for cyclopentane



Each angle in the structure above represents a carbon atom and since all the hydrogen atoms are directly bonded to the carbon atoms, they are ignored. Another example is shown below

Figure 6: Skeletal structure of 3-chlorohexane

In the figure above, there are imaginary carbon atoms in the starting and finishing points. Similarly, all the four (4) angles in between the starting and finishing point indicate carbon atoms. The hysdrogen atoms directly connected to the carbon atoms are ignored. However, from the right, a chlorine atom is attached to the third carbon atom and because chlorine is not hydrogen, it must be clearly illustrated as in the figure above. The condensed formula can be written as $CH_3CH_2CH_2CHClCH_2CH_3$ while the molecular formula is $C_6H_{13}Cl$. Skeletal formulas are commonly used in organic chemistry for organic compounds that have bulky and giant structures.

Conclusion

Organic chemistry is an important aspect of chemistry that furnishes us with the knowledge of organic compounds and processes both of which are vital to living organisms; example, in medicine. We have seen that carbon is the focal element in organic compounds due to its tetracovalency and ability to catenate thereby giving rise to millions of organic compounds in existence. The simplest of organic compounds which include alkanes, alkenes and alkynes have been introduced; similarly, different formulas with which an organic compound can be represented have been discussed. These, among other vital concepts discussed in this chapter provide sound foundational basis for further learning of organic compounds.

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