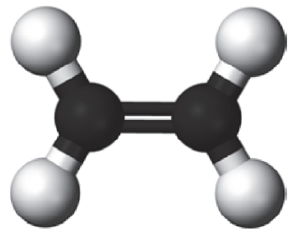
Chapter 15

Hydrocarbons



We read about different covalent compounds in the chapter on chemical bonding. We were introduced to covalent compounds of hydrogen with different elements like nitrogen, oxygen and carbon. Recall that the covalent compound of nitrogen and hydrogen is called ammonia and water is one of the covalent compounds of hydrogen and oxygen. What are the names of the covalent compounds formed by hydrogen and carbon? We saw some of them in the previous chapter such as methane, ethane, ethene etc. In fact, there are many more compounds formed by carbon and hydrogen and not just these three. The compounds of carbon and hydrogen are known as hydrocarbons. Nitrogen, oxygen etc. make one or two covalent compounds with hydrogen but carbon makes a large number of hydrocarbons with hydrogen. Let us try to understand why carbon forms such a large number of covalent compounds with hydrogen.

15.1 Catenation

Methane is the simplest compound of carbon. The molecular formula of methane is CH_4 and its structural formula is depicted in Fig.1.

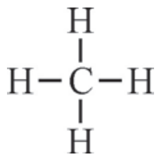


Fig.1 : Structure of methane molecule

Here, one atom of carbon is bonding with four hydrogen atoms.If we remove a hydrogen atom from methane we get the methyl group which is written as -CH_3. What if we replace one hydrogen of methane by a methyl group? We then get the following structure (Fig.2).

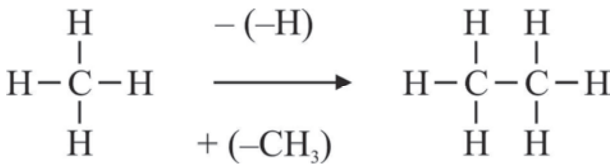


Fig.2 : Structure of ethane molecule

This molecule is ethane and its molecular formula is C_2H_6. In ethane too, we can replace one hydrogen atom by a methyl group. The molecule obtained will have a chain of three carbon atoms.

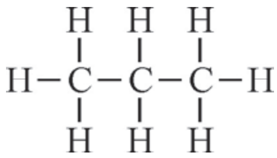


Fig.3 : Chain having three carbon atoms

In this way we can keep extending the chain by increasing the number of carbon atoms in it. This property of an element where its atoms bond with each other to give long chains is known as catenation. Sulphur and silicon also show catenation but they form shorter chains, not to the extent formed by carbon. Only carbon is known to be capable of forming very long chains of its atoms. One of the reasons for catenation in carbon is that carbon forms strong bonds not only with hydrogen and many other elements but also itself. Because of this catenation property of carbon, the number of hydrocarbons is very large.

15.2 Using condensed structural formulas to represent hydrocarbons

So far we have been using structural formulae to show the structures of hydrocarbons. In structural formulas, a single bond between carbon atoms is shown by a dash (Fig.1,2.3), a double dash (=) is used to represent a double bond (Fig.4a) and three parallel dashes (≡) are used to represent a triple bond (fig. 4b).

Fig. 4 : a and b

These structures take a lot of space and it is not always convenient to draw them. So, we use a simpler way of showing structures known as condensed structural formulas. In these structures all single bonds between atoms are omitted, that is, not shown. Then the structure of ethane can be written as CH_3CH_3. We can simplify the formulas even further if we have two or more identical groups of atoms in the molecule. For example, $CH_3CH_2CH_2CH_2CH_2CH_3$ can bewritten as CH_3 $(CH_2)_4$ CH_3.The identical group or the group being repeated is placed inside a bracket and the number of times it repeats is written as a subscript outside the bracket. Thus, the number after the bracket gives the number of times the group is found at that position inside that molecule. The double and triple bonds are shown in condensed structural formulas so the formula of ethene is $H_2C=CH_2$ and that of ethyne is $HC\equiv CH$.

15.3 Alkanes

We know that methane is the simplest hydrocarbon. We get ethane if we extend this carbon chain by one. We can get keep extending the carbon chain to get longer and longer straight or *continuous* chains.

Table-1 : Condensed structures, molecular formula and names of alkanes

No. of carbon atoms (n)	Condensed structure	Molecular formula	Name				
			Root	+	Suffix	=	Name
n=1	CH_4	CH_4	Meth	+	ane	=	Methane
n=2	CH_3CH_3	C_2H_6	Eth	+	ane	=	Ethane
n=3	$CH_3CH_2CH_3$	C_3H_8	Prop	+	ane	=	Propane
n=4	$CH_3(CH_2)_2CH_3$	C_4H_{10}	But	+	ane	=	Butane
n=5	$CH_3(CH_2)_3CH_3$	C_5H_{12}	Pent	+	ane	=	Pentane
n=6	$CH_3(CH_2)_4CH_3$	C_6H_{14}	Hex	+	ane	=	Hexane

Look carefully at the molecular formulas of the structures given in table-1. Do you see any relation between the molecular formulas with the number of carbon atoms, n?We find that all these hydrocarbons have the general molecular formula C_nH_{2n+2}. Compounds with this general formula are called alkanes. Alkanes are compounds of only hydrogen and carbon without any double bonds or triples bonds. The atoms in alkanes are connected to each other by single bonds only.

15.4 Naming of straight chain alkanes

An alkane (in fact, any hydrocarbon) is named according to the number of carbon atoms present in the carbon chain. The names of any continuous chain alkane can be divided into two parts. The first part or the prefixgives the number of carbon atoms in the longest continuous carbon chain. The longest chain is also known as the root or parent chain. The second part is the suffix which tells us the type of bonds present between the carbon atoms ofthe hydrocarbon. Let us understand through a few examples.

In alkanes where n=1, that is where the number of carbon atoms is one, the root is meth- and the suffix is –ane. Thus, the name of the alkane is meth+ane= methane. Similarly, if the alkane has the number of carbon atoms in the longest chain, n=2,3,4,5 or 6, then eth-, prop-, but-, pent- and hex- are used as roots and –ane is the suffix (table-1).

Questions

1. Draw the structural formula of an alkane where n=3. Name it.
2. Write the condensed structural formula of $CH_3CH_2CH_2CH_2$ CH_3
3. C_7H_{16} is called heptane. Identify the root part and suffix in the name.

Look at the molecular formula of methane, CH_4 and ethane, C_2H_6. They differ by a $–CH_2–$ group. Again, look at structural formula of ethane CH_3CH_3 and the next member in the series, propane $CH_3CH_2CH_3$. It is clear that they also differ by a $–CH_2–$ (methylene) group. You can verify this for other pairs of adjacent alkanes, such as propane and butane, butane and pentane, pentane and hexane as well. Each time, the molecules differ by a $–CH_2–$ group. A series of compounds related in this manner is said to form a homologous series. As we have seen, alkanes all have the general formula C_nH_{2n+2} (where n is the number of carbon atoms) and successive members differ by a $–CH_2–$ group. So, we can say that alkanes form a homologous series.

Calculate the molecular weights of methane and ethane and find the difference between them. Also find the difference in molecular weight between ethane and propane, propane and butane, and butane and pentane. Can you see any relation between the molecular weights of members of homologous series of alkanes?

15.5 Trends in physical properties

We have seen that the molecular weights of members of homologous series of alkanes differ by 14 u. Does this have any effect on their physical properties? Let us look at the table showing the boiling points of some alkanes-

Table -2 : Boiling points of the first six alkanes

Name of alkane	Boiling point °C
Methane	–162
Ethane	–89
Propane	–42
Butane	–0.5
Pentane	36
Hexane	69

We can see that the boiling points of the alkanes are gradually increasing as we increase the number of carbon atoms. We can say that straight chain alkanes with longer chains have higher boiling points than shorter chains and that the boiling point of the alkane depends on its molecular weight. In general, the physical properties of homologous members show a gradual and regular change.

Questions

1. What is a homologous series? Explain through examples.
2. Which among butane, propane and pentane will have the highest boiling point? Explain.

15.6 Branching and Structural Isomerism

So far, we extended the carbon chains by replacing a hydrogen from a terminal carbon atom with a methyl group. The hydrocarbons so formed involve continuous chains of carbon atoms. But we can also form branches in the alkanes. When a carbon atom in an alkane is bonded to more than two other carbon atoms, a branch in carbon chain occurs at that position. Let us go back to the example of $CH_3CH_2CH_3$. It has three carbon atoms, two of them are terminal and one is in the middle. The two terminal carbon atoms are chemically equivalent. To increase the carbon chain we can replace the H from either the middle carbon or the terminal carbon. That is we can extend the chain in two ways. If we replace the hydrogen atom from the terminal carbon we get the structure shown in fig.5 and if we replace the hydrogen from the middle carbon we get the structure shown in fig. 6.

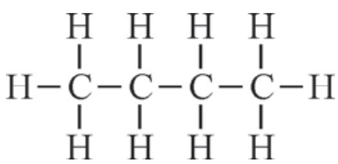


Fig. 5 : Butane

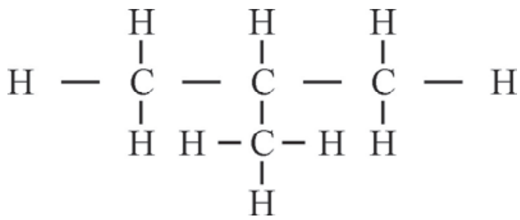


Fig. 6 : 2-methylpropane

Both of these have the same molecular formula C_4H_{10}, that is, the same number and type of atoms.But their structures are different which means that they represent molecules of different compounds. Existence of many different compounds which have the same molecular formula is called as isomerism. The different compounds are called isomers of each other. We can see that there are two possible isomers with the molecular formula C_4H_{10}.

One of them is called butane (fig.5). How do we name the other (fig.6) compound?

We first try to find the longest, continuous chain. It need not be straight, but it should be the longest. In the structures shown in fig.7, the longest chain has three carbon atoms. Note that although it looks as if the structures are different, both molecules are same.

Fig. 7

We see that the longest chain (also called the parent chain) in the second structure has three carbon atoms and so the root will be prop–. Then, we look for the branching point where the substituent is attached and name the substituent at the branching point. Here it is methyl group. Now, we start numbering the carbon atoms in the longest chain so that the branching carbon gets the lowest number. In our example, it does not matter from where we start counting because the branch position will always be at carbon number 2 (Fig.8).The position number of the alkyl group is 2.

Fig. 8 : 2-methylpropane

Now, we can name our compound. When writing the name of the compound,we first write the number of the branching carbon to which the substituent is attached followed by a dash (-). After the dash, the name of the alkyl substituent is written followed by the root to which the suffix is added at the end. Therefore, our compound is 2-methylpropane.

We have already discussed that compounds having the same molecular formula but different structures are called structural isomers. Structural isomerism can be of many types. The types of isomerism seen in butane and 2-methylpropane is called chain isomerism because it arises from differences in the parent carbon chain.

Questions

1. Draw the isomers of C_5H_{12}. (Hint: - three isomers are possible)

Similarly, six isomers are possible for hexane. The number of possible isomers for a given molecular formula increases with the number of carbon atoms present in it.

15.7 Alkene and alkyne

We have already seen homologous series of alkanes. Let us explore whether hydrocarbons having double or triple bonds also make homologous series. The simplest hydrocarbon with double bond that we have seen so far is ethene (also commonly known as ethylene). The structural formula of ethene is $CH_2=CH_2$ and the molecular formula is C_2H_4. Notice that the prefix in ethene is eth– which denotes two and the suffix is –ene. We can replace one of the hydrogen atoms of ethene by a methyl group. We will get $CH_2=CHCH_3$. It is known as propene and has the molecular formula C_3H_6. In general, hydrocarbons containing carbon-carbon double bonds are known as alkenes.

We can see that ethene and propene differ by a methylene group. Just as in the case of alkanes, one way of extending the carbon chains in alkenes is by substituting a hydrogen at a terminal (end) carbon by a methyl group.

Table-3 : Condensed structures, molecular formula and names of alkenes

No. of carbon atoms (n)	Condensed structure	Molecular formula	Name				
			Root	+	Suffix	=	Name
n=2	$H_2C = CH_2$	C_2H_4	Eth	+	ene	=	Ethene
n=3	$H_2C = CH\ CH_3$	C_3H_6	Prop	+	ene	=	Propene
n=4	$H_2C = CH\ CH_2\ CH_3$	C_4H_8	But	+	ene	=	Butene
n=5	$H_2C = CH\ (CH_2)_2\ CH_3$	C_5H_{10}	Pent	+	ene	=	Pentene
n=6	$H_2C = CH\ (CH_2)_3\ CH_3$	C_6H_{12}		?			

It is clear from the table that alkenes have the general formula C_nH_{2n}. They also differ by a methylene group and hence can be said to form a homologous series.

While naming alkenes, we follow the root-suffix rule where the suffix –ene is used to denote alkenes and the root gives the number of carbon atoms in the parent chain of the alkene. So butene means an alkene (-ene) with 4 carbon atoms (but-). *Can you give the name of a six carbon alkene?*

We can do something similar with ethyne (commonly called acetylene). It is the simplest hydrocarbon having a triple bond. Hydrocarbons having triple bonds between carbon-carbon atoms are called alkynes. Their naming is quite simple as we use the prefix-suffix rule where the suffix is –yne and the root gives the number of carbon atoms in the parent chain. Thus propyne would mean an alkyne with three carbons atoms.

In the table given below, the names of first three alkynes have been given. Try to complete the table using what you have learnt so far.

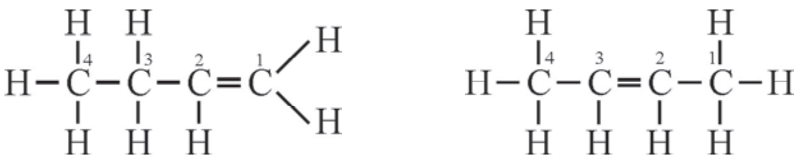
Table-4 : Condensed structures, molecular formula and names of alkynes

No. of carbon atoms (n)	Condensed structure	Molecular formula	Name				
			Root	+	Suffix	=	name
n=2	$HC \equiv CH$	C_2H_2	Eth	+	yne	=	Ethyne
n=3	$CH_3C \equiv CH$	C_3H_4	Prop	+	yne	=	Propyne
n=4	$CH_3\ CH_2\ C \equiv CH$	C_4H_6	But	+	yne	=	Butyne
n=5	?	?	?				
n=6	?	C_6H_{10}	?				

From table-4 it is clear that alkynes follow the general molecular formula C_nH_{2n-2}. Since two successive members of the alkyne family differ by a $-CH_2-$ group therefore alkynes also form a homologous series.

15.8 Isomerism in alkenes and alkynes

Try to draw the structure of the alkene C_4H_8. Where will you place the double bond between the carbon atoms? It is clear that the double bond can be in two different positions. We can either have a double bond between the first and second carbon atoms (Fig.9a) or between the second and third carbon atoms (Fig.9b).



(a) but-1-ene **(b) but-2-ene**

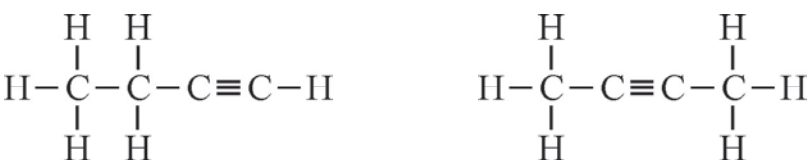
Fig. 9 : (a) and (b)

Both the structures are for alkenes and have the same molecular formula C_4H_8 but the position of atoms is different, so the two molecules are isomers of each other.

This type of isomerism arising from difference in position of a double bond is called position isomerism. Just like chain isomerism, position isomerism is also a type of structural isomerism. Here, the molecular formula of both compounds is same but their properties are different because of difference in structures. Their names are also different.

Structure shown in fig.9 a is called but-1-ene. For naming the alkene, the first part indicates the number of carbon atoms in the longest continuous chain. This is followed by a number, in this case 1, showing the position of the double bond which is followed by –ene showing that the hydrocarbon belongs to the alkene family. Numbers and words are separated by dashes. Similarly, structure shown in fig.9b is called but-2-ene.

Position isomerism is also seen in alkynes. For example, C_4H_6 (Fig.10 a and b) has two position isomers.



(a) but-1-yne **(b) but-2-yne**

Fig. 10

The two structures shown above are position isomers. The first part of their name, but- shows that the longest continuos chain in the molecule has four carbon atoms and –yne shows that it is a member of the alkyne family. The number in between shows the positon of the triple bond in the molecule.

15.9 Types of hydrocarbons on the basis of bonding

So far we have studied about three types of hydrocarbons - alkanes, alkenes and alkynes. We saw that alkenes have a double bond between any two carbon atoms and alkynes have a triple bond between two carbon atoms.The number of double or triple bonds can be more than one. However, in alkanes only single bonds link the different atoms whether carbon to a carbon or carbon to a hydrogen. We use this difference in types of bonds as a means to classify hydrocarbons. Hydrocarbons having multiple bonds are called unsaturated hydrocarbons. Therefore, alkene and alkynes are unsaturated hydrocarbons whereas, alkanes are called saturated hydrocarbons.

All structures that we have studied so far have either continuous chains or branched chains of carbons. However, it is also possible for carbon atoms to join together and form rings. The smallest carbon ring that can be formed has three members (Fig.11).

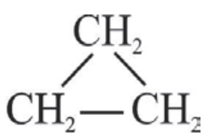


Fig. 11 : Cyclopropane

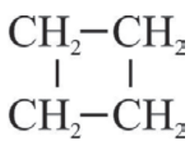


Fig. 12 : Cyclobutane

In this molecule, each carbon is bonded to two other carbon atoms and two hydrogen atoms. The molecular formula of this molecule is C_3H_6. Is the molecular formula similar to the molecular formula of an alkene? We can also have a 4 membered ring with the formula C_4H_8(Fig.12).

In both the molecules, the carbon atoms are arranged together to form rings and only have single bonds between the different atoms. The general formula of these can be written as C_nH_{2n}. This class of hydrocarbons is known as cycloalkanes. C_3H_6 is known as cyclopropane and $C_4H_8$is known as cyclobutane. Note that the molecular formulas of cycloalkanes and some alkenes are same therefore it is important to know the structure of a compound before we can name it. Many more similar cycloalkanes are possible.

Questions

1. How many straight chain isomers are possible for the molecular formula C_5H_8 . Draw their structures.
2. Group the following into saturated and unsaturated hydrocarbons.

Keywords

hydrocarbon, catenation, bond, alkane, alkene, alkyne, isomerism, saturated, unsaturated, homologous series, chain isomerism, position isomerism, (–) hyphen, suffix, structural formula, parent chain

What we have learnt

- Covalent compounds of only carbon and hydrogen are called hydrocarbons.
- The valency of carbon is four and it forms covalent bonds with other atoms. The properties of carbon compounds are similar to each other.
- The property of elements by which its atoms link to one another forming long chains is known as catenation.
- A family (series) of carbon compounds with the same functional group where the formulas of two adjacent members differs by $–CH_2–$ is called a homologous series. The members of the homologous series are homologues of each other, have the same general formula and show a regular gradation in their physical properties.
- Compounds having same molecular formula but different structures are isomers of each other and this property is called isomerism.
- Isomerism arising from difference in the parent chain of carbon compounds is called chain isomerism.
- Isomerism arising from difference in position of the functional group or a double or triple bond in the carbon chain is known as position isomerism.
- Alkanes only have C-C and C-H single bonds and have the general formula C_nH_{2n+2}.
- Alkenes have C=C bonds and have the general formula C_nH_{2n}.
- Alkynes have C≡C bonds and have the general formula C_nH_{2n-2}.
- In cycloalkanes the carbon atoms of the root part are arranged in rings and they have the general formula $C_nH_{2n.}$

Exercises

1. Choose the correct option that fits the descriptions given below:-
   (i) This hydrocarbon only has single bonds.
   (ii) Carbon has the ability to form strong bonds with atoms of other elements. But what is more special is its ability to bond strongly with other carbon atoms.
   (iii) Molecules having same molecular formula but different structures.
   (iv) Butane and 2-methylpropane exhibit this type of isomerism.
   (v) Isomerism that can be exhibited by alkenes and alkynes but not alkanes.
   (vi) Members of this series show a regular gradation in their physical properties.

   (Position isomerism, homologous series, alkanes, isomers, chain isomerism, catenation)

2. Fill in the blanks
   (i) Hex-1-ene and hex-2-ene are ……………………..isomers.
   (ii) The boiling point of butane is …………….than propane.
   (iii) The number of carbon atoms in the parent chain of 2-methylpropane is………
   (iv) The number of hydrogen atoms in cyclobutane is………………
   (v) C_2H_6,C_3H_8, C_4H_{10} are members of the ………………..homologous series.

3. Draw the structures of the following:

   2-methylbutane, prop-1-yne, pent-2-ene

4. Write any three characteristics of the alkane family.

5. Differentiate between position and chain isomerism with examples.

6. What is the relation between the boiling points and number of carbon atoms present in straight chain alkane? Explain.

7. Alkanes, alkynes and alkenes with three or less carbon atoms do not show structural isomerism. Explain.

8. How many structures/isomers are possible for the molecular formula C_4H_8? Draw their structures. (Hint – three are possible).