THE HYDROCARBONS (cont'd) – Alkenes

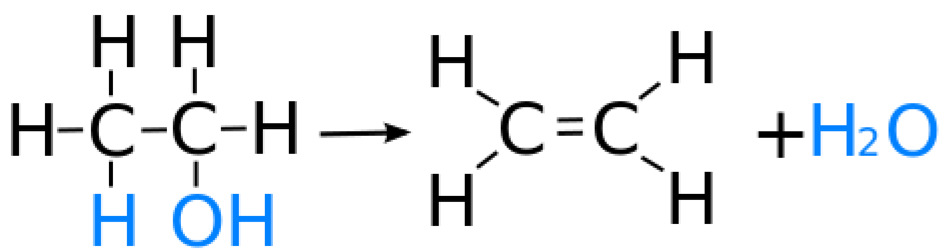
The alkenes have the general formula C_nH_{2n}. They are unsaturated hydrocarbons, containing at least one carbon-carbon double bond. This carbon-carbon double bond is the functional group of alkenes.

Value of n in the general formula (C_nH_{2n})	Molecular formula	Name	Physical state at room temperature
2	C_2H_4	Ethene	Gas
3	C_3H_6	Propene	Gas
4	C_4H_8	Butene	Gas
5	C_5H_{10}	Pentene	Volatile liquid

Sources of Alkenes

Cracking and dehydration of alcohols are the main sources of alkenes.

- Dehydration of alcohols: Alcohols react with excess concentrated sulphuric acid at 180°C to produce their corresponding alkenes. For example, when ethanol is dehydrated, it produces ethane.



Physical Properties of Alkenes

The physical properties of alkenes are similar to those of alkanes. The first three alkenes (ethene, propene and butene) are colourless gases. Members of the alkenes homologous series with between five and 15 carbon atoms are liquids, and chains with more than 15 carbon atoms are solids at room temperature and pressure.

The boiling points of alkenes are similar to those of alkanes with the same number of carbon atoms. The boiling points of alkenes depend on the chain length (molecular mass). The longer the chain length, the greater the boiling points. The intermolecular forces of alkenes become stronger with increasing molecular size.

Chemical Properties of Alkenes

Members of the alkene homologous series are defined primarily by their functional group: the carbon-carbon double bond. The presence of this group makes alkenes unsaturated. This double bond has two pairs of electrons that are shared between the two carbon atoms. This makes alkenes susceptible to addition reactions.

Because the alkene hydrocarbons are unsaturated, they can react with hydrogen atoms in the presence of a catalyst. The resulting compound, with no multiple bonds, is saturated.

Reactions of Alkenes

1. Combustion
   Alkenes, like alkanes, burn in a plentiful supply of oxygen to produce carbon dioxide and steam. The reaction is highly exothermic.

$$C_2H_{4\,(g)} + 3O_{2\,(g)} \rightarrow 2CO_{2\,(g)} + 2H_2O(g) + heat$$

However, alkenes are not used as fuels because:

- They burn with a smoky flame (this is in contrast to alkanes, which burn with a clean blue flame)
- They are prized starting materials for making other valuable organic compounds such as polymers.

$$C_nH_{2n} + (n+1)O_2 \rightarrow nCO_2 + nH_2O + heat$$

Combustion experiments can be used to determine the molecular formulae of hydrocarbons.

Example:

0.25 mol of a hydrocarbon, X, with a molar mass of 72 g mol^{-1}, was burnt completely in an excess of oxygen at room temperature and pressure. The volume of carbon dioxide produced was 30 dm^3. What is the molecular formula of the hydrocarbon X?

Solution:

The aim in a problem such as this is to use the given information to find the number of atoms of carbon and hydrogen in 1 mole of the hydrocarbon X.

Step 1: Find the mass of C in 1 mole of X.
Since X was burnt in excess oxygen, we can deduce that complete combustion has taken place.

This means that all the carbon in X was converted to CO_2. Therefore, the amount of carbon in 0.25 mol of X is the same as the amount of carbon in 30 dm^3 of CO_2.

$$24\ dm^3 of\ gas\ is\ produced\ by\ 1\ mol\ of\ CO_2\ at\ RTP$$
$$30\ dm^3\ of\ gas\ is\ produced\ by \frac{30}{24} \times 1 = 1.25\ mol\ CO_2$$

$$\therefore 0.25\ mol\ of\ X\ produces\ 1.25\ mol\ CO_2$$
$$1\ mol\ of\ X\ produces \frac{1}{0.25} \times 1.25 = 5\ mol\ CO_2$$
$$5\ mol\ of\ CO_2\ contains\ 5\ mol\ of\ C\ atoms, so\ there\ are\ 5 \times 12\ g\ (= 60\ g) of\ C\ in\ 1\ mol\ of\ X$$

Step 2: Find the mass of H in 1 mole of X.
The molar mass of X is 72 g mol^{-1}, and 1 mol of X contains 60 g of C

$$\therefore The\ mass\ of\ H\ atoms\ in\ 1\ mol\ of\ X = 72\ g - 60\ g = 12\ g$$

Since the mass of 1 mol of hydrogen atoms is 1 g, 12 g is equivalent to 12 mol of H.

$$\therefore 1\ mol\ of\ X\ has\ 12\ mol\ of\ H\ and\ 5\ mol\ of\ C$$
$$The\ molecular\ formula\ of\ X\ is\ C_5H_{12}$$

Questions:

1. Is X an alkane or an alkene? Explain your answer.
2. Write a balanced equation for the combustion of X.
3. Calculate the number of moles of oxygen used in the experiment.

Addition Reactions of Alkenes

The typical reactions of the alkenes are addition reactions.

Reaction with Hydrogen to form Alkanes

Hydrogen adds to alkenes in the presence of finely divided nickel, which serves as a catalyst. This reaction, which results in the formation of alkanes, is commonly called hydrogenation.

Alkene + Hydrogen → Alkane

Note that the hydrogen molecule is added across the double bond. One hydrogen atom is added to each of the carbon atoms linked by the double bond.

Hydrogenation reactions with unsaturated alkene-type molecules are carried out in industry.

Hydration of Alkenes to Produce Alkanols

The equation for this reaction is:

$$C_2H_4 + H_2O \rightarrow C_2H_5OH$$

Hydration can be achieved both directly and indirectly.

The indirect method uses sulphuric acid to form an intermediate compound, for e.g.

$$C_2H_4 \xrightarrow{excess\ conc.\ H_2SO_4/heat} C_2H_5SO_3H \xrightarrow{warm\ with\ water} C_2H_5OH$$

The direct hydration of ethene is used to produce ethanol commercially. Ethene is compressed to about 70 atmospheres, mixed with water and passed through a furnace. The heated mixture is then passed over a phosphoric (V) acid catalyst at a temperature of 300°C. Ethanol is formed, and the mixture of gases, ethanol vapour plus uncombined ethene and steam, is then passed through a condenser where ethanol vapour and steam are condensed and drawn off. Unreacted ethene can then be recycled.

Distinguishing Between Alkanes and Alkenes

The differences between alkanes and alkenes are based on the facts that:

- Alkanes are saturated compounds, and therefore undergo substitution reactions;
- Alkenes are unsaturated compounds, and undergo addition reactions.

Alkenes can therefore be told apart from alkanes by testing for the presence of unsaturation. Alkenes rapidly decolorize an acidified solution of potassium manganate (VII). The acidified potassium manganate (VII) reagent has no effect on alkanes.

$$C_2H_4 \xrightarrow{MnO_4^-/H^+} C_2H_4(OH)_2$$

Note that two hydroxyl groups are added across the double bond, forming a di-alcohol. The reaction is rapid and there is an obvious colour change from deep purple to very pale pink.

Alkenes also rapidly decolourize a solution of liquid bromine in 1, 1, 1-trichloroethane from red-brown to colourless. The reaction occurs “in the dark” (in the absence of sunlight).

$$C_2H_4 + Br_2/CH_3CCl_3 \rightarrow C_2H_4Br_2$$

Both of these reactions are addition reactions.

Alkanes do not react with bromine, or other halogens, except in the presence of bright light or ultraviolet radiation (e.g. sunlight). Even then, alkanes react at a slower rate than alkenes.

Uses of Alkenes

Alkenes are versatile compounds, and ethene, in particular, is one of the major building blocks of the chemical industry. Ethene is used to produce ethanol, chloroethene, polychloroethene (PVC), polythene, benzene, phenylethene (styrene) and polyphenylethene (polystyrene).

Obtaining Gasoline and Ethene from Crude Oil

Crude oil is a natural source of hydrocarbons. Fractional distillation is used to separate the various components/constituents.

On an industrial scale, the fractionating column consists of perforated horizontal trays on which the rising vapour condenses and is then vaporized later by more rising vapour. Thus, each tray functions as a condenser and a boiling flask.

The fractions of petroleum range from volatile liquids used as gasoline (boiling at 50 – 200 °C) and kerosene (boiling at 175 – 325°C) to the heavier fractions that are used as diesel (boiling above 275°C). The residue that remains behind after fractional distillation of heavy oil is asphalt, which is used for surfacing roads and highways.

The composition of crude oil from different sources varies considerably. Components that are in lesser demand can be changed into more useful ones by two important processes: cracking and reforming.