

Organic Chemistry I

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Dr. Jasim. H. Hassen

Chapter 1

General Introduction

1.1 Organic Chemistry

Organic chemistry is the chemistry of the compounds of carbon. Inorganic compounds are those obtained from minerals, while organic compounds are those obtained from vegetable or animal sources, that is, from material produced by living organisms. Until about 1850 many chemists believed that organic compounds must have their origin in living organisms, and consequently could never be synthesized from inorganic materials, these compounds from organic sources had this in common; they all contain the element carbon. Even after it had become clear that these compounds did not have to come from living sources but could be made in the laboratory, it was convenient to keep the name organic to describe them and compounds like them. The division between inorganic and organic compounds has been retained to this day.

Today, although many compounds of carbon are still most conveniently isolated from plant and animal sources, most of them are synthesized. They are sometimes synthesized from inorganic substances like carbonates or cyanides, but more often from other compounds. There are two large reservoirs of organic materials from which simple organic compounds can be obtained; petroleum and coal. Both of these are organic in the old sense, being products of the decay of plants and animals. These simple compounds are used as building blocks from which larger and more complicated compounds can be made.

There are many ways in which these complicated molecules can break apart, or rearrange themselves, to form new molecules; there are many ways in which atoms can be added to these molecules, or new atoms substituted for old ones.

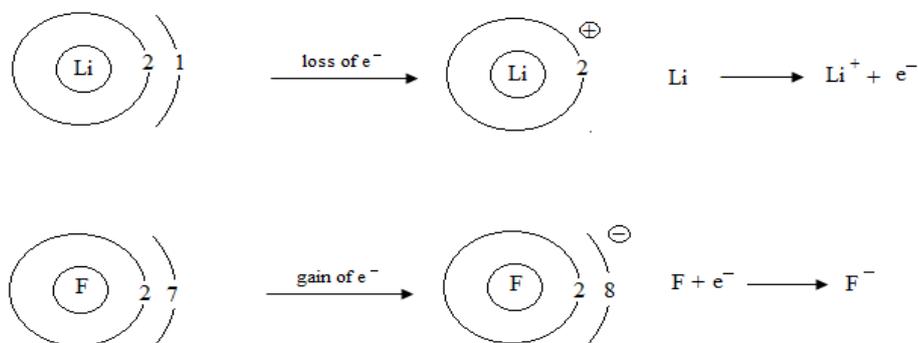
Carbon atoms can attach themselves to one another to an extent not possible for atoms of any other element. Carbon atoms can form chains thousands of atoms long, or rings of all sizes; the chains and rings can have branches and cross-links. To the carbon atoms of these chains and rings there are attached other atoms, chiefly hydrogen, but also fluorine, chlorine, bromine, iodine, oxygen, nitrogen, sulfur, phosphorus, and many others.

Organic chemistry is a field of immense importance to technology: it is the chemistry of dyes and drugs, paper and ink, paint and plastics, gasoline and rubber tires, it is the chemistry of the food we eat and the clothing we wear.

Organic chemistry is fundamental to biology and medicine. Aside from water, living organisms are made up chiefly of organic compounds; the molecules of molecular biology are organic molecules. Ultimately, biological processes are a matter of organic chemistry.

1.2 The Bonds

A positively charged nucleus is surrounded by electrons arranged in shells or energy levels. There are a maximum number of electrons that can be accommodated in each shell: two in the first shell, eight in the second shell, eight or eighteen in the third shell, and so on. The greatest stability is reached when the outer shell is full, as in the noble gases. Both ionic and covalent bonds arise from the tendency of atoms to attain this stable configuration of electrons.



The **ionic bond** results from *transfer of electrons*, as for example, in the formation of lithium fluoride LiF. The **covalent bond** results from *sharing of electrons*, as for example, in formation of the hydrogen molecule H₂. And also HF, H₂O, NH₃, CF₄, and CH₄.



The covalent bond is typical of the compounds of carbon; it is the bond of importance in the study of organic chemistry.

1.3 Atomic Orbitals

The region in space where an electron is likely to be found is called an orbital. There are different kind of orbitals, which have different sizes and different shapes. The particular kind of orbital that an electron occupies depends upon the energy of the electron.

The orbital at the lowest energy level is called the $1s$ orbital. It is a sphere with its center at the nucleus of the atom. The $2s$ orbital is naturally larger than $1s$, and it is also a sphere with its center at the atomic nucleus.

Next there are three orbitals of equal energy called $2p$ orbitals, each of them is dumbbell-shaped. It consists of two lobes with the atomic nucleus lying between them. The axis of each $2p$ orbital is perpendicular to the axes of the two other. They are differentiated by the names $2p_x$, $2p_y$, and $2p_z$ as shown in Figure 1-1.

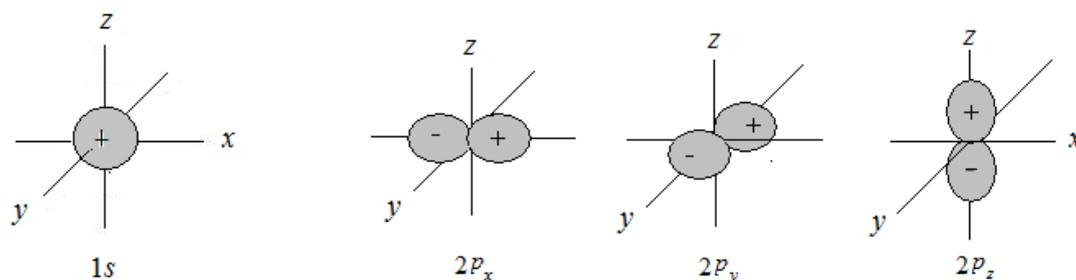


Figure 1-1 The Shapes of $1s$ and $2p$ orbitals

1.4 Molecular Orbitals

In molecule, as in isolated atoms, electrons occupy orbitals, and these molecular orbitals are considered to be centered about many nuclei, perhaps covering the entire molecule.

Each pair of electrons is localized near just two nuclei, and the shapes of these localized molecular orbitals and their disposition with respect to each other are related in a simple way to the shapes and disposition of atomic orbital in the component atoms.

1.5 The covalent bond

Let us consider the formation of a molecule. For a covalent bond to form two atoms must be located so that an orbital of one *overlaps* an orbital of the other; each orbital must contain a single electron. When this happens, the two atomic orbitals merge to form a single *bond orbital* which is occupied by both electrons (of different spins). This arrangement of electrons and nuclei contains less energy, and it is more stable than the arrangement in the isolated atoms. As a result, formation of a bond is accompanied by evolution of energy.

The covalent bond is strong because of the increase in electrostatic attraction. In the isolated atoms, each electron is attracted by, and attracts, one positive nucleus. In the molecule, each electron is attracted by two positive nuclei.

It is the concept of *overlap* that provides the bridge between atomic orbitals and bond orbitals. Overlap of atomic orbitals means that the bond orbital occupies much of the same region in space that was occupied by both atomic orbitals. Figure 1-2 shows the formation of H_2 molecule by overlapping of two H atoms each contain one electron in $1s$ orbital, and formation of F_2 molecule by overlapping of two F atoms each contain five electron in $2p$ orbital, one of these electron is single electron which is unpaired and available for bond formation.

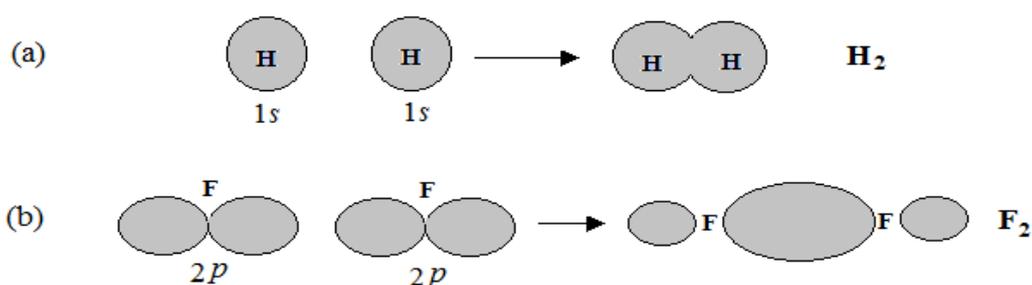
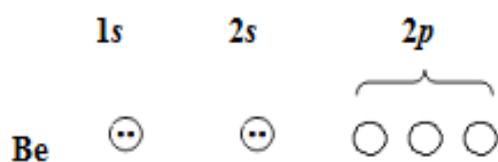


Figure 1-2 Bond Formation of (a) H_2 molecule, (b) F_2 molecule

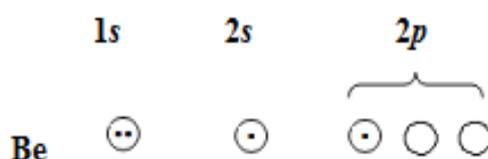
1.6 Hybrid Orbitals

sp Hybridization

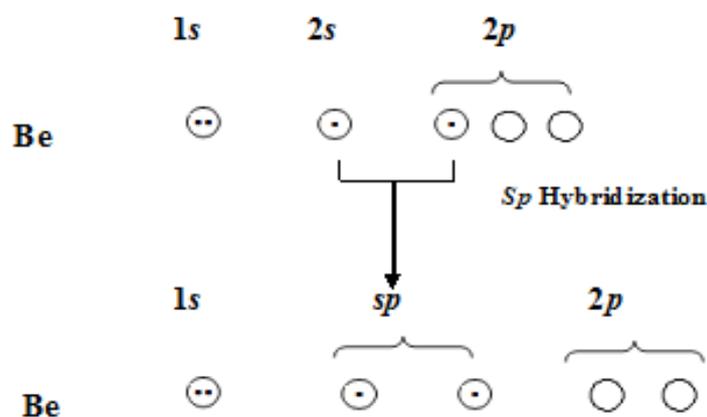
If we consider beryllium chloride, $BeCl_2$, the electronic configuration of Be is:



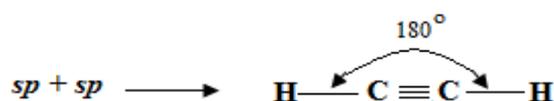
We promote one of the $2s$ electrons to an empty p orbital:



Next, we hybridize the orbitals:

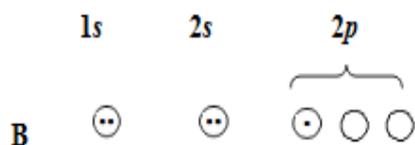


Acetylene ($\text{CH}\equiv\text{CH}$) is an example of sp hybridization. The two carbon atoms are joined by sp - sp sigma (σ) bond. Each carbon atom is also bonded to a hydrogen atom by an sp - s sigma bond. The two p orbitals of one carbon then overlap with the two p orbitals of the other carbon atom to form pi (π) bonds, one above and one below the line of the sigma bond. $\text{C}\equiv\text{C}$ bond is shorter and stronger than $\text{C}=\text{C}$ bond, which is shorter and stronger than $\text{C}-\text{C}$ bond.

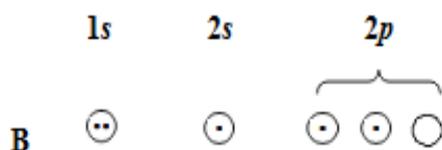


Sp^2 Hybridization

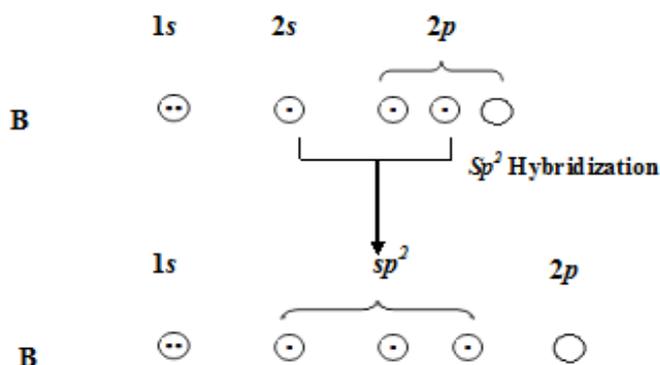
If we consider boron trifluoride, BF_3 , boron has only one unpaired electron, which occupies a $2p$ orbital.



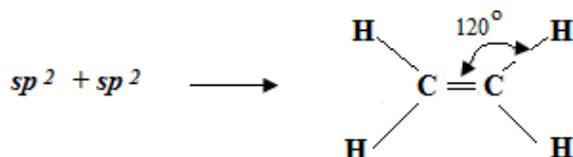
For three bonds we need three unpaired electrons, and so we promote one of the 2s electrons to a 2p orbital:



Next, we hybridize the orbitals:

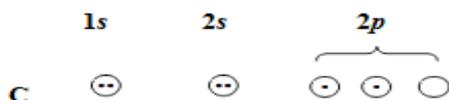


In ethylene $\text{CH}_2=\text{CH}_2$, two sp^2 carbons are joined by a sigma bond formed by the overlap of the sp^2 orbital from each carbon atom. Each carbon atom still has two sp^2 orbitals left for bonding with hydrogen. Also each carbon atom has a p orbital with one electron, the two p orbitals overlap their sides, the result is pi bond. An sp^2 carbon atom is said to be a trigonal (triangular) carbon.



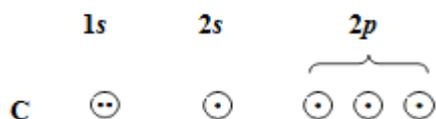
Sp³ Hybridization

Carbon has an unpaired electron in each of the two p orbitals, and on this basis might be expected to form a compound CH_2 .

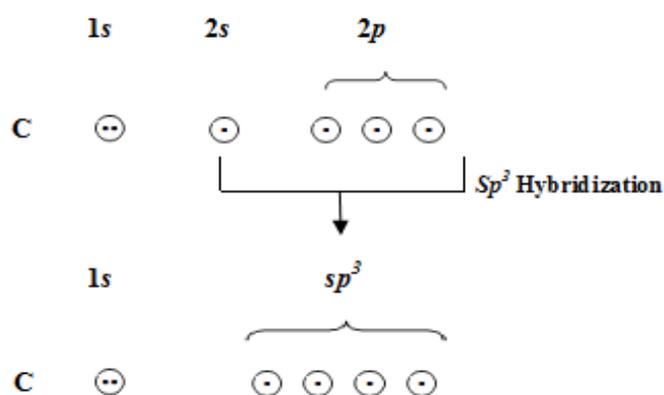


It does, but CH_2 is a highly reactive molecule whose properties center about the need to provide carbon with two more bonds. Again, we see the tendency to form as many bonds as possible: in this case, to combine with four hydrogen atoms.

To provide four unpaired electrons, we promote one of the $2s$ electrons, to the empty p orbital:

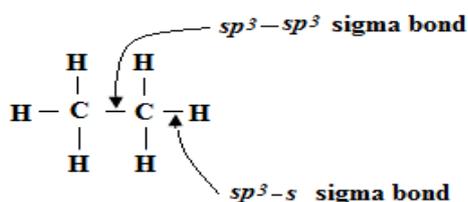


Once more the most strongly directed orbitals are hybrid orbitals: this time, sp^3 orbitals, from the mixing of one s orbital and three p orbitals.



Overlap of each of the sp^3 orbitals of carbon with an s orbital of hydrogen result in methane: carbon at the center of a regular tetrahedron, and the four hydrogens at the corners.

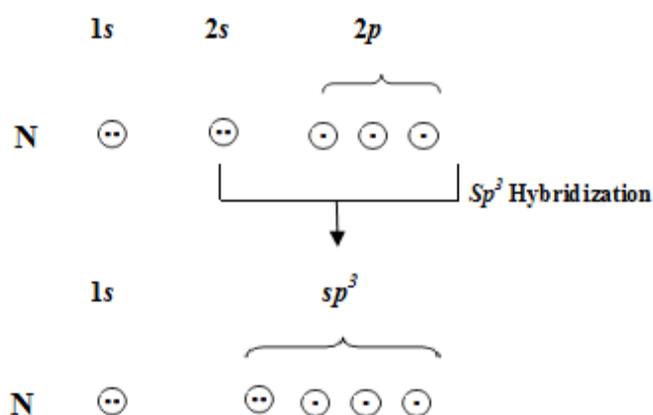
Ethane CH_3CH_3 contains two sp^3 carbon atoms. These two carbon atoms form a C-C sigma bond by the overlap of one sp^3 orbital from each carbon (sp^3 - sp^3 sigma bond). Each carbon atom has three remaining sp^3 orbitals, and each of these overlap with a $1s$ orbital of a hydrogen atom to form a C-H sigma bond. Each carbon atom in ethane is tetrahedral.



1.7 Unshared pairs of electrons

Two compounds, ammonia (NH_3) and water (H_2O), show how *unshared pairs of electrons* can affect molecular structure.

In ammonia, nitrogen is sp^3 hybridized, but has only three unpaired electrons; they occupy three of the sp^3 orbitals. Overlap of each of these orbitals with the s orbital of a hydrogen atom results in ammonia. The fourth sp^3 orbital of nitrogen contains a pair of electrons.



In order to get maximum overlap, the hydrogen nuclei must be located at three corners of a tetrahedron, the fourth corner is occupied by an unshared pair of electrons. Considering only atomic nuclei, we would expect ammonia to be shaped like a pyramid with nitrogen at the apex and hydrogen at the corners of a triangular base. Each bond angle should be the tetrahedral angle 109.5° . Experimentally, ammonia is found to have the pyramidal shape (Figure 1-3). The bond angles are 107° , slightly smaller than the predicted value. The unshared pair of electrons occupies more space than any of the hydrogen atoms, and hence tends to compress the bond angles slightly. The nitrogen-hydrogen bond length is 1.01 \AA . The sp^3 orbital occupied by the unshared pair of electrons is a region of high electron density. This region is a source of electrons for electron-seeking atoms and molecules, and thus gives ammonia its basic properties.

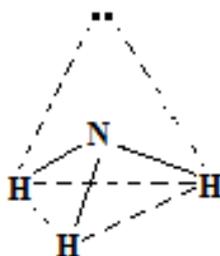
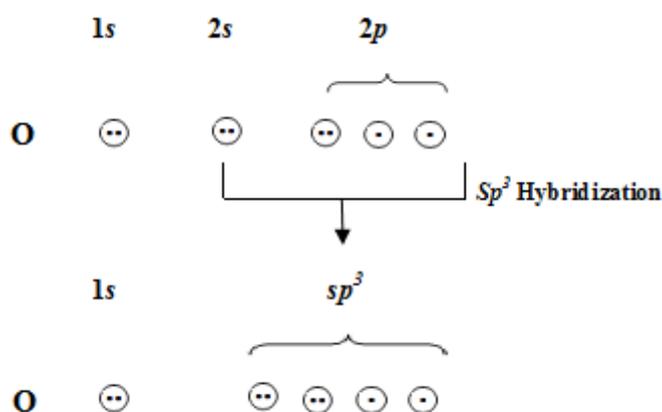


Figure 1-3 Bond formation of NH₃ pyramidal molecule

In water, oxygen has only two unpaired electrons, and hence it bonds with only two hydrogen atoms, which occupy two corners of a tetrahedron. The other two corners of the tetrahedron are occupied by unshared pairs of electrons.



The H-O-H angle is 105°, smaller than the calculated tetrahedral angle, and even smaller than the angle in ammonia. The two unshared pairs of electrons compressing the bond angles. The oxygen-hydrogen length is 0.96 Å (Figure 1-4).

Because of the unshared pairs of electrons on oxygen, water is basic, although less strongly so than ammonia.

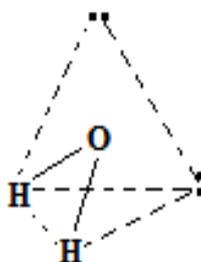


Figure 1-4 Bond formation of H₂O non-linear molecule

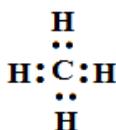
1.8 Intramolecular Forces

The actual structure of a molecule is the net result of a combination of (a) *repulsive* and (b) *attractive* forces, which are related to charge and electron spin.

(a) **Repulsive forces.** Electrons tend to stay as far apart as possible because they have the same charge and also, if they are unpaired, because they have the same spin (Pauli exclusion principle). The like-charge atomic nuclei, too, repel each other.

(b) **Attractive forces.** Electrons are attracted by atomic nuclei as are the nuclei by the electrons, because of their opposite charge, and hence tend to occupy the region between two nuclei. Opposite spin permits (although, in itself, probably does not actually encourage) two electrons to occupy the same region.

In methane, for example, the four hydrogen nuclei are as widely separated as they can be.



The four pairs of bonding electrons are as far as possible from each other, the resulting structure is a tetrahedral.

1.9 Bond Dissociation Energy

Energy is liberated when atoms combine to form a molecule, and for a molecule to break into atoms, an equivalent amount of energy must be consumed. *The amount of energy consumed or liberated when a bond is broken or formed is known as the **bond dissociation energy**.* It is characteristic of the particular bond, and it varies widely, from weak bonds like I-I (36 kcal/mole) to very strong bonds like H-F (136 kcal/mole).

If the two electrons making up the covalent bond, one goes to each fragment (two atoms or atom and group of atoms) such bond is called *homolysis*. If both bonding electrons go to the same fragment, the bond is called *heterolysis*.

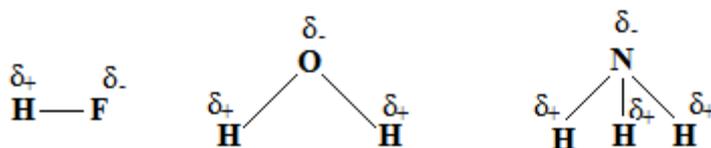


Simple heterolysis of a neutral molecule yields, of course, a positive ion and a negative ion. Separation of these oppositely charged particles takes a great deal of energy: 100 kcal/mole or so more than separation of neutral particles. In the gas phase, therefore, bond dissociation energy takes place by the easier route, homolysis. In an ionizing solvent, on the other hand, heterolysis is the preferred kind of cleavage.

1.10 Polarity of Bonds

Certain covalent bonds have a property of polarity. Two atoms joined by a covalent bond share electrons; their nuclei are held by same electron cloud. But in most cases the two nuclei do not share the electrons equally; the electron cloud is denser about one atom than the other. One end of the bond is thus relatively negative and the other end is relatively positive; that is, there is a negative pole and a positive pole. Such a bond is said to be a polar bond, or to possess polarity.

We can indicate polarity by using the symbols δ_+ and δ_- , which indicate partial + and – charges. For example:



Polar Bonds

We can expect a covalent bond to be polar if it joins atoms differ in their tendency to attract electrons, that is, atoms that differ in *electronegativity*. Furthermore the greater the difference in electronegativity, the more polar the bond will be.

The most electronegative elements are those located in the upper right-hand corner of the Periodic Table. Of the elements we are likely to encounter in organic chemistry, fluorine has the highest electronegativity, then oxygen, then nitrogen and chlorine,

then bromine, and finally carbon. Hydrogen does not differ very much from carbon in electronegativity; it is not certain whether it is more or less electronegative.



Bond polarities are intimately concerned with both physical and chemical properties. The polarity of bond can lead to polarity of molecules, and thus profoundly affect melting point, boiling point and solubility. The polarity of a bond determines the kind of reaction that can take place at that bond, and even affects reactivity at nearby bonds.

1.11 Polarity of Molecules

A molecule is polar if the center of negative charge does not coincide with the center of positive charge. Such a molecule constitutes a dipole: two equal and opposite charge separated in space. A dipole is often symbolized by $+\rightarrow$, where the arrow points from positive to negative. The molecule possesses a dipole moment, μ , which is equal to the magnitude of the charge, e , multiplied by the distance, d , between the centers of the charge:

$$\mu = e \times d$$

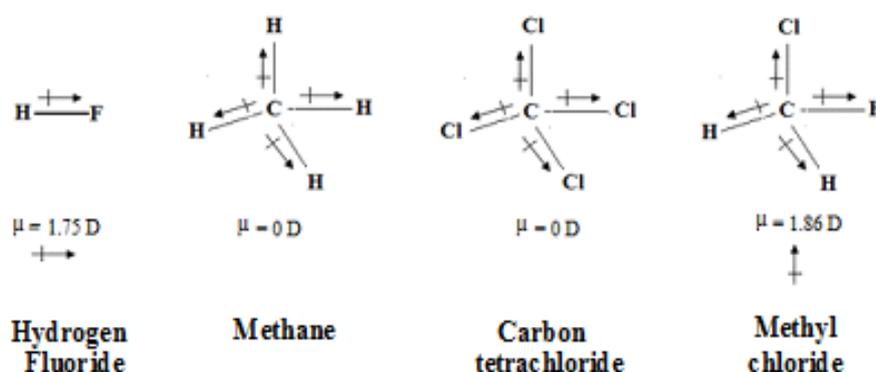
The polarity of a molecule is a composite of the polarities of the individual bonds.

Molecules like H_2 , O_2 , N_2 , Cl_2 , and Br_2 have zero dipole moments, that is are non-polar. The two identical atoms of each of these molecules have, of course, the same electronegativity and share electrons equally; e is zero and hence μ is zero, too.

A molecule like hydrogen fluoride has the large dipole moment of 1.75 Debye (D). Although hydrogen fluoride is a small molecule, the very high electronegative fluorine pulls the electrons strongly; although d is small, e is large, and hence μ is large, too.

Methane and carbon tetrachloride, CCl_4 , have zero dipole moments. We certainly would expect the individual bonds of carbon tetrachloride at least to be polar; because of the very symmetrical tetrahedral arrangement, however, they exactly cancel each other

In methyl chloride, CH_3Cl , the polarity of the carbon-chlorine bond is not cancelled, however, and methyl chloride has a dipole moment of 1.86 D. Thus the polarity of a molecule depends not only upon the polarity of its individual bonds but also upon the way the bonds are directed, that is, upon the shape of the molecule.



1.12 Melting Point

In a crystalline solid the particles acting as structural units, ions or molecules, are arranged in some very regular, symmetrical way; there is a geometric pattern repeated over and over within a crystal.

Melting is the change from the highly ordered arrangement of particles in the crystalline lattice to the more random arrangement that characterizes a liquid. Melting occurs when a temperature is reached at which the thermal energy of the particles is great enough to overcome the intracrystalline forces that hold them in position.

An ionic compound forms crystals in which the structural units are ions. Solid sodium chloride, for example, is made up of positive sodium ions and negative chloride ions alternating in a very regular way. Surrounding each positive ion and equidistant from it are six negative ions: one on each side of it, one above and one below, one in front and one in back. Each negative ion is surrounded in a similar way by six positive ions. There is nothing that we can properly call a molecule of sodium chloride.

A particular sodium ion does not belong to any one chloride ion; it is equally attracted to six chloride ions. The crystal is an extremely strong, rigid structure, since the electrostatic force holding each ion in position are powerful. These powerful

interionic forces are overcome only at a very high temperature; sodium chloride has a melting point of 801°C .

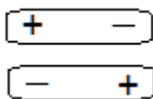
Crystals of other ionic compounds resemble crystals of sodium chloride in having an ionic lattice, although the exact geometric arrangement may be different. As a result, these other ionic compounds, too, have high melting points. Many molecules contain both ionic and covalent bonds. Potassium nitrate, KNO_3 , for example, is made up of K^+ ions and NO_3^- ions; the oxygen and nitrogen atoms of the NO_3^- ion are held to each other by covalent bonds. The physical properties of compounds like these are largely determined by the ionic bonds; potassium nitrate has very much the same sort of physical properties as sodium chloride.

A non-ionic compound, one whose atoms are held to each other entirely by covalent bonds, forms crystals in which the structure units are molecules. It is the forces holding these molecules to each other that must be overcome for melting to occur. In general, these intermolecular forces are very weak compared with the forces holding ions to each other. To melt sodium chloride we must supply enough energy to break ionic bonds between Na^+ and Cl^- . To melt methane, CH_4 , we do not need to supply enough energy to break covalent bonds between carbon and hydrogen; we need only supply enough energy to break CH_4 molecules away from each other. In contrast to sodium chloride, methane melts at -183°C .

1.13 Intermolecular Forces

Like interionic forces, the forces holding neutral molecules seem to be electrostatic in nature, involving attraction of positive charge for negative charge. There are two kinds of intermolecular forces: dipole-dipole interactions and van der Waals forces.

Dipole-dipole interaction is the attraction of the positive end of one polar molecule for the negative end of another polar molecule. In hydrogen chloride, for example, the relatively positive hydrogen of one molecule is attracted to the relatively negative chlorine of another:

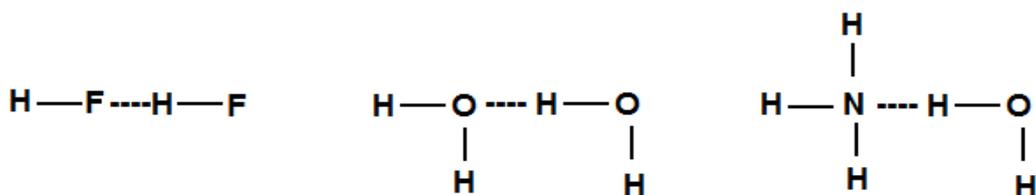


As result of dipole-dipole interaction, polar molecules are generally held to each other more strongly than non-polar molecules of comparable molecular weight; this difference in strength of intermolecular forces is reflected in the physical properties of the compounds concerned.

An especially strong kind of dipole-dipole attraction is *hydrogen bonding*, in which a hydrogen atom serves as a bridge between two electronegative atoms, holding one by a covalent bond and the other by purely electrostatic force. When hydrogen is attached to a highly electronegative atom, the electron cloud is greatly distorted toward the electronegative atom, exposing the hydrogen nucleus.

The strong positive charge of the thinly shielded hydrogen nucleus is strongly attracted by the negative charge of the electronegative atom of a second molecule. This attraction has a strength of about 5 kcal/mole, and is thus much weaker than the covalent bond, about 50-100 kcal/mole, that holds it to the first electronegative atom. It is however, much stronger than other dipole-dipole attractions.

Hydrogen bonding is generally indicated in formulas by broken line:

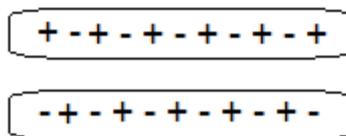


For hydrogen bonding to be important, both electronegative atoms must be come from the group: F, O, N. Only hydrogen bonded to one of these three elements is positive enough, and only these three elements are negative enough, for the necessary attraction to exist. These three elements owe their special effectiveness to the concentrated negative charge on their small atoms.

Hydrogen bonding, not only exerts profound effects on the boiling point and solubility properties of compounds, but also plays a key role in determining the shapes of large molecules like proteins and nucleic acids, shapes that in a very direct way

determine, in turn, their biological properties: the size of the pockets in the hemoglobin molecule, just big enough to hold heme groups with their oxygen-carrying iron atoms; the helical shape of α -keratin and collagen molecules that makes wool and hair strong, and tendons and skin tough. It is hydrogen bonding that makes the double helix of DNA double, and thus permits the self-duplication of molecules that is the basis of heredity.

There must be forces between the molecules of non-polar compound, since even such compounds can solidify. Such attractions are called *van der Waals forces*. They are arising in the following way. The average distribution of charge about, say, a methane molecule is symmetrical, so that there is no net dipole moment. However, the electrons move about, so that at any instant of time the distribution will probably be distorted, and a small dipole will exist. This momentary dipole will affect the electron distribution in a second methane molecule nearby. The negative end of the dipole tends to repel electrons, and the positive end tends to attract electrons; the dipole thus induces an oppositely oriented dipole in the neighboring molecule:



Although the momentary dipoles and induced dipoles are constantly changing, the net result is attraction between the two molecules. These van der Waals forces have a very short range; they act only between the portions of different molecules that are in close contact, that is, between the surfaces of molecules.

1.14 Boiling Point

Although the particles in a liquid are arranged less regularly and are freer to move about than in crystal, each particle is attracted by a number of other particles. Boiling involves the breaking away from the liquid of individual molecules or pairs of oppositely charged ions. This occurs when a temperature is reached at which the

thermal energy of the particles is great enough to overcome the cohesive forces that hold them in the liquid.

In the liquid state the unit of an ionic compound is again the ion. Each ion is still held strongly by a number of oppositely charged ions. Again there is nothing we could properly call a molecule. A great deal of energy is required for a pair of oppositely charged ions to break away from the liquid; boiling occurs only at a very high temperature. The boiling point of sodium chloride, for example, is 1413°C. In the gaseous state we have an ion pair, which can be considered a sodium chloride molecule.

In the liquid state the unit of a non-ionic compound is again the molecule. The weak intermolecular forces here, dipole-dipole interactions and van der Waals forces, are more readily overcome than the strong interionic forces of ionic compounds, and boiling occurs at a very much lower temperature. Non-polar methane boils at -161.5°C, and even polar hydrogen chloride boils at -85°C.

Liquids whose molecules are held together by hydrogen bonds are called associated liquids. Breaking these hydrogen bonds takes considerable energy, and so an associated liquid has a boiling point that is abnormally high for a compound of its molecular weight and dipole moment. Hydrogen fluoride, for example, boils 100 degree higher than the heavier, non-associated hydrogen chloride; water boils 160 degree higher than hydrogen sulfide.

The bigger the molecule, the stronger the van der Waals forces. Other things being equal, polarity, hydrogen bonding, boiling point rises with increasing molecular size. Boiling points of organic compounds range upward from that of tiny, non-polar methane, but we seldom encounter boiling points much above 350°C; at higher temperature, covalent bonds within the molecules start to break, and decomposition competes with boiling. It is to lower the boiling point and thus minimize decomposition that distillation of organic compound is often carried out under reduced pressure.

1.15 Solubility

When a solid or liquid dissolves, the structure units ions or molecules become separated from each other, and the space in between become occupied by solvent molecules. In dissolution, as in melting and boiling, energy must be supplied to overcome the interionic or intermolecular forces. The energy required to break the bonds between solute particles is supplied by the formation of bonds between the solute particles and the solvent molecules: the old attractive forces are replaced by new ones.

A great deal of energy is necessary to overcome the powerful electrostatic forces holding together an ionic lattice. Only water or other highly polar solvents are able to dissolve ionic compounds appreciably. What kinds of bonds are formed between ions and a polar solvent? By definition, a polar molecule has a positive end and a negative end. Consequently, there is electrostatic attraction between a positive ion and the negative end of the solvent molecule, and between a negative ion and the positive end of the solvent molecule. These attractions are called ion-dipole bonds. Each ion-dipole bond is relatively weak, but in the aggregate they supply enough energy to overcome the interionic forces in the crystal. In solution each ion is surrounded by a cluster of solvent molecules, and is said to be solvated; if the solvent happens to be water, the ion is said to be hydrated. In solution, as in the solid and liquid states, the unit of a substance like sodium chloride is the ion, although in this case it is a solvated ion, as shown in Figure 1.5.

To dissolve ionic compounds a solvent must also have a high dielectric constant, that is, have high insulating properties to lower the attraction between oppositely charged ions once they are solvated.

Water owes its superiority as a solvent for ionic substances not only to its polarity and its high dielectric constant, but to another factor as well: it contains the $-OH$ group and thus can form hydrogen bonds. Water solvates both cations and anions: cations, at its negative pole (its unshared electrons, essentially); anions, through hydrogen bonding.

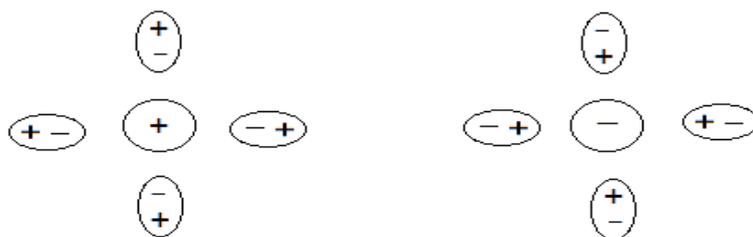


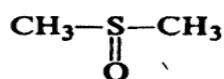
Figure 1.5 Ion-dipole interactions: solvated cation and anion

The solubility characteristics of non-ionic compounds are determined chiefly by their polarity. Non-polar or weakly polar compounds dissolve in non-polar or weakly polar solvents; highly polar compounds dissolve in highly polar solvents. "Like dissolves like" is an extremely useful rule of thumb. Methane dissolves in carbon tetrachloride because the force holding methane molecules to each other and carbon tetrachloride molecules to each other are replaced by very similar forces holding methane molecules to carbon tetrachloride molecules.

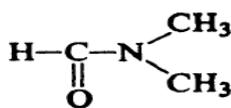
Neither methane nor carbon tetrachloride is readily soluble in water. The highly polar water molecules are held to each other by very strong dipole-dipole interactions hydrogen bonds; there could be only very weak attraction forces between water molecules on the one hand and the non-polar methane or carbon tetrachloride molecules on the other hand.

In contrast, the highly polar organic compound methanol, CH_3OH , is quite soluble in water. Hydrogen bonds between water and methanol can readily replace the very similar hydrogen bonds between different methanol molecules and different water molecules.

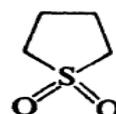
Solvents like water or methanol are called protic solvents: solvents containing hydrogen that is attached to oxygen or nitrogen, and hence is appreciably acidic. Aprotic solvents: polar solvents of moderately high dielectric constants, which do not contain acidic hydrogen. For example:



Dimethyl sulfoxide
DMSO



N,N-Dimethylformamide
DMF



Sulfolane

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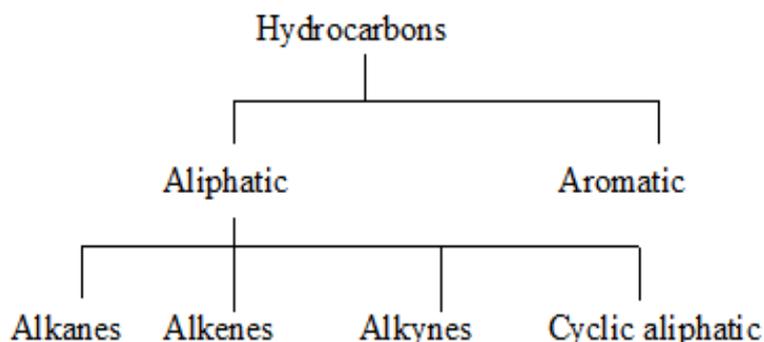
Dr. Jasim. H. Hassen

Chapter 2

Methane

2.1 Hydrocarbons

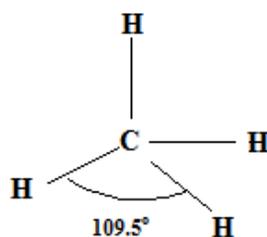
Hydrocarbons are organic compounds contain only two elements, hydrogen and carbon, and hence are known as hydrocarbons. On the basis of structure, hydrocarbons are divided into two main classes, aliphatic and aromatic. Aliphatic hydrocarbons are further divided into families: alkanes, alkenes, alkynes, and their cyclic analogs (cycloalkanes, etc.).



The simplest member of the alkane family and one of the simplest of all organic compounds is methane, CH₄.

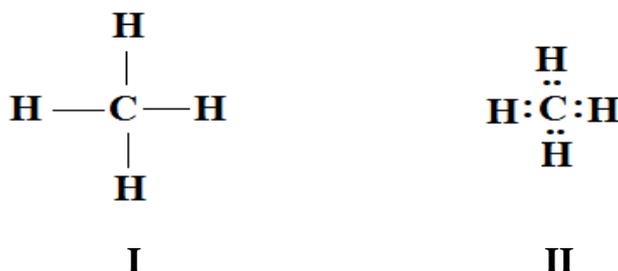
2.2 Structure of Methane

When carbon is bonded to four other atoms, its bonding orbitals (sp^3 orbitals, formed by the mixing of one s and three p orbitals) are directed to the corners of a tetrahedron. This tetrahedral arrangement is the one that permits the orbitals to be as far as apart as possible, as shown:



For each of these orbitals to overlap most effectively the spherical s orbital of a hydrogen atom, and thus to form the strongest bond, each hydrogen nucleus must be located at a corner of this tetrahedron.

We shall ordinarily write methane with a dash to represent each pair of electrons shared by carbon and hydrogen (I). To focus our attention on individual electrons, we may sometimes indicate a pair of electrons by a pair of dots (II).



2.3 Physical Properties of Methane

The unit of such a non-ionic compound, whether solid, liquid, or gas, is the molecule. Because the methane molecule is highly symmetrical, the polarities of the individual carbon-hydrogen bonds cancel out; as a result, the molecule itself is non-polar.

Attraction between such non-polar molecules is limited to van der Waals forces; for such small molecules, these attractive forces must be tiny compared with the enormous forces between, say, sodium and chloride ions. It is not surprising, then, that these attractive forces are easily overcome by thermal energy, so that melting and boiling occur at very low temperature: m.p. -183°C , b.p. -161.5°C . (Compare these values with the corresponding ones for sodium chloride: m.p. 801°C , b.p. 1413°C). As a consequence, methane is a gas at ordinary temperatures.

Methane is colorless and, when liquefied, is less dense than water (relative density 0.4). It is only slightly soluble in water, but very soluble in organic liquids.

2.4 Source of Methane

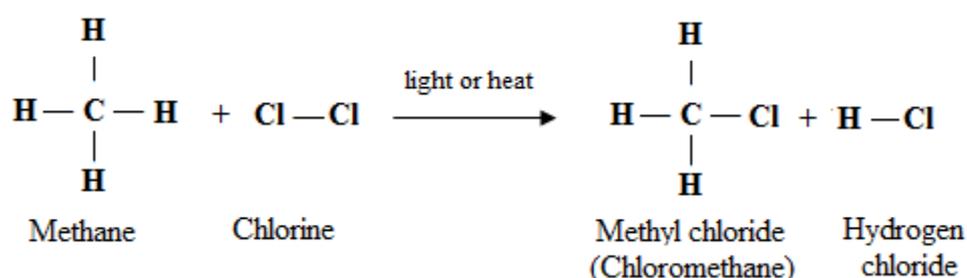
Methane is an end product of the anaerobic (without air) decay of plants, that is, of the breakdown of certain very complicated molecules. It is the major constituent (up to 97%) of natural gas. It is the dangerous firedamp of the coal mine, and can be seen as marsh gas bubbling to the surface of swamps.

Chlorination: A Substitution Reaction

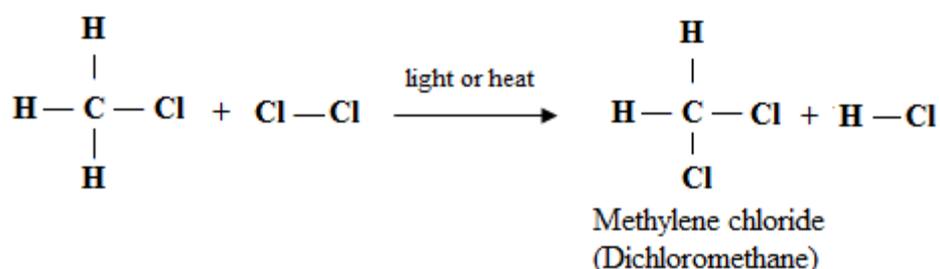
Under the influence of ultraviolet light or at a temperature of 250-400°C a mixture of the two gases, methane and chlorine, reacts vigorously to yield hydrogen chloride and a compound of formula CH₃Cl. We say that methane has undergone **chlorination**, and we call the product, CH₃Cl *chloromethane* or *methyl chloride* (CH₃ = **methyl**).

Chlorination of methane may yield any one of four organic products, depending upon the stage to which the reaction is carried.

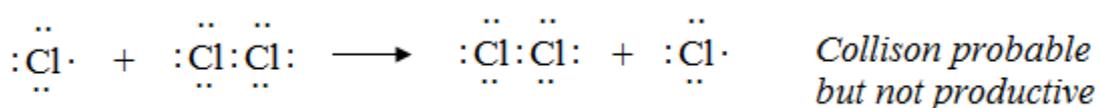
Chlorination is a typical example of a broad class of organic reactions known as *substitution*. A chlorine atom has been substituted for a hydrogen atom of methane, and the hydrogen atom thus replaced is found combined with a second atom of chlorine.



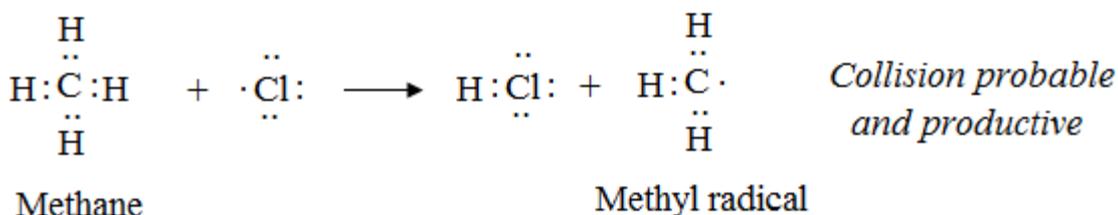
The methyl chloride can itself undergo further substitution to form more hydrogen chloride and the compound CH₂Cl₂, *dichloromethane* or *methylene chloride* (CH₂ = **methylene**).



To form a new chemical bond, that is, to react, the chlorine atom must collide with some other molecule or atom. What is it most likely to collide with? Obviously, it is most likely to collide with the particles that are present in the highest concentration: chlorine molecules and methane molecules. Collision with another chlorine atom is quite unlikely simply because there are few of these reactive, short-lived particles around at any time. Of the likely collisions, that with a chlorine molecule cause no change; reaction may occur, but it can result only in the exchange of one chlorine atom for another.

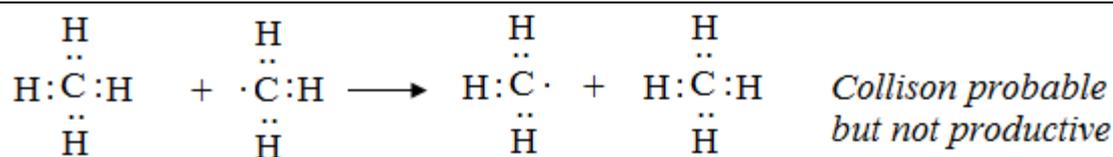


Collision of a chlorine atom with a methane molecule is both *probable* and *productive*. The chlorine atom abstracts a hydrogen atom, with one electron, to form a molecule of a hydrogen chloride:

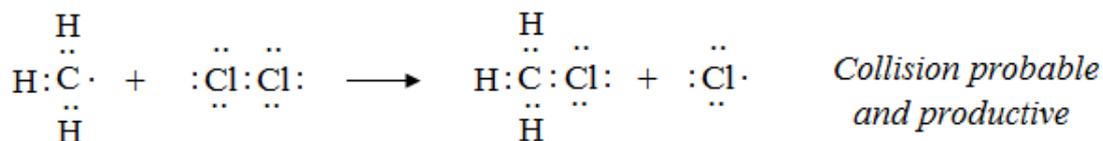


Now the methyl group is left with an odd, unpaired electron; the carbon atom has only seven electrons in its valence shell. One free radical, the chlorine atom, has been consumed, and a new one, the methyl radical, $\text{CH}_3\cdot$, has been formed in its place. This is step (2) in the mechanism.

Now, what is this methyl radical most likely to do? Like the chlorine atom, it is extremely reactive, and for the same reason: the tendency to complete its octet, to lose energy by forming a new bond. Again, collisions with chlorine molecules or methane molecules are probable ones, not collisions with the relatively scarce chlorine atoms or methyl radicals. But collision with a methane molecule could at most result only in the exchange of some methyl radical for another:



The collision of methyl radical with a chlorine molecule is, then, the important one. The methyl radical abstracts a chlorine atom, with one of the bonding electrons, to form a molecule of methyl chloride:



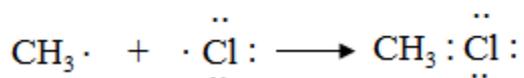
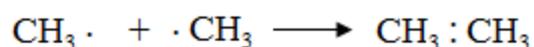
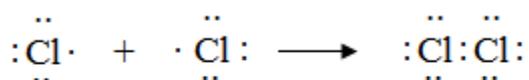
Methyl radical

Methyl chloride

The other product is a chlorine atom. This is step (3) in the mechanism.

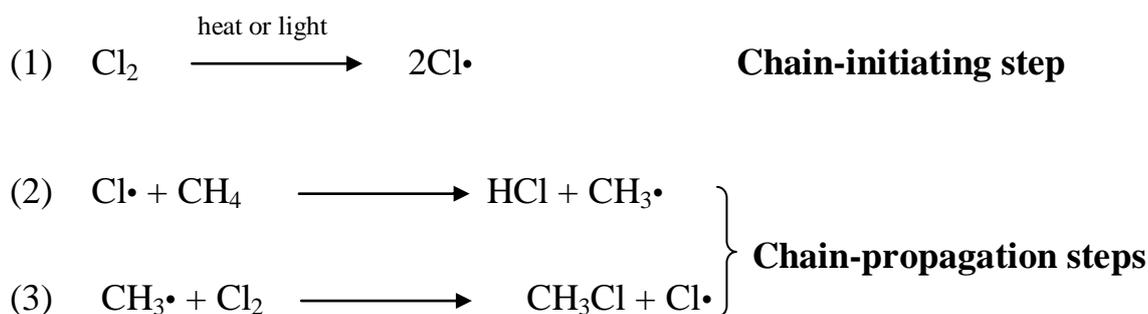
Here again the consumption of one reactive particle has been accompanied by the formation of another. The new chlorine atom attacks methane to form a methyl radical, which attacks a chlorine molecule to form a chlorine atom, and so the sequence is repeated over and over. Each step produces not only a new reactive particle but also a molecule of product: methyl chloride or hydrogen chloride.

This process cannot, however, go on forever. As saw earlier, union of two short-lived, relatively scarce particles is not likely; but every so often it does happen, and when it does, this particular sequence of reactions stops. Reactive particles are consumed but not generated.

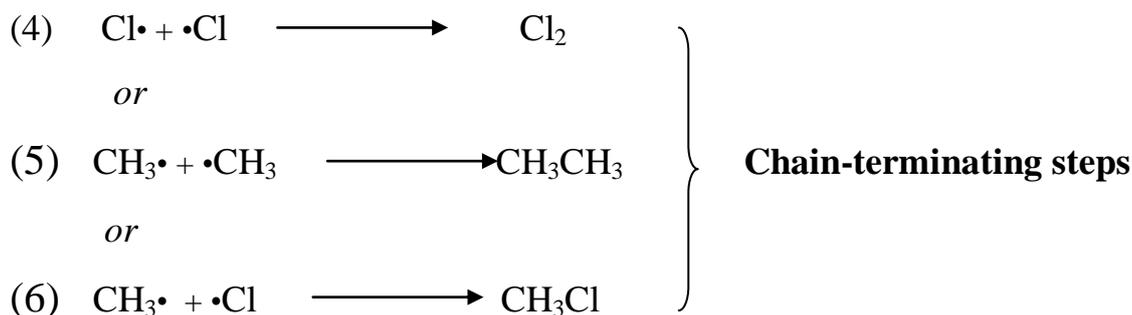


2.6 Chain Reaction

The chlorination of methane is an example of a **chain reaction**, a reaction that involves a series of steps, each of which generates a reactive substance that brings about the next step. While chain reactions may vary widely in their details, they all have certain fundamental characteristics in common.



then (2), (3), (2), (3), etc., until finally:



First in the chain of reactions is a **chain-initiating step**, in which energy is absorbed and a reactive particle generated; in the present reaction it is the cleavage of chlorine into atoms (step 1).

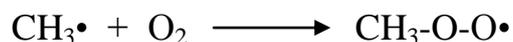
There are one or more **chain-propagating steps**, each of which consumes a reactive particle and generates another; here they are the reaction of chlorine atoms with methane (step 2), and of methyl radical with chlorine (step 3).

Finally, there are **chain-terminating steps**, in which reactive particles are consumed but not generated; in the chlorination of methane these would involve the union of two of the reactive particles, or the capture of one of them by the walls of the reaction vessel.

2.7 Inhibitors

A small amount of oxygen slows down the reaction for a period of time, which depends upon the amount of oxygen, after which the reaction proceeds normally.

Oxygen is believed to react with a methyl radical to form a new free radical:



The $\text{CH}_3\text{OO}\cdot$ radical is much less reactive than the $\text{CH}_3\cdot$ radical, and can do little to continue the chain. By combining with a methyl radical, one oxygen molecule breaks a chain, and thus prevents the formation of thousands of molecules of methyl chloride; this, of course, slows down the reaction tremendously. After all the oxygen molecules present have combined with methyl radicals, the reaction is free to proceed at its normal rate.

*A substance that slows down or stops a reaction even though present in small amount is called an **inhibitor**. The period of time during which inhibition lasts, and after which the reaction proceeds normally, is called the inhibition period.*

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Chapter 3

Alkanes

3.1 Introduction

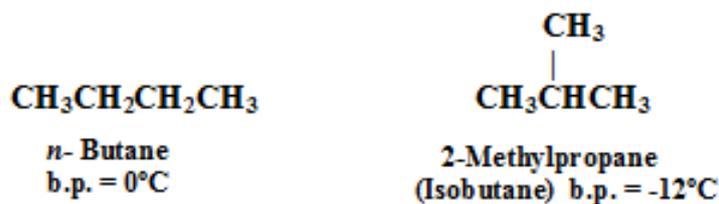
The atoms of the alkane hydrocarbons are joined to one another only through single bonds. The carbon-carbon single bond is of low reactivity. The general formula is C_nH_{2n+2} , where n is the number of carbon atoms. For example, if the molecule contains three carbon atoms, $n = 3$ and $(2n + 2) = 8$, the formula is C_3H_8 . If the molecule contains ten carbon atoms, $n = 10$ and $(2n + 2) = 22$, the formula is $C_{10}H_{22}$. Each member of the alkanes series differ from the preceding and the succeeding members by CH_2 atoms, and each carbon atom of an alkane molecule is covalently bonded to for other atoms. The first ten members of this series are listed in Table 3.1.

Table 3.1 The first ten member of the alkanes

General formula	Structure	Name
CH_4	CH_4	Methane
C_2H_6	CH_3CH_3	Ethane
C_3H_8	$CH_3CH_2CH_3$	Propane
C_4H_{10}	$CH_3(CH_2)_2CH_3$	Butane
C_5H_{12}	$CH_3(CH_2)_3CH_3$	Pentane
C_6H_{14}	$CH_3(CH_2)_4CH_3$	Hexane
C_7H_{16}	$CH_3(CH_2)_5CH_3$	Heptane
C_8H_{18}	$CH_3(CH_2)_6CH_3$	Octane
C_9H_{20}	$CH_3(CH_2)_7CH_3$	Nonane
$C_{10}H_{22}$	$CH_3(CH_2)_8CH_3$	Decane

3.2 Isomerism in Alkanes

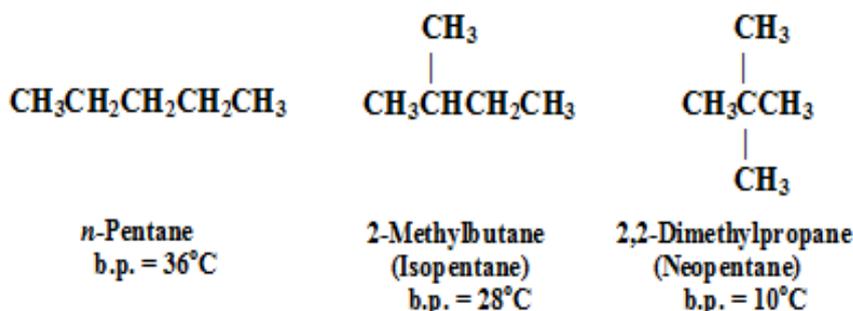
Compounds that have the same molecular formula but different structural formulas were defined as isomers. Isomeric compounds are not possible in the alkanes series until we reach the molecular formula C_4H_{10} . There are two arrangements for the formula C_4H_{10} , and two isomers are known as shown:



(C₄H₁₀ isomers)

They differ both chemically and physically from one another. Experimentally, they can be identified by differences in their melting points, boiling points, densities, solubilities and some other features.

For the formula C₅H₁₂, three isomers have been found, as shown:

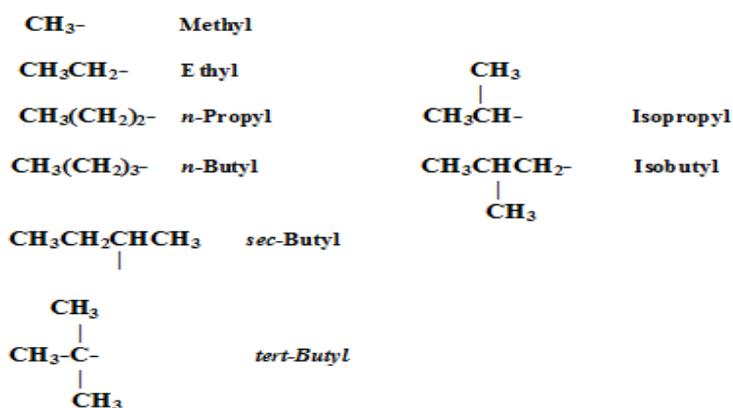


(C₅H₁₂ isomers)

The difference in the structure is due to different arrangements of the carbon atoms.

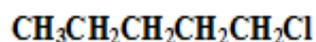
3.3 Alkyl Groups

Any branch consisting of only carbon and hydrogen and only single bond is called **alkyl group**. The general formula for an alkyl group is C_nH_{2n+1}, since it contains one less hydrogen than the parent alkane, C_nH_{2n+2}.

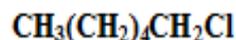


Beyond butyl the number of groups becomes so great that it is impracticable to designate them all by various prefixes. Even though limited, this system is so useful for the small groups just described.

However large the group concerned, the prefix *n*- is used to designate any alkyl group in which all carbons form a single continuous chain and in which the point of attachment is the very end carbon.

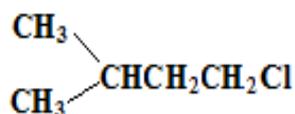


n-Pentyl chloride

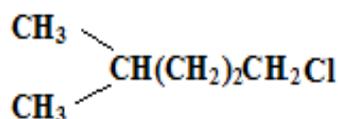


n-Hexyl chloride

The prefix *iso*- is used to designate any alkyl group (of six carbons or fewer) that has a single one-carbon branch on the next-to-last carbon of a chain and has the point of attachment at the opposite end of the chain.



Isopentyl chloride



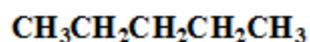
Isohexyl chloride

If the branching occurs at any other position, or if the point of attachment is at any other position, this name does not apply.

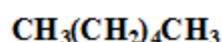
3.4 Nomenclature

Common names:

The prefixes *n*-, *iso*-, and *neo*- are adequate to differentiate the various butanes and pentanes, but beyond this point an impracticable number of prefixes would be required. However, the prefix *n*- has been retained for any alkane, no matter how large, in which all carbon form a continuous chain with no branching:

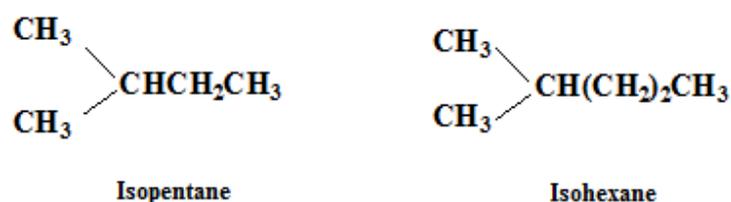


n-Pentane



n-Hexane

An *isoalkane* is a compound of six carbons or fewer in which all carbons except one from a continuous chain and that one carbon is attached to the next-to-end carbon:



In naming any other of the higher alkanes, we make use of the IUPAC system.

IUPAC system:

Essentially the rules of the IUPAC system (International Union of Pure and Applied Chemistry) are:

- 1- Use the ending (*-ane*) for all alkanes.
- 2- Attach a prefix to this, to specify the number of carbon atoms in the longest continuous chain in the molecule. The prefixes through C-10 are:

Meth-	1C	Hex-	6C
Eth-	2C	Hept-	7C
Prop-	3C	Oct-	8C
But-	4C	Non-	9C
Pent-	5C	Dec-	10C
- 3- Pick the longest continuous chain in a branched chain alkane as the basis for the name.
- 4- To specify which carbon atom of the parent chain holds a branch, number the parent chain from whichever end of its chain reaches the first branch with the lower number.

5- Determine the correct name for each branch or any other group or atom such as a halogen atom.

6- If the same group occurs more than ones as a side chain, indicate this by the prefix di-, tri-, tetra-, etc., to show how many of these groups are, and indicate by various numbers the positions of each group.

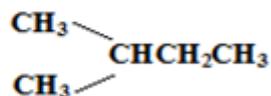
7- If there are several different groups attached to the parent chain, name them in alphabetical order.



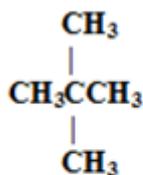
Pentane
(*n*-Pentane)



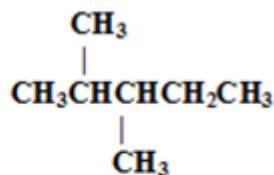
2-Methylpentane
(Isohexane)



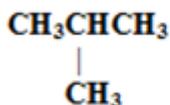
(Isopentane)



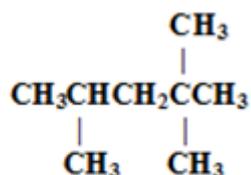
Dimethylpropane
(Neopentane)



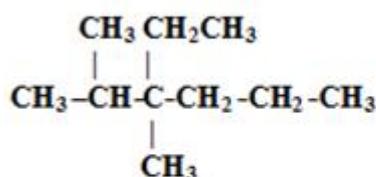
2,3-Dimethylpentane



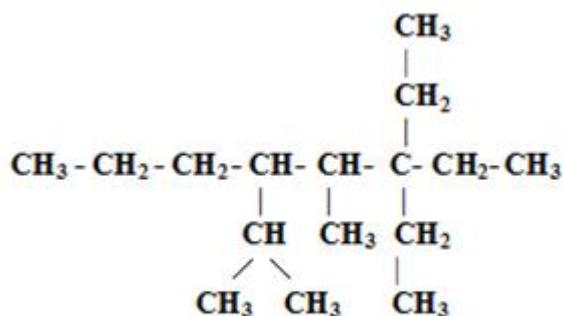
Methylpropane
(Isobutane)



2,2,4-Trimethylpentane

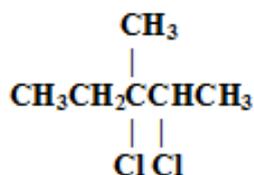
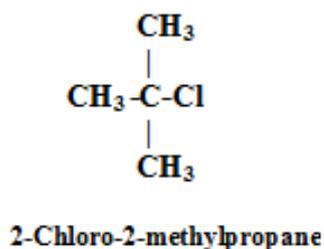
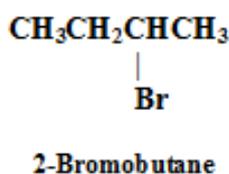
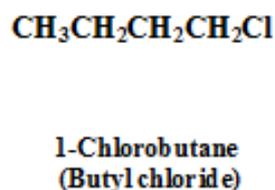
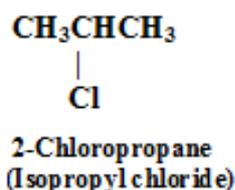
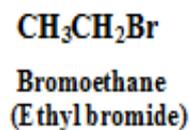
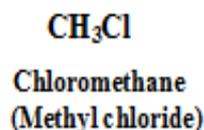


3-Ethyl-2,3-dimethylhexane

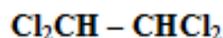


3,3-Diethyl-5-isopropyl-4-methyloctane

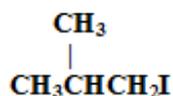
The alkyl halides which appear so often in the alkane chemistry are named *haloalkanes*; that is, halogen is simply treated as a side chain. We first name the alkane as though no halogen were present, and then add *fluoro*, *chloro*, *bromo*, or *iodo*, together with any needed number and prefixes.



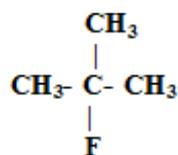
2,3-Dichloro-3-methylpentane



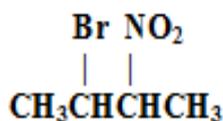
1,1,2,2-Tetrachloroethane



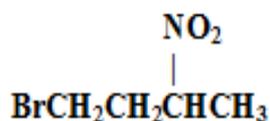
1-Iodo-2-methylpropane



2-Fluro-2-methylpropane



2-Bromo-3-nitrobutane



1-Bromo-3-nitrobutane

The names shown beneath the structural formulas are systematic names. Those shown in parentheses are common names.

3.5 Physical Properties of Alkanes

The alkane molecule is held together entirely by covalent bonds, which either join two atoms of the same kind and hence are non-polar, or join atoms that differ very little in electronegativity and hence are only slightly polar. Furthermore, these bonds are directed in a very symmetrical way, so that the slight bond polarities tend to cancel out. As a result an alkane molecule is either non-polar or very weakly polar. The forces holding non-polar molecules are limited to van der Waals forces, they are weak and of very short range. They act only between the portions of different molecules that are in close contact, that is, between the surfaces of molecules. Within a family, therefore, we would expect that the larger the molecule and hence the larger its surface area the stronger the intermolecular forces.

The boiling points and the melting points of the alkanes rise as the number of the carbons increases. That is because boiling and melting require overcoming the intermolecular forces of liquid and a solid; the boiling point and melting points rise because these intermolecular forces increase as the molecules get larger.

The branching, lower the boiling points because with branching the shape of the molecule tends to approach that of a sphere; and as this happens the surface area

decreases, with the result that the intermolecular forces become weaker and are overcome at a lower temperature.

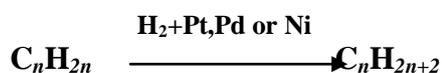
In agreement with the rule of thumb, “like dissolves like”, alkanes are soluble in non-polar solvents such as benzene, ether, and chloroform, and are insoluble in water and other highly polar solvents. Considered themselves as a solvent, the liquid alkanes dissolve compounds of low polarity and do not dissolve compounds of high polarity.

The relative density increases with size of the alkanes, and all alkanes are less dense than water. In general, to be denser than water a compound must contain a heavy atom like Br or I, or several atoms like Cl.

3.6 Preparation of Alkanes

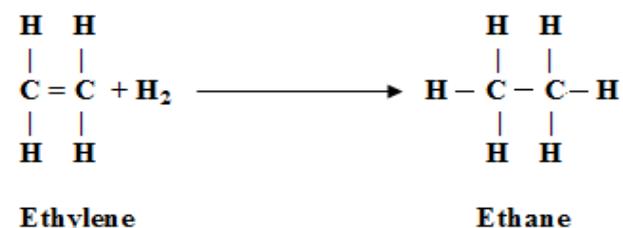
1- Hydrogenation of alkenes

Hydrogenation is the most useful method for preparing alkanes. It is the addition of H₂ to a multiple bond.



Alkene

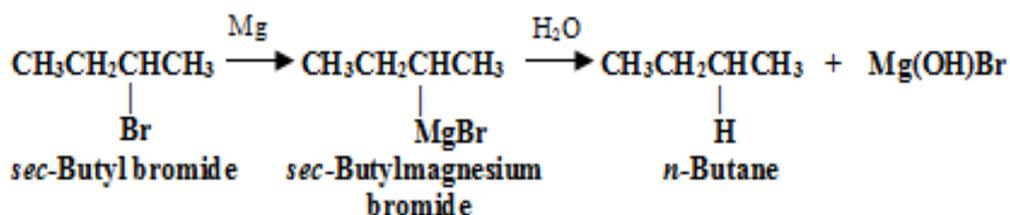
Alkane



2- Reduction of alkyl halides

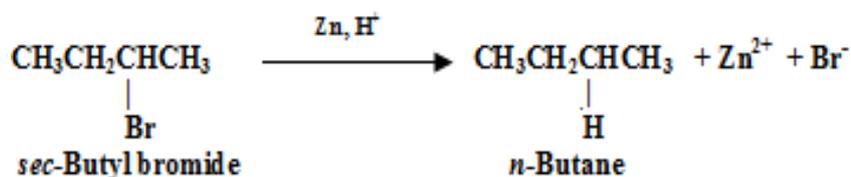
(a) Hydrolysis of Grignard reagent

When a solution of an alkyl halide in dry ethyl ether, is allowed to stand over turnings of metallic magnesium, the resulting solution is known as a Grignard reagent. The reaction with water gives an alkane.

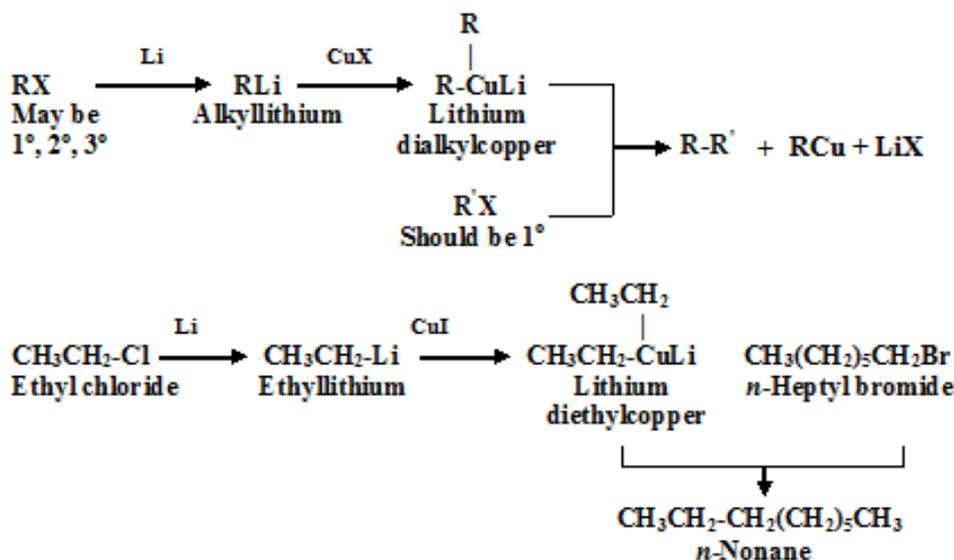


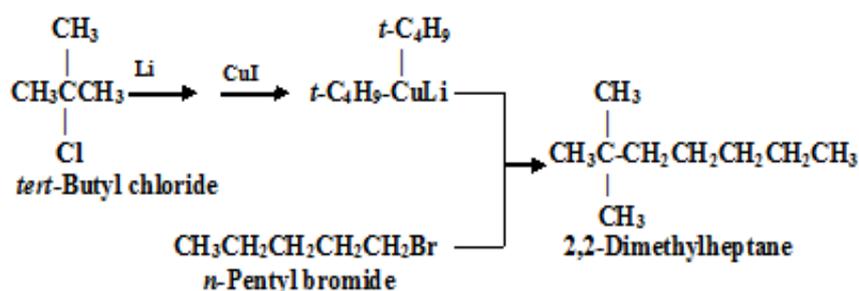
(b) Reduction by metal and acid

Reduction of an alkyl halide with metal and acid, involves the replacement of a halogen atom by a hydrogen atom. The product is an alkane.



3- Coupling of alkyl halides with organometallic compounds



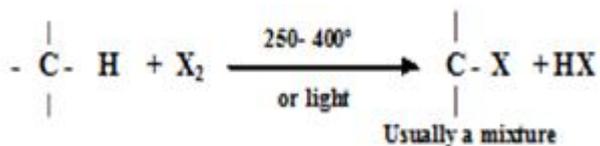


3.7 Reactions of Alkanes

Alkanes are generally not considered to be very reactive substance. However, under suitable conditions they do react.

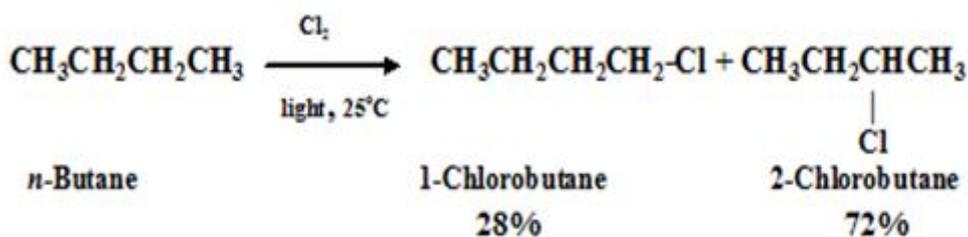
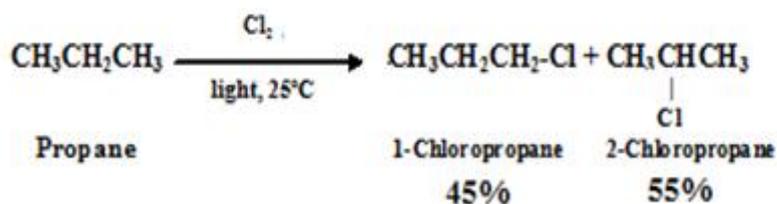
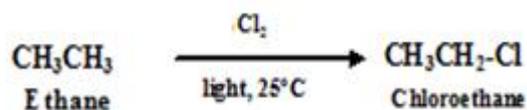
1- Halogenation

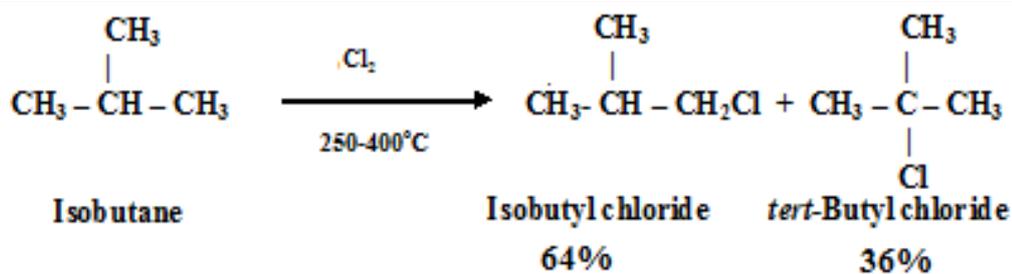
Alkanes react with the halogens (except iodine) to form substitution products.



Reactivity X_2 : $\text{Cl}_2 > \text{Br}_2$

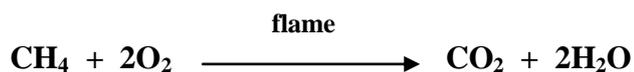
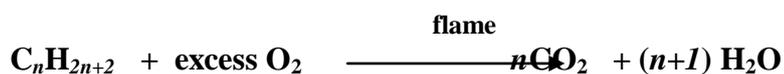
H_2 : $3^\circ > 2^\circ > 1^\circ > 2^\circ \text{ CH}_3\text{-H}$





2- Oxidation (Combustion)

Although alkanes are resistant to attack by oxidizing agents generally, they all undergo combustion in air or oxygen, the products of complete oxidation being carbon dioxide and water.



Organic Chemistry I

College of Pharmacy - University of Anbar / First Year 2017 - 2018

Dr. Jasim. H. Hassen

Chapter 4

Alkenes

4.1 Introduction

Molecules of the alkene (also called olefins) series of hydrocarbons are characterized by having two adjacent carbon atoms joined to one another by a double bond. The carbon-carbon double bond is unsaturated and hence highly reactive toward a wide variety of reagents.

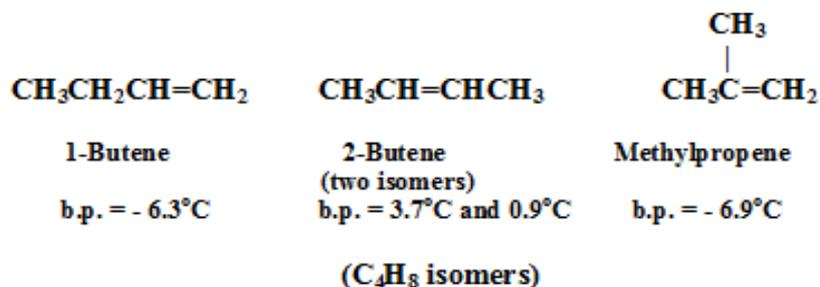
The general formula of alkenes is C_nH_{2n} , where n is the number of carbon atoms. The first nine members of this series are listed in Table 4.1.

Table 4.1 The first nine member of the alkenes

General formula	Structure	Name
C_2H_4	$CH_2 = CH_2$	Ethene
C_3H_6	$CH_2 = CHCH_3$	Propene
C_4H_8	$CH_2 = CHCH_2CH_3$	1-Butene
C_5H_{10}	$CH_2 = CH(CH_2)_2CH_3$	1-Pentene
C_6H_{12}	$CH_2 = CH(CH_2)_3CH_3$	1-Hexene
C_7H_{14}	$CH_2 = CH(CH_2)_4CH_3$	1-Heptene
C_8H_{16}	$CH_2 = CH(CH_2)_5CH_3$	1-Octene
C_9H_{18}	$CH_2 = CH(CH_2)_6CH_3$	1-Nonene
$C_{10}H_{20}$	$CH_2 = CH(CH_2)_7CH_3$	1-Decene

4.2 Isomerism in Alkenes

Isomeric compounds are also possible in the alkenes. For the molecular formula C_4H_8 , there are three different ways of organizing the four carbon atoms and the double bond:



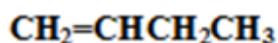
4.3 Nomenclature

Common names are seldom used except for three simple alkenes; ethylene, propylene, and isobutylene. Most alkenes are named by the IUPAC system.

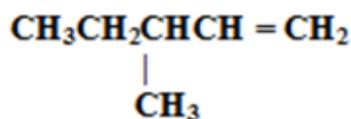
- 1- The longest continuous chain of carbon atoms containing the double bond serves as the parent compound.
- 2- The ending *-ane* of the corresponding alkane hydrocarbon name is replaced by the ending *-ene*.
- 3- The position of the double bond is indicated by the lower number of the numbers of the carbon atoms to which it is attached. The number that represents this position is placed before the parent compound name. Alkyl groups attached to the parent compound are designated as is done for the alkane.
- 4- If a geometric isomer is designated, the name begins with *cis-* or *trans-*.



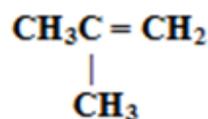
1-Hexene



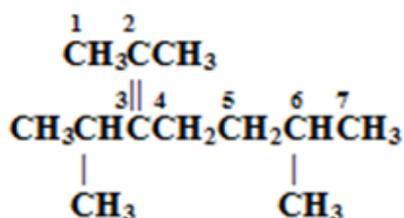
1-Butene



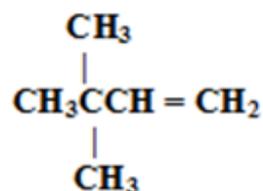
3-Methyl-1-pentene



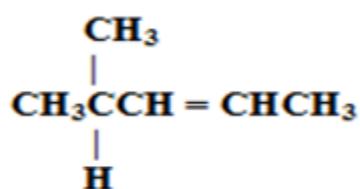
2-Methylpropene



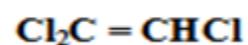
3-Isopropyl-2,6-dimethyl-2-heptene



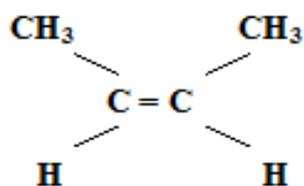
3,3-Dimethyl-1-butene



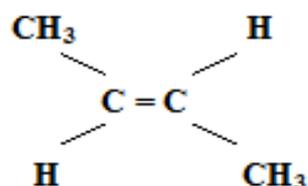
4-Methyl-2-pentene



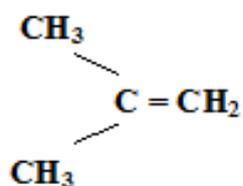
Trichloro ethene



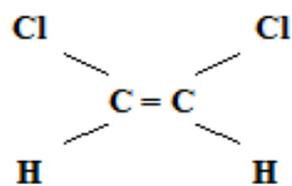
cis-2-Butene



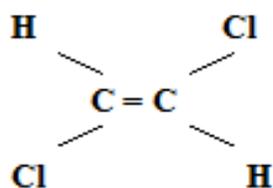
trans-2-Butene



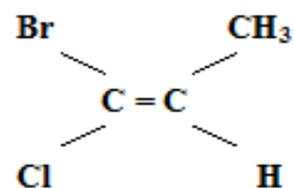
2-Methylpropene



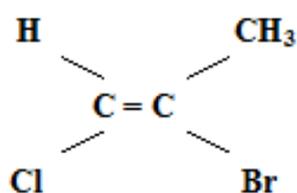
cis-1,2-Dichloroethene



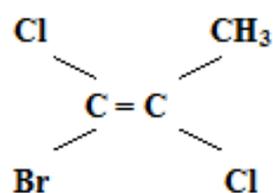
trans-1,2-Dichloroethene



1-Bromo-1-chloropropene



2-Bromo-1-chloropropene



1-Bromo-1,2-dichloropropene

4.4 Physical Properties of Alkenes

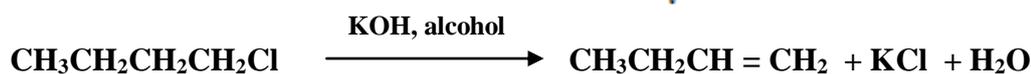
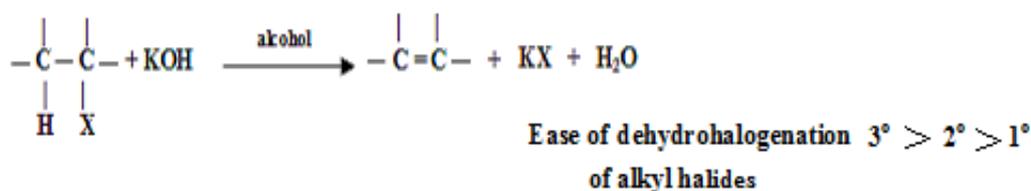
The alkenes possess physical properties that are essentially the same as those of the alkanes. They are insoluble in water, but quite soluble in non-polar solvents like benzene, ether, and chloroform. They are less dense than water. The boiling point rises with increasing carbon number; as with alkane, branching lowers the boiling point.

Like alkanes, alkenes are at most only weakly polar. Since the loosely held π electrons of the double bond are easily pulled or pushed, dipole moments are larger than for alkanes.

4.5 Preparation of Alkenes

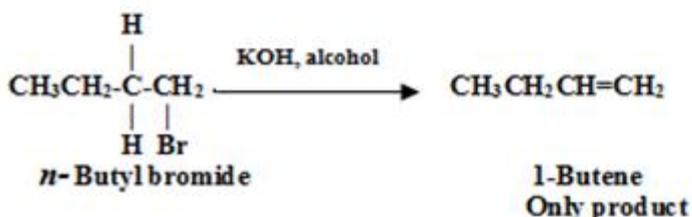
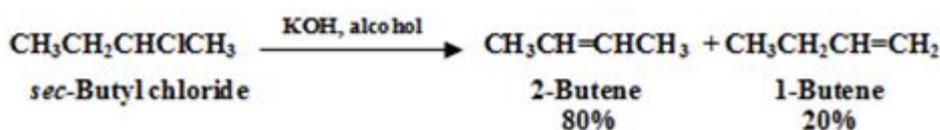
1- Dehydrohalogenation of alkyl halides

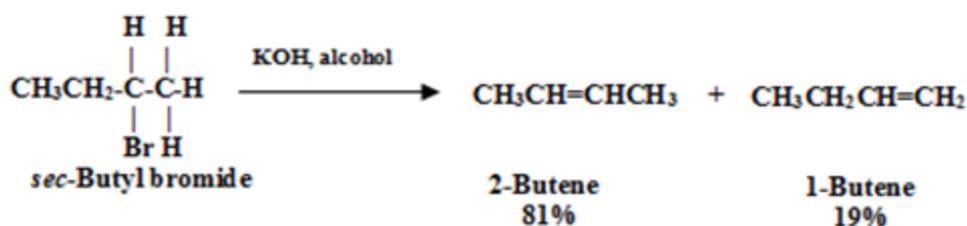
Dehydrohalogenation involves loss of the halogen atom and of hydrogen atom from a carbon adjacent to the one losing the halogen (*1,2-elimination*).



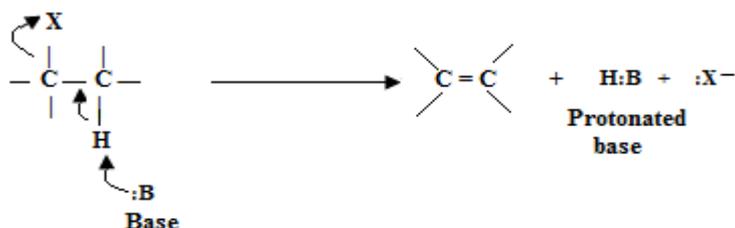
n-Butyl chloride

1-Butene





Mechanism:

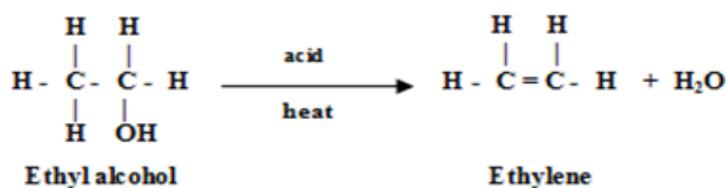
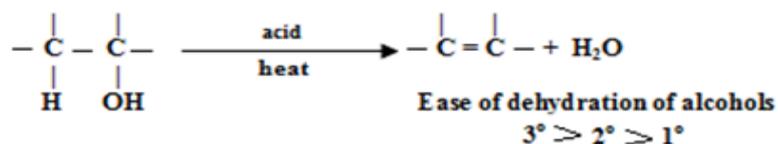


The base :B can be neutral or negatively charged: for example, H₂O or OH⁻. The conjugate acid H:B will then be positively charged or neutral: for example, H₃O⁺ or H₂O.

Halogen leaves the molecule as halide ion, and hence must take its electron pair along. Hydrogen is abstracted by the base as a proton, and hence must leave its electron pair behind; it is this electron pair that is available to form the π bond between the carbon atoms.

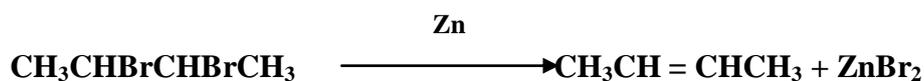
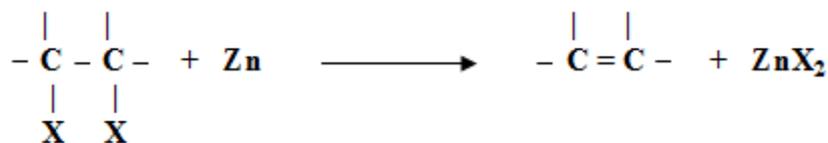
2- Dehydration of alcohols

In the dehydration of alcohols, the H and OH are lost from adjacent carbons (*1,2-elimination*). An acid catalyst is necessary and application of heat.



3- Dehalogenation of vicinal dihalides

Alkenes can be prepared by elimination of two halide atoms from a vicinal (neighboring) dihalides.

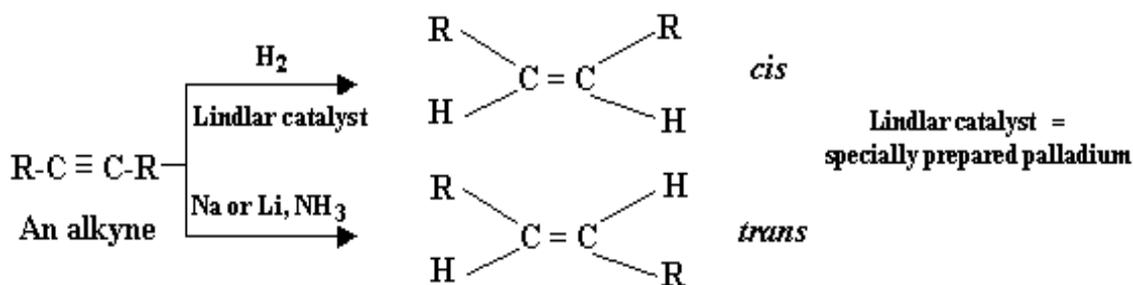


2,3-Dibromobutane

2-Butene

4- Reduction of alkynes

Trans alkene can be obtained by reduction of alkynes with sodium or lithium in liquid ammonia. Cis alkene is obtained by hydrogenation of alkynes with a specially prepared palladium called Lindlar catalyst.



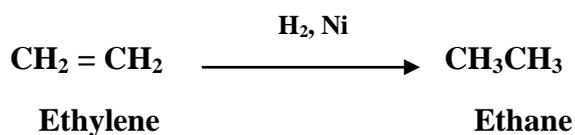
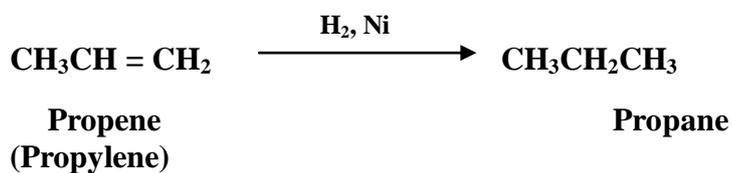
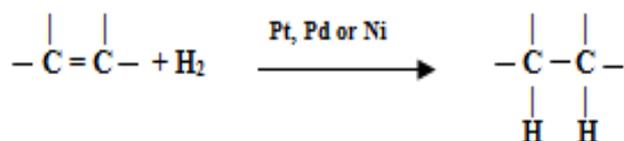
4.6 Reactions of alkenes

The presence of the carbon-carbon double bond confers very considerable chemical activity on the alkenes and consequently they react with a much wider variety of reagents than do the alkanes. The π -bond component of the double bond is weaker than the σ -bond component and the π -electrons are more easily accessible to attacking reagents.

(Addition Reactions)

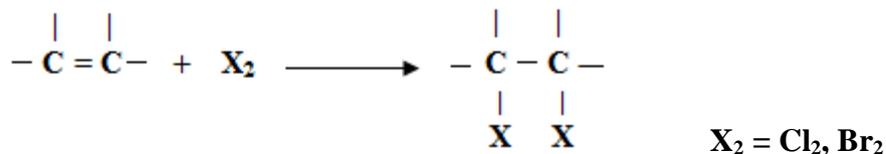
1- Addition of hydrogen

When an alkene is mixed with hydrogen, there is no appreciable reaction, but in the presence of certain metal catalysts such as nickel, platinum or palladium, a fairly rapid reaction occurs leading to the uptake of hydrogen.



2- Addition of halogen

Chlorine and bromine react readily with alkenes, in the liquid or vapour states, to form dihalogeno addition products, the two halogen atoms are attached to adjacent carbons. Iodine generally fails to react.

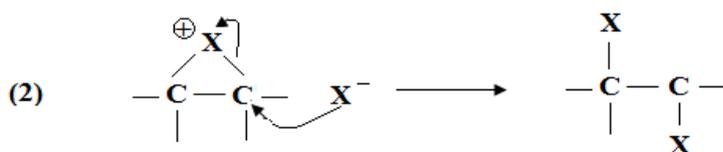
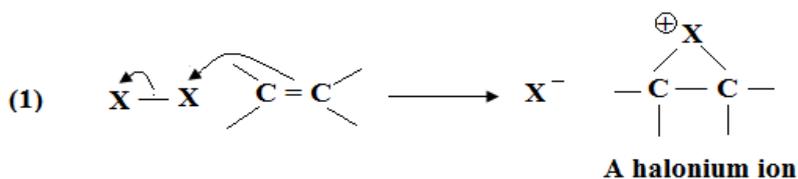




Propene
(Propylene)

1,2-Dibromopropane
(Propylene bromide)

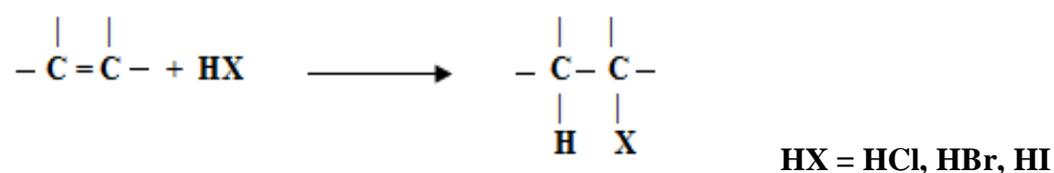
Mechanism:



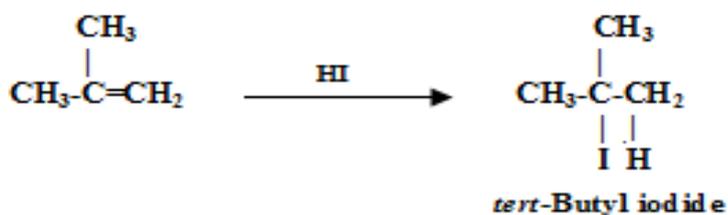
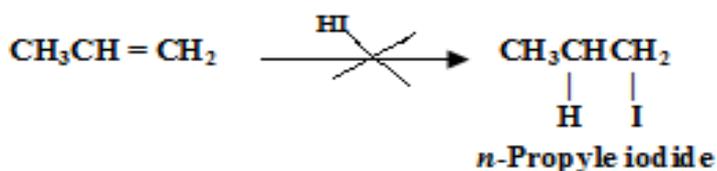
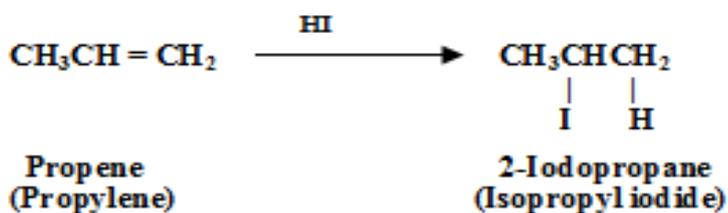
In step (1) a halogen is transferred, without a pair of electrons, from a halogen molecule to the carbon-carbon double bond; there is formed a halide ion and organic cation. In step (2) this cation reacts with a halide ion to yield the addition product.

3- Addition of hydrogen halides

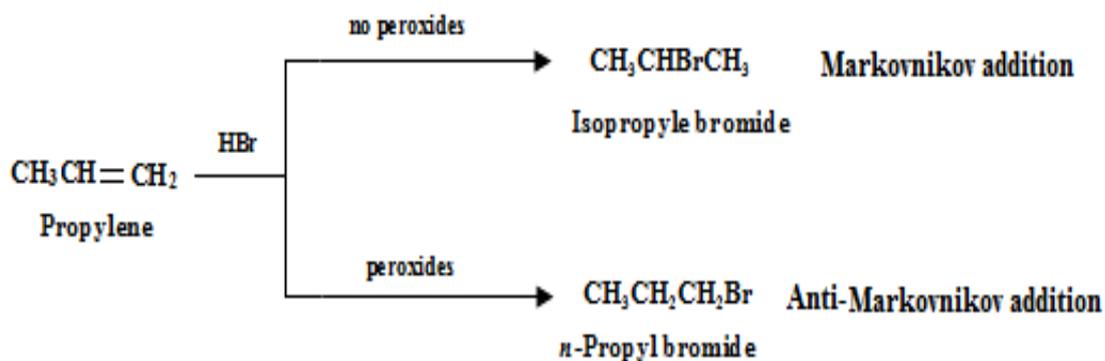
Alkenes react, usually on heating, with hydrogen halides (either gaseous or in concentrated solution) to form an addition product.



The hydrogen attaches itself to the carbon that already holds the greater number of hydrogens. This statement is called *Markovnikov's rule*.

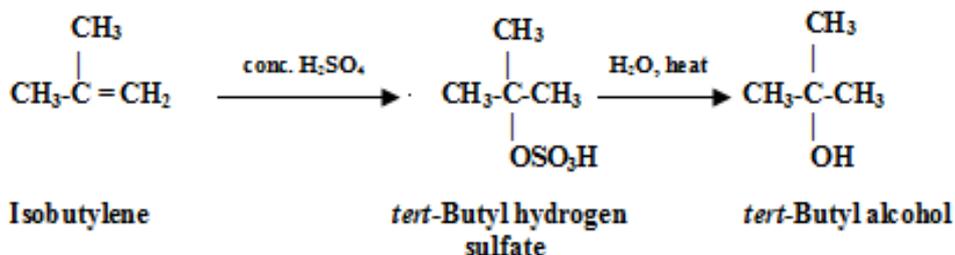
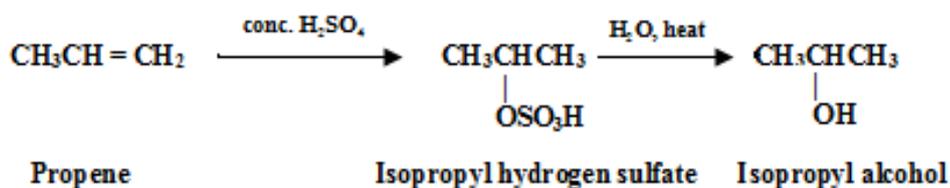


If the reaction takes place in the absence of peroxide, the addition of HBr, to alkenes follows Markovnikov's rule. On the other hand, if the reaction takes place in the presence of peroxide, HBr adds to alkenes in the reverse direction.



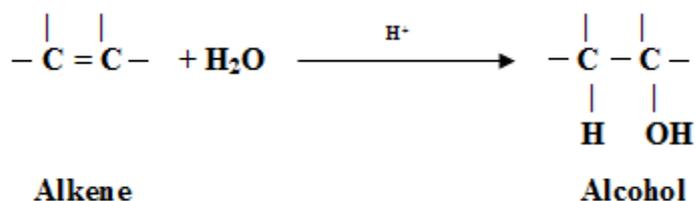
4- Addition of sulfuric acid

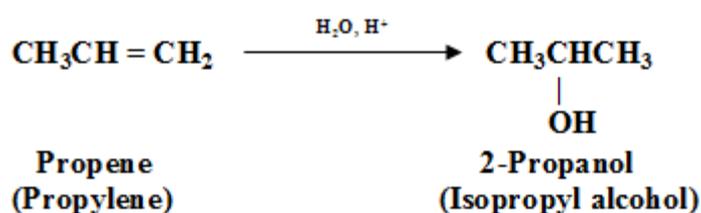
Alkenes are slowly absorbed when they are bubbled through, or shaken with, cold concentrated sulphuric acid. The reaction involves the addition of H and HSO₄ groups across the double bond, to form alkyl hydrogen sulfates, which is on dilution with water and heating yield alcohol.



5- Addition of water. Hydration

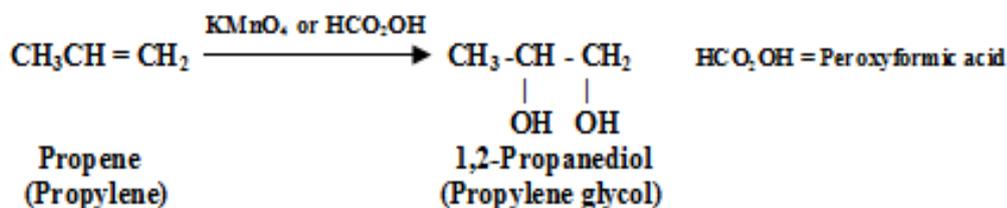
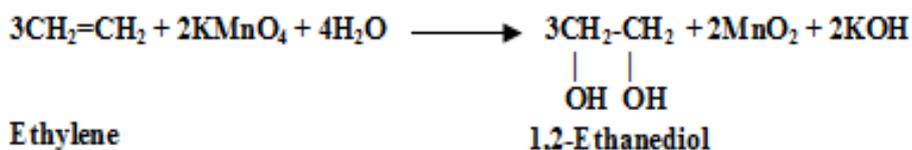
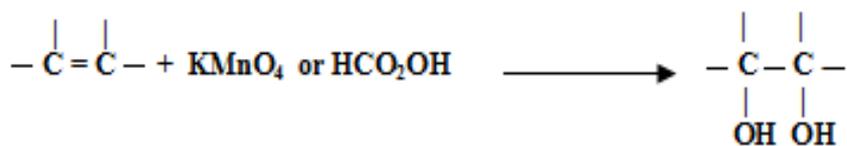
Alkenes are also reacting with water, and this reaction is carried out in a dilute acid medium. The reaction follows Markovnikov's rule.





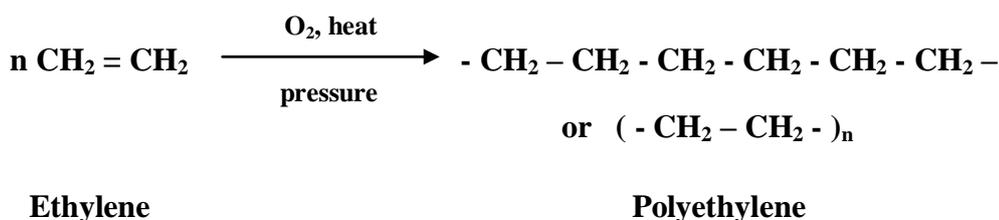
6- Hydroxylation – glycol formation

Alkanes are highly resistant to chemical oxidizing agents under normal conditions. In contrast, alkenes are quite sensitive to oxidation by several oxidizing agent. If an alkene is shaken with a few drops of a dilute acidified solution of KMnO_4 , the purple solution is rapidly decolorized. The alkene is oxidized to an addition product, in which two hydroxyl groups have been added across the carbon-carbon double bond; the product is a di-alcohol or diol.



7- Polymerization

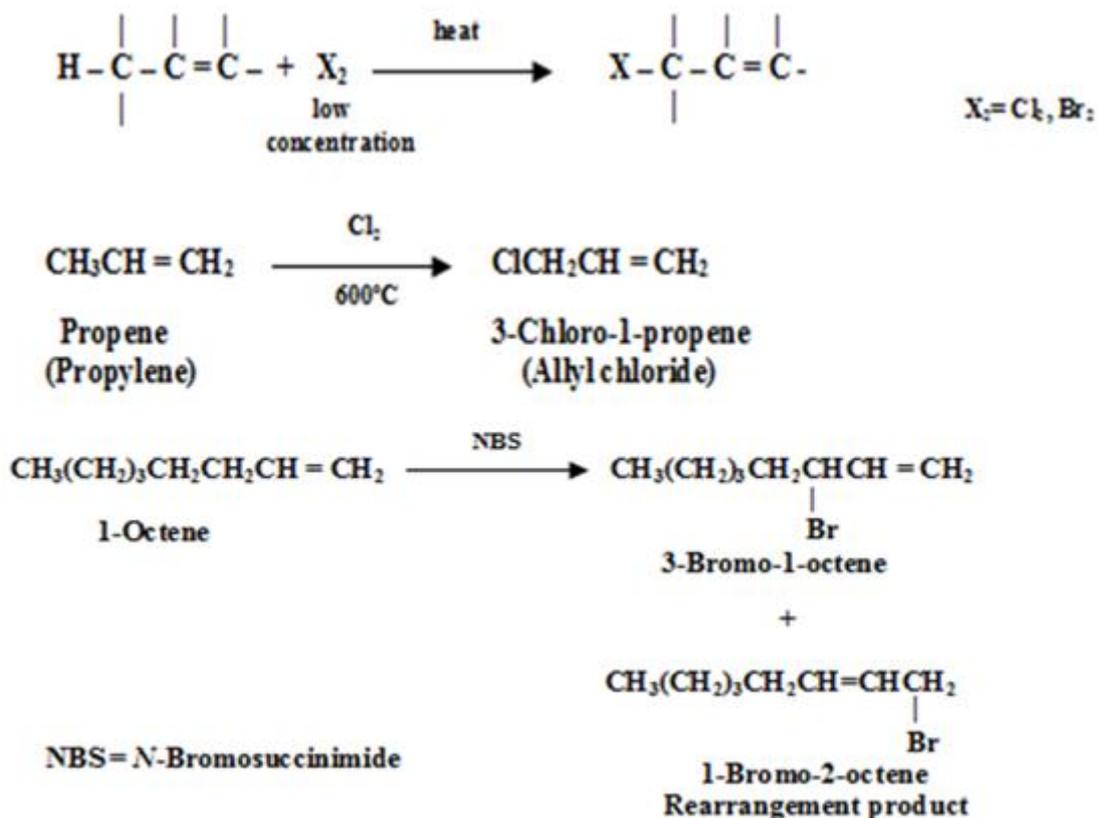
In the presence of a certain catalyst, alkene molecule can add on to each other in a head-to-tail fashion to form long-chain molecules of a very high relative molecular mass.

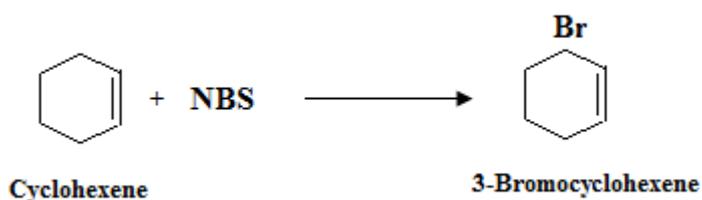


(Substitution Reactions)

Halogenation. Allylic substitution

Alkenes react with halogens, substitution reaction. The reaction carried out as follow:

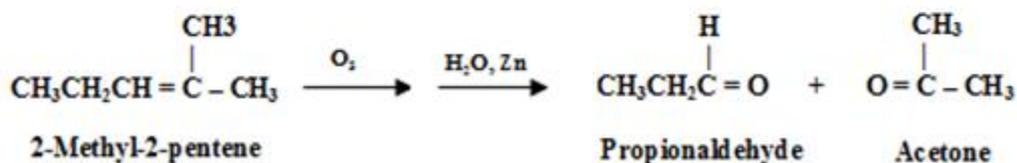
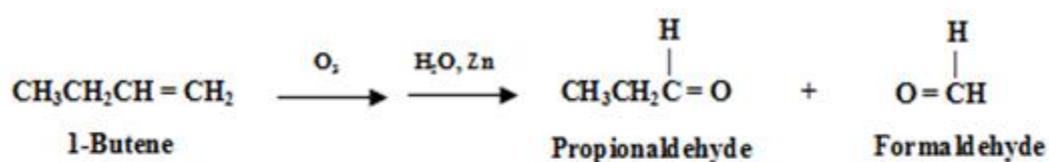
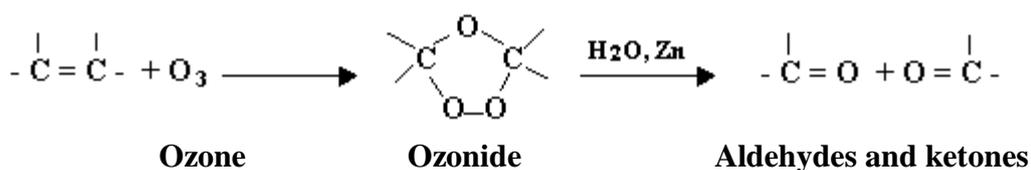




(Cleavage Reactions)

Ozonolysis

O₃ (ozone) is produced by passage of an electric discharge through oxygen O₂. If the mixture of gases is bubbled through a solution of an alkene at low temperature, an unstable product known as an ozonide is formed. Ozonides are unstable and are readily hydrolysed to form aldehydes or ketones.



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Chapter 5

Dienes

5.1 Introduction

Dienes are simply alkenes that contain two carbon-carbon double bonds. They therefore have essentially the same properties as the alkenes we have already studied. For certain of the dienes, these alkene properties are modified in important ways; we shall focus our attention on these modifications.

Dienes are named by the IUPAC system in the same way as alkenes, except that the ending **-diene** is used, with two numbers to indicate the position of the two double bonds. This system is easily extended to compounds containing any number of double bonds.



1,3-Butadiene

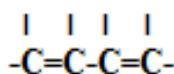


1,4-Pentadiene

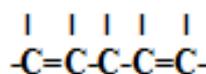


1,3,5-Hexatriene

Dienes are divided into two important classes according to the arrangement of the double bonds. Double bonds that alternate with single bonds are said to be conjugated; double bonds that are separated by more than one single bond are said to be isolated.

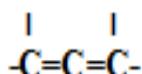


**Conjugated
double bonds**



**Isolated
double bonds**

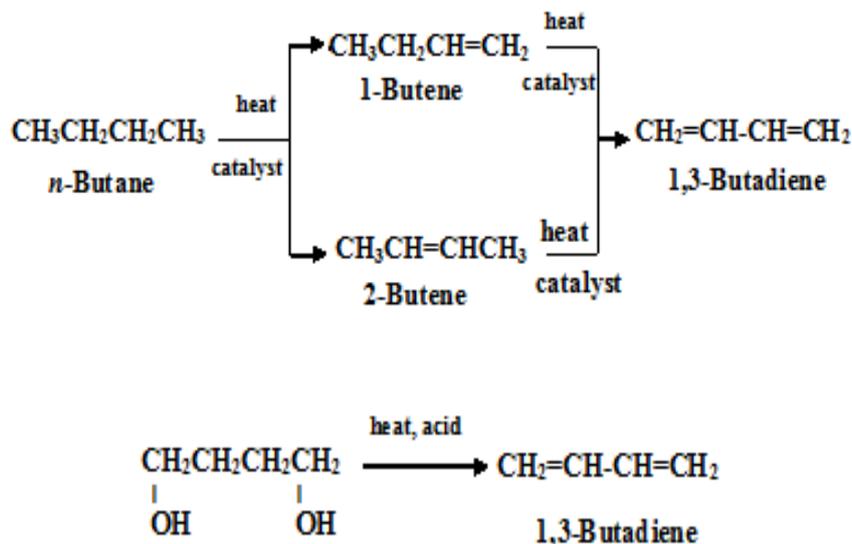
A third class of dienes, of increasing interest to organic chemists, contain cumulated double bonds; these compounds are known as allenes;



Cumulated double bonds: allenes

5.2 Preparation and Properties of Dienes

Dienes are usually prepared by adaptations of the methods used to make simple alkenes. For example, the most important diene, 1,3-butadiene (used to make synthetic rubber), has been made by cracking process, or by dehydration of an alcohol containing two –OH groups:

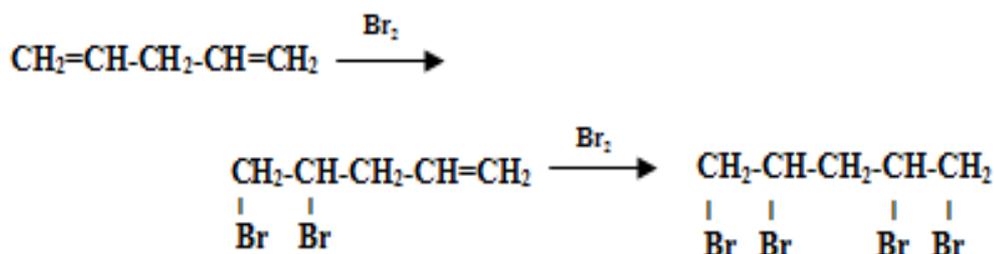


The chemical properties of a diene depend upon the arrangement of its double bonds. Isolated double bonds exert little effect on each other, and hence each reacts as though it were the only double bond in the molecule. Except for the consumption of larger amounts of reagents, then, the chemical properties of the non-conjugated dienes are identical with those of the simple alkenes.

Conjugated dienes differ from simple alkenes in three ways: (a) they are more stable, (b) they undergo 1,4-addition, and (c) toward free radical addition, they are more reactive.

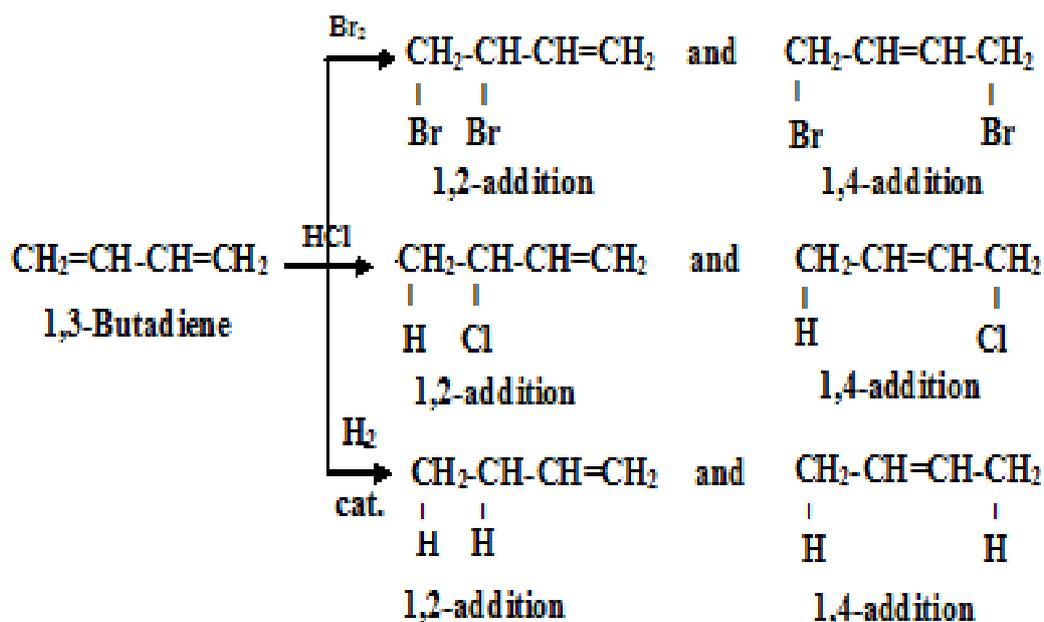
5.3 Electrophilic Addition to Conjugated dienes, 1,4-Addition

When 1,4-Pentadiene is treated with bromine under conditions that favor formation of the dihalide, there is obtained the expected product, 4,5-dibromo-1-pentene. Addition of more bromine yield the 1,2,4,5-tetrabromopentane.



This is typical of the behavior of dienes containing isolated double bonds: the double bonds react independently, as though they were in different molecules.

When 1,3-butadiene is treated with bromine under similar conditions, there is obtained not only the expected 3,4-dibromo-1-butene, but also 1,4-dibromo-2-butene. Treatment with HCl yields not only 3-chloro-1-butene, but also 1-chloro-2-butene. Hydrogenation yields not only 1-butene but also 2-butene.

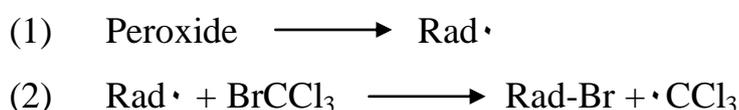


Study of many conjugated dienes and many reagents shows that such behavior is typical: in addition to conjugated dienes, a reagent may attach itself not only to a pair of adjacent carbons (1,2-addition), but also to the carbons at the two ends of the conjugated system (1,4-addition). Very often the 1,4-addition product is the major one.

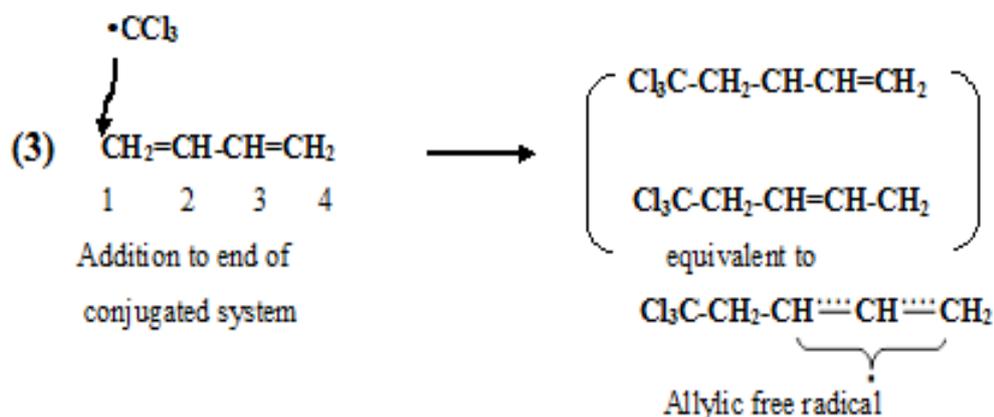
5.4 Free-Radical Addition to Conjugated Dienes: Orientation

Like other alkenes, conjugated dienes undergo addition not only by electrophilic reagents but also by free radical. In free-radical addition, conjugated dienes show two special features: they undergo 1,4-addition as well as 1,2-addition, and they are much more reactive than ordinary alkenes. We can account for both features, orientation and reactivity, by examining the structure of the intermediate free radical.

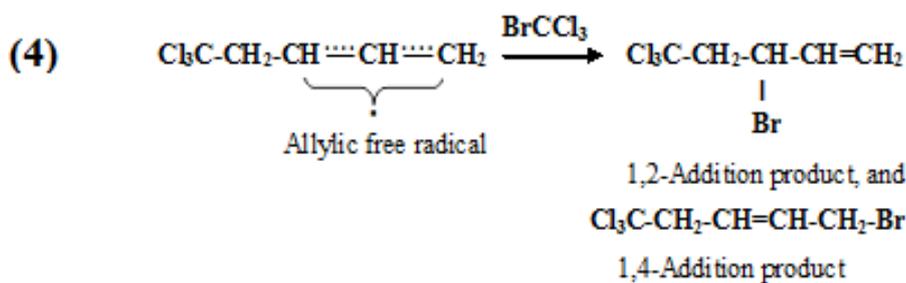
Let us take, as an example, addition of BrCCl_3 to 1,3-butadiene in the presence of a peroxide. The peroxide decomposes (step 1) to yield a free radical, which abstracts bromine from BrCCl_3 (step 2) to generate a CCl_3 radical.



The $\cdot\text{CCl}_3$ radical thus formed adds to the butadiene (step 3). Addition to one of the ends of the conjugated system is the preferred reaction, since this yields a resonance-stabilized allyl free radical.

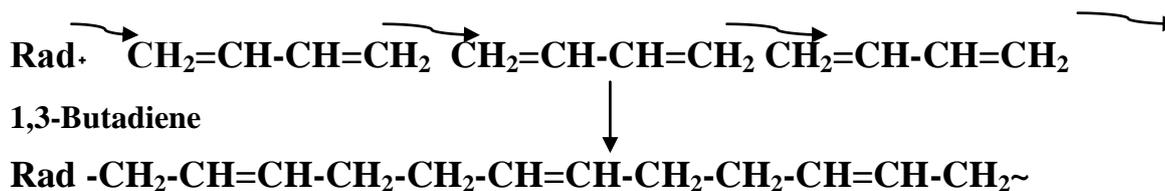
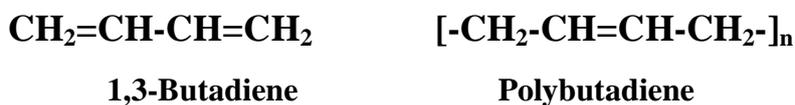


The allyl free radical then abstracts bromine from a molecule of BrCCl_3 (step 4) to complete the addition, and in doing so forms a new $\cdot\text{CCl}_3$ radical which can carry on the chain. In step (4) bromine can become attached to either C-2 or C-4 to yield either the 1,2- or 1,4-product.



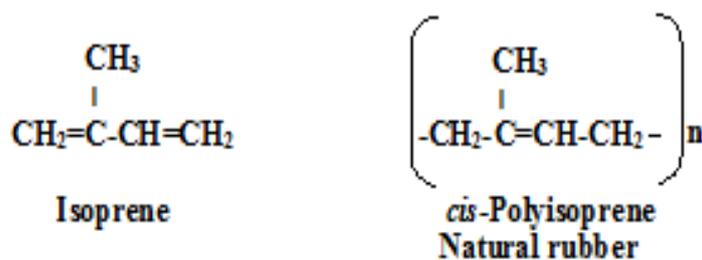
5.5 Free-radical Polymerization of Dienes: Rubber and Rubber Substitutes

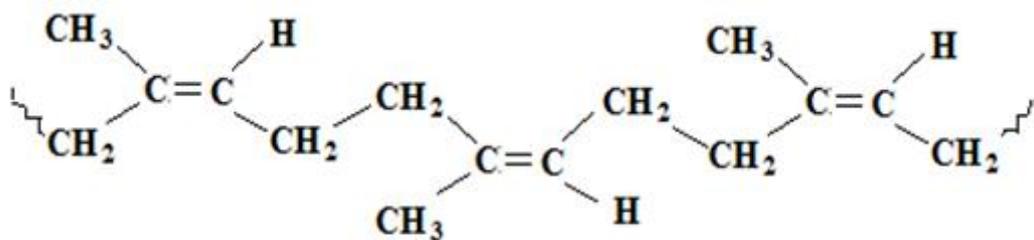
Like substituted ethylenes, conjugated dienes, too, undergo free-radical polymerization. From 1,3-butadiene, for example, there is obtained a polymer whose structure indicates that 1,4-addition occurs predominantly:



Such a polymer differ from the polymer of simple alkenes in one of very important way: each unit still contains one double bond.

Natural rubber has a structure that strongly resembles these synthetic polydienes. We could consider it to be a polymer of the conjugated diene 2-methyl-1,3-butadiene, **isoprene**.

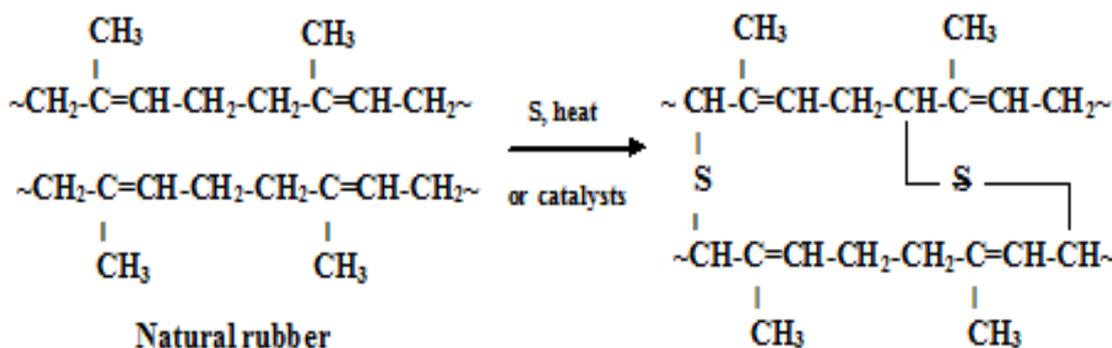




Natural rubber

All-cis configuration

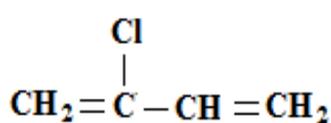
The double bonds in the rubber molecule are highly important, since apparently by providing reactive allylic hydrogens, they permit vulcanization, the formation of sulfur bridges between different chains. These cross-links make the rubber harder and stronger, and do away with the tackiness of the untreated rubber.



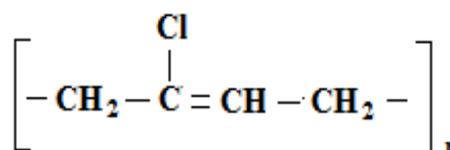
Natural rubber

Vulcanized rubber

Polymerization of dienes to form substitutes for rubber was the forerunner of the enormous present-day plastics industry. Polychloroprene (Neoprene, Duprene) was the first commercially successful rubber substitute in the United States.



Chloroprene



Polychloroprene

5.6 Isoprene and the isoprene rule

The isoprene unit is one of nature's favorite building blocks. It occurs not only in rubber, but in a wide variety of compounds isolated from plant and animal sources.

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Chapter 6

Alkynes

6.1 Introduction

Molecules of alkyne series of hydrocarbon are characterized by having two adjacent carbon atoms joined to one another by a triple bond. The carbon-carbon triple bond is unsaturated and highly reactive toward the reagents that double bonds react with.

The general formula is C_nH_{2n-2} .

$HC \equiv CH$	Ethyne (acetylene)
$HC \equiv CCH_3$	Propyne
$HC \equiv CCH_2CH_3$	1-Butyne
$HC \equiv C(CH_2)_2CH_3$	1-Pentyne
$HC \equiv C(CH_2)_3CH_3$	1-Hexyne
$HC \equiv C(CH_2)_4CH_3$	1-Heptyne
$HC \equiv C(CH_2)_5CH_3$	1-Octyne
$HC \equiv C(CH_2)_6CH_3$	1-Nonyne
$HC \equiv C(CH_2)_7CH_3$	1-Decyne

6.2 Nomenclature

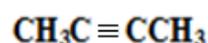
The alkynes are named according to two systems. In one, they are considered to be derived from acetylene by replacement of one or both hydrogen atoms by alkyl group.



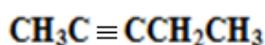
For more complicated alkyne the IUPAC names are used. The rules are exactly as for the alkenes, except that the ending **-yne** is used in place of **-ene**.



1-Butyne



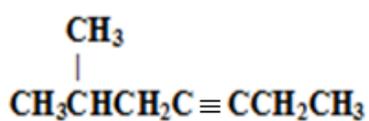
2-Butyne



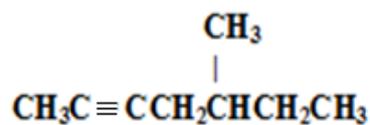
2-Pentyne



4-Hexen-1-yne



6-Methyl-3-heptyne



5-Methyl-2-heptyne

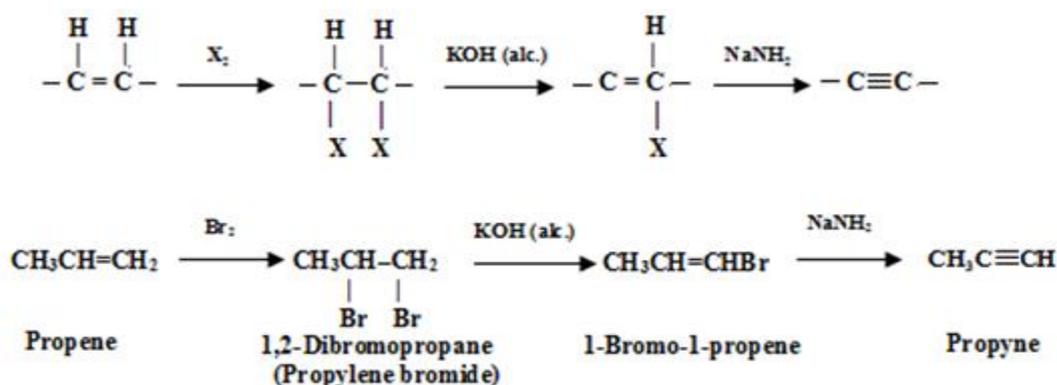
6.3 Physical Properties of Alkynes

Being compounds of low polarity, the alkynes have physical properties that are essentially the same as those of the alkanes and alkenes. They are insoluble in water but quite soluble in the usual organic solvents of low polarity: ether, benzene, and carbon tetrachloride. They are less dense than water. Their boiling points show the usual increase with increasing carbon number, and the usual effects of chain branching; they are very nearly the same as the boiling points of alkanes and alkenes with the same carbon skeletons.

6.4 Preparation of Alkynes

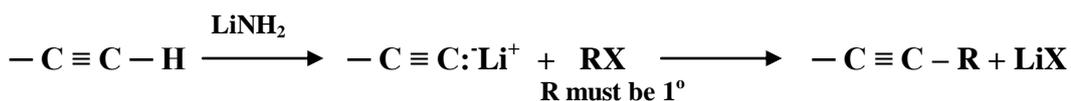
1- Dehydrohalogenation of alkyl halides

A carbon-carbon triple bond is formed in the same way as a double bond: elimination of atoms or groups from two adjacent carbons.



2- Reaction of metal acetylides with alkyl halides

Lithium or sodium acetylides can react with primary alkyl halides. The alkyl group becomes attached to the triply bonded carbon, and a new, larger alkyne has been generated.



Lithium acetylide *n*-Butyl bromide

1-Hexyne
(*n*-Butylacetylene)

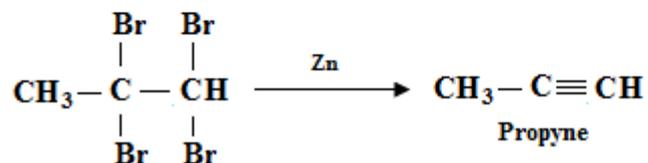
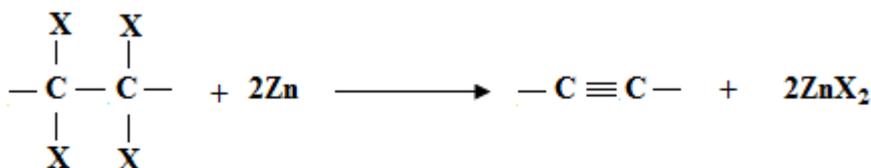


Lithium *n*-pentylacetylide *n*-Pentyl chloride

6-Dodecyne

3- Dehalogenation of tetrahalides

Alkynes can be prepared by dehalogenation of tetrahalides.



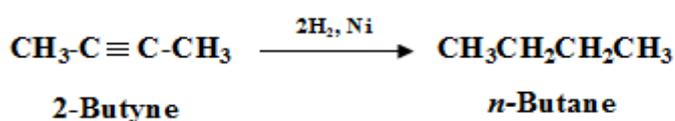
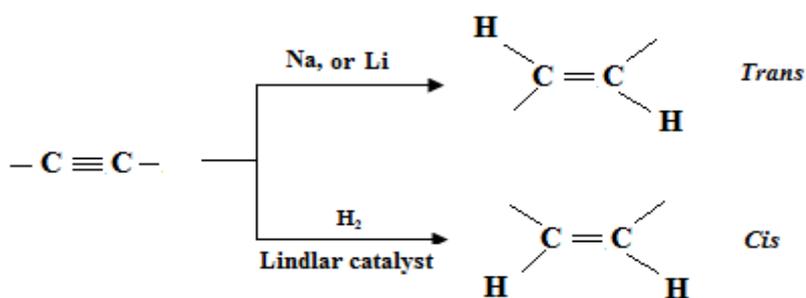
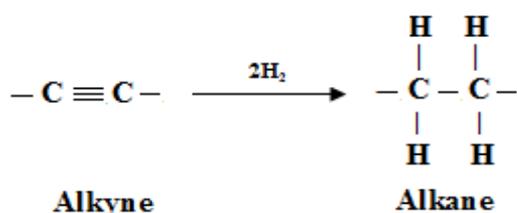
6.5 Reactions of Alkynes

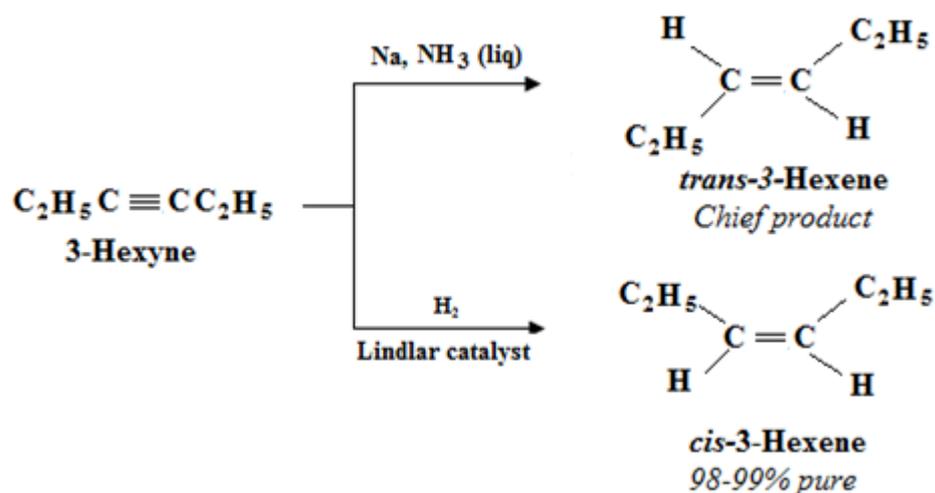
The carbon-carbon triple bond $\text{--C}\equiv\text{C--}$ consists of one σ -bond and two weaker π -bonds, so it is not surprising that addition reactions are a characteristic feature of this functional group. Despite its high formal unsaturation, the triple bond does not usually react so vigorously as a carbon-carbon double bond, as in alkenes, and it is therefore sometimes possible to stop the addition reaction after the uptake of 1 mol of reactant, rather than 2 mol which would be possible in principle.

(Addition Reactions)

1- Addition of hydrogen

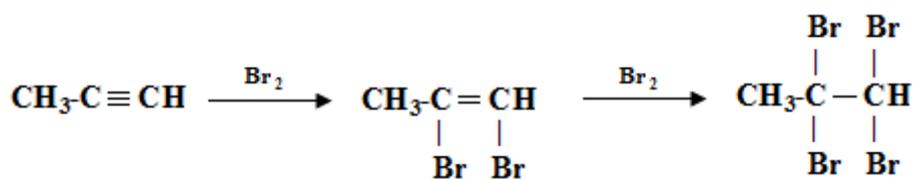
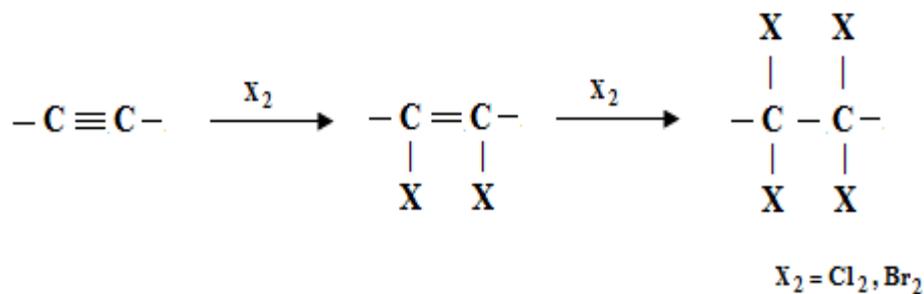
As would be expected, alkynes can be hydrogenated catalytically, taking up 2 mol of hydrogen per mol of alkyne to form the corresponding saturated molecule. Careful control of the hydrogenation can stop the reaction at the alkene stage.





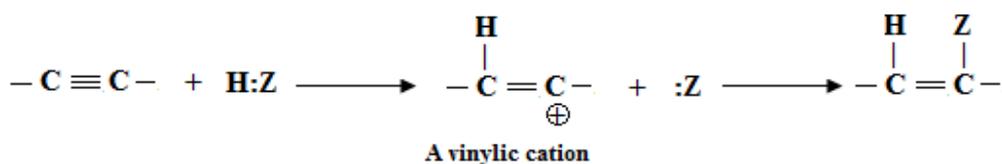
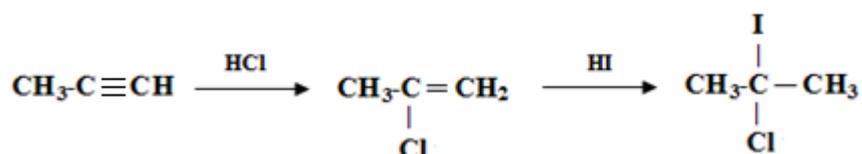
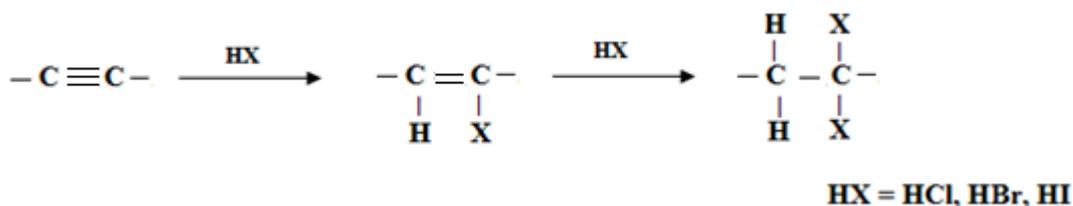
2- Addition of halogen

Alkynes can react with chlorine and bromine to yield tetrahaloalkanes. A dihaloalkene is an intermediate.



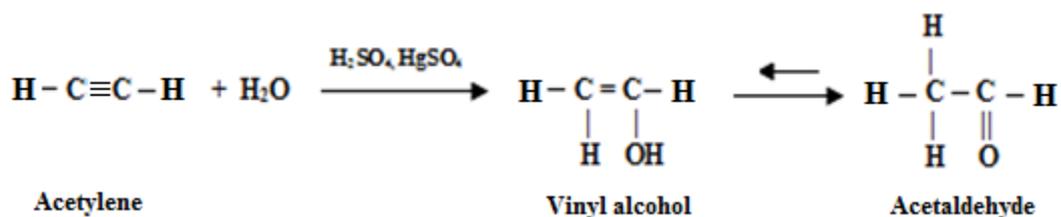
3- Addition of hydrogen halides

Alkynes also react with hydrogen halides to form alkyl halides. Addition of acids like hydrogen halides is electrophilic addition, and it appears to follow the same mechanism with alkynes as with alkenes: via an intermediate carbocation. The difference is that here the intermediate is a *vinyl cation*.



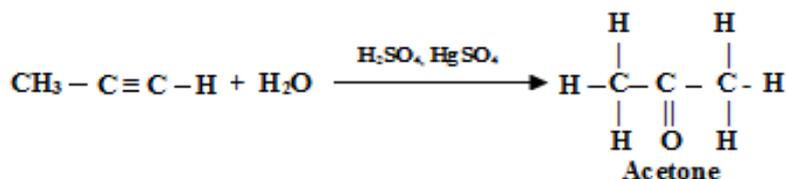
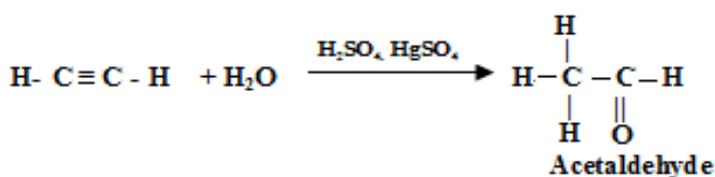
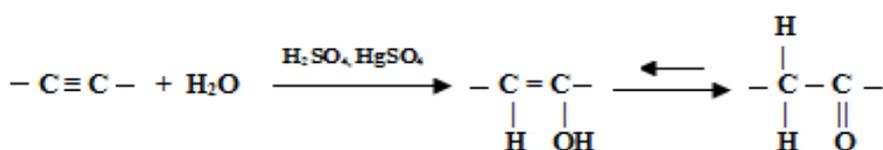
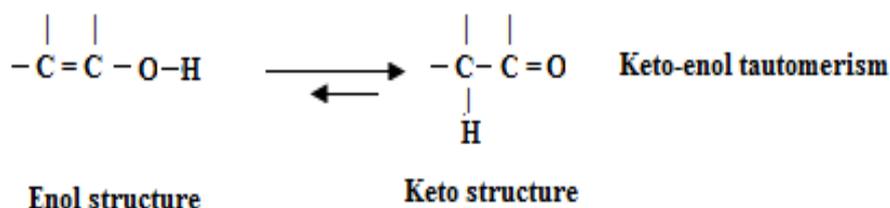
4- Addition of water (hydration)

In the presence of dilute sulphuric acid and a mercury(II) sulphate catalyst at about 60°C, water adds across a triple bond and alkyne is said to be hydrated.

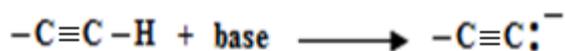


If hydration of acetylene followed the same pattern as hydration of alkenes, we would expect addition of H- and -OH to the triple bond to yield *vinyl alcohol*. But all attempts to prepare vinyl alcohol result, like hydration of acetylene, in the formation of acetaldehyde.

A structure with -OH attached to doubly bonded carbon is called **enol** (-ene for the carbon-carbon double bond, -ol for *alcohol*). It is almost always true that when we try to make a compound with the enol structure, we obtain instead a compound with **ketostructure** (one that contains a C=O group). There is an equilibrium between the two structures, but it generally lies very much in favor of the keto form.

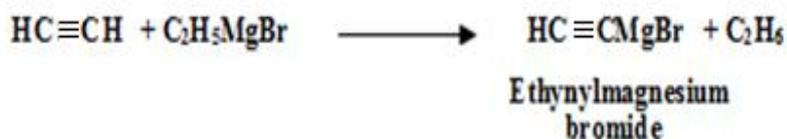
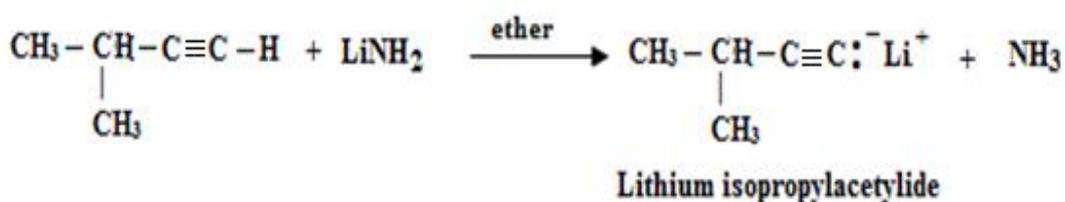


(Reaction as Acid)



Formation of metal acetylides

Hydrogen attached to triply bonded carbon, as in acetylene or any alkyne with the triple bond at the end of the chain ($\text{RC}\equiv\text{C}-\text{H}$), shows appreciable acidity. So when a terminal triple bond is treated with an alkylmagnesium halide or an alkyllithium, the alkane is displaced from its salt, and the metal acetylide is obtained.



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Chapter 7

Stereochemistry

Stereochemistry I

7.1 Stereochemistry and Stereoisomerism

The science of organic chemistry is based on the relationship between molecular structure and properties. That part of the science which deals with structure *in three dimensions* is called **stereochemistry** (Gr.: stereos, solid).

One aspect of stereochemistry is stereoisomerism. Isomers are different compounds that have the same molecular formula. The particular kind of isomers that are different from each other only in the way the atoms are oriented in space (but are like one another with respect to which atoms are joined to which other atoms) are called stereoisomers.

Pairs of stereoisomers, despite their close similarity, one isomer of such a pair may serve as a nourishing food, or as an antibiotic, or as a powerful heart stimulant, and the other isomer may be useless.

7.2 Optical Activity

There are an infinite number of planes passing through the line of propagation, and ordinary light is vibrating in all these planes. **Plane-polarized light** is light whose vibrations take place in only one of the possible planes (Figure 7-1). Ordinary light is turned into plane-polarized light by passing it through a lens made of the material known as Polaroid or more traditionally through pieces of calcite (a particular crystalline form of CaCO_3) so arranged as to constitute what is called a *Nicol prism*.

An **optically active substance** is one that rotates the plane of polarized light. When polarized light, vibrating in a certain plane, is passed through an optically active substance, it emerges vibrating in a different plane.

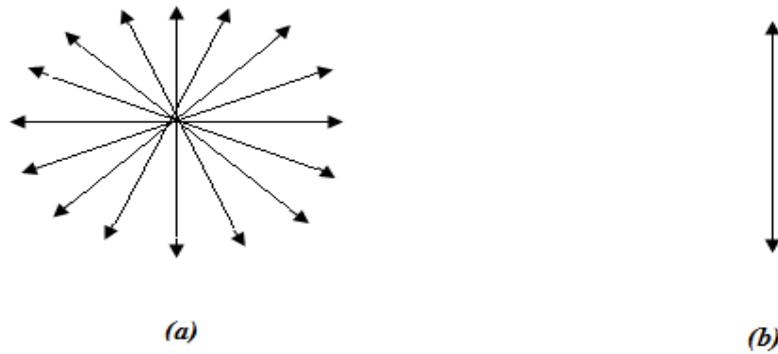


Figure 7-1 Schematic representation of (a) ordinary light and (b) plane polarized light.

The plane-polarized light can be detected and measured by the **polarimeter** (Figure 7-2), which consists of a light source, two lenses (Polaroid or Nicol), and between the lenses a tube to hold the substance that is being examined for optical activity. These are arranged so that the light passes through one of the lenses (*polarizer*), then the tube, then the second lens (*analyzer*), and finally reaches our eye. When the tube is empty, we find that the maximum amount of light reaches our eye when the two lenses are so arranged that they pass light vibrating in the same plane. If we rotate the lens that is nearer our eye, say, we find that the light dims, and reaches a minimum when the lens is at right angle to its previous position.

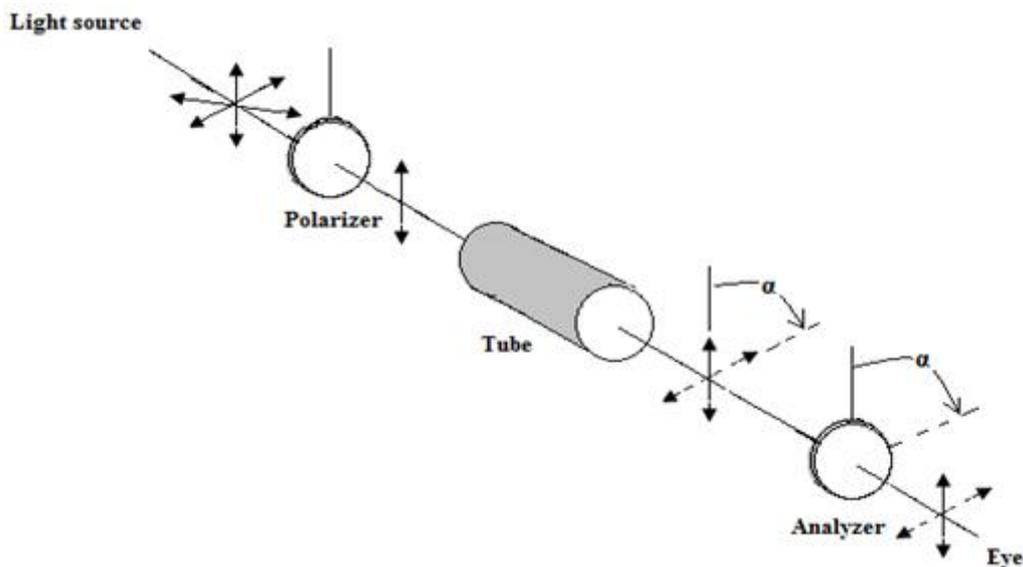


Figure 7-2 Schematic representation of a polarimeter. Solid lines: before rotation. Broken lines: after rotation. α is the angle of rotation.

Let us adjust the lenses so that a maximum amount of light is allowed to pass. (In practice, it is easier to detect a minimum than a maximum; the principle remains the same). Now let us place the sample to be tested in the tube. If the substance does not affect the plane of polarization, light transmission is still at a maximum and the substance is said to be **optically inactive**, if, on the other hand, the substance rotates the plane of polarization, then the lens nearer our eye must be rotated to conform with this new plane if light transmission is again to be a maximum, and the substance is said to be **optically active**. If the rotation of the plane, and hence our rotation of the lens, is to be right (clockwise), the substance is **dextrorotatory** (Latin: dexter, right); if the rotation is to the left (counterclockwise), the substance is **levorotatory** (Latin: laevus, left).

We can determine not only that the substance has rotated the plane, and in which direction, but also *by how much*. The amount of rotation is simply the number of degrees that we must rotate the lens to confirm with the light. The symbols + and – are used to indicate rotations to the right and to the left, respectively.

7.3 Specific Rotation

The amount of rotation depends upon how many molecules the light encounters in passing through the tube. The light will encounter twice as many molecules in a tube 20 cm long as in a tube 10 cm long, and the rotation will be twice as large. If the active compound is in solution, the number of molecules encountered by the light will depend upon the concentration. For a given tube length, light will encounter twice as many molecules in a solution of 2 g per 100 cc of solvent as in a solution containing 1 g per 100 cc of solvent, and the rotation will be twice as large. When allowances are made for the length of tube and the concentration, it is found that the amount of rotation, as well as its direction, is a characteristic of each individual optically active compound.

Specific rotation is the number of degrees of rotation observed if a 1-decimeter tube is used, and the compound being examined is present to the extent of 1 g/cc. This

is usually calculated from observation with tubes of other lengths and at different concentrations by means of the equation:

$$[\alpha] = \frac{\alpha}{l \times d}$$

$$\text{specific rotation} = \frac{\text{observed rotation (degrees)}}{\text{length (dm)} \times \text{g/cc}}$$

where d represents density for a pure liquid or concentration for solution.

The specific rotation is as much a property of a compound as its melting point, boiling point, density, or refractive index. Thus the specific rotation of the 2-methyl-1-butanol obtained from fusel oil is:

$$[\alpha]_D^{20} = -5.756^\circ$$

Here 20 is the temperature and D is the wavelength of the light used in the measurement (D line of sodium, 5893 Å).

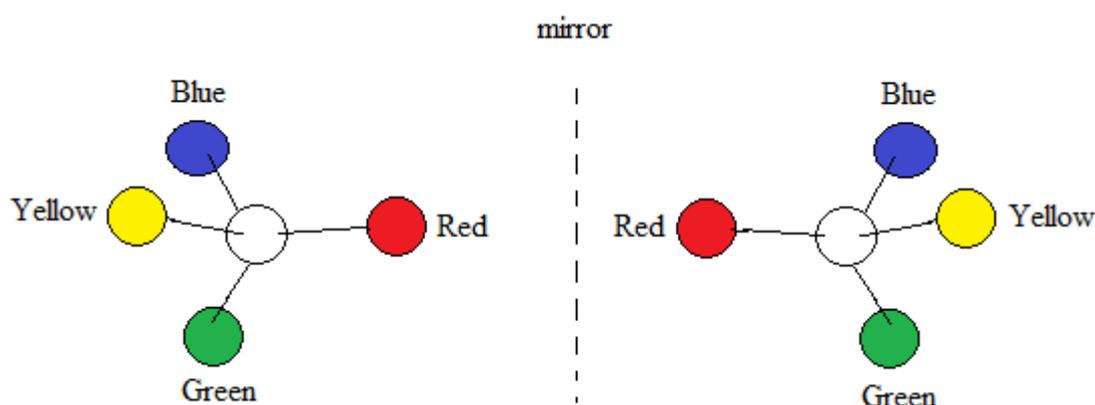
7.5 Enantiomerism

Louis Pasteur found that optically active sodium ammonium tartrate existed as a mixture of two different kinds of crystals, which were *mirror images* of each other. Using a hand lens and a pair of tweezers, he carefully and laboriously separated the mixture into two tiny piles, one of right-handed crystals and the other of left-handed crystals. Now, although the original mixture was optically inactive, each set of crystals dissolved in water was found to be *optically active*. Furthermore, the specific rotations of the two solutions were exactly *equal, but of opposite sign*; that is to say, one solution rotated plane-polarized light to the right, and the other solution an equal number of degrees to the left. In all other properties the two substances were identical.

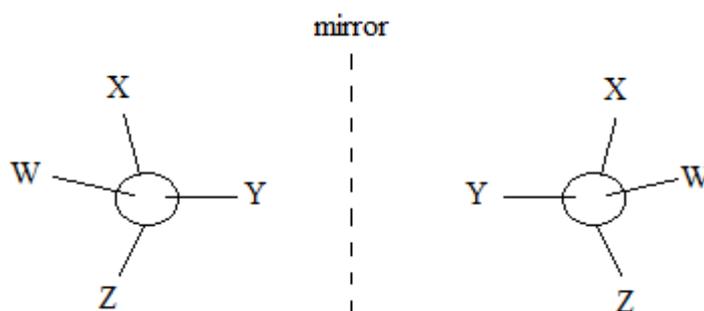
Since the difference in optical rotation was observed *in solution*, it is characteristic, not of the crystals, but of the *molecules*. Like the two sets of crystals

themselves, the molecules making up the crystals were *mirror images of each other*. There are two isomers whose structures differ only in being mirror images of each other, and whose properties differ only in the direction of rotation of polarized light.

Starting with the actual, tetrahedral arrangement for methane, let us make a model of a compound CWXYZ, using a ball of a different color for each different atom or group represented as W, X, Y, and Z. Let us then imagine that we are holding this model before a mirror, and construct a second model of what its mirror image would look like. We now have two models which look something like this:



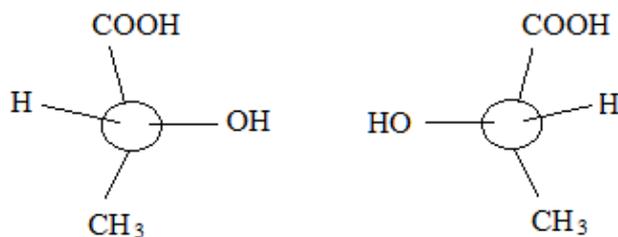
which are understood to stand for this:



Not superimposed: isomers

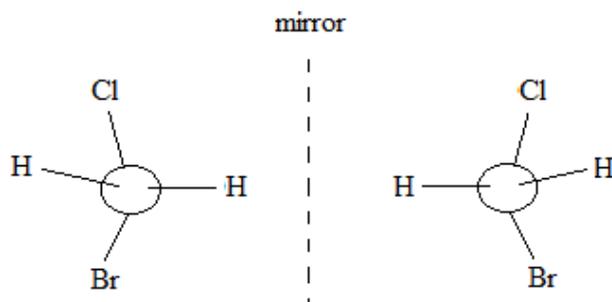
Are these two models superimposed? *No*. We may twist and turn them as much as we please (so long as no bonds are broken), but although two groups of each may coincide, the other two do not. The models are not superimposable, and therefore must represent two isomers of formula CWXYZ.

As predicted, mirror-image isomers do indeed exist, and thousands of instances besides the tartaric acids are known. There are, for example, two isomeric lactic acids:



Lactic acid

Most molecules, however, are superimposed on their mirror images, as, for example, bromochloromethane, and do not show this mirror-image isomer.



Bromochloromethane

Superimposed: no isomerism

Mirror-image isomers are called *enantiomers*. Since they differ from one another only in the way the atoms are oriented in space, enantiomers belong to the general class called *stereoisomers*.

Stereoisomers that are not mirror images of each other called *diastereomers*. Any two stereoisomers are thus classified either as *enantiomers* or as *diastereomers*, depending upon whether or not they are mirror images of each other.

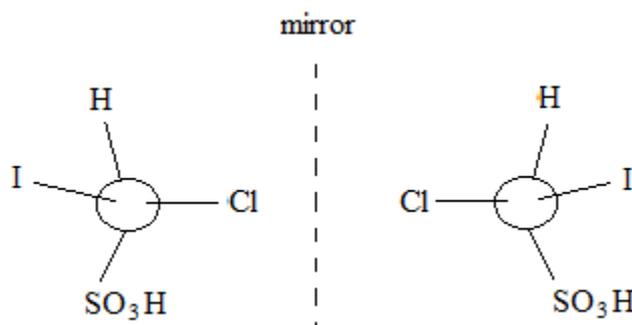
7.6 Chirality

*Molecules that are not superimposable on their mirror images are **chiral**.*

Chirality is the necessary and sufficient condition for the existence of enantiomers. That is to say: *a compound whose molecules are chiral can exist as enantiomers; a*

compound whose molecules are achiral (without chirality) cannot exist as enantiomers.

Some compounds are not superimposable on their mirror images, like these:

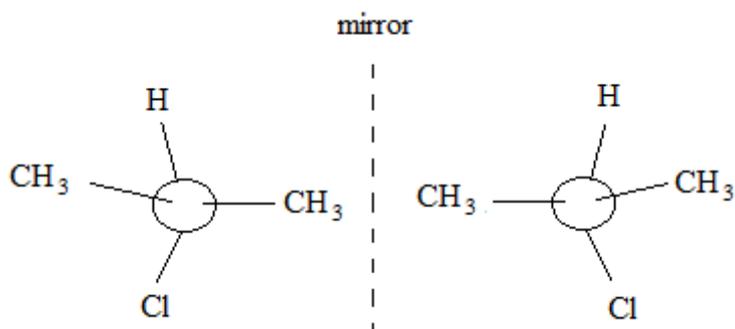


Chloriodomethanesulfonic acid

Not superimposable: enantiomers

These molecules are chiral, and we know that chloriodomethanesulfonic acid can exist as enantiomers, which have the structures we have just made or drawn.

Others, we find, are superimposable, like these:



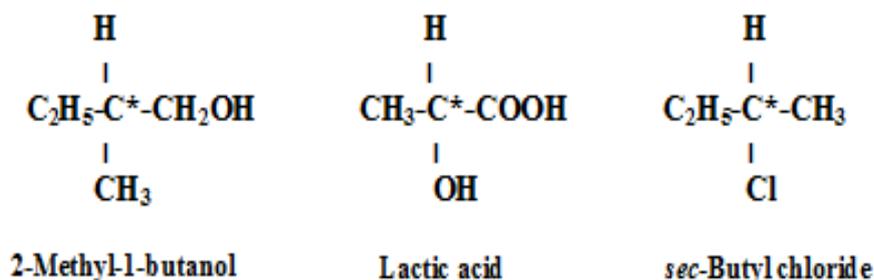
Isopropyl chloride

Superimposable: no enantiomers

These molecules are achiral, and so we know that isopropyl chloride cannot exist as enantiomers.

7.7 The Chiral Center

So far, all the chiral molecules we have talked about happen to be of the kind CWXYZ; that is, in each molecule there is a carbon (C^*) that holds four different groups.



A carbon atom to which four different groups are attached is a **chiral center**.

Many, *but not all*, molecules that contain a chiral center are chiral. Many, *but not all*, chiral molecules contain a chiral center. There are molecules that contain chiral centers and yet are achiral. There are chiral molecules that contain no chiral center. The chiral center is located where the lines cross. Chemists have agreed that such a diagram stands for a particular structure: *the horizontal lines represent bonds coming toward us out of the plane of the paper, whereas the vertical lines represent bonds going away from us behind the plane of the paper.*

7.8 The Racemic Modification

A mixture of equal parts of enantiomers is called a **racemic modification**. A racemic modification is optically inactive: when enantiomers are mixed together, the rotation caused by a molecule of one isomer is exactly canceled by an equal and opposite rotation caused by a molecule of its enantiomer.

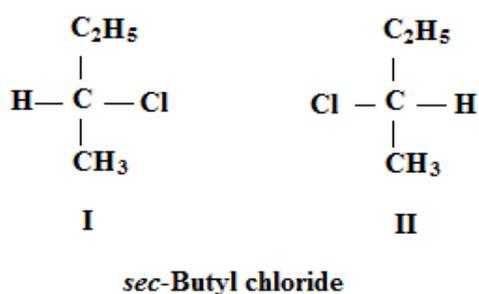
The prefix \pm is used to specify the racemic nature of the particular sample, as, for example, (\pm) -lactic acid or (\pm) -2-methyl-1-butanol.

It is useful to compare a racemic modification with a compound whose molecules are superimposable on their mirror images, that is, with an achiral compound. They are both optically inactive, and for exactly the same reason. Because of the random distribution of the large number of molecules, for every molecule that the light encounters there is a second molecule, a mirror image of the first, aligned just right to cancel the effect of the first one. In a racemic modification this second molecule happens to be an isomer of the first; for an achiral compound it is not isomer, but another, identical molecule.

7.9 Configuration

The arrangement of atoms that characterizes a particular stereoisomers is called its **configuration**.

Using the test of superimposability, we conclude, for example, that there are two stereoisomers *sec*-butyl chloride; their *configurations* are I and II.



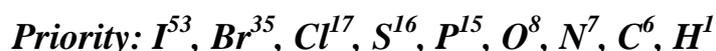
Compound I rotates the plane of polarized light to the right, and the other to the left.

7.10 Specification of Configuration: *R* and *S*

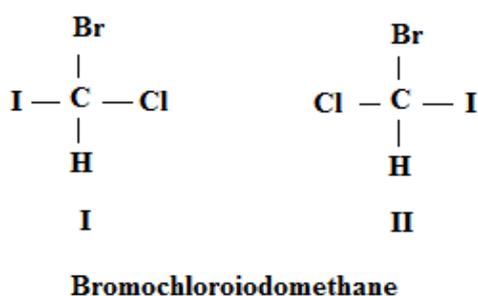
Now, a further problem arises. How can we specify a particular configuration in some simpler, more convenient way than always having to draw its picture?

Step 1. Following a set of *sequence rule*, we assign a sequence of priority to the four atoms or group of atoms attached to the chiral center.

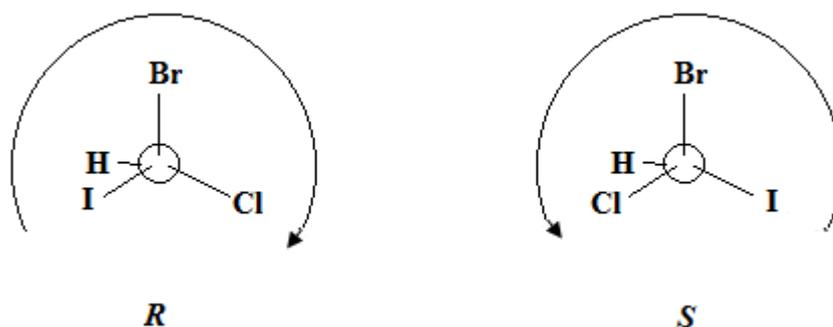
In the case of CHClBrI, for example, the four atoms attached to the chiral center are all different and priority depends on atomic number, the atom of higher number having higher priority:



Thus, in our example, the priority is I, Br, Cl, H.



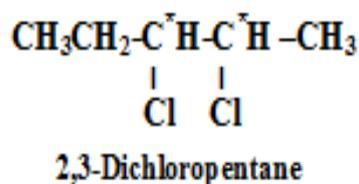
Step 2. We visualize the molecule oriented so that the ligand of lowest priority is directed away from us, and observe the arrangement of the remaining ligands. If, in proceeding from the ligand of highest priority to the ligand of second priority and thence to the third, our eye travels in a clockwise direction, the configuration is *R* (Latin: *rectus*, right); if counterclockwise, the configuration is *S* (Latin: *sinister*, left).



7.11 Diastereomers

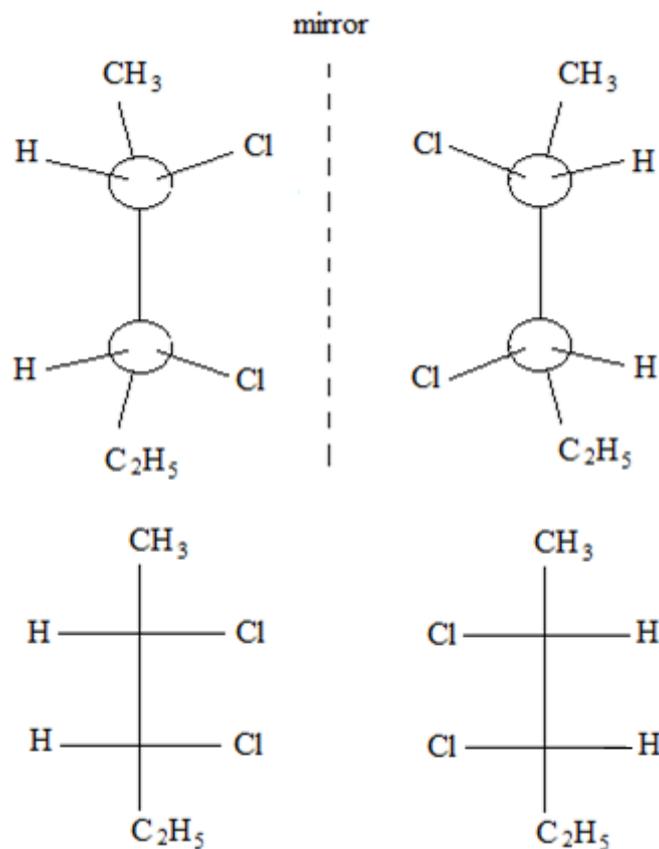
We must learn what stereoisomers are possible for compounds whose molecule contain, not just one, *but more than one chiral center*.

Let us start with 2,3-dichloropentane. This compound contains two chiral centers, C-2 and C-3.



Using models, let us first make structure I and its mirror image II, and see if these are superimposable. We find that I and II are not superimposable, and hence must be enantiomers.

Next, we try to interconvert I and II by rotations about carbon-carbon bonds. We find that they are not interconvertible in this way, and hence each of them is capable of retaining its identity and, if separated from its mirror image, of showing optical activity.



III

IV

Not superimposable

Enantiomers

Diastereomers have similar chemical properties, since they are members of the same family. Their chemical properties are *not identical*, however. In the reaction of two diastereomers with a given reagent, neither the two sets of reactants nor the two transition states are mirror images, and hence, except by sheer coincidence, will not be of equal energies.

Diastereomers have different physical properties, different melting points, boiling points, solubilities in a given solvent, densities, refractive indexes, and so on. Diastereomers differ in specific rotation; they may have the same or opposite signs of rotation, or some may be inactive.

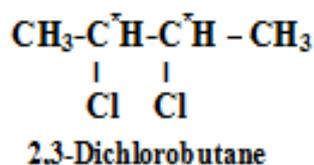
As a result of their differences in boiling point and in solubility, they can, in principle at least, be separated from each other by fractional distillation or fractional

crystallization; as a result of differences in molecular shape and polarity, they differ in adsorption, and can be separated by chromatography.

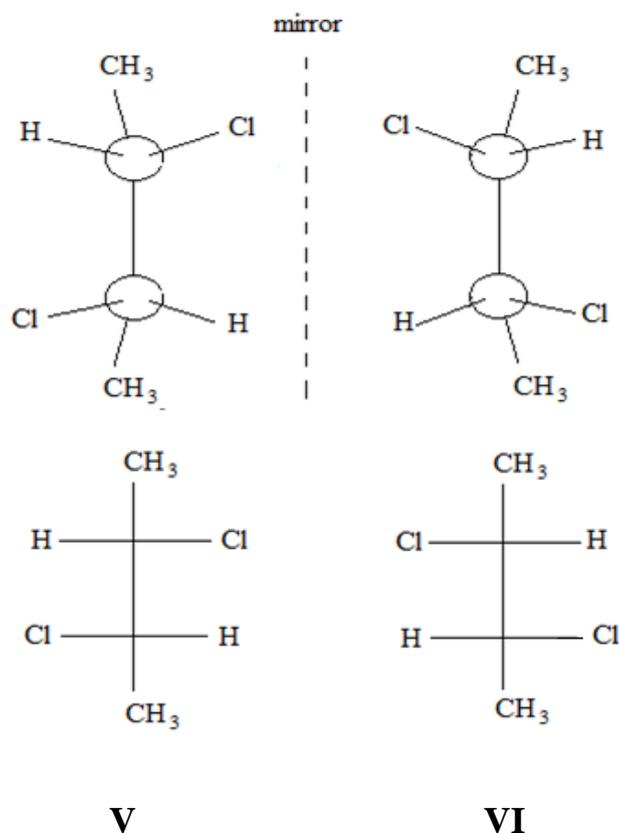
Thus the presence of two chiral centers can lead to the existence of as many as four stereoisomers. The maximum number of stereoisomers that can exist is equal to 2^n , where n is the number of chiral centers.

7.12 Meso structures

Now let us look at 2,3-dichlorobutane, which also has two chiral centers. Does this compound, too, exist in four stereoisomers forms?



Using models as before, we arrive first at the two structures V and VI.

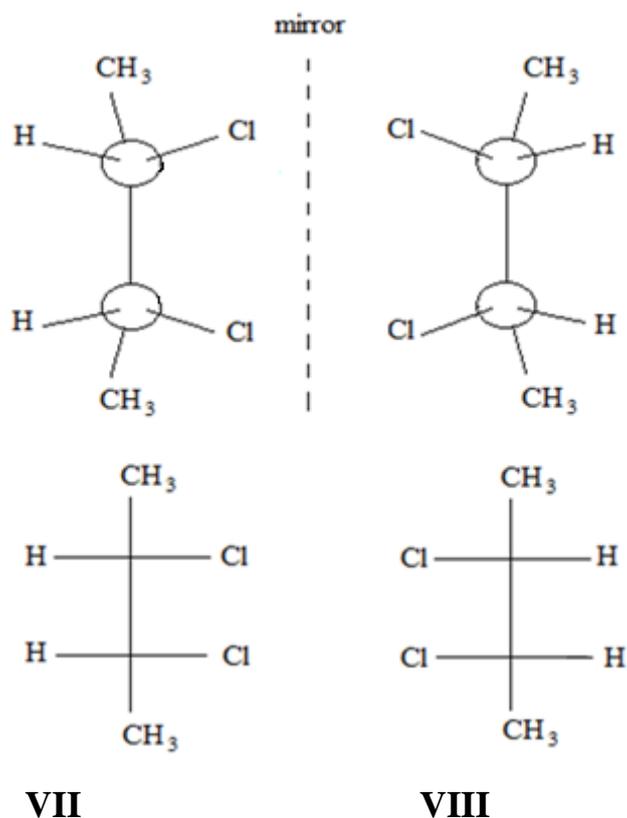


Not superimposable

Enantiomers

These are mirror images that are not superimposable or interconvertible; they are therefore enantiomers, and each should be capable of optical activity.

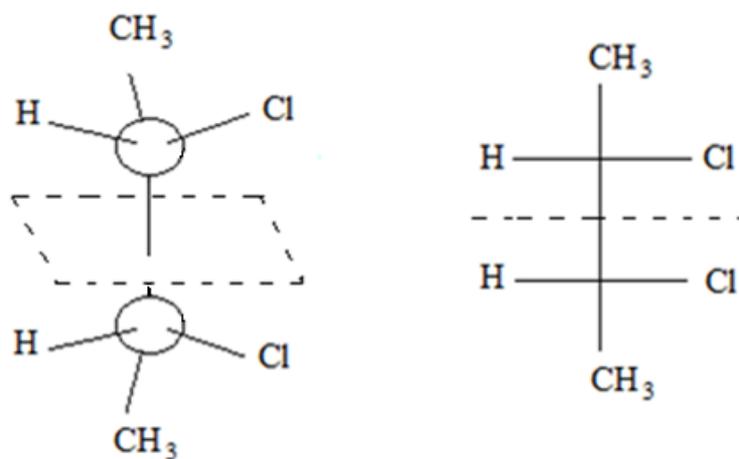
Next, we make VII, which we find to be a diastereomer of V and of VI. We now have three stereoisomers; is there a fourth? No. If we make VIII, the mirror image of VII, we find the two to be superimposable; turned end-for-end, VII coincides in every respect with VIII. In spite of its chiral center, VII is not chiral. It cannot exist in two enantiomeric forms, and it cannot be optically active. It is called a meso compound.



Superimposable
A meso compound

A **meso compound** is one whose molecules are superimposable on their mirror images even though they contain chiral centers. A meso compound is optically inactive for the same reason as any other compound whose molecules are achiral: the rotation caused by any one molecule is cancelled by an equal and opposite rotation caused by another molecule that is the mirror image of the first.

We can often recognize a meso structure on sight by the fact that (in at least one of its conformations) one half of the molecule is the mirror image of the other half. This can be seen for *meso*-2,3-dichlorobutane by imagining the molecule to be cut by a plane lying where the dotted line is drawn. The molecule has a *plane of symmetry*, and cannot be chiral. If we do not see a plane of symmetry, however, this does not necessarily mean that the molecule is chiral.

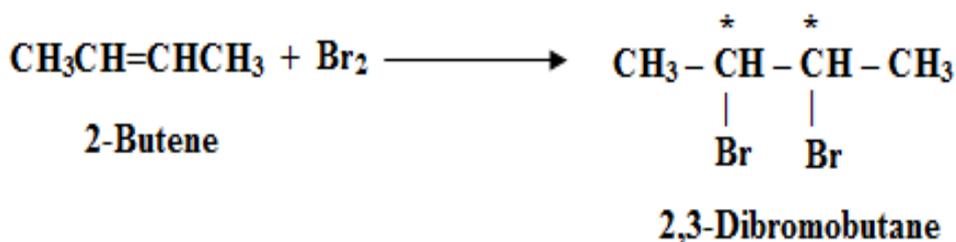


Stereochemistry II

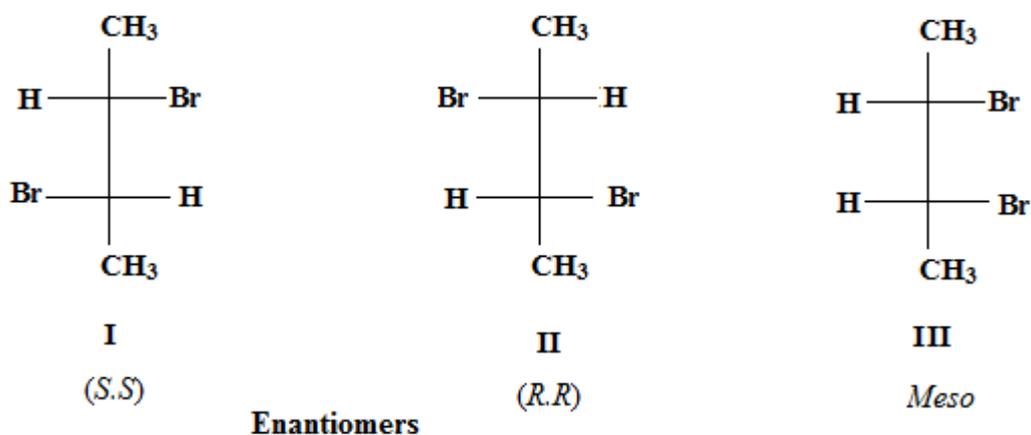
7.13 Stereochemistry of Addition of Halogens to alkenes. *syn*- and *anti*-Addition

Let us begin with the stereochemistry of *addition*, using as our example a familiar reaction: addition of halogens to alkenes.

Addition of bromine to 2-butene yields 2,3-dibromobutane.

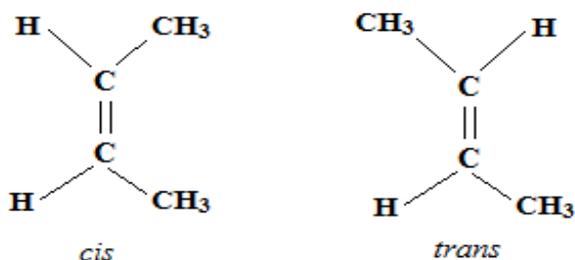


Two chiral centers are generated in the reaction, and the product, can exist as a pair of enantiomers (I and II) and a *meso* compound (III).



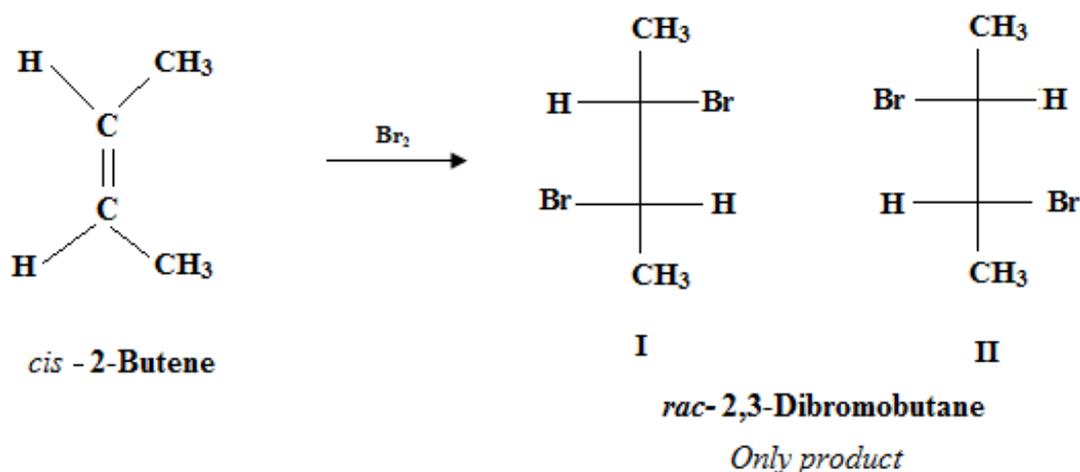
2,3-Dibromobutane

The reactants, too, exist as stereoisomers: a pair of geometric isomers, *cis* and *trans*.



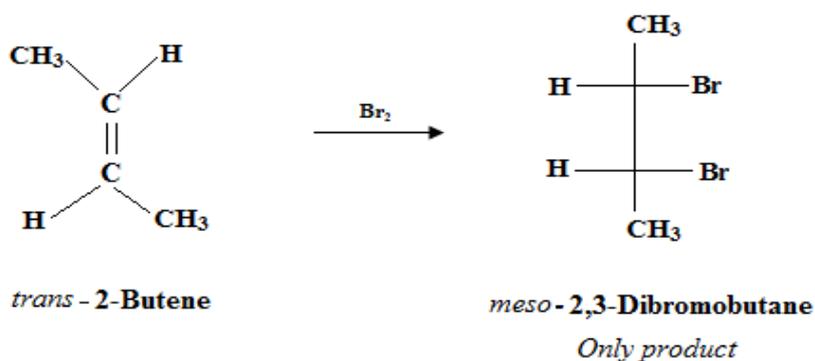
2-Butene

If we start with, say, *cis*-2-butene, we get only racemic 2,3-dibromobutane, I and II.



A reaction that yields predominantly one stereoisomer (or one pair of enantiomers) of several possible diastereomers is called a **stereoselective reaction**.

Now, suppose we start with *trans*-2-butene. Does this, too, yield the racemic dibromide? No. The *trans* alkene yields only *meso*-2,3-dibromobutane.

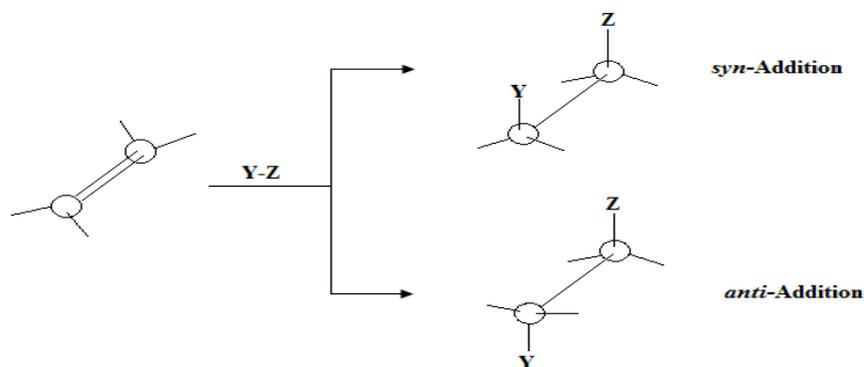


Just which product we obtain depends upon which stereoisomer we start with. A reaction in which stereochemically different molecules react differently is called a **stereospecific reaction**.

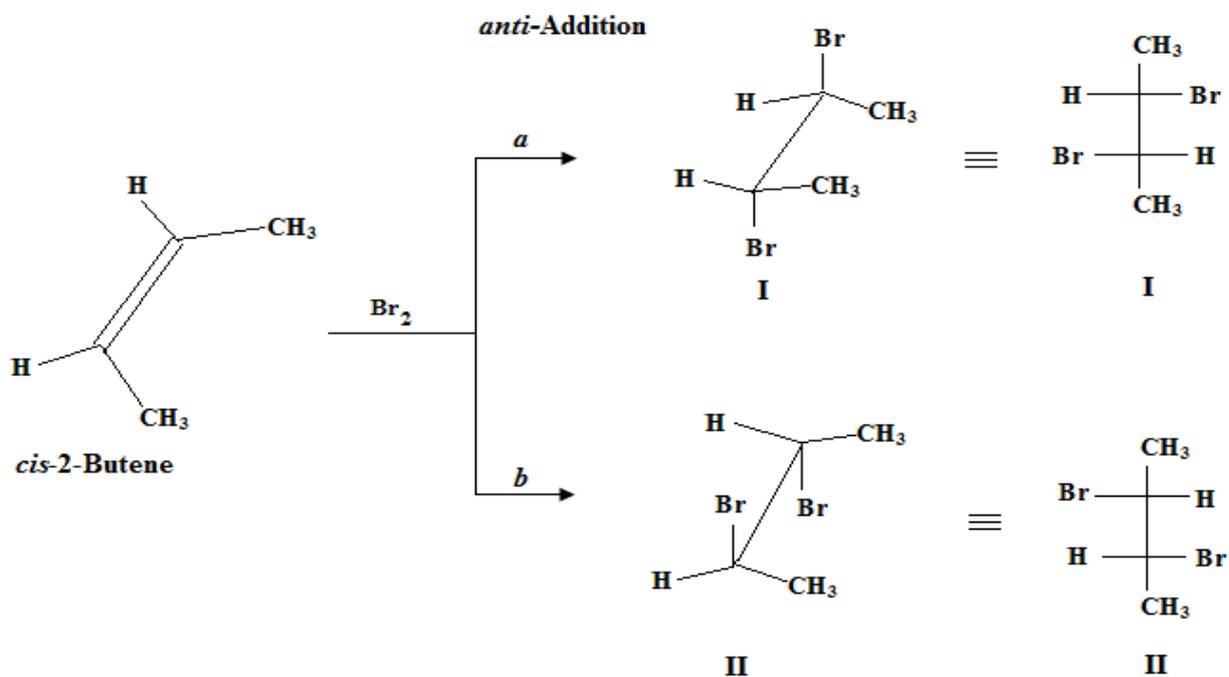
Addition of bromine to alkenes is both stereoselective and stereospecific. We say it is completely stereoselective since, from a given alkene, we obtain only one diastereomer (or one pair of enantiomers). We say it is stereospecific, since stereoisomeric alkenes react differently: they give (stereochemically) different products.

To describe stereospecificity in addition reactions, the concept of *syn*-addition and *anti*-addition are used. These terms indicate the stereochemical fact: that the added

groups become attached to the same face (*syn*) or to opposite face (*anti*) of the double bond.

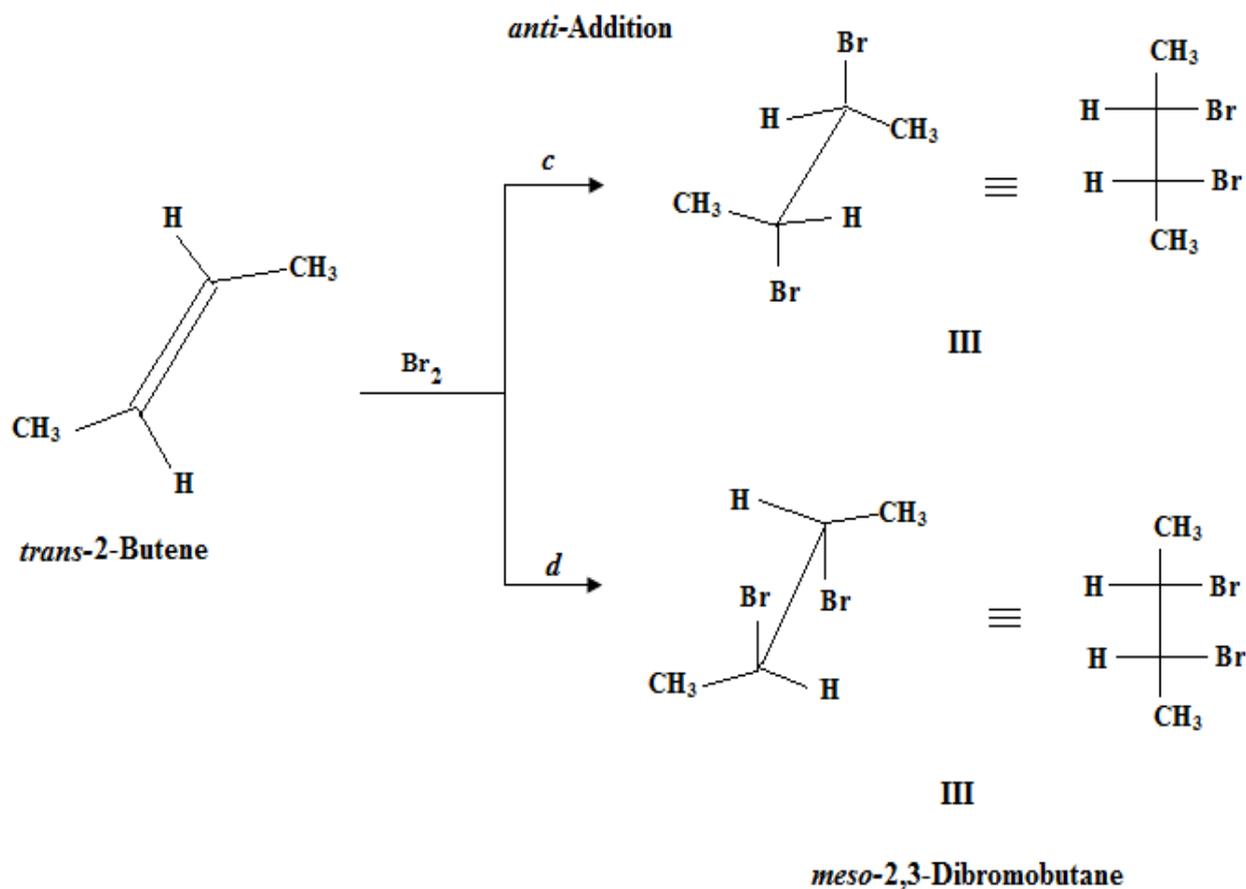


Addition of bromine to the 2-butenes involves *anti*-addition. Let us see that this so. If we start with *cis*-2-butene, we can attach the bromines to opposite faces of the double bond in two different ways. Attachment as in (a) gives enantiomer I; attachment as in (b) gives enantiomer II. Since, whatever the mechanism, (a) and (b) are equally likely, we obtain the racemic modification.



I and II are enantiomers
rac-2,3-Dibromobutane

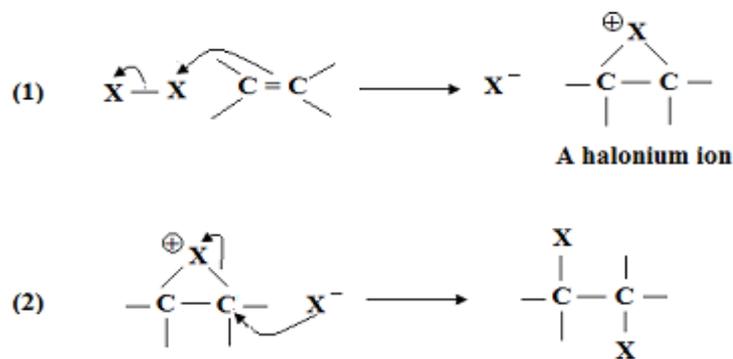
Starting with *trans*-2-butene, we can again attach the bromines to opposite faces of the double bond in two ways: as in (c) or in (d). Whichever way we choose, we obtain III, which we recognize as the *meso* dibromide.



Anti-Addition is the general rule for the reaction of bromine or chlorine with simple alkenes.

7.14 Mechanism of Addition of Halogens to Alkenes

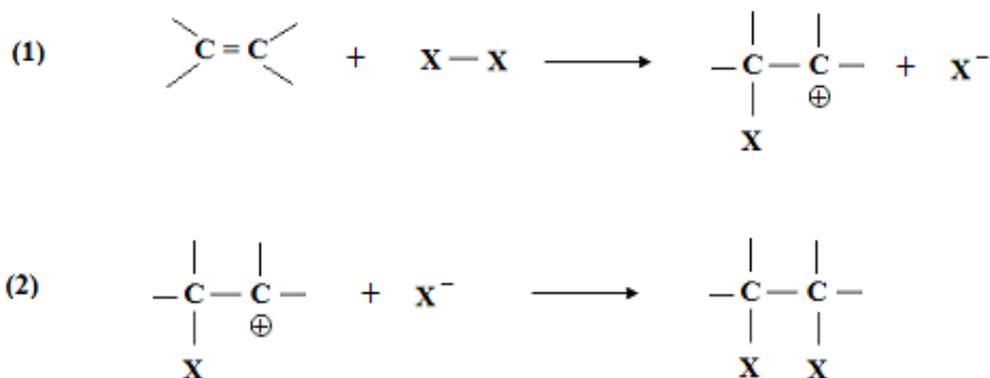
We saw that the addition of halogens to alkenes proceed by two steps. In step (1) a halogen is transferred, without a pair of electrons, from a halogen molecule to the carbon-carbon double bond; there is formed a halide ion and organic cation. In step (2) this cation reacts with a halide ion to yield the addition product.



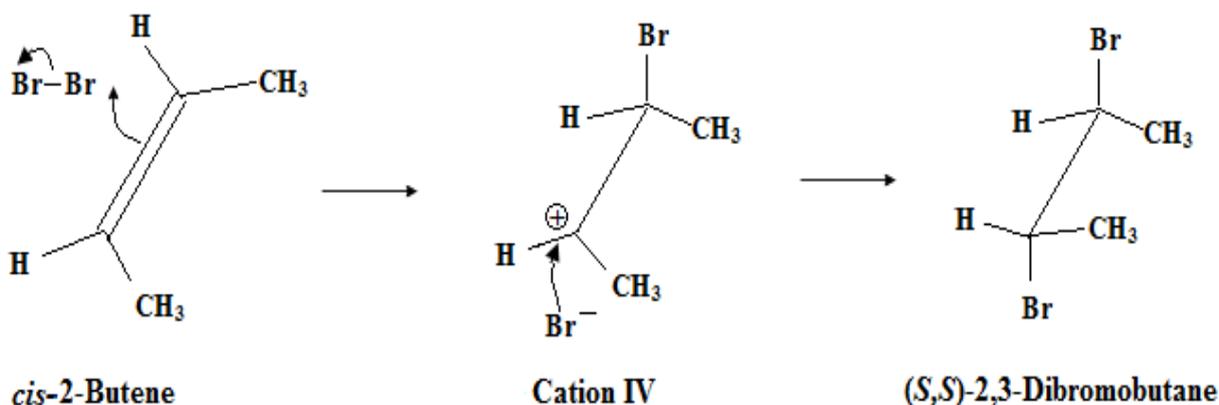
The nature of the intermediate cation that is our chief concern here, it is the halonium ion: a cyclic ion in which halogen is attached to both carbons and carries a positive charge.

Halogen addition with complete stereoselectivity and in the anti sense. What does this stereochemistry tell us about the nature of the intermediate?

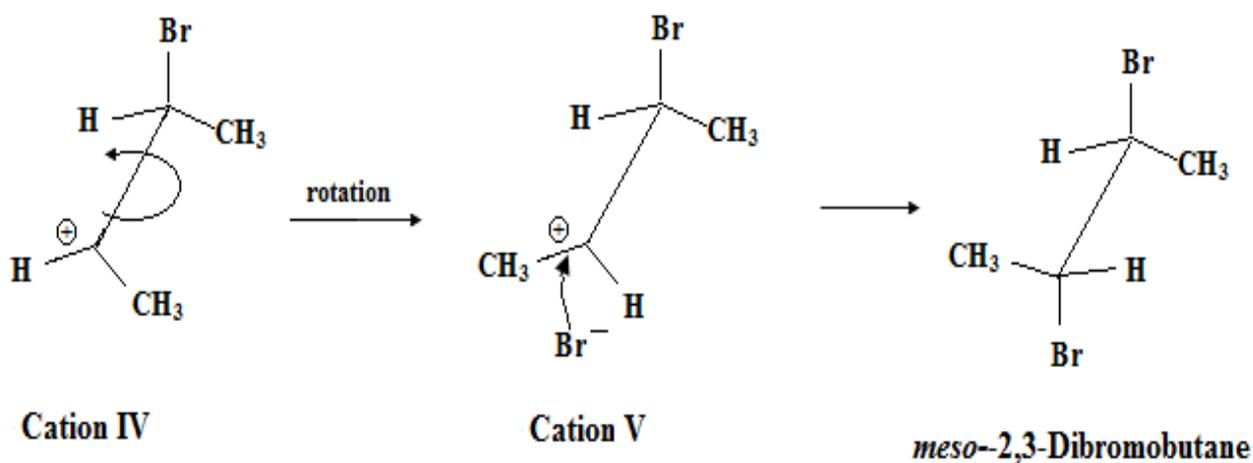
Assume first that reaction proceeds via an open carbocation.



Is the observed stereochemistry consistent with a mechanism involving such an intermediate? Let us use addition of bromine to *cis*-2-butene as an example. A positive bromine ion is transferred to, the top face of the alkene to form carbocation IV. Then, a bromide ion attacks the bottom face of the positively charged carbon to complete the *anti*-addition; attack at this face preferred, we might say, because it permits the two bromines to be as far apart as possible in the transition state. (We obtain the racemic product: the *S,S*-dibromide as shown; the *R,R*-dibromide through attachment of positive bromine to the near end of the alkene molecule).

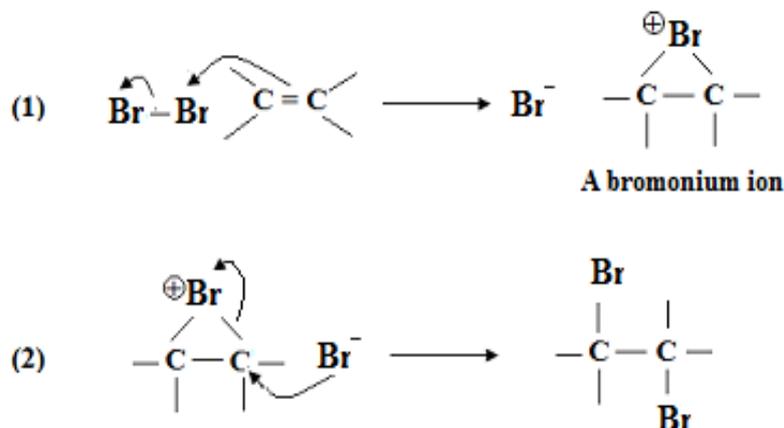


But this picture of the reaction is not satisfactory, and for two reasons. First, to account for the complete stereospecificity of addition, we must assume that attack at the bottom face of the cation is not just preferred, but is the only line of attack: conceivable, but especially in view of other reactions of carbocations not likely. Then, even if we accept this exclusively bottom-side attack, we are faced with a second problem. Rotation about the carbon-carbon bond would convert cation IV into cation V; bottom-side attack on cation V would yield not the racemic dibromide but the *meso* dibromide, in effect *syn*-addition, and contrary to fact.

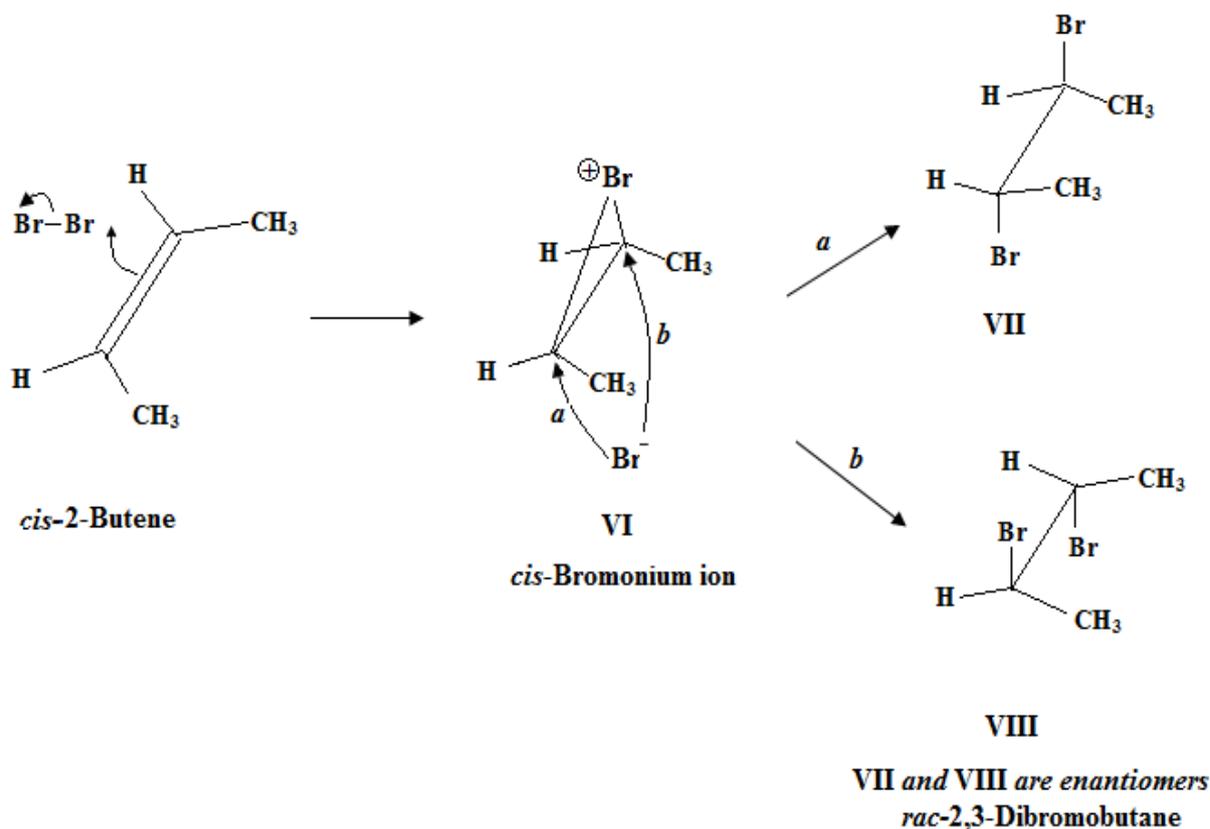


To accommodate the stereochemical facts, then, we would have to make two assumptions about halogen addition: after the carbocation is formed, it is attacked by bromide ion (a) before rotation about the single bond can occur, and (b) exclusively from the face away from the halogen already in the cation. Neither of these assumptions is very likely; together, they make the idea of an open carbocation intermediate hard to accept.

It was to account better for the observed stereochemistry that proposed the bromonium ion mechanism that we have given.



Now, how does the bromonium ion mechanism account for *anti*-addition? Using models, let us first consider addition of bromine to *cis*-2-butene.



In the first step, positive bromine becomes attached to either the top or bottom face of the alkene. Let us see what we get if bromine becomes attached to the top face. When this happens, the carbon atom of the double bond tends to become tetrahedral, and the

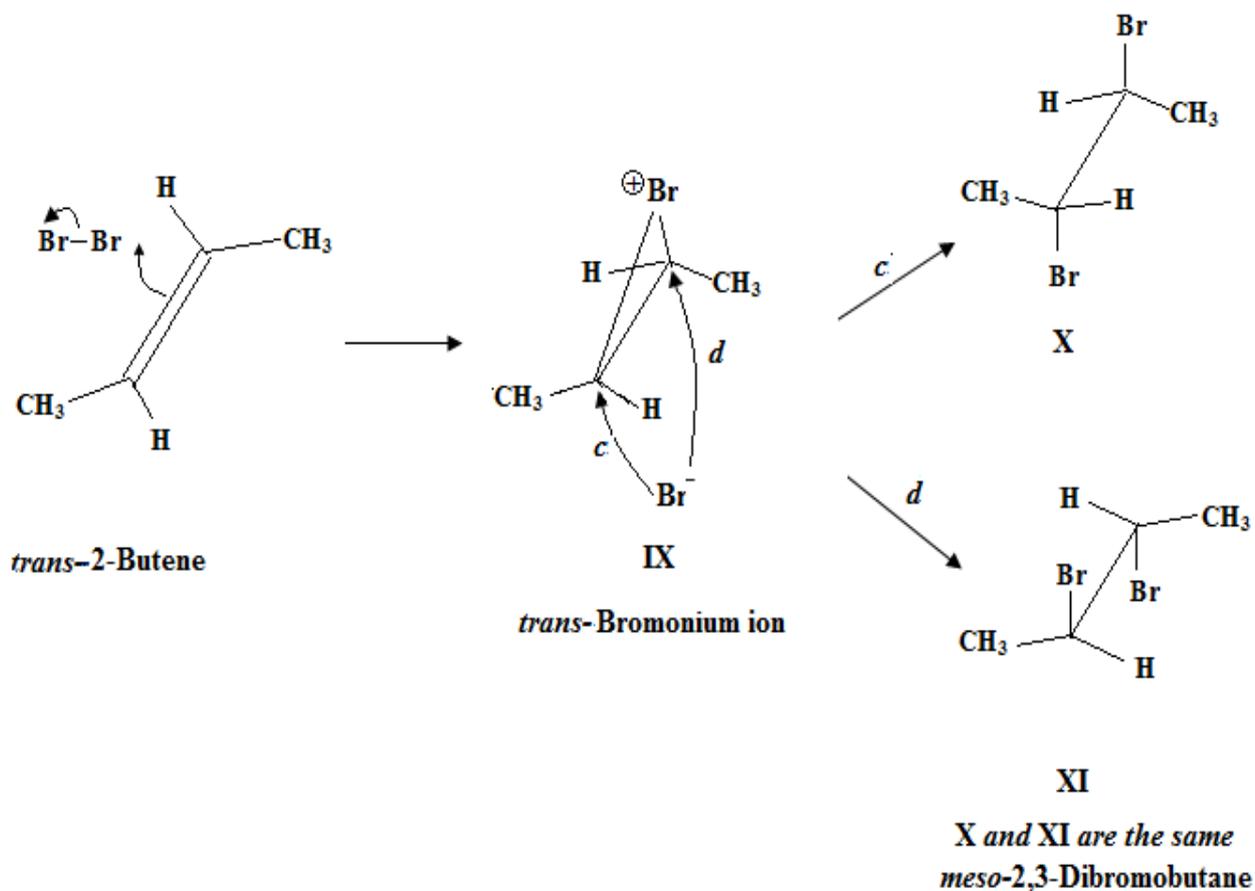
hydrogens and methyls are displaced downward. The methyl groups are still located across from each other, however, as they were in the alkene. In this way, bromonium ion VI is formed.

Now bromonium ion VI is attacked by bromide ion. A new carbon-bromine bond is formed, and an old carbon-bromine bond is broken. This is a familiar reaction, nucleophilic substitution; bromide ion is the nucleophile, and the positive bromine is the leaving group. As we might expect, then, attack by bromide ion is from the back side; on the bottom face of VI, so that the bond being formed is on the opposite side of carbon from the bond being broken. There is inversion of configuration about the carbon being attacked.

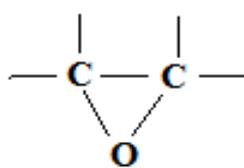
Attack on VI can occur by path (a) to yield structure VII or by path (b) to yield structure VIII. We recognize VII and VIII as enantiomers. Since attack by either (a) or (b) is equally likely, the enantiomers are formed in equal amounts, and thus we obtain the racemic modification. The same results are obtained if positive bromine initially becomes attached to the bottom face of *cis*-2-butene.

Now, let us carry through the same operation on *trans*-2-butene. This time, bromonium ion IX is formed. Attack on it by path (c) yields X; attack by (d) yields XI. If we simply rotate either X or XI about the carbon-carbon bond, we readily recognize the symmetry of the compound. It is *meso*-2,3-dibromobutane; X and XI are identical. The same results are obtained if positive bromine is initially attached to the bottom face of *trans*-2-butene.

The concept of a halonium ion solves both of the problems associated with an open carbocation: a halogen bridge prevents rotation about the carbon-carbon bond, and at the same time restricts attack by bromide ion exclusively to the opposite face of the intermediate. The stereochemistry of halogen addition thus not only gives powerful support for a two-step mechanism, but it shows, in a way no other evidence could, just what those two steps almost certainly are.



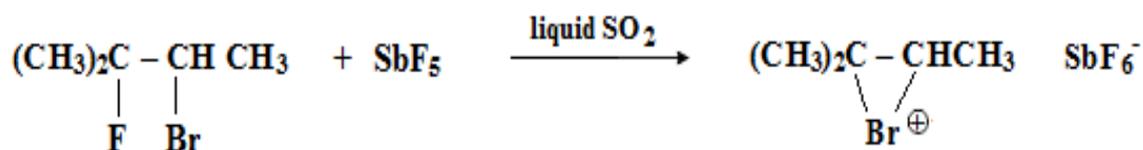
That such cyclic intermediates can give rise to *anti*-addition is demonstrated by hydroxylation with peroxy acids: there, analogous intermediates, perfectly respectable compounds called epoxides, can be isolated and studied.



An epoxide

Cyclic halonium ions were first proposed, then, simply as the most reasonable explanation for the observed stereochemistry. Since that time, however, more direct evidence has been discovered.

Olah prepared cations whose NMR spectra indicate that they are indeed cyclic halonium ions.



7.15 Stereochemistry of the E2 Reaction. Syn- and Anti-Elimination

Let us look at the stereochemistry of elimination, using as our example another familiar reaction: dehydrohalogenation under E2 conditions.

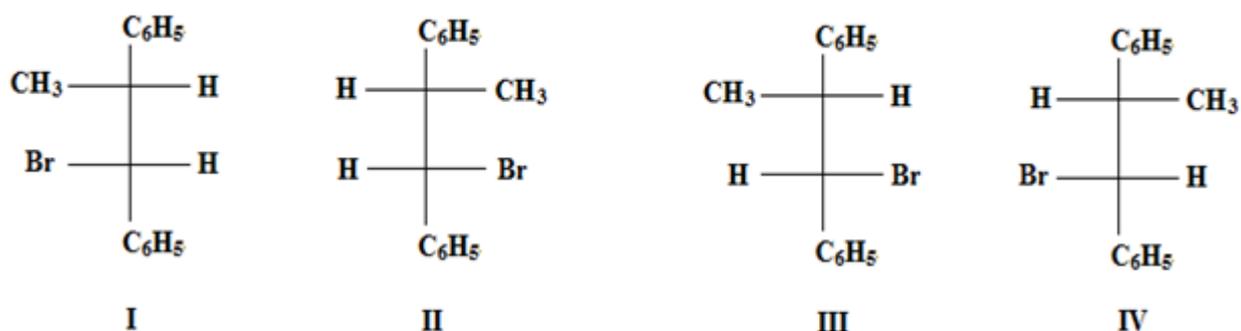
Consider dehydrohalogenation of the alkyl halide 1-bromo-1,2-diphenylpropane. (Phenyl, - C₆H₅, is an aromatic hydrocarbon group that is inert under these reaction conditions).



1,2-Diphenylpropene

1-Bromo-1,2-diphenylpropane

This compound contains two chiral centers, and we can easily show that it can exist as two pairs of enantiomers: I and II, called *erythro*; and III and IV, called *threo*. Each pair is diastereomeric with the other pair.

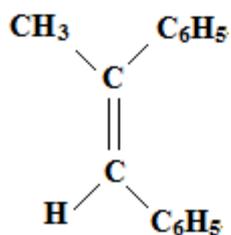


Erythro

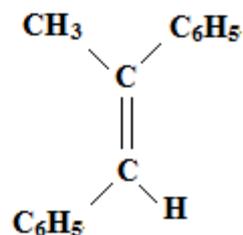
Threo

1-Bromo-1,2-diphenylpropane

The product, too, exists as stereoisomers: a pair of geometric isomers, *Z* and *E*.



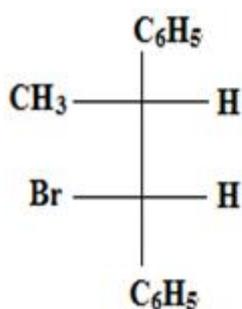
(Z)



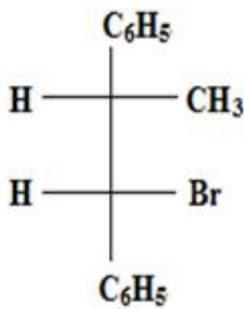
(E)

1,2-Diphenyl-1-propene

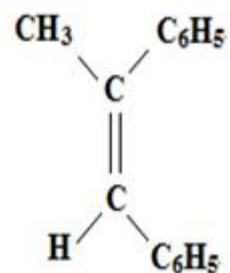
Now, if we start with the *erythro* halide, I and II, we obtain only the Z alkene.



I



II

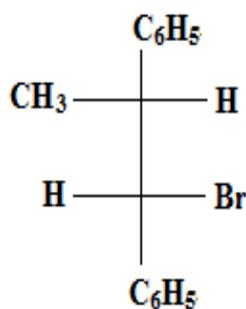


(Z)-1,2-Diphenyl-1-propene

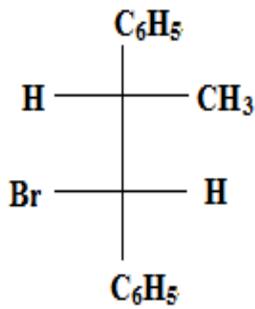
Erythro

1-Bromo-1,2-diphenylpropane

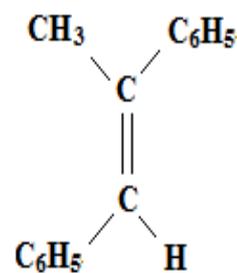
If we start with the *threo* halide, III and IV, we obtain only the E alkene.



III



IV



(E)-1,2-Diphenyl-1-propene

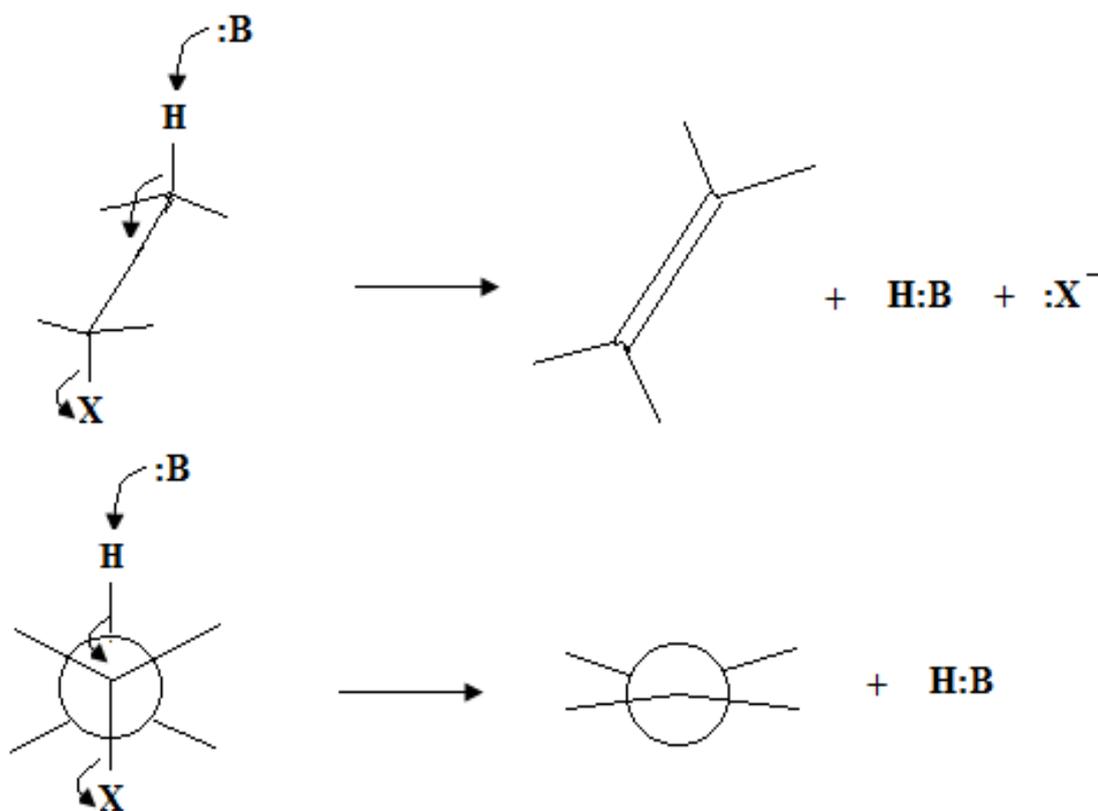
Threo

1-Bromo-1,2-diphenylpropane

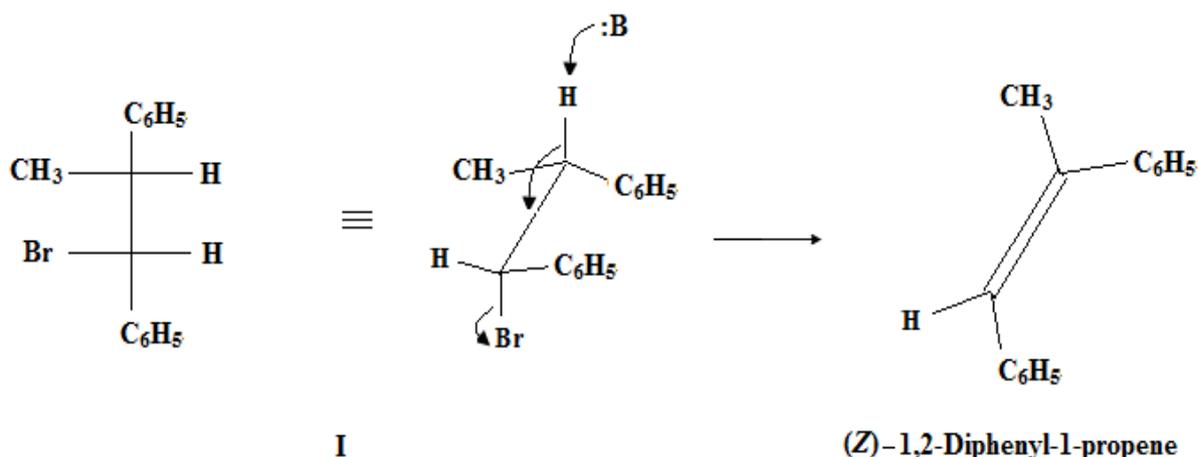
Other studies have shown that these results are typical: *E2 elimination is both stereoselective and stereospecific.*

To describe the kinds of stereoselectivity that may be observed in elimination reactions, the concept of *syn-elimination* and *anti-elimination* are used. These terms are not the names of specific mechanisms. They simply indicate the stereochemical facts: that the eliminated groups are lost from the same face (*syn*) or opposite face (*anti*) of the developing double bond.

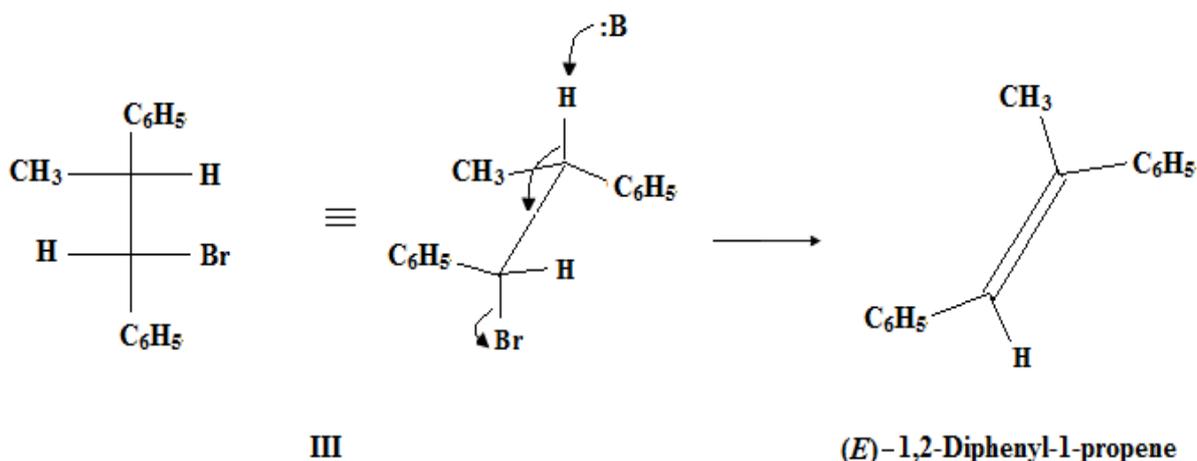
As this example and many others show, E2 elimination typically involves *anti-elimination*: in the transition state the hydrogen and the leaving group are located in the *anti* relationship as contrasted to *gauche* or *eclipsed*.



Thus, diastereomer I (or its enantiomer, II) gives the *Z* alkene:



and diastereomer III (or its enantiomer, IV) gives the *E* alkene:



7.16 Stereospecific Reactions

We have defined a stereospecific reaction as one in which stereochemically different molecules react differently. Let us look more closely at what is meant by this definition.

By "stereochemically different molecules" is meant stereoisomers: enantiomers or diastereomers. To "react differently" means to show any difference whatsoever in chemical behavior. In a stereospecific reaction, stereoisomers can:

- (a) yield different stereoisomers as product;
- (b) react at different rates, in some cases to such an extent that, while one stereoisomer reacts readily, the other does not react at all;

- (c) react by different paths to yield quite different kinds of compounds as products.

Stereospecificity toward enantiomers is called **enantiospecificity**. In reactions with achiral reagents, enantiomers can show only difference (a): they can yield different stereoisomers as products, as in the S_N2 reaction, but in all other respects they must react identically, at identical rates to yield products that are identical except for their stereochemistry.

On the other hand, in reaction with optically active reagents, or in a chiral medium of any sort, enantiomers may show all the differences in behavior that we have listed. We have already encountered enantiospecificity in the resolution of racemic modifications by use of optically active reagents. There, they yielded stereochemistry different products, not enantiomers, as in the S_N2 reaction, but diastereomers.

Biological systems generally discriminate sharply between stereoisomers. The organism responds to only one enantiomer of a pair, or responds differently to the two; only one is metabolized, or serves as a hormone or drug, tastes sweet, and so on. Now, biological activity, in the final analysis, depends upon chemical reactions in the organism, in this case, reactions with one enantiomer or the other. The discrimination is the result of virtually complete enantiospecificity in these reactions. Such enantiospecificity is the rule for the countless reactions taking place in the chiral medium provided by the optically active enzymes of living organisms.

Stereospecificity toward diastereomers is called **diastereospecificity**. Diastereomers can differ in all the ways that we have listed above, whether the reagent is optically active or inactive. A difference in rate of reaction is the rule for diastereomers; in this respect at least, diastereomers will always react stereospecifically, although often to only a modest degree.

7.17 Stereoselectivity vs. Stereospecificity

Many reactions are, like the addition of bromine, both stereoselective and stereospecific. But this is not always true. Some reactions are stereoselective but not

stereospecific: one particular stereoisomer is the predominant product regardless of the stereochemistry of the reactant, or regardless of whether the reactant even exists as stereoisomers.

Some reactions are stereospecific but not stereoselective. Stereoisomers may react at widely different rates, but yield the same stereoisomers as the product, or yield products that differ in ways other than in their stereochemistry. Sometimes one stereoisomer reacts readily, and another does not react at all, as in the biological reactions.

The quality of **stereoselectivity** is focused on the **reactants** and their stereochemistry; it is concerned with the products, too, but only as they provide evidence of a difference in behavior between reactants. Of stereoisomeric reactants, each behaves in its own specific way.

The stereospecificity of biological reactants has given a powerful impetus to the development of synthetic methods that are highly stereoselective. In synthesizing a drug, for example or a hormone, a chemist wants to use (stereoselective) reactions that produce just the correct stereoisomer, since only that stereoisomer will show (stereospecific) activity in a biological system.

Organic Chemistry I

College of Pharmacy - University of Anbar / First Year 2017 - 2018

Dr. Jasim. H. Hassen

Chapter 8

Alcohols

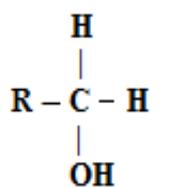
8.1 Introduction

All alcohols contain the hydroxyl group (-OH) attached to a saturated carbon. These have the general formula **R-OH**, where **R** is an alkyl or substituted alkyl group. The group may be primary, secondary, or tertiary; it may be open chain or cyclic; it may contain a double bond, a halogen atom, an aromatic ring, or additional hydroxyl group. The -OH group is the functional group, determines the properties characteristic of this family. Variations in structure of the **R** group may affect the rate at which the alcohol undergoes certain reactions, and even, in a few cases, may affect the kind of reaction.

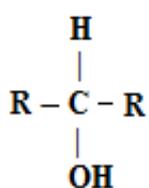
Compound in which the hydroxyl group is attached directly to an aromatic ring are not alcohols; they are phenols.

8.2 Classification of alcohols

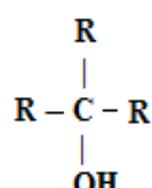
Alcohols other than methanol, are classified as, primary, secondary, or tertiary, depending on the number of carbons bonded to the carbon atom bearing the -OH group. If one carbon is bonded to this carbon atom, the alcohol is primary, if two carbons are bonded, it is secondary, and if three carbons are bonded, it is tertiary.



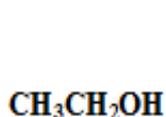
Primary (1°)



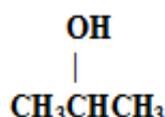
Secondary (2°)



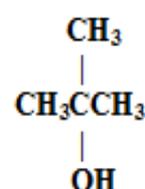
Tertiary (3°)



Ethanol (1°)



2-Propanol (2°)



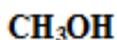
2-Methyl-2-propanol (3°)

8.3 Nomenclature

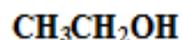
Among the simple alcohols the common names are very commonly used. To write these names, simply put the name of its alkyl group and follow it by the word alcohol. For example; CH_3OH methyl alcohol.

The IUPAC rules for naming the alcohols are very similar to those for naming alkanes, and the following principle are followed:

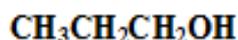
- 1- The longest carbon chain that contains the hydroxyl group is considered the parent compound.
- 2- The $-e$ ending of the name of this carbon chain is replaced by $-ol$.
- 3- The location of the hydroxyl and any other groups are shown by the smallest possible numbers, with the position of the hydroxyl group having the highest priority.



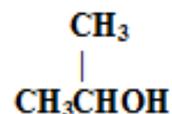
Methanol (Methyl alcohol)



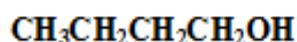
Ethanol (Ethyl alcohol)



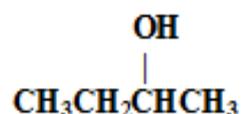
1-Propanol



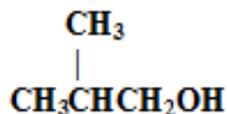
2-Propanol (Isopropyl alcohol)



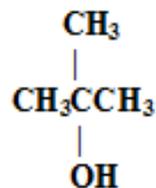
1-Butanol



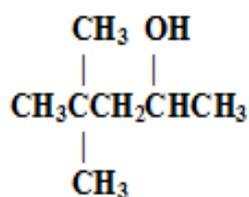
2-Butanol (*sec*-Butyl alcohol)



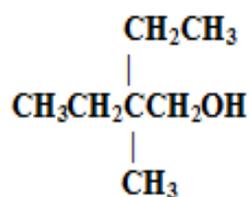
2-Methyl-1-propanol
(Isobutyl alcohol)



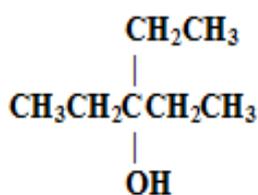
2-Methyl-2-propanol
(*tert*-Butyl alcohol)



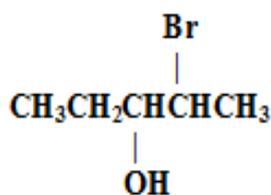
4,4-Dimethyl-2-pentanol



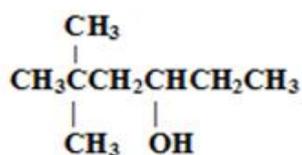
2-Ethyl-2-methyl-1-butanol



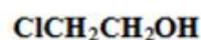
3-Ethyl-3-pentanol



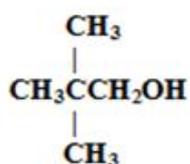
2-Bromo-3-pentanol



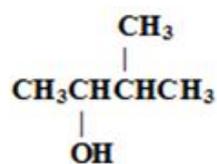
5,5-Dimethyl-3-hexanol



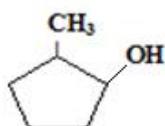
2-Chloroethanol



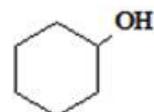
2,2-Dimethyl-1-propanol



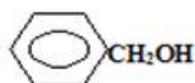
3-Methyl-2-butanol



2-Methylcyclopentanol



Cyclohexanol

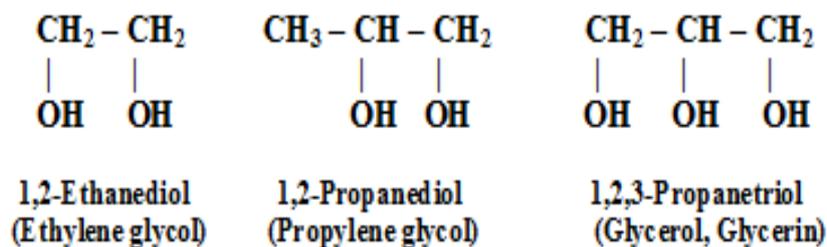


(Benzyl alcohol)

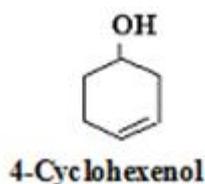
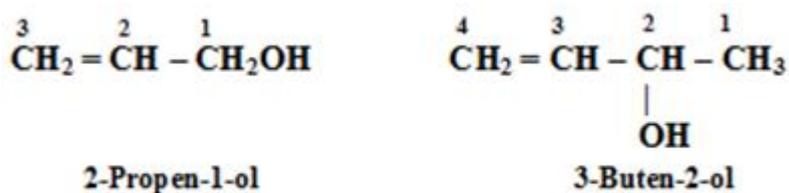


(*p*-Nitrobenzyl alcohol)

In the IUPAC system, a compound containing two hydroxyl groups is named as a diol, one containing three hydroxyl groups is named as a triol, and so on.



An alcohol containing a double bond is named as an alkenol, with number to indicate the position of the double bond and the hydroxyl group.

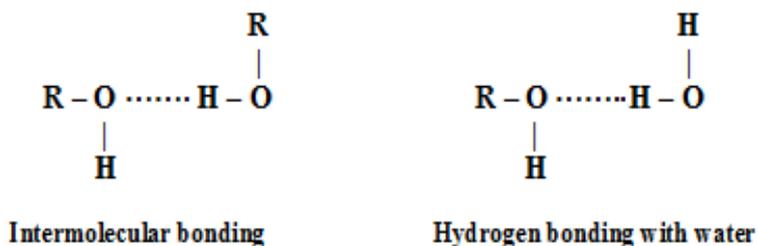


8.4 Physical Properties of Alcohols

Alcohol molecules are polar, because the -OH group is highly polar. To show this, only compare boiling of ethane for example (formula weight 30, b.p. -89), with methyl alcohol (formula weight 32, b.p. 65).

Force of attraction between alcohol molecules obviously must be greater than between molecules of alkanes. Hydrogen bonding accounts for this.

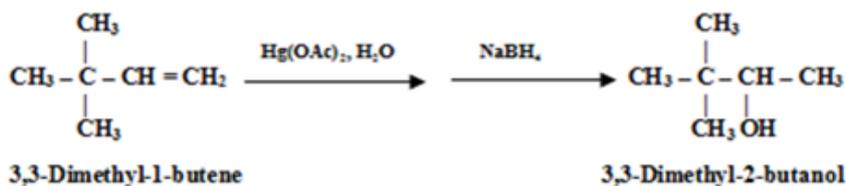
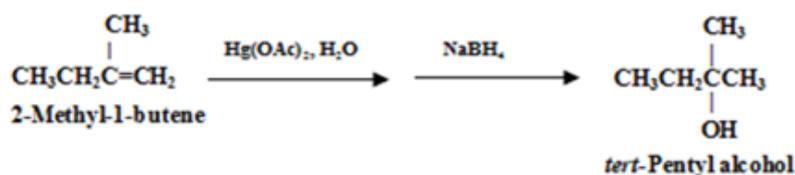
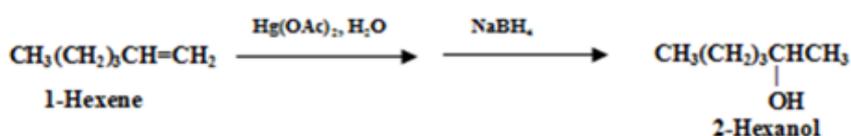
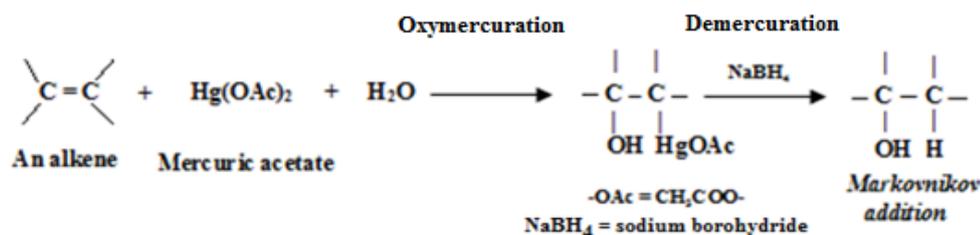
The presence of an alcohol group sharply increases the tendency to dissolve in water. Methane, for example, is insoluble in water, but methyl alcohol is completely soluble, because of the hydrogen bonding with water as illustrated:



8.5 Preparation of Alcohols

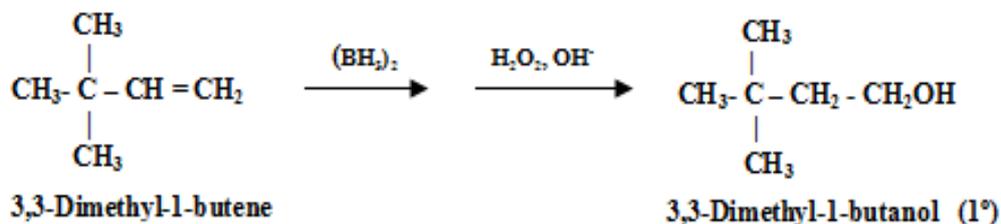
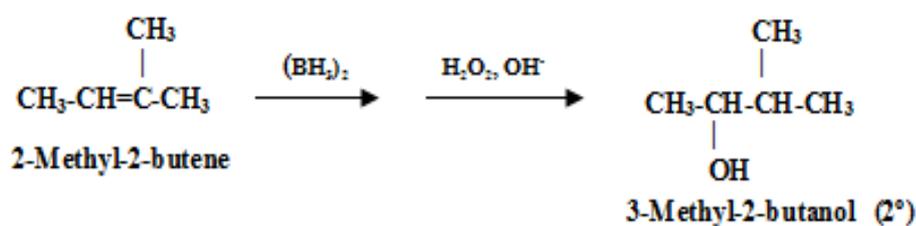
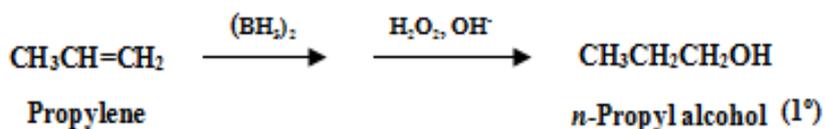
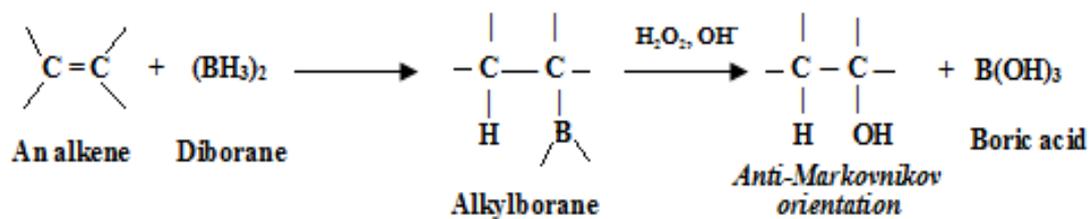
1- Oxymercuration – demercuration

Alkenes react with mercuric acetate in the presence of water to give hydroxymercurial compounds which on reduction yield alcohols.



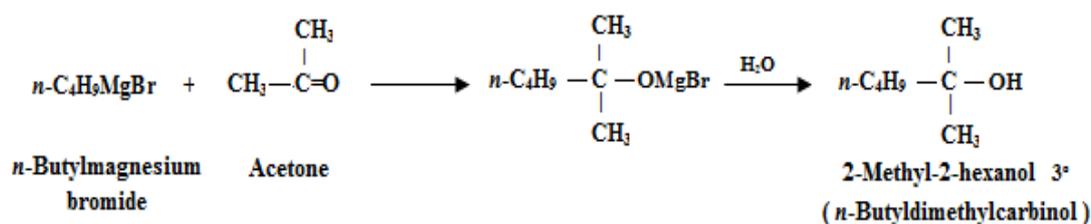
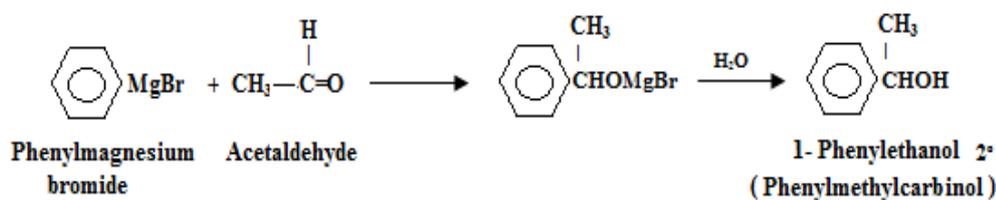
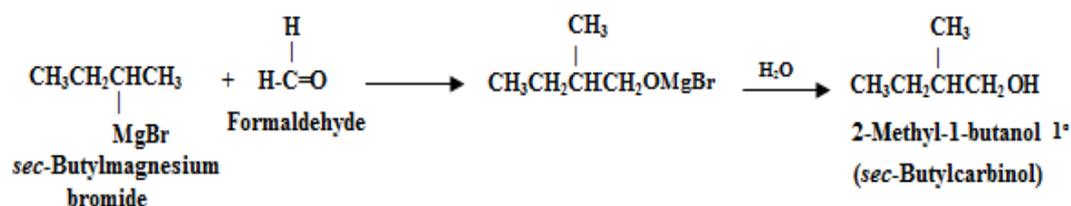
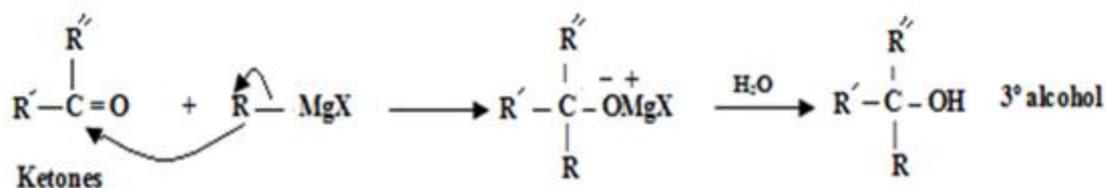
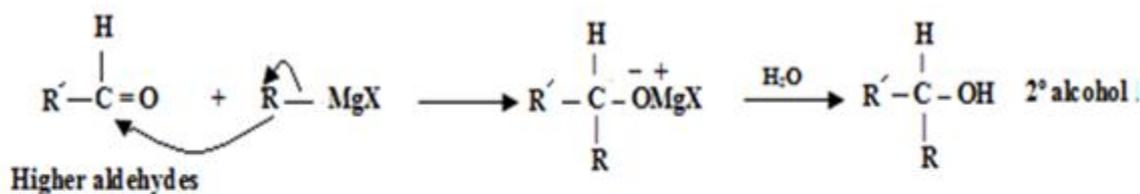
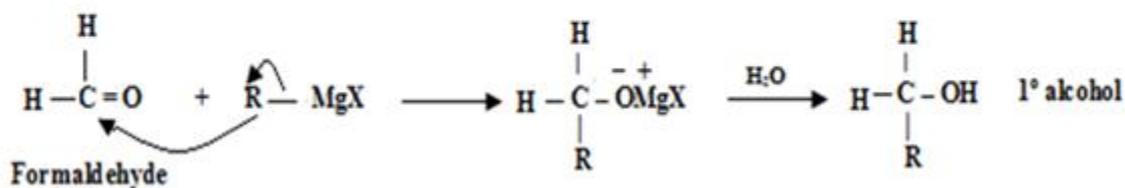
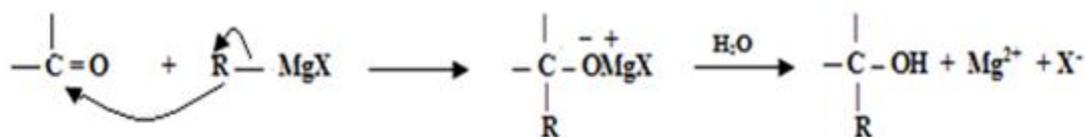
2-Hydroboration - oxidation

With the reagent diborane, (BH₃)₂, alkene undergo hydroboration to yield alkylboranes, which on oxidation give alcohols. Hydroboration involves addition of BH₃ to the double bond, with hydrogen becoming attached to one doubly bonded carbon, and boron to the other. The alkylborane can then undergo oxidation, in which the boron is replaced by -OH.



3- Grignard reaction

One of the most important uses of the Grignard reagent lies in its reaction with aldehydes and ketones. The product is the magnesium salt of the weakly acidic alcohol and is easily converted into alcohol itself by the addition of the stronger acid, water.



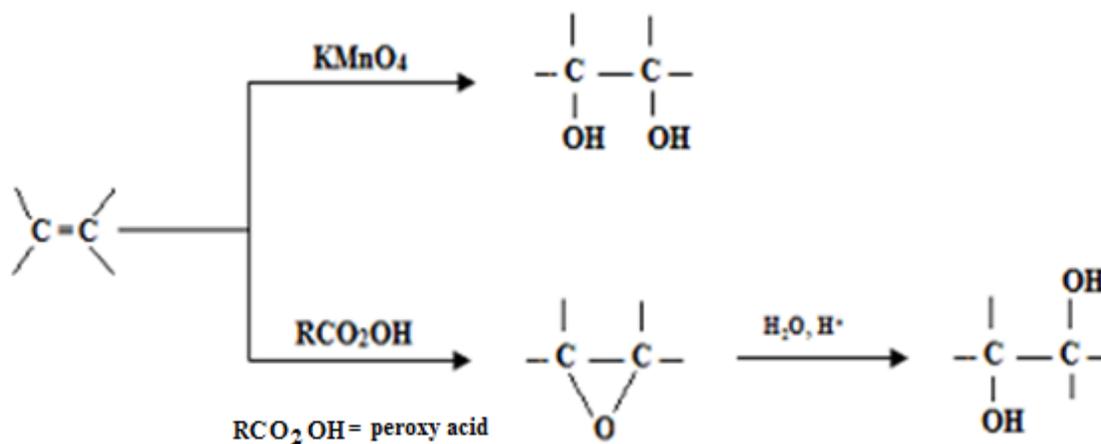
4- Hydrolysis of alkyl halides

Alcohols can be prepared by the hydrolysis of alkyl halides.



5- Hydroxylation of alkenes

Certain oxidizing agents convert alkenes into **1,2-diols**: dihydroxy alcohols containing the two $-OH$ groups on adjacent carbons. (They are also known as *glycols*).

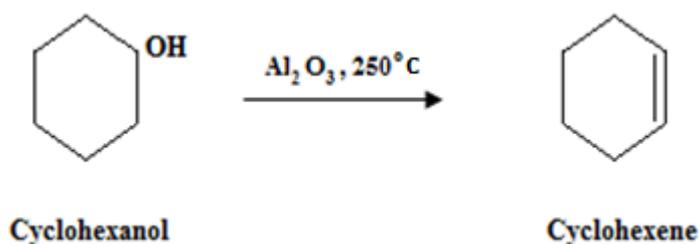
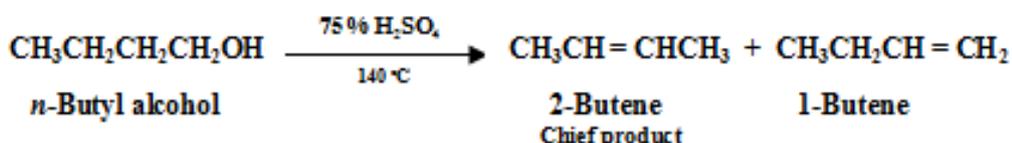
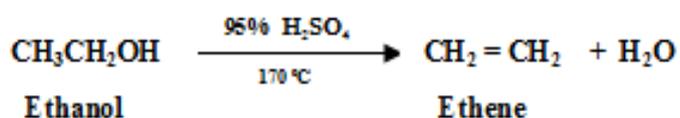
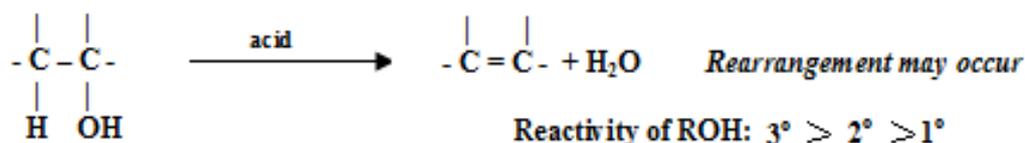


8.6 Reactions of Alcohols

Alcohols are saturated compounds containing the functional group –OH. They can undergo nucleophilic substitution reactions, in which the hydroxyl group is displaced by other groups, or they can undergo elimination reactions, involving the loss of the elements of water when reacted with a dehydrating agent. Primary and secondary alcohols also undergo oxidation and the hydroxyl group shows acidic properties when treated with reactive metals.

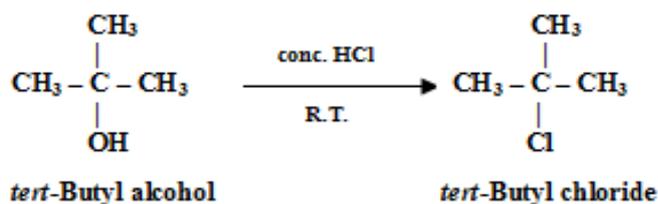
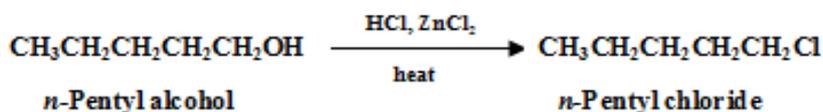
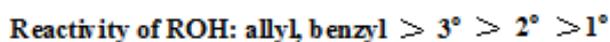
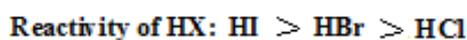
1- Dehydration

As alcohols contain the hydroxyl group –OH, they may undergo the elimination of the elements of water. Concentrated sulphuric acid has a very strong affinity for water and behaves as a dehydrating agent towards alcohols. When heated with sulphuric acid, alcohols can be dehydrated to alkenes.

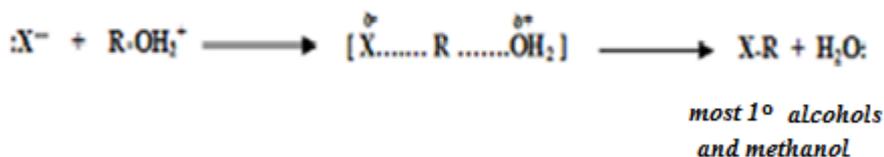
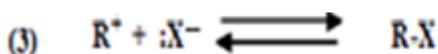
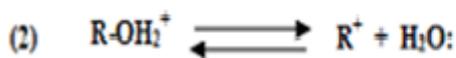
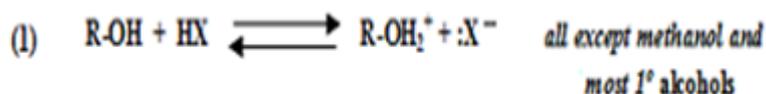


2- Reaction with hydrogen halides

Under a variety of conditions, and using a variety of reagents, alcohols may be converted into alkyl halides. The reaction is catalyzed by acids, and rearrangement of the alkyl group occurs, except with most 1° alcohols.



Mechanism:



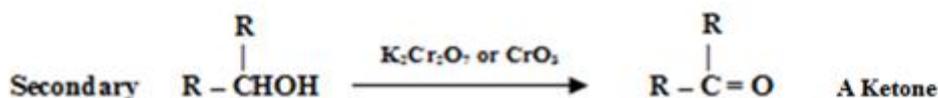
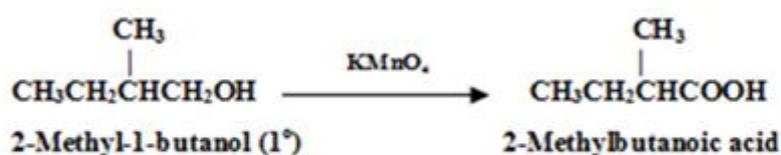
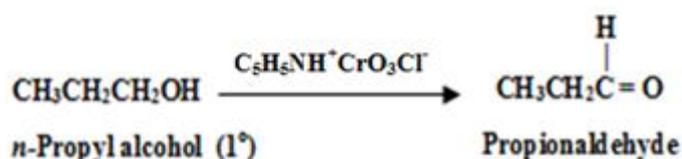
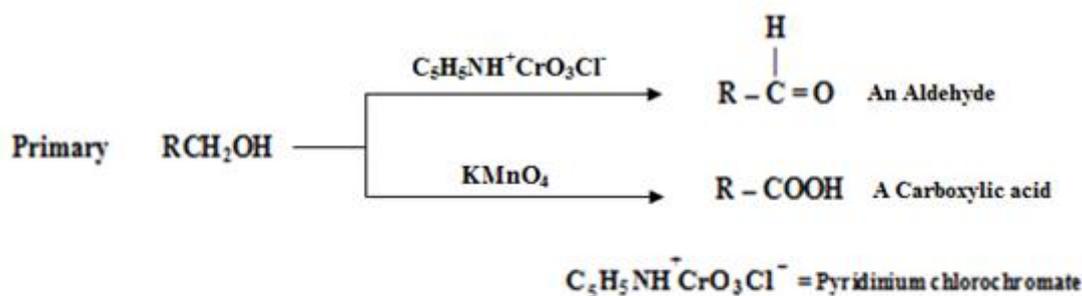
3- Oxidation

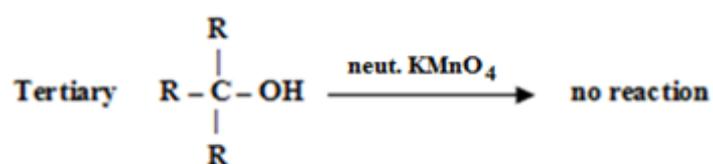
Alcohols react with strong oxidizing agents, to give products which depend on the structure of the alcohol. The reaction involves the loss of one or more hydrogens (α -hydrogen) from the carbon bearing the $-\text{OH}$ group.

A **primary alcohol** contains two α -hydrogens, and can either lose one of them to form an *aldehyde*, or both of them to form a *carboxylic acid*.

A **secondary alcohol** can lose its only α -hydrogen to form a *ketone*.

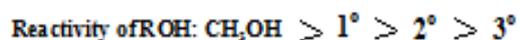
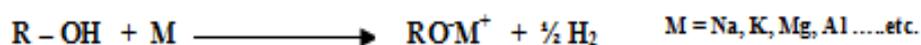
A **tertiary alcohol** contains no α -hydrogen and is *not oxidized*.





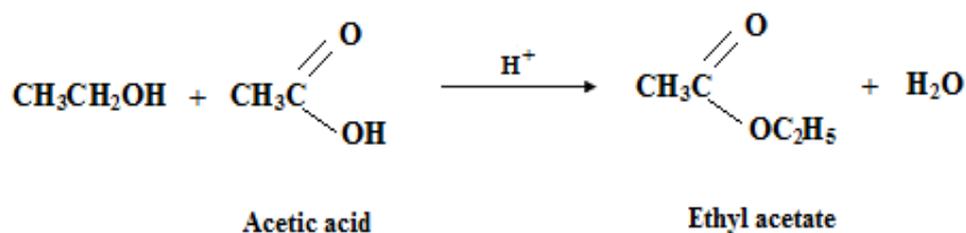
4- Reaction as acids: reaction with active metals

The alcohols react with metals like sodium and potassium to form ionic compounds called alkoxides.



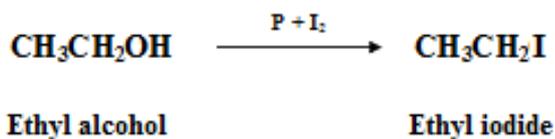
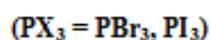
5- Ester formation

Alcohols react with acids to form esters.



6- Reaction with phosphorus trihalides

Alkyl halides are formed from reaction of alcohols with hydrogen halides or phosphorus halides. Phosphorus halides are often preferred because they tend less to bring about rearrangement.



Organic Chemistry I

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Chapter 9

Ethers

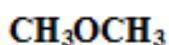
9.1 Introduction

Compounds in whose molecules two organic groups are joined to the same oxygen atom are called ethers:

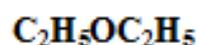


9.2 Nomenclature

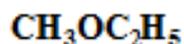
The common names of simple ethers are made by naming the groups attached to oxygen and follow these names by word ether.



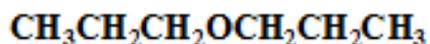
Dimethyl ether



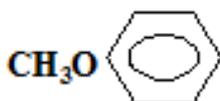
Diethyl ether



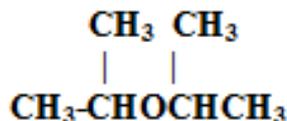
Ethyl methyl ether



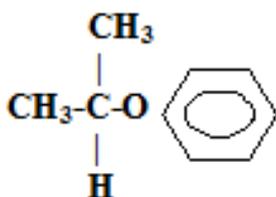
Dipropyl ether



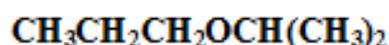
Methyl phenyl ether



Diisopropyl ether



Isopropyl phenyl ether

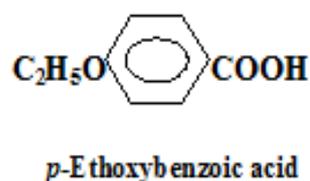
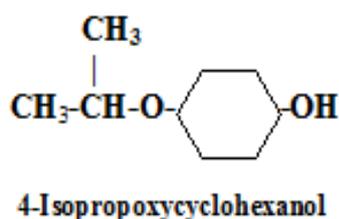
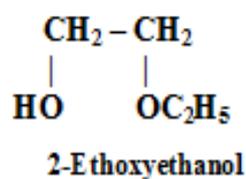
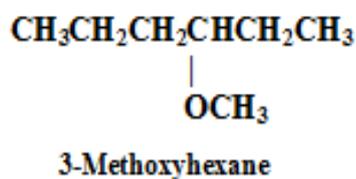
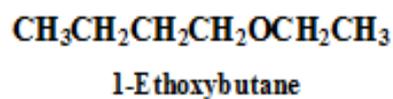
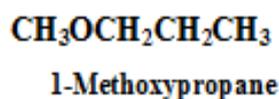


Isopropyl *n*-propyl ether

In the IUPAC system, ethers are named by selecting the longest carbon chain as the parent alkane and naming the **-OR** group attached to it as alkoxy group.

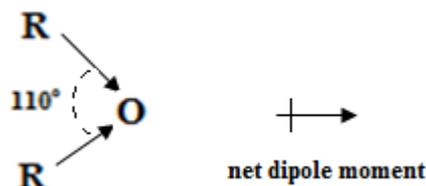
-OCH₃ **methoxy**

-OCH₂CH₃ **ethoxyetc.**



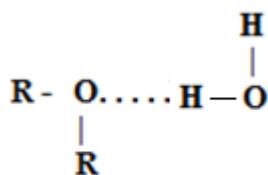
9.3 Physical Properties of Ethers

Since the C-O-C bond angle is not 180° , the dipole moment of the two C-O bonds do not cancel each other; consequently, ethers possess a small net dipole moment.



This weak polarity does not appreciably affect the boiling point of the ethers, which are about the same as those of alkanes having comparable molecular weights, and much lower than those of isomeric alcohols. The hydrogen bonding that holds alcohol molecules strongly together is not possible for ethers, since they contain hydrogen bonded only to carbon.

On the other hand, ethers show solubility in water comparable to that of the alcohols, both diethyl ether and *n*-butyl alcohol, for example, being soluble to the extent of about 8 g per 100 g water. We attributed the water solubility of the lower alcohols to hydrogen bonding between water molecules and alcohol molecules; the water solubility of ether arises in the same way.

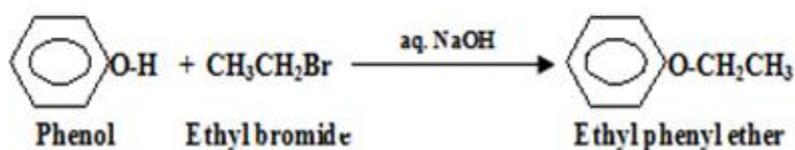
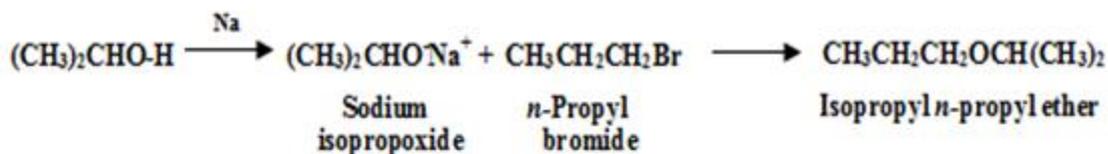
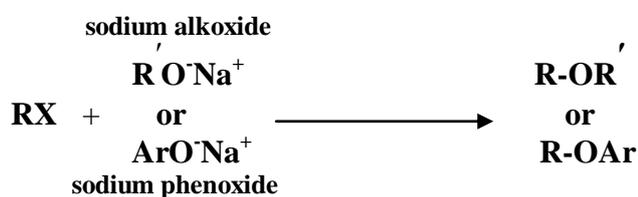


Hydrogen bonding with water

9.4 Preparation of Ethers

1- Williamson synthesis

In the Williamson synthesis an alkyl halide (or substituted alkyl halide) is allowed to react with a sodium alkoxide or sodium phenoxide.

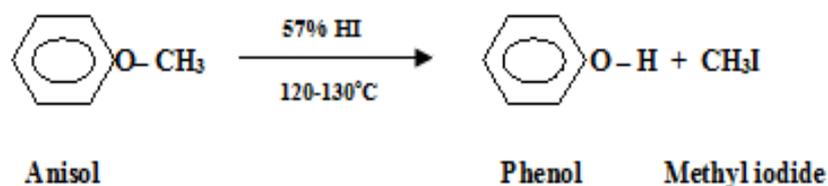
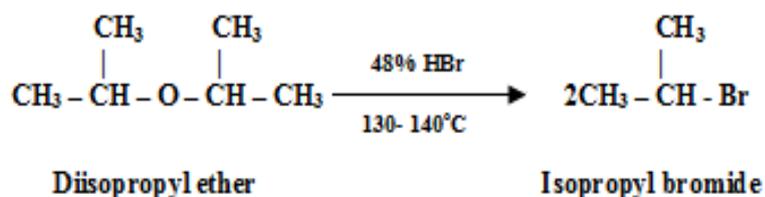


2- Alkoxymercuration – demercuration

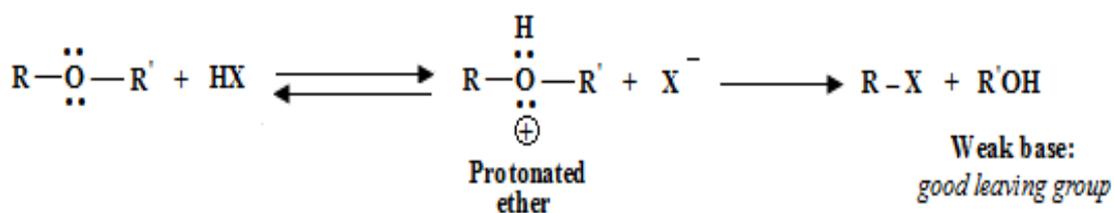
Alkenes react with mercuric trifluoroacetate in the presence of an alcohol to give alkoxymercurial compounds which on reduction yield ether.

Cleavage takes place only under quite vigorous conditions: concentrated acids (usually HI or HBr) and high temperatures.

A dialkyl ether yields initially an alkyl halide and an alcohol; the alcohol may react further to form a second mole of halide.



Cleavage involves nucleophilic attack by halide ion on this protonated ether, with displacement of the weakly basic alcohol molecule.



Organic Chemistry I

College of Pharmacy - University of Anbar / First Year 2017 - 2018

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Chapter 10

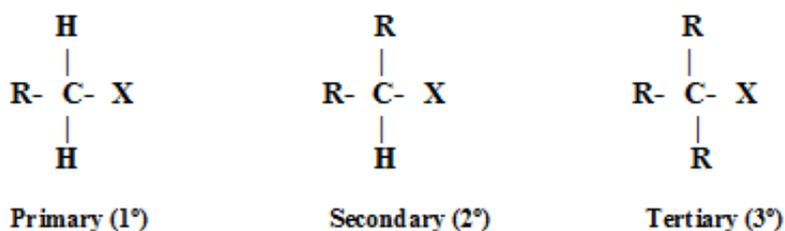
Alkyl halides

10.1 Introduction

Alkyl halides a group of compounds have a general structure RX, where R is alkyl group, X halogen. The functional group is the halogen atom. The characteristic reactions of an alkyl halide are those that take place at the halogen atom.

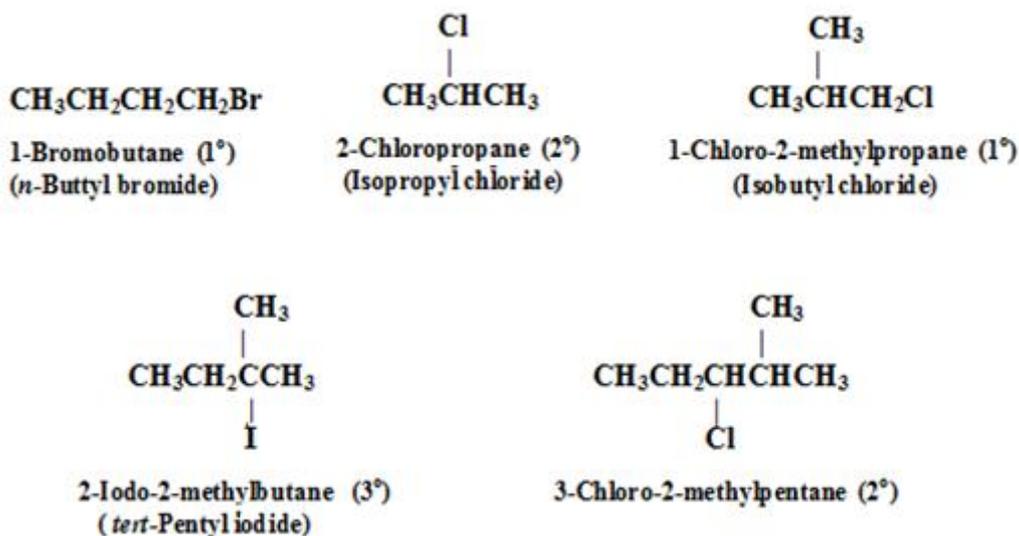
10.2 Nomenclature

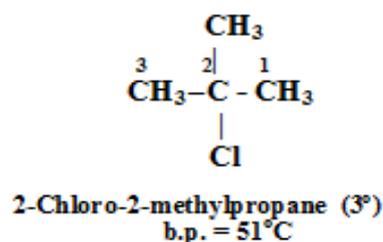
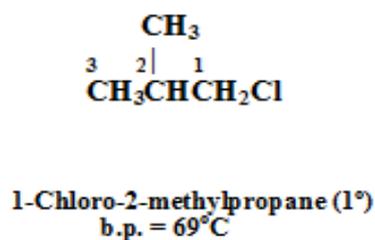
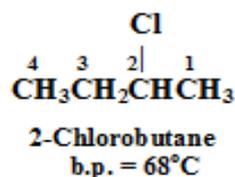
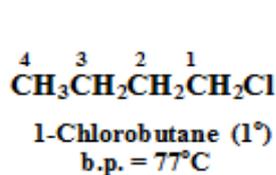
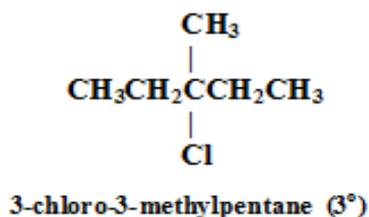
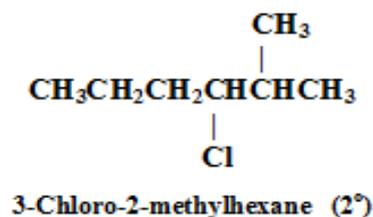
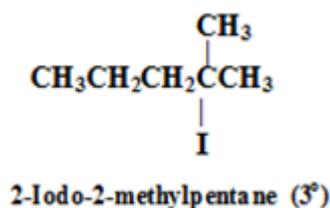
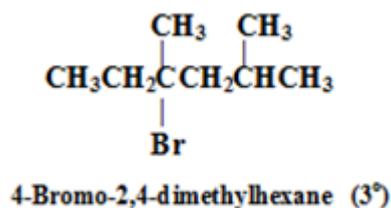
The carbon atom can be classified as primary, secondary or tertiary, according to the number of other carbon atoms attached to it. An alkyl halide is classified according to the kind of carbon that bears the halogen:



Two kinds of names can be given, common names for the simpler halides, and IUPAC names, in which the compound is simply named as an alkane with a halogen attached as a side chain. Common names consist of the name of the alkyl group followed by the name of the halide as a separated word.

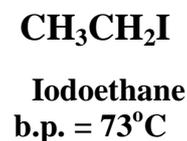
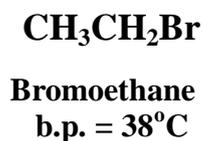
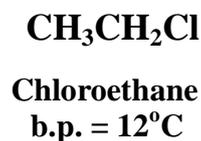
In the following examples, the IUPAC name is given first and then, in parentheses, its common name.





10.3 Physical Properties of Alkyl Halides

For a given alkyl group, the boiling point increases with increasing atomic weight of the halogen.



The size effect also account for the sharp rise in the boiling point as the degree of halogen substitution increase. Branching involving either alkyl groups or the halogen itself, lower the boiling point.

CH₃Cl	CH₂Cl₂	CHCl₃	CCl₄
Chloromethane	Dichloromethane	Trichloromethane	Tetrachloromethane
b.p. = -24°C	b.p. = 40°C	b.p. = 61°C	b.p. = 77°C
CH₃CH₂Br	BrCH₂CH₂Br		
Bromoethane	1,2-Dibromoethane		
b.p. = 38°C	b.p.=131°C		

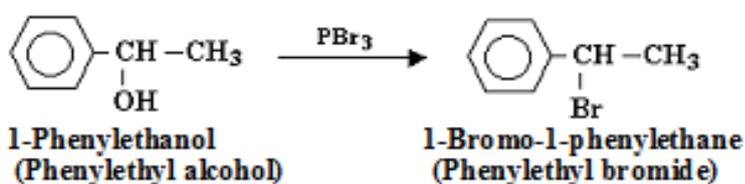
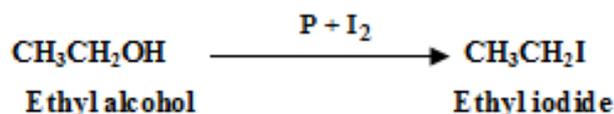
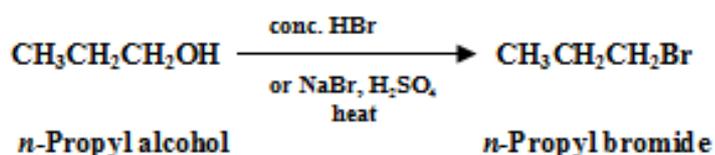
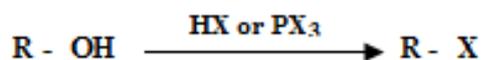
Because of the greater molecular weight of haloalkanes, they have considerable higher boiling points than alkanes with the same number of carbons.

In spite of their modest polarity, alkyl halides are insoluble in water, probably because of their inability to form hydrogen bonds. They are soluble in the typical organic solvents of low polarity, like benzene, ether, and chloroform.

10.4 Preparation of Alkyl Halides

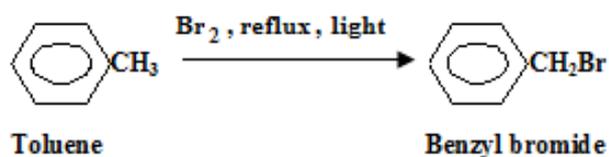
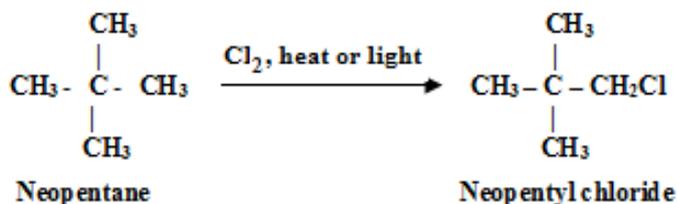
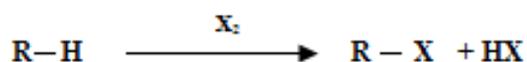
1- From alcohols

Alcohols react readily with hydrogen halides to yield alkyl halides and water. The reaction is carried out either by passing the dry halogen halide gas into the alcohol, or by heating the alcohol with the concentrated aqueous acid.



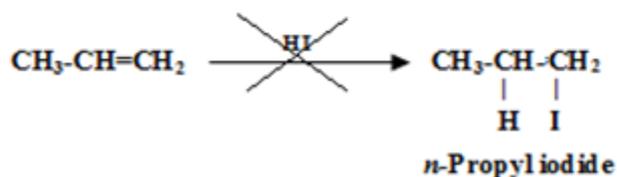
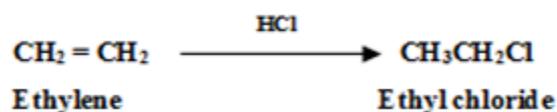
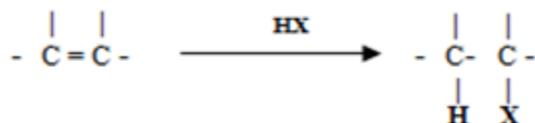
2- Halogenation of certain hydrocarbons

Under the influence of ultraviolet light, or 250-400°C, chlorine or bromine convert alkane into alkyl chloride or alkyl bromide.



3- Addition of hydrogen halides to alkenes

An alkene is converted by hydrogen chloride, hydrogen bromide, or hydrogen iodide into the corresponding alkyl halide. The reaction is carried out by passing the dry gaseous hydrogen halide directly into the alkene.



5- Halide exchange

An alkyl iodide is often prepared from the corresponding bromide or chloride by treatment with solution of sodium iodide in acetone. The less soluble sodium bromide or sodium chloride precipitate from solution and can be removed by filtration.



10.5 Reactions of Alkyl Halides

The relative bond strengths (C-F 485, C-Cl 339, C-Br 284 and C-I 213 kJ mol⁻¹) indicate that the iodo compounds, are the most reactive, and these are frequently used in synthetic work in the laboratory. The C-F bond is certainly the most inert and so the fluoro compounds find special use where lack of reactivity is an important factor.

In the main, being saturated compound, the halogenoalkanes undergo two characteristic types of reaction, namely substitution and elimination.

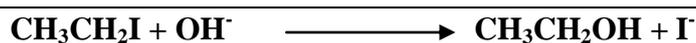
(Substitution reactions)

1- Reaction with water or alkali

The carbon-halogen bond is polarized, the bonding electron-pair being shared unequally between the two atoms. Consequently, the carbon is electropositive and is an electrophilic centre, so that it should be susceptible to attack by a nucleophilic species (either a negative ion or neutral molecule, possessing one or more lone-pairs electrons).

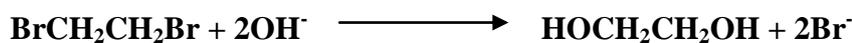
Water is such a reagent. Halogenoalkanes are only slowly attacked, or hydrolysed, by water but reaction takes place readily when the halogenoalkane is warmed with alkali. Usually, aqueous ethanol is employed as a solvent.





Iodoethane

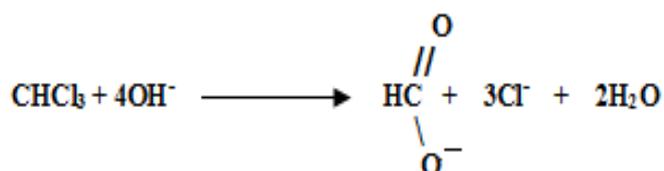
Ethanol



1,2-Dibromoethane

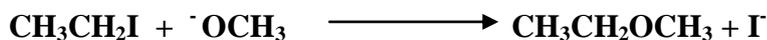
Ethane-1,2-diol

Trichloromethane (chloroform) is hydrolysed by boiling with alkali to the salt of carboxylic acid.



2- Reaction with alkoxides

Alcohols react with metallic sodium to form ionic salts called alkoxides. When alkyl halide is heated with a solution of the alkoxide in its corresponding alcohol, substitution takes place and an ether is formed, the halogen atom having been substituted by an alkoxy group OR.



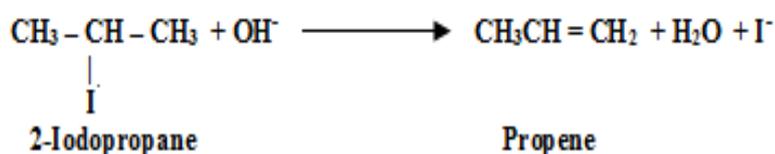
Iodoethane

Methoxyethane

(Elimination reactions)

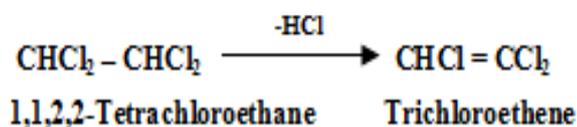
1- Reaction with alkali

If a hot, concentrated alcoholic solution of a base and alkyl halide is reacted, then an elimination reaction, rather than substitution, reaction occurs and an alkene is formed. Such an elimination reaction is the converse of an addition reaction, the elements of a hydrogen halide been removed or eliminated from the molecule to give an unsaturated product.



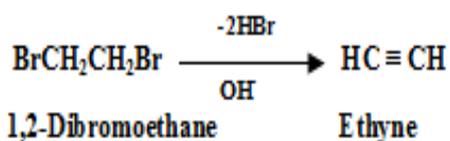
2- Elimination of HCl

An elimination reaction is used to prepare various chlorinated solvents industrially, including the important degreasing solvent trichloroethene.



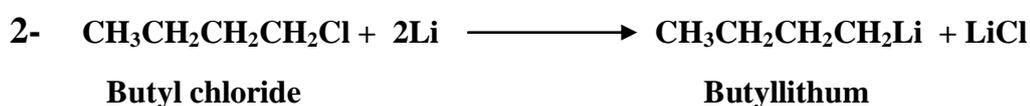
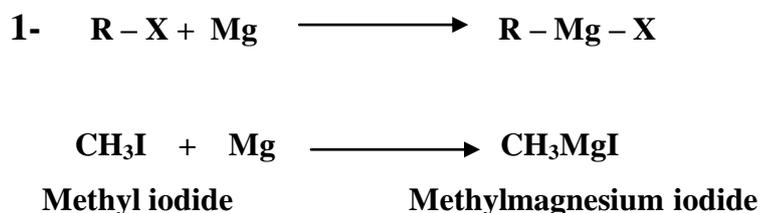
3- Elimination of 2HBr

Disubstituted halogeno compound may also eliminate 2 mol of hydrogen halide per mol of alkyl halide.

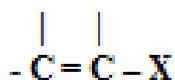


(Reactions with metals)

Under the appropriate conditions, alkyl halides react with a variety of metals such as zinc, magnesium and lithium, to form organometallic compounds, in which the metal atom becomes bonded to a carbon atom.

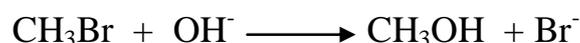


Vinyl halides compounds in which halogen is attached directly to a doubly bonded carbon.



10.6 The S_N2 Reaction: Mechanism and Kinetics

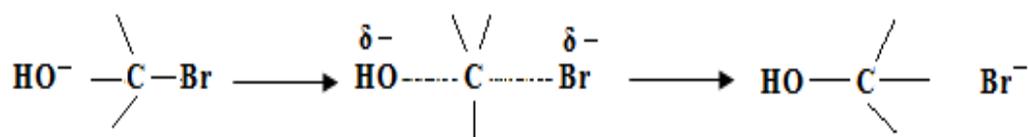
The reaction between methyl bromide and hydroxide ion to yield methanol follows second-order kinetics (S_N2); that is, the rate depends upon the concentrations of both reactants:



$$\text{rate} = k[\text{CH}_3\text{Br}][\text{OH}^-]$$

It is known that in its attack the hydroxide ion stays as far away as possible from the bromine; that is to say, it attacks the molecule from the rear.

When hydroxide ion collides with a methyl bromide molecule at the face most remote from the bromine, and when such a collision has sufficient energy, a C–OH bond forms and the C–Br bond breaks, liberating the bromide ion.

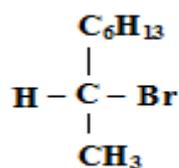


This is the mechanism that is called S_N2 : *substitution nucleophilic bimolecular*. The term bimolecular is used here since the rate-determining step involves collision of two particles.

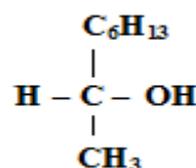
10.7 The S_N2 Reaction: Stereochemistry. Inversion of Configuration

Both 2-bromooctane and 2-octanol are chiral; that is, they have molecules that are not superimposable on their mirror images. Consequently, these compounds can exist as enantiomers, and can show optical activity. Optically active 2-octanol has been obtained by resolution of the racemic modification, and from it optically active 2-bromooctane has been made.

The following configurations have been assigned:



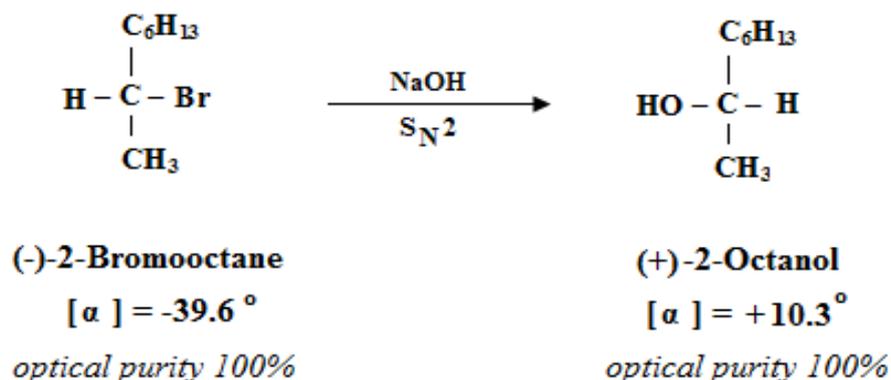
(-)-2-Bromooctane
 $[\alpha] = -39.6^\circ$



(-)-2-Octanol
 $[\alpha] = -10.3^\circ$

We noticed that the (-)-bromide and the (-)-alcohol have similar configurations; that is, -OH occupies the same relative position in the (-)-alcohol as -Br does in the (-)-bromide. As we know, compounds of similar configuration do not necessarily rotate light in the same direction; they just happen to do so in the present case. (As we also know, compounds of similar configuration are not necessarily given the same specification of *R* and *S*; it just happens that both are *R* in this case).

Now, when (-)-2-bromooctane is allowed to react with sodium hydroxide under conditions where second-order kinetics are followed, there is obtained (+)-2-octanol.

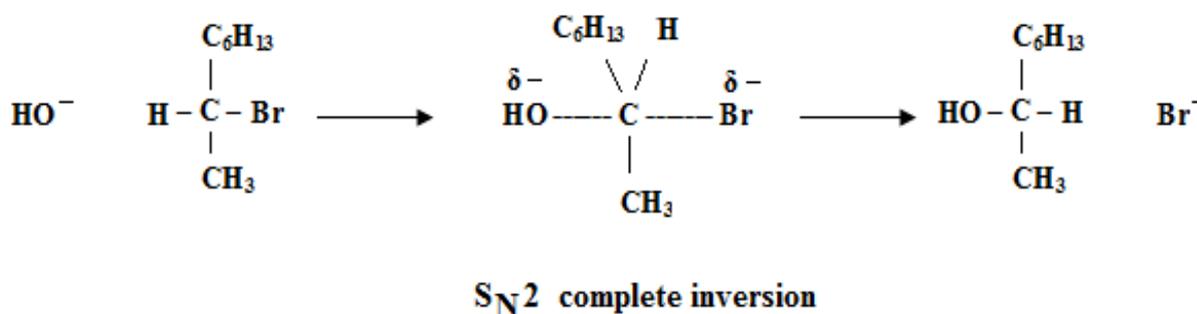


We see that the –OH group has not taken the position previously occupied by –Br; the alcohol obtained has a configuration opposite to that of the bromide. A reaction that yields a product whose configuration is opposite to that of the reactant is said to proceed with **inversion of configuration**.

(In this particular case, inversion of configuration happens to be accompanied by a change in specification, from *R* to *S*, but this is not always true).

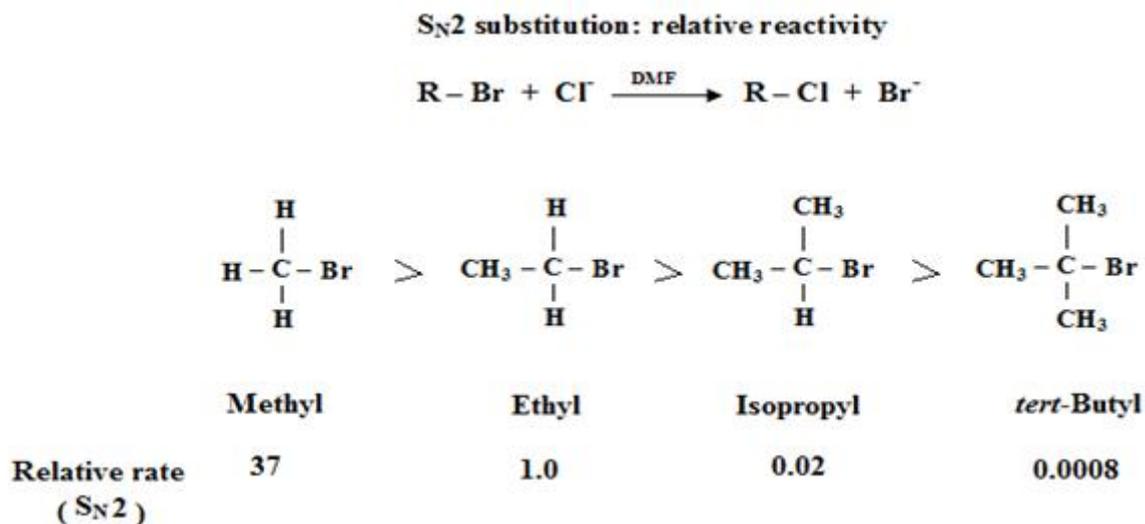
We can say that an S_N2 reaction proceeds with complete stereochemical inversion.

The back-side attack was first proposed for substitution of the S_N2 kind. As –OH becomes attached to carbon, three bonds are forced apart until they reach the planar arrangement of the transition state; then, as bromide is expelled, they move on to a tetrahedral arrangement opposite to the original one. This process has often been likened to the turning side-out of an umbrella in a gale.



10.8 The S_N2 Reaction: Reactivity. Steric Hindrance

Direct measurement of S_N2 rates for a series of substrates gives result like the following. (DMF is dimethylformamide), a solvent that favors the S_N2 reaction here).



As postulated, then, the reactivity of substrates in the S_N2 reaction is:

Reactivity in S_N2 CH₃W > 1° > 2° > 3°

An interpretation that is generally accepted today is differences in rate between two S_N2 reactions are due chiefly to steric factor. As the number of substituents attached to the carbon bearing the halogen is increased, the reactivity toward S_N2 substitution decreases.

The steric factor is confirmed by the relative rate of another series of substrates. This time all the substrates are primary, but the size of the substituent is steadily increased.

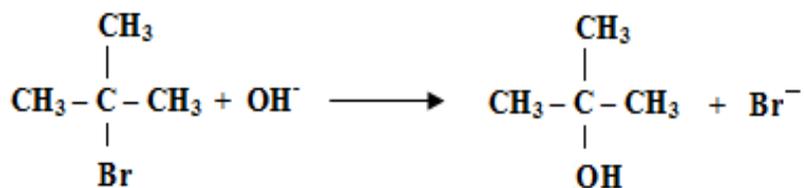
S_N2 substitution: relative reactivity



	$\text{CH}_3\text{CH}_2\text{-Br}$	$>$	$\text{CH}_3\text{CH}_2\text{CH}_2\text{-Br}$	$>$	$\begin{array}{c} \text{CH}_3 \\ \\ \text{CH}_3\text{CHCH}_2\text{-Br} \end{array}$	$>$	$\begin{array}{c} \text{CH}_3 \\ \\ \text{CH}_3\text{-C-CH}_2\text{Br} \\ \\ \text{CH}_3 \end{array}$
	Ethyl		<i>n</i> -Propyl		Isobutyl		Neopentyl
Relative rate S_N2	1.0		0.69		0.33		0.000 006

10.9 The S_N1 Reaction: Mechanism and Kinetics. Rate-Determining Step

The reaction between *tert*-butyl bromide and hydroxide ion yield *tert*-butyl alcohol follows first-order kinetics; that is, the rate depends upon the concentration of only one reactant, *tert*-butyl bromide.

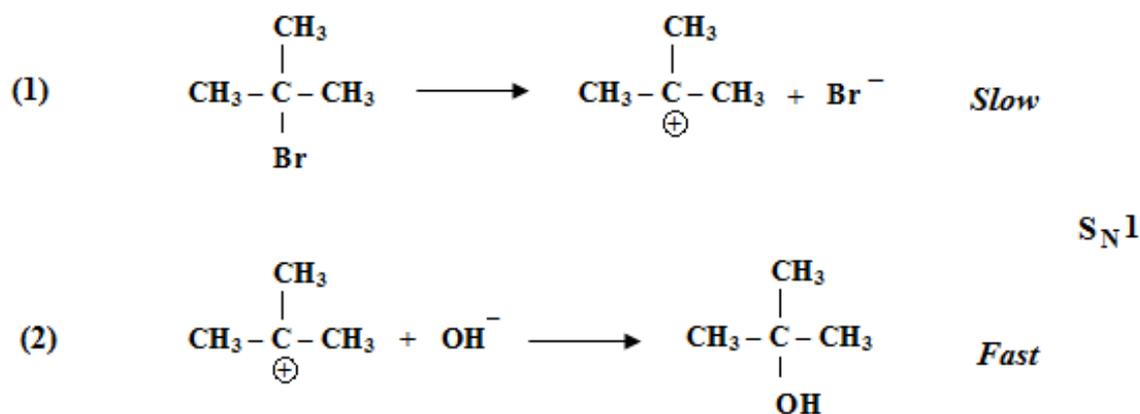


$$\text{rate} = k[\text{RBr}]$$

How are we interpret the fact that the rate is independent of $[\text{OH}^-]$? If the rate of reaction does not depend upon $[\text{OH}^-]$, it can only mean that the reaction whose rate we are measuring does not involve OH^- .

These observations are quite consistent with the following mechanism. *tert*-Butyl bromide slowly dissociates (step 1) into a bromide ion and a cation derived from the *tert*-butyl group: a *carbocation*. This carbocation then combines rapidly (step 2) with a hydroxide ion to yield *tert*-butyl alcohol.

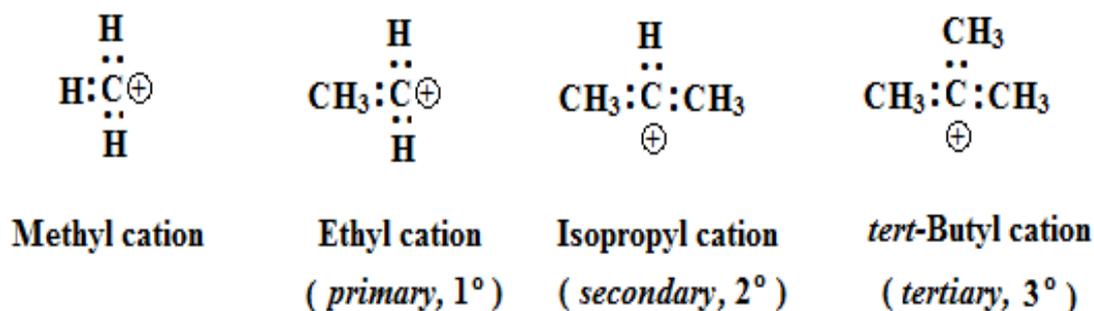
The rate of the overall reaction is determined by the slow breaking of the C–Br bond to form the carbocation; ones formed, the carbocation reacts rapidly to form the product. It is step (1) whose rate we are actually measuring; this step does not involve OH^- , and its rate does not depend upon $[\text{OH}^-]$. *A single step whose rate determines the overall rate of a stepwise reaction is called a rate-determining step.*



The rate-determining step is the one that involves the breaking of a bond, an energy-demanding process. It is an example of heterolysis, cleavage in which both bonding electrons go to the same fragment: a process that takes even more energy than the homolysis that we encountered in free-radical substitution.

This is the mechanism that is called S_N1 : *substitution nucleophilic unimolecular*.

The carbocation is a group of atoms that contains a carbon atom bearing only six electrons. Carbocations are classified as primary, secondary or tertiary after the carbon bearing the positive charge. They are named by use of the word cation. For example:

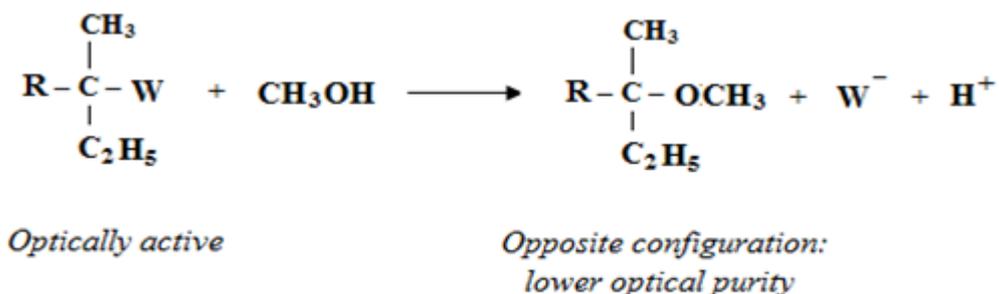


10.10 The S_N1 Reaction: Stereochemistry

Here, as in stereochemical studies of the S_N2 reaction, substitution is carried out on an optically active substrate; the product is isolated, and its configuration and optical purity are compared with those of the starting material.

Such studies have been made of the reactions between several tertiary substrates and the solvent methanol, CH_3OH : reactions of a type most likely to proceed by S_N1 . In each case there is obtained a product of opposite configuration from the starting

material, and of considerably lower optical purity. Optically pure substrate, for example, gives a product that is only about 50% optically pure, and in some cases much less pure than that.



S_N1 racemization plus inversion

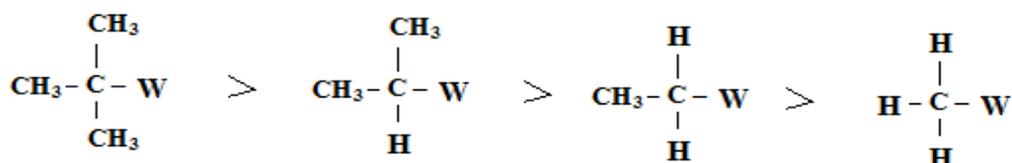
Now, optically pure starting material contains only the one enantiomer, whereas the product clearly must contain both. The product is thus a mixture of the inverted compound and the racemic inversion plus partial racemization.

10.11 The S_N1 Reaction: Reactivity. Ease of Formation of Carbocation

We have already seen that reactivity in S_N2 decreases along the series CH_3W , 1° , 2° , 3° . Now, does reactivity by S_N1 change in the opposite direction along this same series?

Under conditions that greatly favor S_N1 , results like the following have been obtained:

S_N1 substitution: relative reactivity



Relative rate	<i>tert</i> -Butyl	Isopropyl	Ethyl	Methyl
(S_N1)	$> 10^6$	1.0	$< 10^{-4}$	$< 10^{-5}$

The reactivity of substrates in the S_N1 reaction, then, follows the sequence:

Reactivity in S_N1 $3^\circ > 2^\circ > 1^\circ > \text{CH}_3\text{W}$

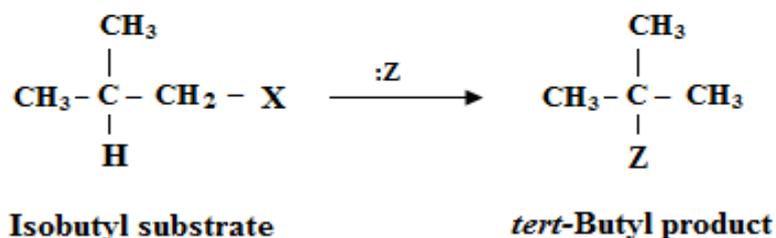
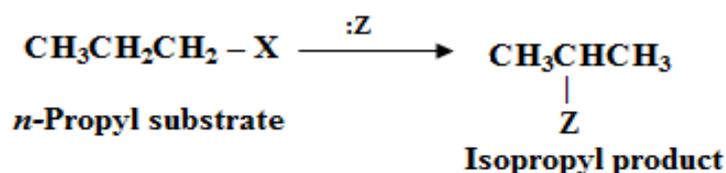
Now, the rate-determining step in S_N1 is formation of the carbocation; that is to say, one substrate undergoes S_N1 faster than another because it forms a carbocation faster. The reactivity sequence therefore follows the relative rates of formation of carbocations:

Rate of formation of carbocations: $3^\circ > 2^\circ > 1^\circ > \text{CH}_3^+$

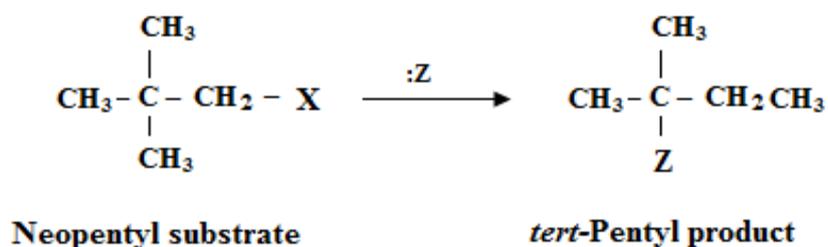
10.12 Rearrangement of carbocations

The most striking feature of the carbocation theory is the occurrence of rearrangements.

In nucleophilic substitution, for example, it is sometimes observed that the entering group, Z becomes attached to a different carbocation than the one that originally held the leaving group, X. For example:



Sometimes, there is even a rearrangement of the carbon skeleton:



In reactions of different types; elimination, addition, rearrangements are also observed, and they all have one feature in common: at some stage the same intermediate is formed, and it is this that undergoes the actual rearrangement.

Now, of the two mechanisms advanced for nucleophilic substitution, only S_N1 is postulated to involve an intermediate carbocation, and therefore we expect only reactions proceeding by S_N1 to be accompanied by these characteristic rearrangements. By contrast, the single step postulated for S_N2 simply provides no opportunity for such rearrangements.

10.13 S_N2 vs. S_N1

The S_N2 characterized by:

- 1- Second-order kinetics
- 2- Complete stereochemical inversion
- 3- Absence of rearrangement
- 4- The reactivity sequence $CH_3W > 1^\circ > 2^\circ > 3^\circ$

and the S_N1 characterized by:

- 1- First-order kinetics
- 2- Racemization
- 3- Rearrangement
- 4- The reactivity sequence $3^\circ > 2^\circ > 1^\circ > CH_3W$

Organic Chemistry I

College of Pharmacy - University of Anbar / First Year 2017 - 2018

Dr. Jasim. H. Hassen

Chapter 11

Cyclic Hydrocarbons

11.1 Introduction

In the cyclic compounds, the carbon atoms are arranged to form rings. Cycloalkane for example, is an alkane, and in general acts like one. But the cyclic nature of some of these compounds confers very special properties on them.

The formula do not fit the general one, a cyclic compound must necessarily contain two hydrogen atoms fewer than its corresponding straight-chain compound.

The cyclic alkanes tend to boil at slightly higher temperature than their straight-chain counterparts.

11.2 Nomenclature

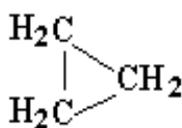
Cyclic aliphatic hydrocarbons are named by prefixing **cyclo-** to the name of the corresponding open-chain hydrocarbon having the same number of carbon as the rings. For example:



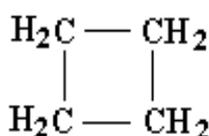
Cyclopentane



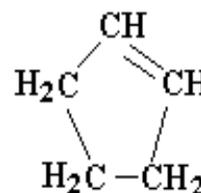
Cyclohexane



Cyclopropane

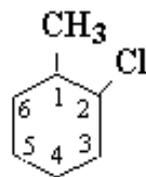
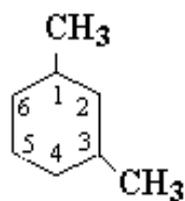


Cyclobutane

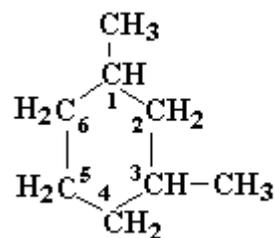
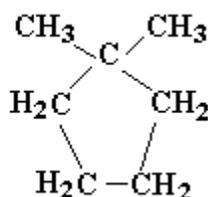
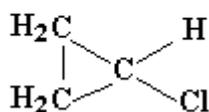


Cyclopentene

Substituents on the ring, alkyl groups, halogens, are named and their positions are indicated by numbers. We assign position 1 to a particular carbon and then number either clockwise or counterclockwise around the ring; we do all this in such a way to give the lowest combination of numbers. For example:

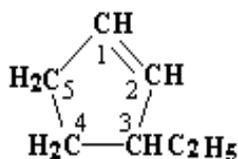


1,3-Dimethylcyclohexane 2-Chloro-1-methylcyclohexane

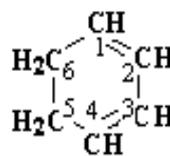


Chlorocyclopropane 1,1-Dimethylcyclopentane 1,3-Dimethylcyclohexane

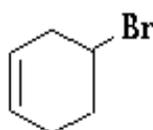
In simple cycloalkenes and cycloalkynes, the doubly and triply bonded carbons are considered to occupy positions 1 and 2. For example:



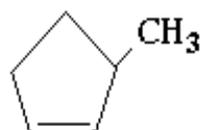
3-Ethylcyclopentene



1,3-cyclohexadiene



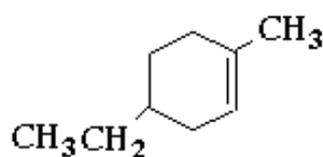
4-Bromocyclohexene



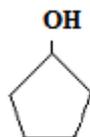
3-Methylcyclopentene



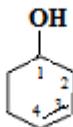
1,3-Cyclopentadiene



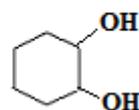
4-Ethyl-1-methylcyclohexene



Cyclopentanol

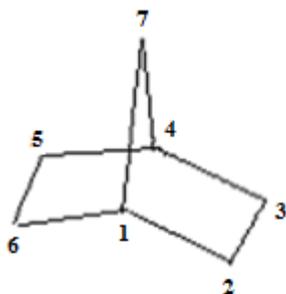


3-Cyclohexenol

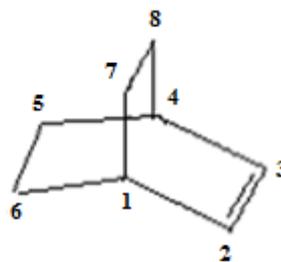


1,2-Cyclohexanediol

Polycyclic compounds contain two or more rings that share two or more carbon atoms. We can illustrate the naming system with *norboranane*, whose systematic name is bicyclo[2.2.1]heptane: (a) *heptane*, since it contains a total of seven carbon atoms; (b) *bicycle*, since it contains two rings, that is, breaking two carbon-carbon bonds converts it into an open-chain compound; (c) [2.2.1], since the number of carbons between bridgeheads (shared carbons) is two (C-2 and C-3), two (C-5 and C-6), and one (C-7).



Bicyclo[2.2.1]heptane



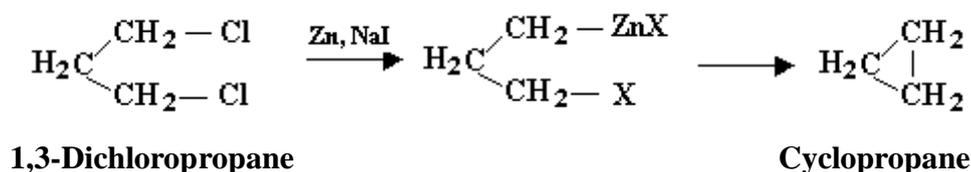
Bicyclo[2.2.2]octa-2-ene

11.3 Preparation of Cyclic Hydrocarbons

Preparation of alicyclic compounds from other aliphatic compounds generally involves two stages: (a) conversion of some open-chain compound or compounds into a compound that contains a ring, a process called cyclization; (b) conversion of the cyclic compound thus obtained into the kind of compound that we want: for example, conversion of a cyclic alcohol into a cyclic alkyl halide, or a cyclic alkene into a cyclic alkane.

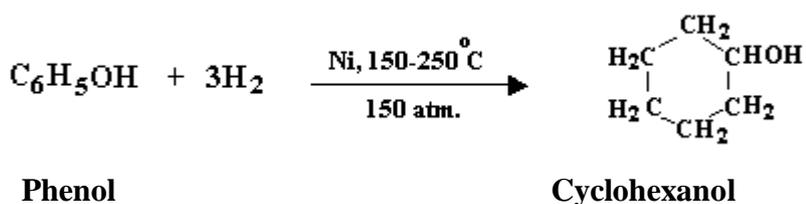
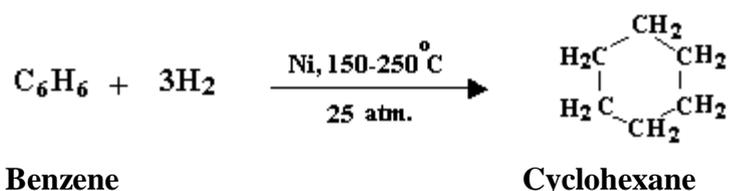
1- Cyclization

A dihalides can bring about coupling between two alkyl groups that are part of the same molecule.



2- Hydrogenation (Industrial source)

Addition of hydrogen to aromatic compounds yields cyclic aliphatic compounds, specifically cyclohexane derivatives. An important example of this is the hydrogenation of benzene to yield pure cyclohexane.

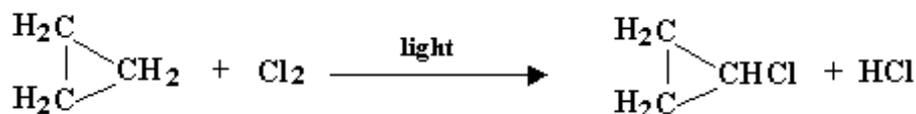


11.4 Reactions of Cyclic Hydrocarbons

Cyclic hydrocarbons show similar chemical properties to the open-chain compounds of the same structure. Cycloalkanes, like alkanes are quite unreactive toward most reagents.

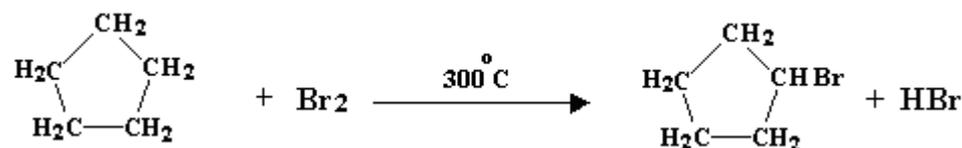
1- Substitution reaction

Cycloalkanes undergo chiefly free-radical substitution reaction.



Cyclopropane

Chlorocyclopropane



Cyclopentane

Bromocyclopentane

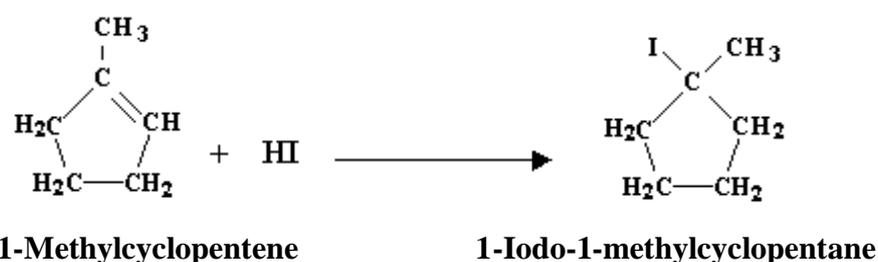
2- Addition and cleavage reactions

Cycloalkenes undergo chiefly addition reactions, both electrophilic and free-radical; like other alkenes, they can also undergo cleavage and allylic substitution.



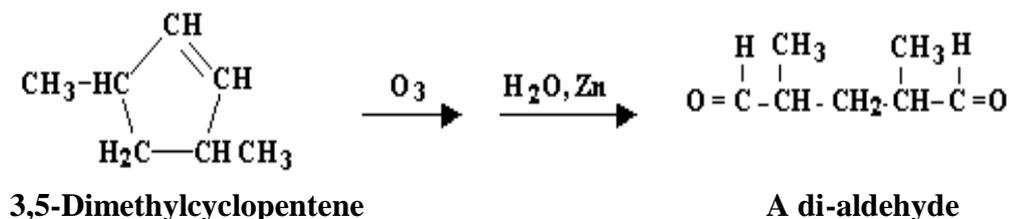
Cyclohexene

1,2-Dibromocyclohexane



1-Methylcyclopentene

1-Iodo-1-methylcyclopentane

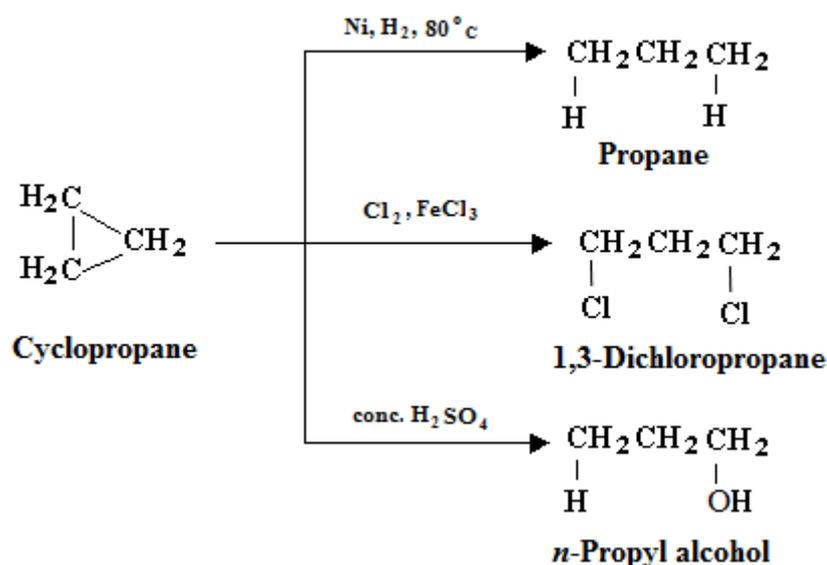


3,5-Dimethylcyclopentene

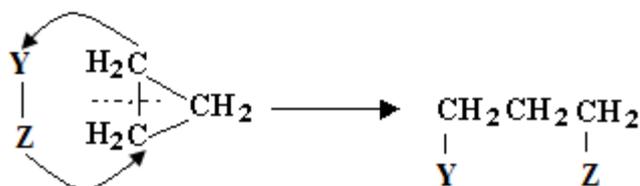
A di-aldehyde

Reactions of small-ring compounds. Cyclopropane and cyclobutane

Besides the free-radical substitution reactions that are characteristic of cycloalkanes and of alkanes in general, cyclopropane and cyclobutane undergo certain addition reactions. These addition reactions destroy the cyclopropane and cyclobutane ring system, and yield open-chain products.



In each of these reactions a carbon-carbon bond is broken, and the two atoms of the reagent appear at the ends of the propane chain:



11.5 Conformations of Cycloalkanes

If we start with cyclohexane and make a model of the molecule, and examine the conformations that are free of *angle strain*.

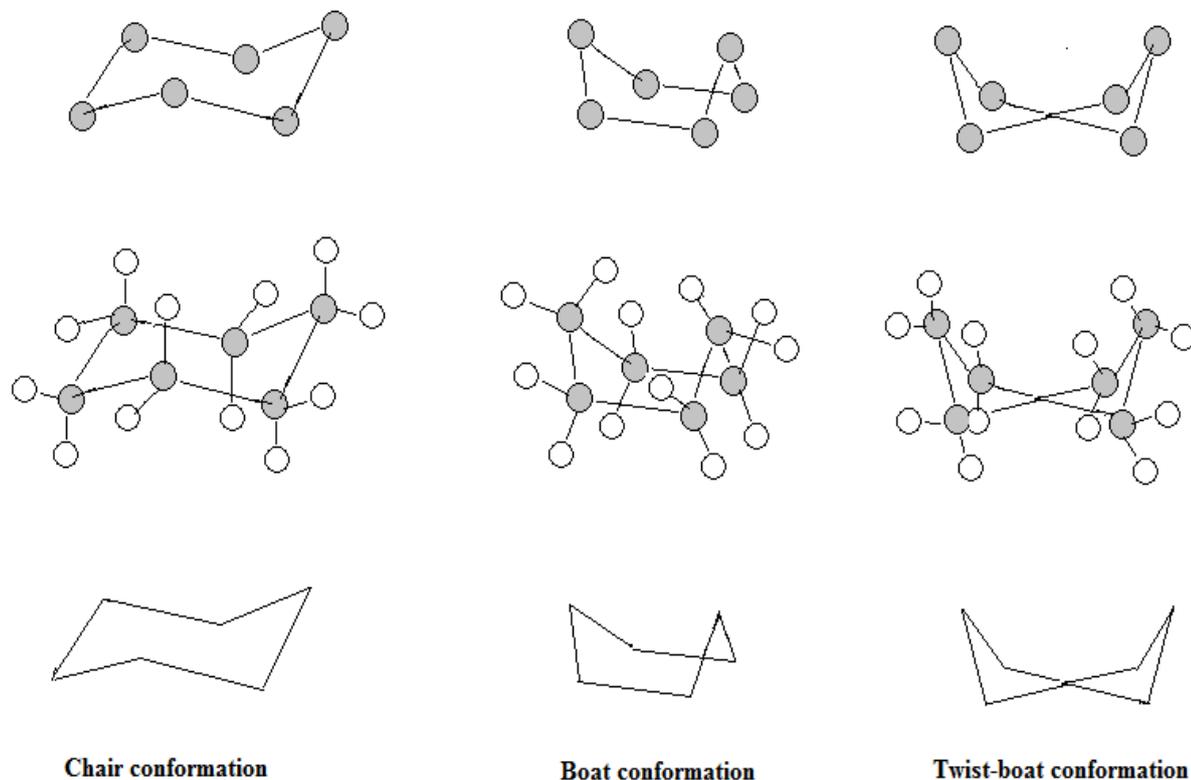
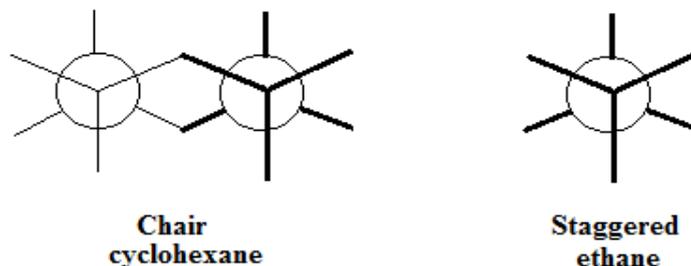


Figure 11-1 Conformations of cyclohexane that are free of angle strain

(Baeyer proposed that when carbon is bonded to four other atoms, the angle between any pair of bonds is the tetrahedral angle 109.5° . But the ring of cyclopropane is a triangle with three angles of 60° , and the ring of cyclobutane, is a square with four angle of 90° . In cyclopropane and cyclobutane, therefore, one pair of bonds to each carbon cannot assume the tetrahedral angle, but must be compressed to 60° or 90° to fit the geometry of the ring.

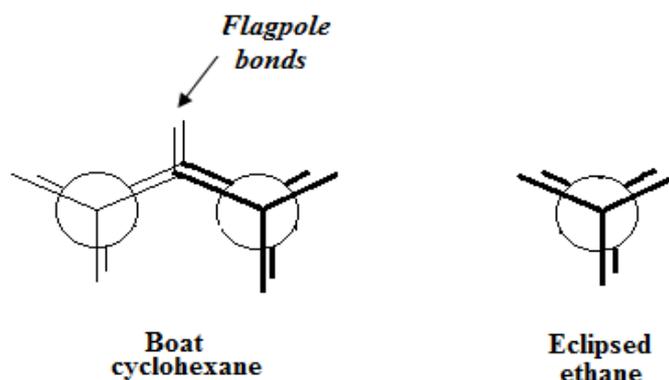
These deviations of bond angles from the normal tetrahedral value cause the molecules to be *strained*, and hence to be unstable compared with the molecules in which the bond angles are tetrahedral. Cyclopropane and cyclobutane undergo ring-opening reactions since these relieve the strain and yield the more stable open-chain compounds).

In the **chair form**, (Figure 11.1) if we look along each of the carbon-carbon bonds in turn, we see in every case perfectly staggered bonds.

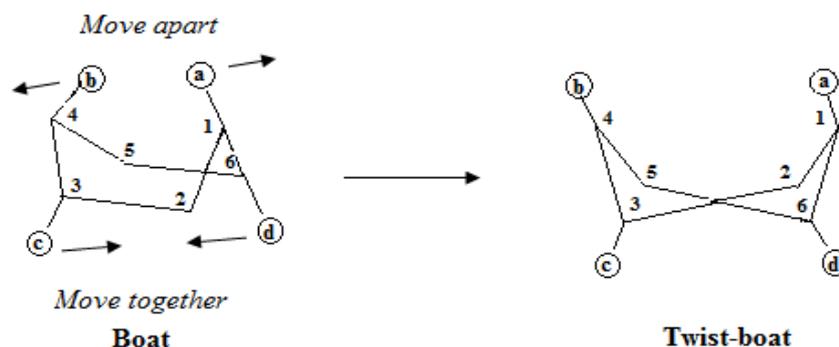


The conformation is thus not only free of angle strain but free of torsional strain as well. It lies at an energy minimum, and is therefore a conformational isomer. The chair form is the most stable conformation of cyclohexane, and, indeed, of nearly every derivative of cyclohexane.

If we flip the left end of the chair cyclohexane up to make the boat conformation, this involves only rotations about single bonds; what we are making are indeed conformations. If we look along either of two carbon-carbon bonds, we see sets of exactly eclipsed bonds, and hence we expect considerable torsional strain: as much as in two ethane molecules. In addition, there is van der Waals strain due to crowding between the flagpole hydrogens, which lie only 1.83 \AA apart. The boat conformation is less stable than the chair conformation; it is thus not a conformer, but a transition state between two conformers.



To see these two conformers, let us hold a model of the boat conformation with the flagpole hydrogens (H_a and H_b) pointing up, and look down through the ring.



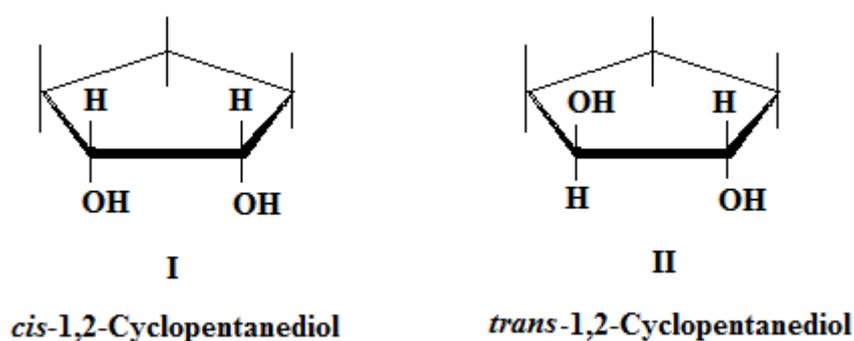
Cyclohexane

We grasp C-2 and C-3 in the right hand and C-5 and C-6 in the left hand, and twist the molecules so that, C-3 and C-6 go down, and C-2 and C-5 come up. As we do this, H_a and H_b move diagonally apart, and we see (below the ring) a pair of hydrogens, H_c and H_d (on C-3 and C-6, respectively), begin to approach each other. (If this motion is continued, we make a new boat conformation with H_c and H_d becoming flagpole hydrogen). When the $H_a - H_b$ distance is equal to the $H_c - H_d$ distance, we stop and examine the molecule. We have minimized the flagpole-flagpole interaction, and at the same time have partly relieved the torsional strain at the C(2) – C(3) and C(5) – C(6) bonds.

This new configuration is the **twist-boat form**, which is a conformer.

11.6 Stereoisomerism of Cyclic Compounds: *cis* and *trans* Isomers

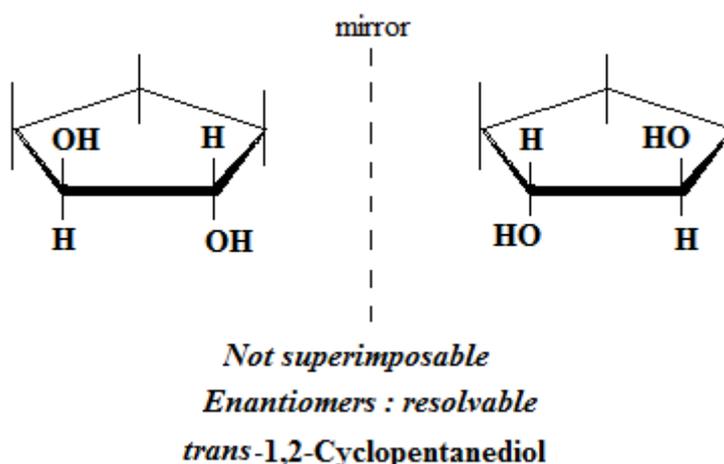
In the compound 1,2-Cyclopentanediol, if both hydroxyls lie below (or above) the plane of the ring, it is *cis*, or one hydroxyl lies above and the other lies below the plane of the ring, it is *trans*. I and II cannot be superimposed, and hence are isomers.



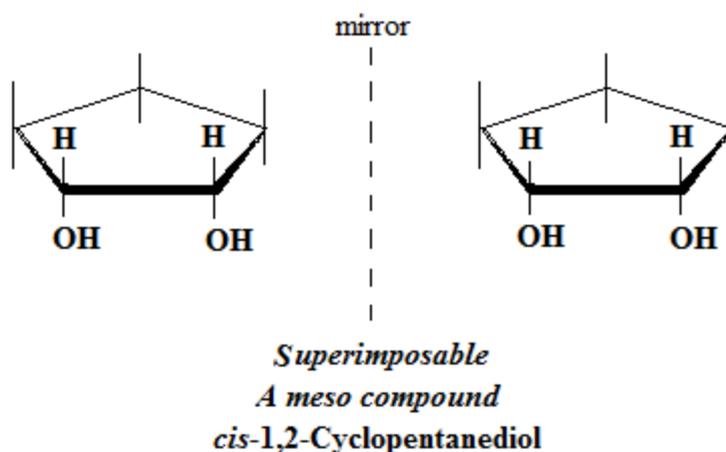
No amount of rotation about bonds can interconvert I and II, and hence they are not conformational isomers. They are configurational isomers; they are interconverted only by breaking of bonds. They are not mirror images, and hence are diastereomers, they should, therefore, have different physical properties.

If we examine models of *cis* and *trans*-1,2-Cyclopentadiol, we find that each of them contains two chiral centers. Compounds containing more than one chiral center are often but not always, chiral.

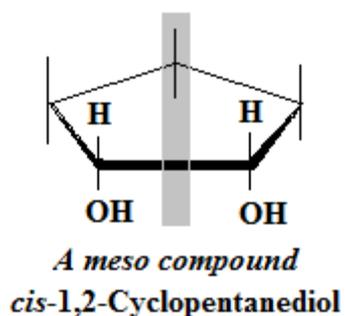
The *trans* diol is chiral, and the two models we have constructed therefore correspond to enantiomers. The models are not interconvertible by rotation about single bonds. They therefore represent, not conformational isomers, but configurational isomers; they should be capable of isolation (resolution), and when isolated, each should be optically active.



The compound *cis*-1,2-Cyclopentane-1,2-diol also contains two chiral centers, but it is not chiral. It is superimposable on its mirror image. It cannot exist in two enantiomeric forms, and cannot be optically active. It is a *meso* compound.



We can recognize the compound as a *meso* structure on sight from the fact that one half of the molecule is the mirror image of the other half.



What is the relationship between the *meso cis* diol and either of the enantiomeric *trans* diols? They are diastereomers, since they are stereoisomers that are not enantiomers.

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