alicyclic compounds

Geometrical isomers are now classified as diastereoisomers. According to the new definition, diastereoisomers are an stereoisomers which are not enantiomers of each other. i.e. the restriction that diastereoisomers acc optical isomers has been dropped. Thus This type of isomerism cis-trans or geometrical is a sub-class of general phenomenon of diastereoisomerism.

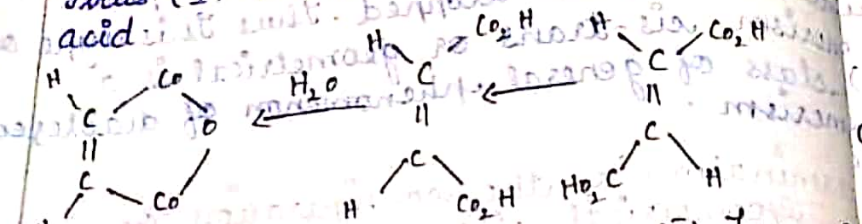
Determination of the configuration of Geometrical isomers

There is no general method for determining the configuration of geometrical isomers. In practice one uses a number of different methods; the method used depending on the nature of the compound. The following are methods which may be used mainly for compounds that owe thei geometrical isomerism to the presence of a double bond, but several of the methods ar special to geometrical isomers possessing a cyclic structure.

Method of Cyclisation

Waslicenus was the first to suggest the principle that intramolecular reactions are more likely to occurs the closes together the reacting gps are in th molecule. This principle appears always to be true for reactions in which ring are formed but does not hold for reactions in which a double (or is produced.

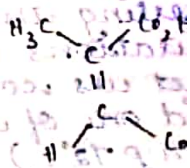
(a) Of the two acids malic and only the former readily forms a anhydride when heated; the latter not form an anhydride of its own, when strongly and gives maleic Thus (I) maleic acid and (II) is fu acid



(I) Maleic acid (II) Fumaric

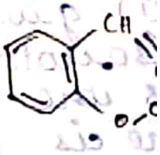
Cyclisation reactions must be per carefully since one isomer may connected into the other during the cyclising process and so lead to unreliable results. Since maleic acid cyclises readily, and fumaric acid after prolonged heating, the former most probably the cis-isomer and latter the trans which forms maleic anhydride via the formation of mal acid. The correctness of conclusion of the configurations of two acids may tested for hydrolysing maleic anhy in the cold, only maleic acid is obtained. Under these mild condition it is most unlikely that interconv occurs and so we may accepts (I) as the configuration of maleic acid.

(b) Citracon readily, wh mesaconic but much acids are



citraconic

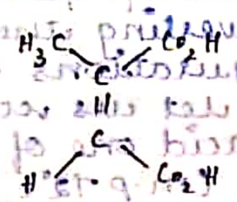
(c) There one of coumari the form acid. a coumar



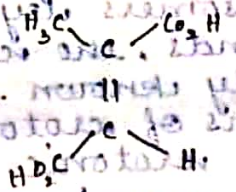
couma

(d) acid cycli Thus the

(b) Citraconic acid forms a cyclic anhydride readily, whereas the geometrical isomer, mesaconic acid, gives the same anhydride but much less readily. Thus these two acids are :

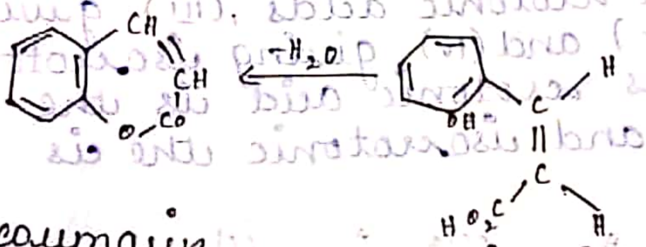


citraconic acid



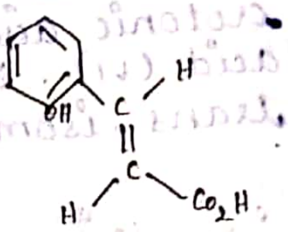
mesaconic acid

(c) There are two o-hydroxy cinnamic acids, one of which spontaneously forms the lactone, coumarin, whereas the other does not. Thus the former is the cis-isomer, coumarinic acid, and the latter the trans-isomer, coumaric acid



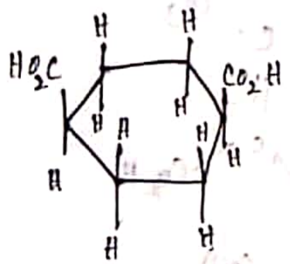
coumarin

coumaric acid

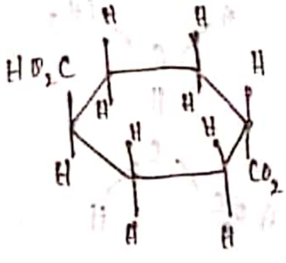


coumarinic acid

(d) Two forms of hexahydroterephthali acid are known, one of which forms a cyclic anhydride, and the other does not. Thus the former is the cis-isomer, and the latter the trans



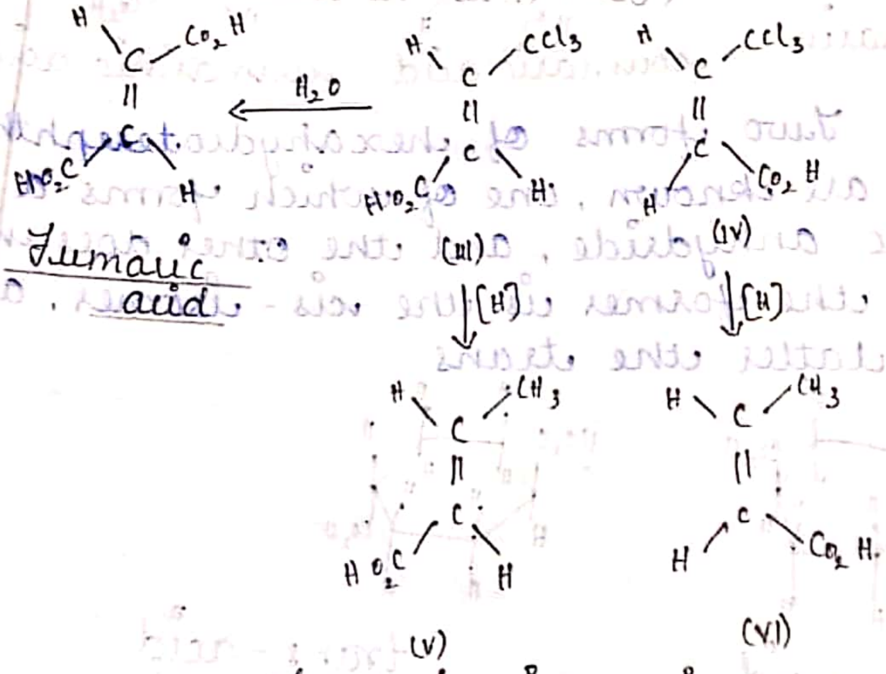
cis-acid



trans-acid

Method of conversion into compounds known configuration

In a no. of cases it is possible determine the configurations of pai geometrical isomers by converting then into compounds, the configurations of which already known. eg: let us con the two forms of crotonic acid one of w is known as crotonic acid (m.p 72°c) others as iso-crotonic acid (m.p. 15.15°c) Now there are two trichlorocrotonic acids and (IV), one of which can be hydrolys to fumaric acid: this trichlorocrotonic must be the trans-isomer (III) consequen the other is cis-isometric. Both these trichlorocrotonic acids may be reduced sodium amalgam and H_2O or by Zn a CH_3COOH to the crotonic acids, (III) givi crotonic acid (v) and (IV) giving isocroto acid (VI). Thus crotonic acid is the trans-isomer and isocrotonic the cis (Von auwers et al., 1923)

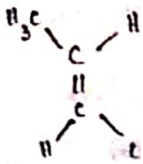


Fumaric acid

crotonic acid

isocrotonic ac

eg: Redu
the tran
(seq. tra



Method

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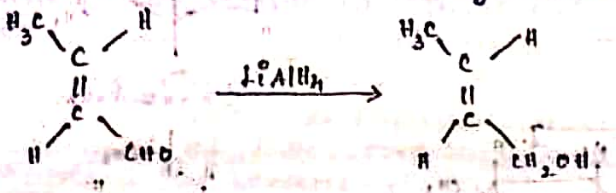
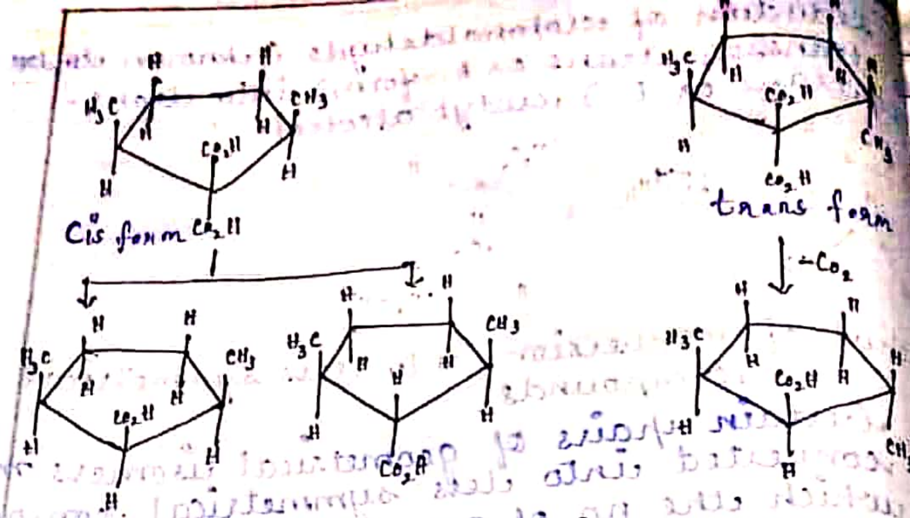
Eg: Reduction of crotonaldehyde (known to be the trans(seq trans or E-form) into trans-(seq trans or E-) crotyl alcohol"



Method of conversion into less symmetrical compounds

Certain pairs of geometrical isomers may be converted into less symmetrical compounds in which the no. of geometrical isomers is increased and by considering the no. of products obtained from each original stereoisomer it is possible to deduce the configurations of the latter.

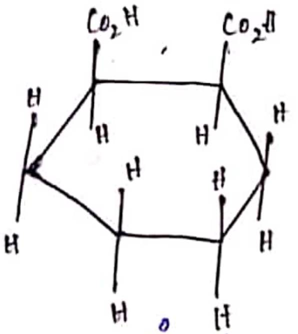
Eg: there are two 2,5-dimethyl cyclopentane 1,1-dicarboxylic acid and these, on heating are decarboxylated to 2,5-dimethyl cyclopentane-1-carboxylic acid. Consideration of following chart shows that cis-form of the original dicarboxylic acid can give rise to two stereoisomeric monocarboxylic acids, whereas the trans-form can produce only one product. Thus the configuration of dicarboxylic acids are determino

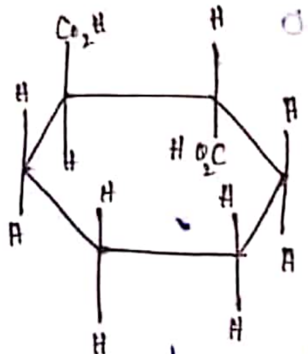


Methods of optical activity

In many pairs of geometrical isomers one for may posseses the requisments for optical activity, where the other form may not. In such cases success of resolution of one form will determine the configuration.

Eg: There are two hexahydroterephtha acids; the cis-for possesses a plane symmetry and consequently is opticall in active. The trans-form, however, possesses elements of symmetry, and so should be resolvable; this has actua been resolved.


Cis-form
Optically inactive


trans-form
re-Solvable

Methods of dipole moments

The use of dipole moments to assign configurations to geometrical isomers must be used with caution. The method is satisfactory so long as gps attached to the olefinic carbon atoms have linear moments

Eg: cis-1,2-dichloroethylene has a dipole moment of 1·85D the value of the dipole moment of trans-isomer is zero. when, however, the gps have non-linear moments then the vector sum in the trans-isomer will also longer be zero and the difference between dipole moments of cis and trans-isomers may be too small to assign configuration with any confidence

Eg: The dipole moment of diethyl maleate is 2·54D and that of diethyl fumarate is 2·38D.

Methods based on generalisations of Physical properties

Comparison of the physical properties of geometrical isomers of known configurations has led to the following generalisations.

(a) The melting point and intensity of adsorption of the cis-isomer are lower than those of the trans.

(b) The boiling point, solubility, heat of combustion heat of hydrogenation, density, refractive index, dipole moment and dissociation constant (if the compound is an acid) of the cis-isomer are greater tha those of the trans

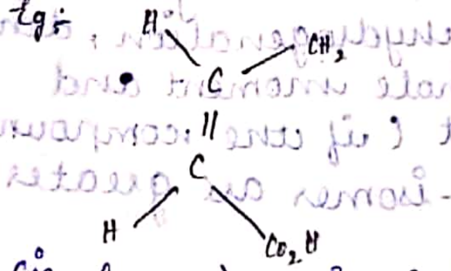
Based on certain of these gen ations is the Auwers-Skita rule (19 viz in a pair of cis-trans isomers the the higher boiling point, density and index. This rule has been used to configurations, particularly in terpene chemistry.

(Eg) the methones shown that the this rule. It can be seen from the physical properties that the trans- usually the stabler of the two isomers that is the trans-isomer is the form the lower internal energy.

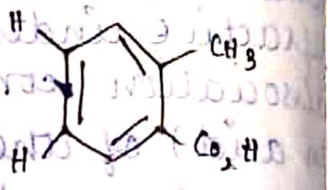
Thus in general, the above physi properties may be used to determine configurations of unknown geometrical isomers, but the results should always accepted .... Since exceptions are

Another method based on generalisati physical properties is suggested by (1904) pointed out that ethylenic cis isomers may be compared with the o and para-isomers in the benzene se the assumption being made the me point of the cis- and ortho-isomers lower than those of corresponding tra and para-isomers.

Eg:



Cis – (or -) crotonic acid
M.P. 15.5°c



O- toluic acid
M.P -105°c

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Conformation of Alkanes.

Alkanes are characterised by sigma bonds. As electron distribution of the sigma molecular orbital is symmetrical around the internuclear axis of a sigma bond (say, a carbon-carbon bond), the sigma bond or the single covalent bond permits free rotations around its axis. As a result, it is possible for such a compound to have different relative arrangements of their atoms in space which can change into one another. Such arrangements of atoms which can be converted into one another by rotation around single bonds are called conformations. Alkanes for example, have an infinite number of conformations by rotation around carbon-carbon single bonds. Each form is known as a conformer and this type of isomerism is known as conformational isomerism.

(1) Conformations of ethane.

Ethane molecule contains a carbon-carbon single bond and each carbon is further attached to three hydrogen atoms. If we allow one of the carbon atoms to rotate about the carbon-carbon bond while the other carbon remains stationary, an infinite number of arrangements of the hydrogens of one carbon with respect to other are obtained (this can be more easily demonstrated if we take a ball-and-stick model of ethane. In all these arrangements called conformations, the bond angles and bond lengths characteristic of the ethane molecule remain the same.

In the conformation given on the (also known as the staggered conform hydrogens are as far apart as possible whereas in the conformations given on right (aka eclipsed conformation) hy are crowded together and almost eclip each other. The infinite number of intermediate conformations are known skew conformations.

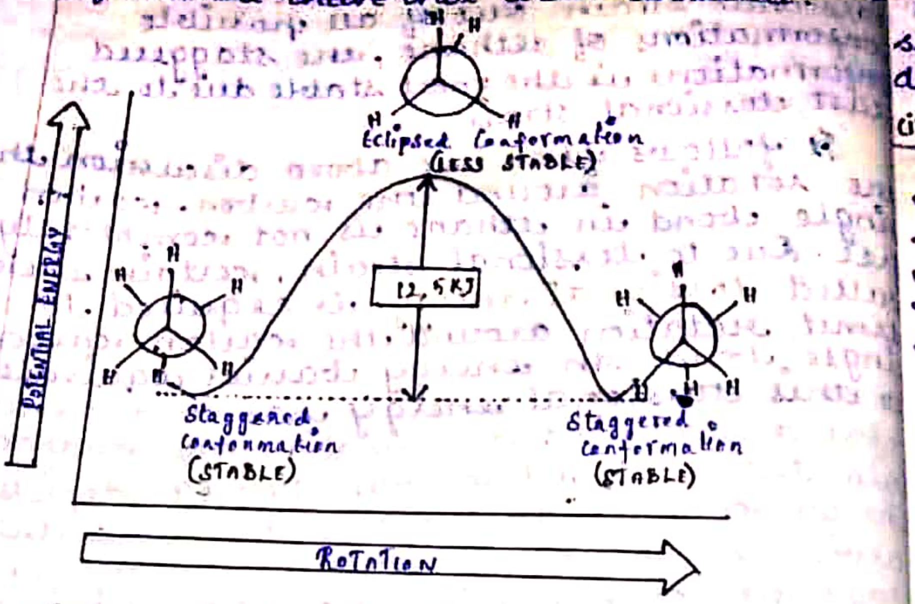
Dominant conformations of ethane.

The actual structure of ethane no doubt represented by all the infi number of possible conformations of mentioned above, but the ethane mo spends most of its time in the stagg conformation. In other words, stagge conformation is the dominant conform of ethane molecule.

Ethane molecule has six carbon hydrogen bonds attached to the centr carbon-carbon single bond. In the staggered conformation, the electron of these carbon-hydrogen bonds are as apart as possible. When the staggered conformation changes into the eclipse conformation, these electron clouds are to each other. There would be maxim repulsive interactions between these electrons clouds in the eclipsed confo thereby increasing the energy of the molecule (hence lowest stability) in eclipsed conformation as compared t other conformations (skew and stagge

Hence, the staggered conformation will have least energy and maximum stability for similar reasons. This repulsive interaction between the electron clouds which affects the stability of a conformation is known as torsional strain. Out of all possible conformations of ethane, the staggered conformations is the most stable due to the least torsional strain.

It follows from the above discussion that the rotation around the carbon-carbon single bond in ethane is not completely free. Due to torsional strain, certain energy called torsional energy, is required to permit rotation around the carbon-carbon single bond. An energy barrier equivalent to this torsional energy has to be overcome before a staggered conformation can change into the eclispsed conformation. eg: depicts energy changes during rotation about the carbon-carbon single bond in ethane. The staggered conformation has the minimum and the eclisped conformation the maximum potential energy. The energy difference between the two extreme conformations is 12.5 KJ/mol and it constitutes the energy barrier to rotation about the carbon-carbon bond. This energy barrier of 12.5 KJ/mol is rather small. Even at ordinary temperatures, the ethane molecules possess thermal or kinetic energy sufficient to overcome this energy barrier of just 12.5 KJ/mol through effective intermolecular collisions and the different conformations of ethane can read change into one another. In other words, rotation about the carbon-carbon single bond in ethane is almost free for al practical purposes, and it is not pos to separate the different conformations ethane. Actually, these different con of ethane have not been isolated.



ENERGY CHANGES DURING ROTATION ABOUT CARBON- CAR SINGLE BOND IN ETHANE

The study of the energetics of diffe conformations of a molecule is known a conformational analysis. It can help us predict which conformations of a molecu are favoured or unfavoured in a reaction.

Let us try to understand how the Planar representation of a conformation i done in practice. Two systems currentl used for drawing conformations on paper

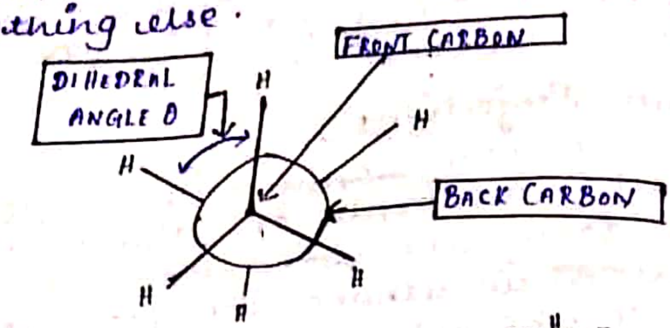
(i) Newman projections
(ii) Sawhorse

structures. Let us consider these two systems in detail before we continue our discussion about the " conformations of alkanes.

(i) Newman Projections.

We can explain this system by taking the example of ethane. Look straight down the bond connecting the two carbons in ethane. The front carbon nearer to the eye is represented by a point and three atoms or groups are shown as attached to it by three lines drawn at an angle of 120° to each other (Y Shape). The back carbon farther from the eye is represented by a circle around the point and the three atoms/groups are shown by shorter lines at an angle of 120° at each other. Better make models and compare. The angle between the C-H bonds on the front carbon and the C-H bonds on the back carbon in Newman projections is called dihedral angle often represented by the Greek symbol θ. This can take n infinite number of values corresponding o the infinite number of conformations hat are possible. The eclipsed conformation as $\theta = 0^\circ$. The Newman projection of this nformation that are possible shows the ydrogen atoms on the back carbon to be dden (eclipsed) by those on the front rbon. The staggered conformation has

$\theta = 60°$ i.e the hydrogen atoms are stag halfway between the hydrogens on th carbon. The skew conformation has θ anything else.

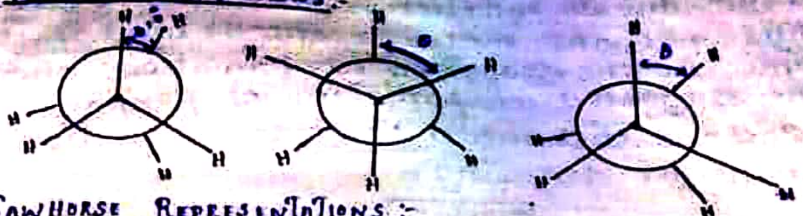


NEWMAN PROJECTION OF ETHANE

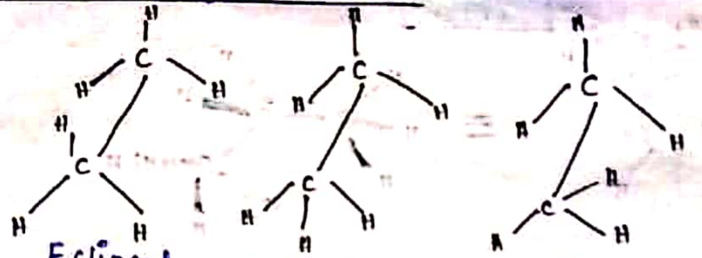
(ii) Sawhorse representations.

Here the molecule is viewed above and from the right. It is then projected on paper as indicated below central bond between two carbon atom drawn as a straight line slightly til right. For the sake of clarity the line drawn somewhat longer. The front ca is shown as the lower left hand carb whereas the rear carbon is shown as t upper right hand carbon. Each carbon has three lines attached to it correspo to the three atoms/groups, and these are at an angle of 120° to each other. E for example depicts the sawhorse representations of ethane staggered, eclipsed and skew conformations together with Newman projections.

NEWMAN PROJECTIONS:-



SAWHORSE REPRESENTATIONS:-

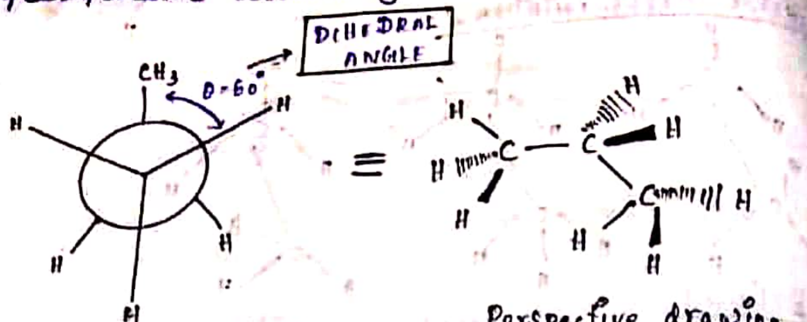


Eclipsed (θ = 0°) Staggered (θ = 60°) Skew (θ = anything else)

2) conformations of propane

Propane is a three-carbon alkane derived from ethane by replacing one of its six hydrogens with a methyl group. Rotation can take place about either of the two carbon-carbon single bonds. As in the case of ethane, rotation about the carbon-carbon single bond is almost free and the difference in energy between the staggered and eclipsed conformations of propane is 13.8 kJ/mol, only 1.3 kJ more than ethane. This energy difference is again too small to permit separation of the two extreme conformations of propane. The staggered conformations, with dihedral angle θ = 60° is the most stable conformation due to least torsional strain. The eclipsed conformation with θ = 0° is the least

stable due to maximum torsional stra
Thus, propane molecule spends most of
time in the staggered conformation. Th
the staggered conformation of propane
(Ball and stick model, Newman projection
perspective drawing)



Newman Projection - Perspective drawing

The eclipsed conformation of propane h
not been shown in, but in can be ea
imagined from the eclipsed conformati
of ethane, if we remember that prop
is just methyl substituted ethane. The
torsional strain arising from a carbon-
hydrogen bond eclipsing a carbon-meth
bond is only 1.3 kJ more than the strai
eclipsing two C-H bonds in ethane.

(3) conformation of n-butane.

n- Butane is four- carbon alkane de
from ethane by replacing one hydrogen
on each carbon with a methyl group. Th
is somewhat a complex molecule from
standpoint of conformations because there
are three carbon-carbon single bonds
(one central and two terminal) around wh

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which ro
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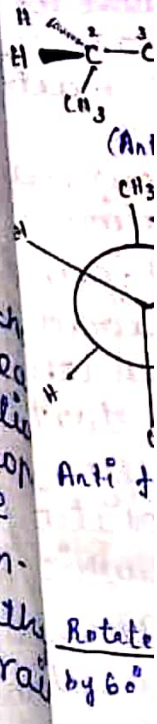
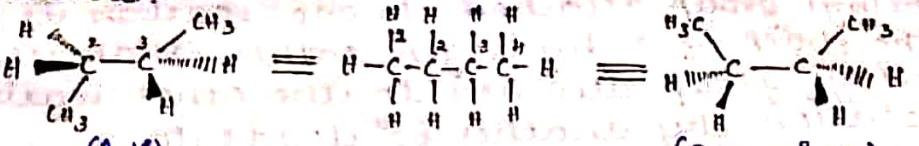
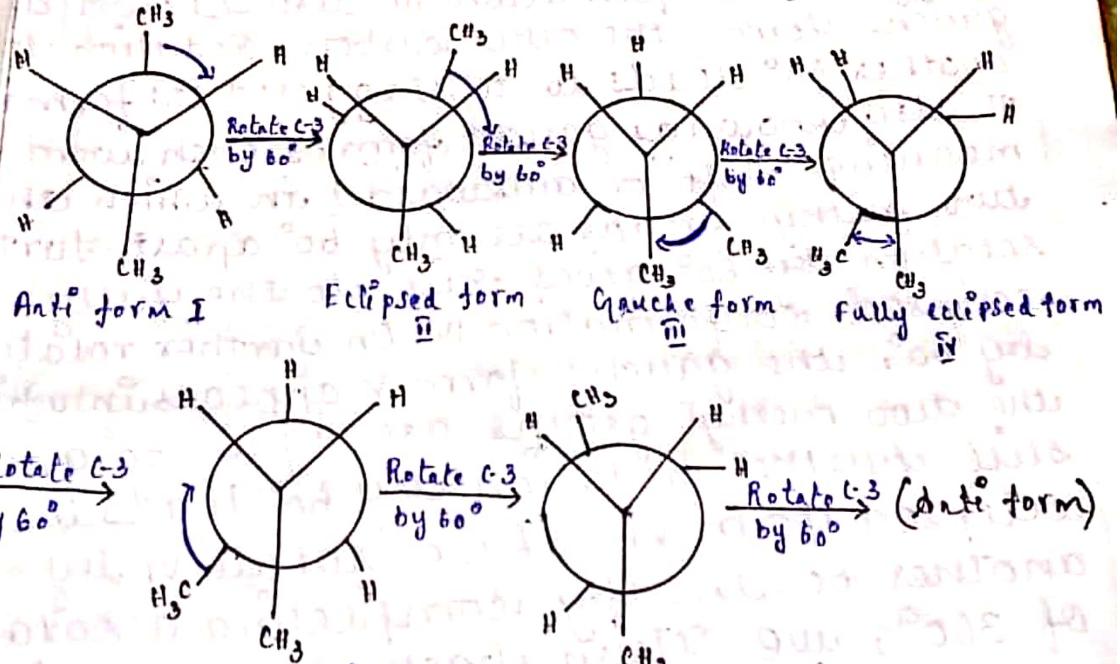


which rotation can take place. If we consider rotation about the central carbon-carbon bond ($C_2 - C_3$), situation is quite similar to that in the case of ethane, except that n-butane molecule has more than one staggered and eclipsed conformations. staggering/eclipsing in these conformations may be complete or partial, as shown below:



(Anti)

(Fully eclipsed)



Anti form I

Eclipsed form II

Gauche form III

Fully eclipsed form IV

Gauche form V

NEWMAN PROJECTIONS OF N-BUTANE CONFORMATIONS

The completely staggered confor
called the anti form shows the max
groups are as far apart as possible.
Assuming that the angle of rotation
the central C_2-C_3 bond is zero for
conformation I, if we rotate the C_3
atom through an angle of 60°, the
from II appears. In conformation II
methyl group attached to one carbon
the back of a hydrogen, rather than
methyl group attached to the other
Rotation by another 60° leads to a
staggered conformation III also know
gauche form, the other carbon. Rotati
another 60° leads to a staggered conf
III also known as gauche form (French
meaning "left" or awkward) in which
two methyl groups are only 60° apart.
rotation by 60° gives rise to the full
eclipsed conformation IV. On further rot
by 60°, the gauche form V appears in
the two methyl groups are again 60° a
still further rotation by 60° leads to
eclipsed form VI. If we rotate VI by
another 60° thereby completing a rota
of 360°, we return back to the anti

Relative stabilities of the conformation
n - Butane.

depicts the energy changes during rotation about C_2-C_3 bond in n-butane. The difference in energy contents of the anti conformation I and the fully eclips

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v) wo
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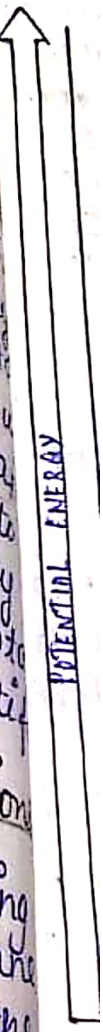
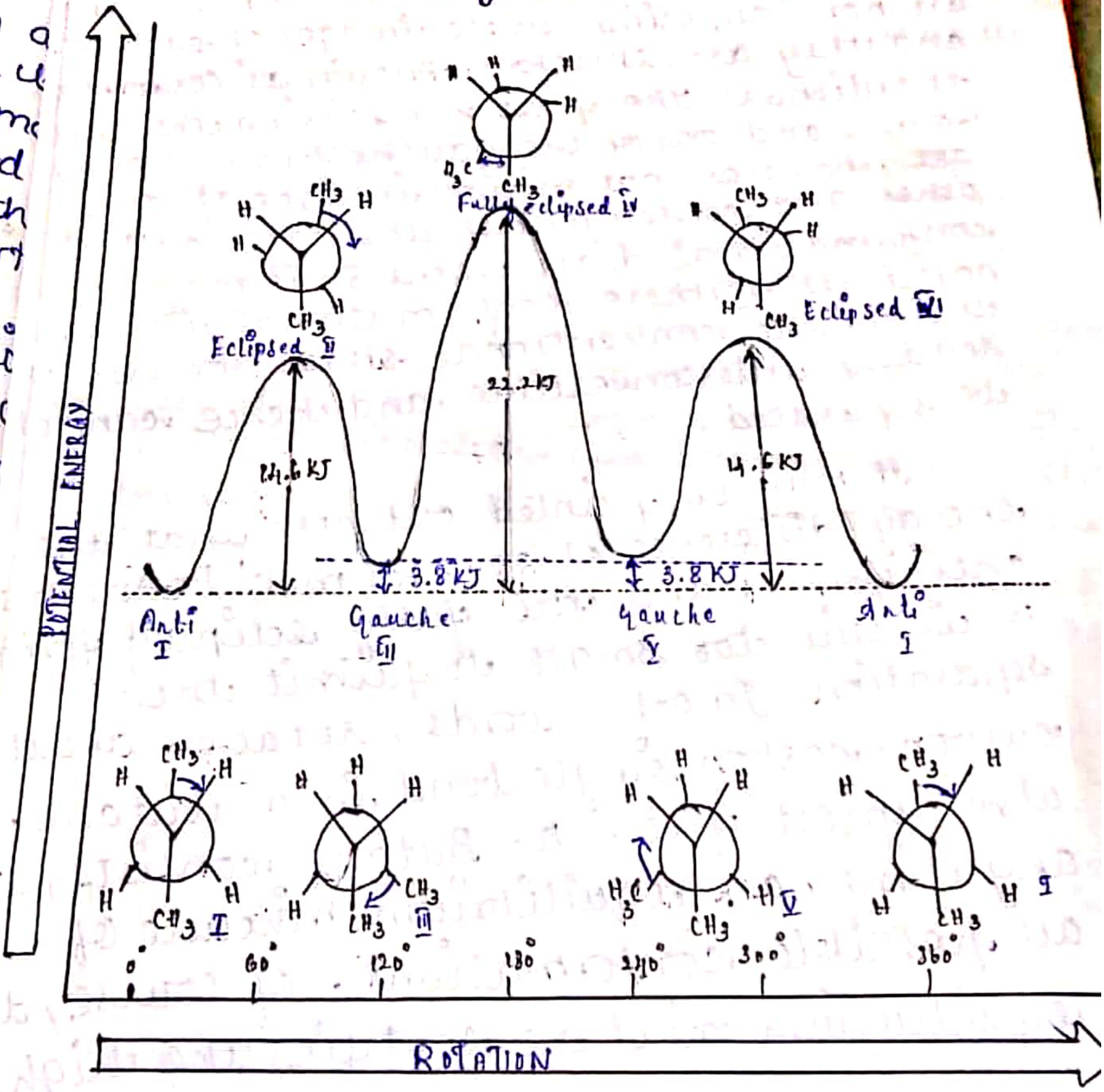
IV (t



conformation iv is about 22.2 kJ mol^{-1}; between the anti conformation I and gauche conformations (III or v) is about 3.8 kJ mol^{-1}. Obviously, the anti conformation I would be the most stable and the fully eclipsed conformation iv the least stable conformation of n-butane. The gauche conformations (III and v) would be slightly less stable than the anti conformation I, and the eclipsed conformations (II and VI) would be slightly more stable than the fully eclipsed conformation iv (two close -CH_3 groups).

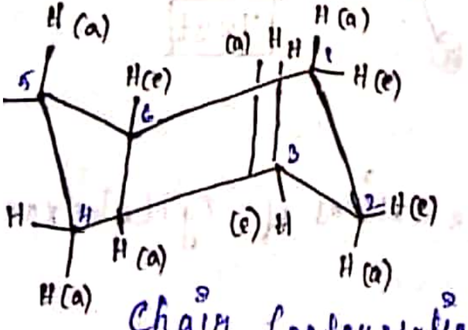


It is apparent from above that conformation I is only slightly (3.8 more stable than gauche conformati (III and V). Such staggered conformati have minimum or nearly minimum are often referred to as conformation isomers or conformers. As these conform isomers differ from one another only spatial relationship of atoms consti them, they are a kind of stereoisome other stereoisomers, conformational is may or may not be mirror images of e The two gauche forms (III and V) of n-bu are non-superimposable images of ea and they are, therefore, known as con enantiomers. The pair comprising the form I and one of the gauche forms (III are, however, not mirror images of e others and consequently they are cal conformational diastereomers. It may noted that these conformational iso unlike the conventional stereoisome readily interconvertible, and hence ca be separated

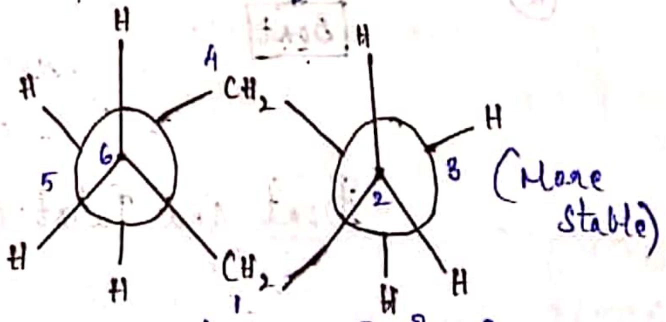
It may be pointed out here that energy difference of 22.2 kJ mol⁻¹ betw anti form I and the fully eclipsed IV is still too small to permit their separation. In other words, rotation ab carbon-carbon single bond in n-butan also almost free. n-Butane consists any time, an equilibrium mixture of all possible conformations. Of course equilibrium mixture contains the ch proportion of the anti conformation I and the least proportion of the fully eclipsed conformation IV.

Chair and Boat Conformations

It can be easily seen by constructing a model that cyclohexane can assume puckered conformations (chair and boat conformations). depicts the chair and boat conformations of cyclohexane. It shows that chair conformations has bond angles of 109.5° (no angle strain), has one CH_2 group puckered upwards and the next one puckered downwards. Further, Newman Projection in shows that the chair conformation has no eclipsing of the carbon-carbon bonds. Although boat conformation too has no angle strain (bond angle = 109.5°), it suffers some torsional strain due to the eclipsing of bonds. This eclipsing forces two of the hydrogens on the ends of the boat to interfere with each other. These end hydrogens have been designated as flagpole hydrogens because they point upwards from the ends of the boat like flagpoles. Newman projection of the boat conformation also shows eclipsing of the bonds more clearly. The symmetrical boat conformations shown actually exists as a slightly skewed twist boat conformation.



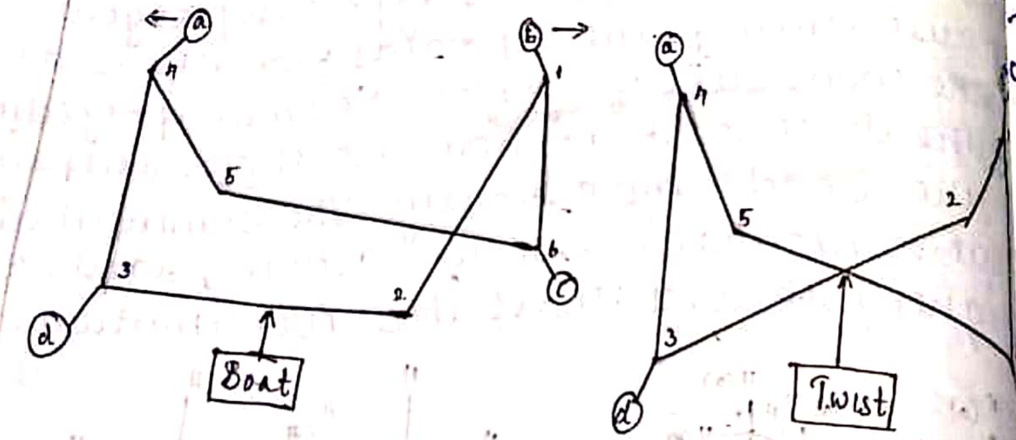
Chair Conformation
(a = axial, e = equatorical)



Newman Projection

Chair and Boat Conformations of Cyclohexane

Consider a model of the boat conforma
cyclohexane. If we hold C_2 and C_3 in
hand and C_5- C_6 in the other, and twis
molecule so that C_2 and C_5 come up a
and C_6 go down. During this twisting
flagpole hydrogens H_a and H_b move ap
hydrogens H_c and H_d tend to move clos
each other. As we continue this motion
boat conformation, in which H_c and H
become the flagpole hydrogens, is
obtained. The distance separating H
H_b is equal to that separating H_c an



Boat and Twist Conformations of Cyclohexane

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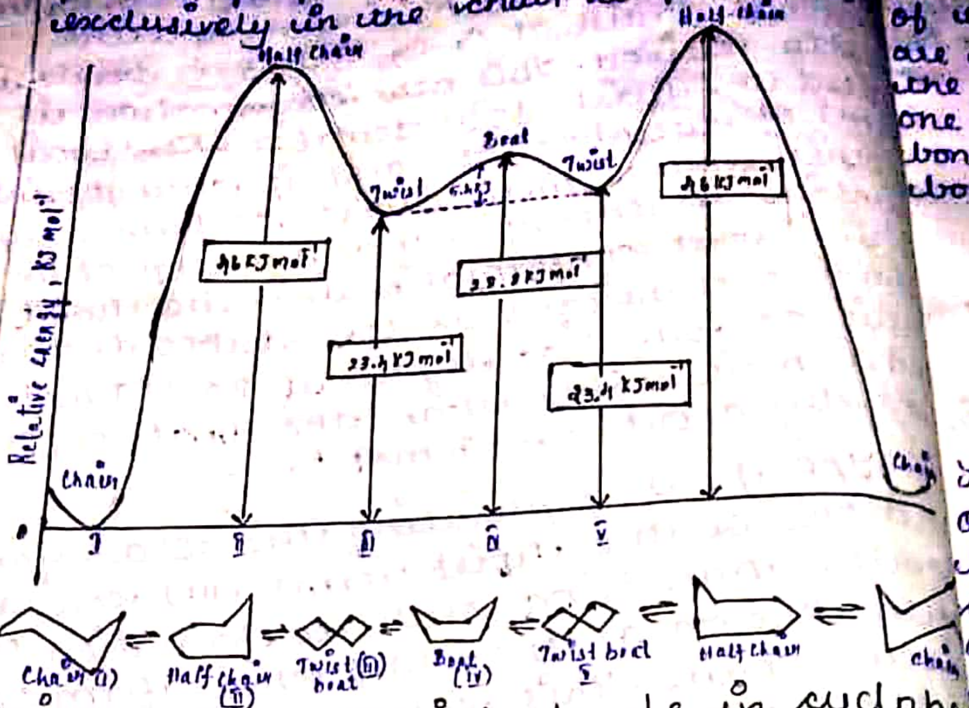
The non-bonded interactions between Ha and Hb and Hc and Hd are minimum, and the torsional strain at C_2-C_3 and C_5-C_6 bonds is partly releived. This new conformation is called the twist boat form (or skew boat form) of cyclohexane, and it changes into another enantiomeric twist conformer by climbing an energy hill at the top of which is the boat conformation (IV). The twist boat form of cyclohexane is less stable than the chair conformation by about 23.4 kJ mol^{-1}, and is more stable than the boat conformations by about 5.4 kJ mol^{-1}.

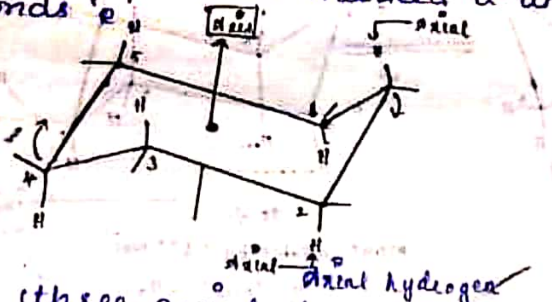
The peak separating the chair form(I) and one of the twist forms (III) corresponds to the transition state conformation (II), often known as the half chair form of cyclohexane. This conformation having considerable angle strain and torsional strain has about 46 kJ more energy than the chair conformation.

The chair form (I) and the two twist forms (III and V) are conformers but the transition state conformations viz. the half-chair form (II) and the boat form (IV) are not. The chair conformation (I) is, of course, the most stable conformation of cyclohexane. The relative distribution of cyclohexane molecules with chair conformation and the two twist conformations is about 0,000 to 1 at room temperature. For all practical purposes, cyclohexane exists al exclusively in the chair conformation



Axial and equatorial bonds in cyclohe

If we examine the model of the chair conformation of cyclohexane, we f that all the carbon atoms lie roughly a plane. six hydrogens lie in the pl and six hydrogens lie above or below plane. The hydrogens lying in the pl of the ring are called equatorial hydro because they are situated essentially the equator of the ring. The bonds hol such hydrogens are called the equato bonds. The hydrogens lying above or w the plane of the ring are called the axial hydrogens because they are sit along an axis perpendicular to the pla of the ring. The bonds holding such hydrogens are known as axial bonds. Each carbon in the chair conformation of cyclohexane has one equatorial and one axial bond. Axial bonds have been marked 'a' and equatorial bonds 'e'

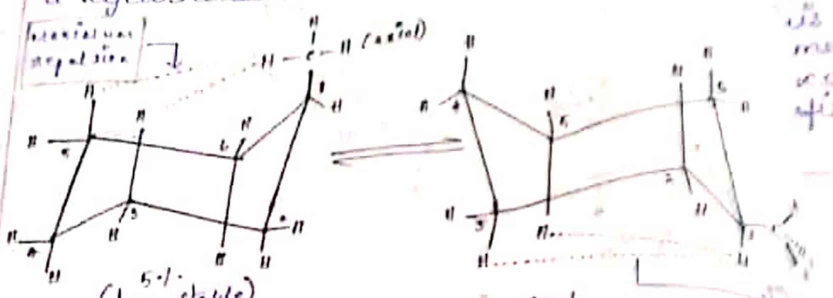


The three axial hydrogens on the same side of the molecule are located rather closely together, although they are attached to alternate carbon atoms. The distance between hydrogens on adjacent carbon atoms in cyclohexane is 230 pm and this distance is the same as observed between corresponding hydrogens in staggered ethane.

1,3-And 1,5-Diaxial interactions in Cyclohexane Derivatives

When a hydrogen in cylohexane is replaced by a larger atom (eg. Br) or a bulky group (eg - CH_3), it leads to crowding especially among atoms located on the three axial bonds on the same side (C-1, C-3, C-5) of the molecule. The non-bonded interactions between such axial atoms or groups which results from this crowding are referred to as 1,3-diaxial interactions. These 1,3-diaxial interactions can account for the

relative stabilities of various conform
a cyclohexane derivative, as illustrated



5% (less stable)

(a) axial - CH_3

95%

more stable by 7.5 KJ mol^{-1}

b) equatorial - CH_3

depicts the two chair conformations of cyclohexane, one in which $-CH_3$ group an equatorial position and the other, which the $-CH_3$ group occupies an axi position. It is obvious from their m that no hydrogens approach the equ $-CH_3$ as much as the axial $-CH_3$. The hydrogens on C-3 and C-5, in particul approach the axial $-CH_3$ on C-1 rather The axial $-CH_3$ group on C-1 is thus m crowded than the equatorial $-CH_3$ grou this should make the axial conformatio less stable than the equatorial confor Actually, the energy difference between equatorial and axial conformations is 7.5 KJ/mol and the equatorial conforma is almost the exclusive conformation most molecules of methylcyclohexane. Since the 1,3-diaxial interaction involv two hydrogens, the energy difference between equatorial and axial conformati is thus 3.7 KJ/mole for each 1,3-diaxial methyl hydrogen interaction. This crowding can be seen by constructing models of space filling molecular orbitals