

STEREOMERISM

ISOMERISM

Compounds having same molecular formula but different structures and properties are called isomers and the phenomenon is called isomerism



TYPES OF ISOMERISM

Basically isomerism is of two types

1. *Structural isomerism*
2. *Stereoisomerism*

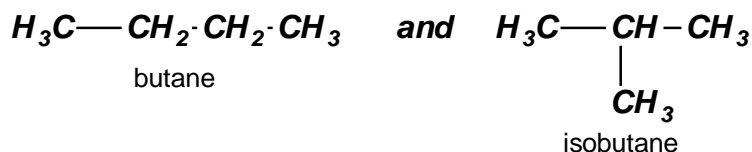
1. Structural Isomerism

Structural isomers differ from each other in the connectivity of atoms.

Structural isomerism is of five types

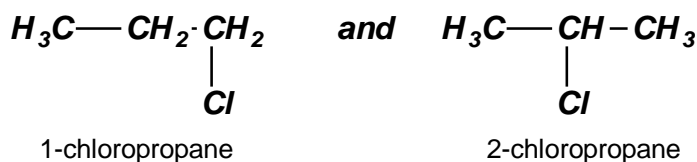
i) Chain Or Skeleton Isomerism

The isomers having same molecular formula but different carbon chains or skeletons are called chain isomers and the phenomenon is called chain or skeleton isomerism.



ii) Position Isomerism

The isomers having same molecular formula but different position of substituent or double or triple bond are called position isomers and the phenomenon is called position isomerism.



iii) Functional Group Isomerism

The isomers having same molecular formula but different functional groups are called functional group isomers and the phenomenon is called functional group isomerism.



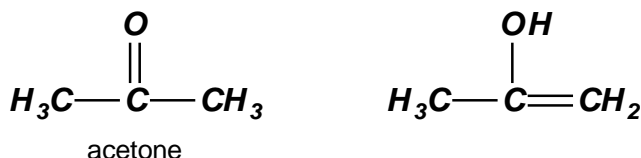
iv) Metamerism

The isomers having same molecular formula but different alkyl groups are attached to the same multivalent atom are called metamers and the phenomenon is called metamerism.



v) Tautomerism

The isomers having same molecular formula but different in the position of hydrogen atom with corresponding adjustment of the double bond are called tautomers and the phenomenon is called tautomerism.

2. Stereoisomerism

The isomers having equal number of same types of bonds with identical connectivity, but differing in spatial arrangement of atoms are called stereoisomers and the phenomenon is called stereoisomerism.

Stereoisomerism is of two types

i) Conformational Isomerism

The stereoisomers formed due to free rotation around a single bond and which can't be isolated at room temperature are called conformational isomers or rotational isomers or simply conformers. This phenomenon is called conformational isomerism.

ii) Configurational Isomerism

The stereoisomers, which can't be interconverted readily at room temperature and thus can be isolated are called configurational isomers and the phenomenon is called configurational isomerism.

It is of two types

a) Geometrical Isomerism

The isomerism, which arises due to restricted rotation around double bond, is called geometrical isomerism.

b) Optical Isomerism

The isomerism, which arises due to presence of property of handedness in organic molecules, is called optical isomerism.

CONFORMATIONAL ISOMERISM

The stereoisomers formed due to free rotation around a single bond and which can't be isolated at room T are called conformational isomers or rotational isomers or simply conformers. This phenomenon is called conformational isomerism.

The various conformers are interconvertible by about a single bond. However, the isolation of conformers is usually not possible because potential energy barrier for their interconversion is very low, which can be easily surmounted at room temperature.

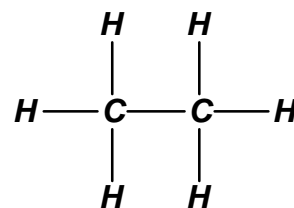
The study of energy changes of a molecule during free rotation around a single bond is called conformational analysis

COFORMATIONAL ANALYSIS OF ACYCLIC COMPOUNDS

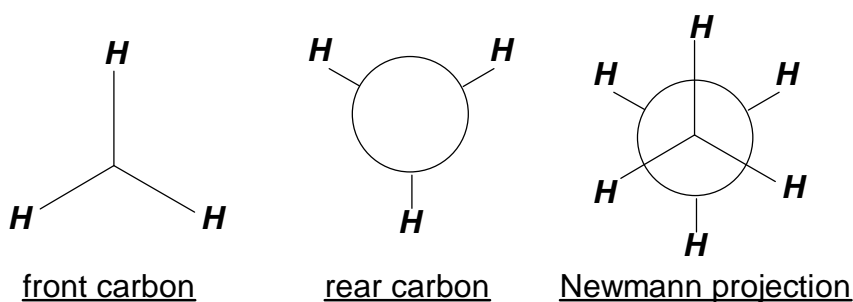
Ethane

In aliphatic hydrocarbons, there is present an energy barrier for rotation about single bonds. This energy barrier gives rise to various structure with different energies.

Consider the molecule of ethane. It's formula is shown
Ethane molecule contains two carbons. To see energy changes conveniently, both carbons of ethane molecule are represented on paper by Newmann projection.

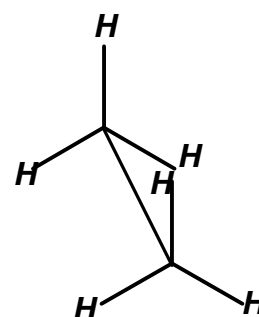
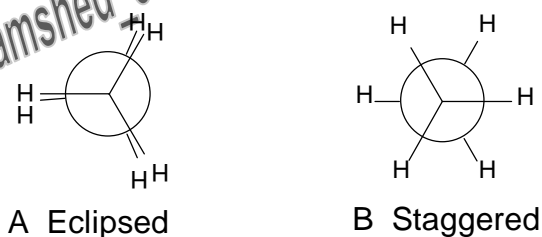


In Newmann projection, molecule is viewed from front to back along the direction of bond linking the two atoms. Thus front carbon with its bonds is completely visible, while rear carbon is not visible but its bonds are partially visible.



Ethane molecule can also be represented by saw horse projection.

Two extreme conformations of ethane are



In structures (A), hydrogens of front carbon are directly eclipsed by hydrogens of rear carbon. This conformation is called eclipsed conformation.

In this hydrogen are very close to each other, therefore, due to repulsions between them, energy of this form is the highest.

Now if the rear carbon is held stationary and front carbon is rotated by 60° then structure (B) is obtained. In structure (B), hydrogens are maximum distance apart, it is called staggered conformation. In this repulsions are minimum , therefore, energy of this form is the lowest.

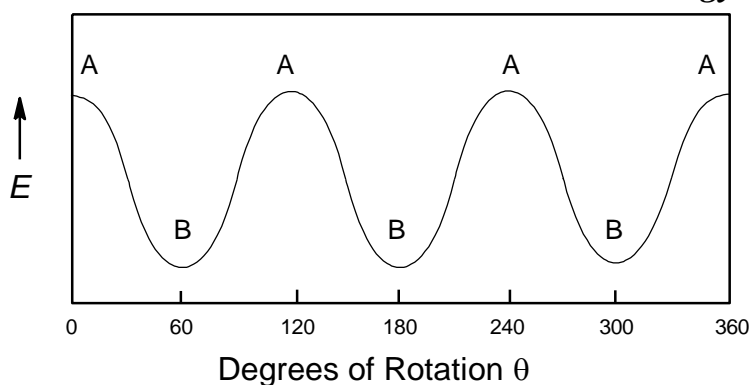
When angle is rotated from staggered position to eclipsed position, the potential energy of the ethane system gradually increases and molecule tends to resist rotation. This resistance is called torsional strain.

The angle of rotation is called torsional angle or dihedral angle.

The energy difference between staggered and eclipsed conformation is about 12.5 KJ/mol. In between these two conformations there also appears infinite conformations each with specific energy.

At room T , enough energy is available to molecules to surmount the energy barrier, hence conformers of ethane interchange so rapidly that they can't be isolated. However, most of the ethane molecules will be in staggered conformation due to its greater stability.

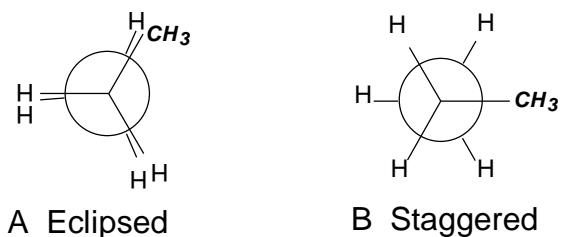
The energy diagram for complete 360° rotation is shown in the fig.



Propane

Two extreme conformations of propane are shown in the fig.

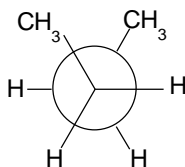
In eclipsed propane, hydrogen and methyl groups eclipse each other. Due to larger methyl group, the repulsive interaction between hydrogen and methyl group is greater than in ethane. Thus energy barrier between staggered and eclipsed conformation is 14.2 KJ/mol , which is greater than that in ethane.



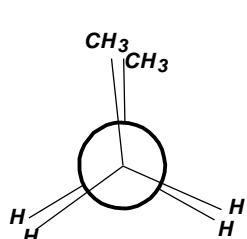
It also has 3 maxima and 3 minima during complete 360° rotation.

n-butane

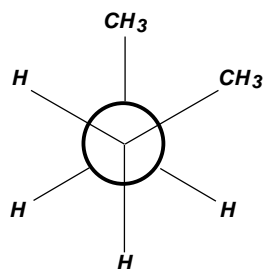
In Newmann projection n – butane can be represented as



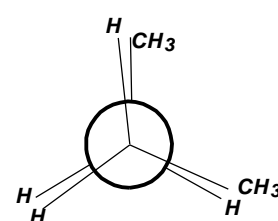
n – butane gives a number of conformers during a complete rotation of 360° . These conformers involve combination of methyl – methyl, methyl – hydrogen and hydrogen – hydrogen interactions.



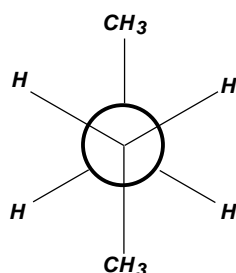
A-Fully Eclipsed



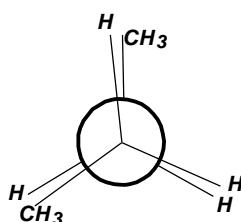
B Gauche Staggered



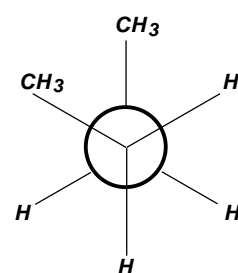
C Partially Eclipsed



D Antistaggered



E Partially Eclipsed



F Gauche Staggered

In addition to torsional strain between bonds, there is also Vander waals non – bonded repulsive interaction. This interaction is greater in methyl – methyl

combination than methyl – hydrogen combination, which in turn is greater than that of hydrogen – hydrogen interaction.

In butane there are two types of staggered conformations.

- In one form, methyl groups are maximum distance apart from each other. It is called antistaggered conformation (D). It has no torsional strain and is most stable form.
- In other form, methyl groups are adjacent to each other. It is called Gauche staggered conformation. There are two Gauche conformations (B and F), both of equal energy.

The difference of energy between antistaggered and Gauche staggered conformations is about 3.5 KJ/mol

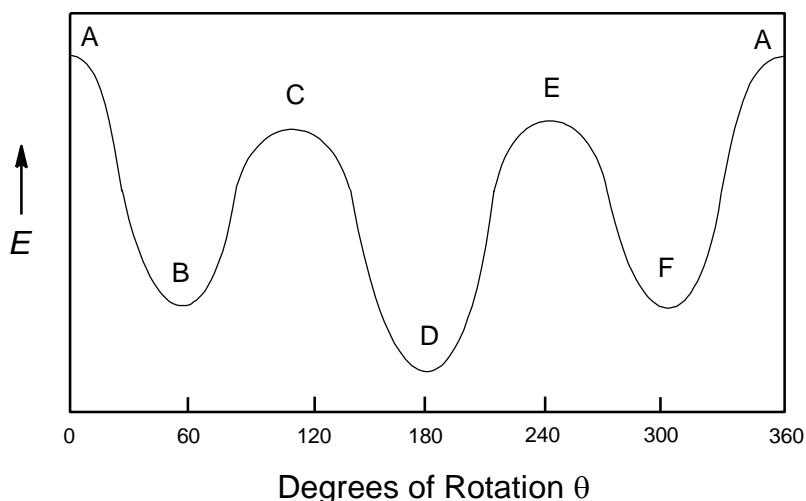
Similarly, in *n* – butane there are two types of eclipsed conformations.

- In one form, there are two methyl – hydrogen and one hydrogen – hydrogen eclipsed interactions. It is called partially eclipsed conformation. There are two such conformations (C and E), both of equal energy. Their energy relative to antistaggered conformation is 15.9 KJ/mol.
- In other form, there are two hydrogen – hydrogen and one methyl – methyl eclipsed interactions. It is called fully eclipsed conformation (A).

Its energy relative to antistaggered conformation is 18.8 KJ/mol

n – butane, largely exists in staggered conformations. Eclipsed conformations are generally transitory.

At room *T*, various conformers of *n* – butane are readily interconvertible, hence can not be isolated. However, at very low *T*, e.g. at -230°C , *n* – butane is considered to be a mixture of 70% anti and 30% Gauche forms.

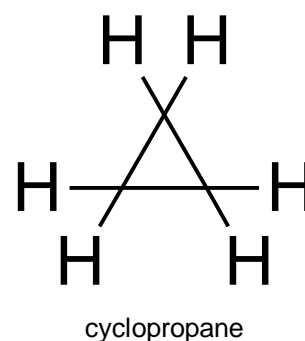


CONFORMATIONAL ANALYSIS OF CYCLOALKANES

Cyclopropane

Cyclopropane has a planar triangular geometry, with bond angles of about 60° .

Due to very small angles, there is a lot of angle strain in cyclopropane in addition to the torsional strain due to six eclipsed hydrogens.

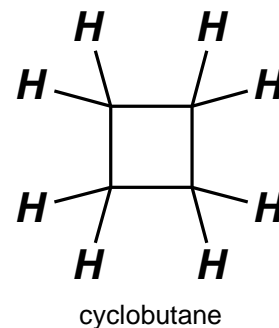


Cyclobutane

In cyclobutane, the angles are of 90° . This angle is smaller than normal tetrahedral angle 109.5° but greater than that of cyclopropane. Thus angle strain in cyclobutane is less than in cyclopropane.

In cyclobutane torsional strain is greater than in cyclopropane, due to eight eclipsed hydrogens.

However, cyclobutane can exist in non – planar



conformation, with one out of plane carbon. This conformation has increased angle strain than normal, which is, however, compensated by less eclipsing interactions of hydrogens.

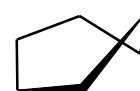
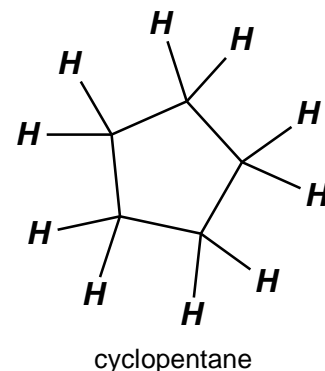
Cyclopentane

In planar cyclopentane, the angles are of 108° , very close to normal tetrahedral angle 109.5° .

However, in this structure, ten eclipsing hydrogens cause significant torsional strain.

In another conformation, molecule adopt an envelope shape with one out of plane carbon.

This form is a dynamic conformation, in which all five carbon go out of plane one by one. These conformations has increased angle strain but less eclipsing interactions, because hydrogens of out of plane carbon atom are fully staggered.



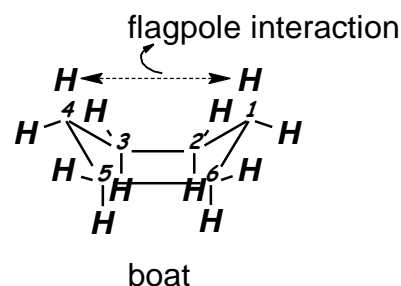
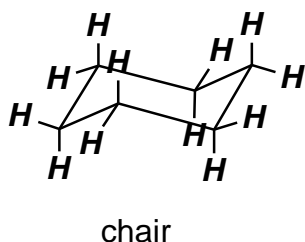
Cyclohexane

If cyclohexane is considered planar, then all the angles would be of 120° . But in this structure there is large torsional strain due to large eclipsing action of 12 – hydrogens.

But cyclohexane is considered to be the most strain free cycloalkane. This is possible only if cyclohexane ring is considered non – planar. Such ring is called puckered.

Two main conformations of cycloalkanes are chair conformation and Boat conformation.

Both these conformation are shown below



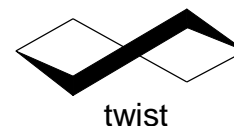
In chair conformation, angles are normal tetrahedral angles. All the hydrogens in cyclohexane are fully staggered, thus chair conformation is free of torsional strain.

Chair form is a rigid conformation

In boat conformation, there are four pairs of eclipsed hydrogens. Thus it has torsional strain. Moreover, hydrogens on C – 1 and C – 4 are very close to each other and have Vanderwaal's non-bonded repulsive interaction. This interaction is called flag – pole interaction. Both torsional strain and flag pole interaction makes the boat form less stable than chair form.

Boat form is a flexible form and can twist to get some what stable twist conformation.

In twist form, although there develops some angle strain, but torsional strain and flag – pole interactions are very less, which makes it stable than boat form.



Chair conformation is more stable than boat conformation by about 27.2 KJ/mole .

Twist conformation is more stable than boat conformation by about 6.3 KJ/mole .

In chair conformation, six carbons are present in two parallel planes, each containing three alternate carbons.

12 – H atoms of cyclohexane can be divided into two sets of bonds.

Axial C – H Bonds

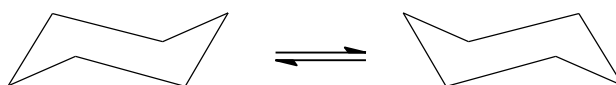
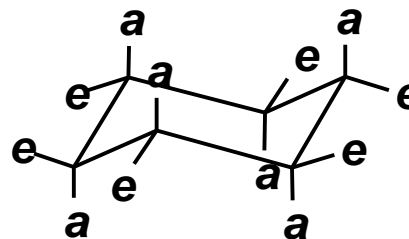
These are perpendicular to the average plane of ring and parallel to the axis of ring. These bonds point upward and downward alternately.

Equatorial C – H Bonds

These bonds are pointing outwards, more or less along the plane of ring. Three are slightly above and three are slightly below the plane of ring, alternately.

Each carbon of chair form has one axial and one equatorial bond.

Cyclohexane possesses a dynamic structure, in which one chair form converts into other in such a way that after change, all axial bonds become equatorial and all equatorial bonds become axial.

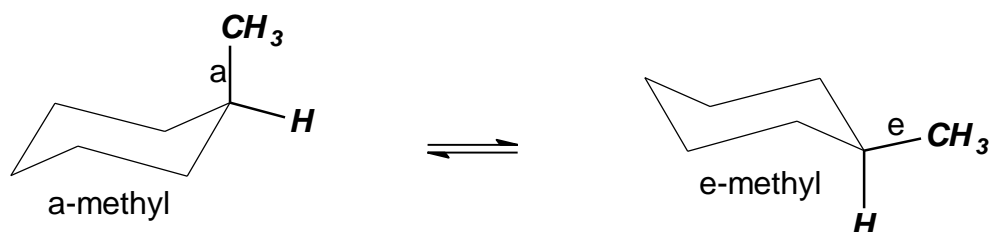


The conversion of one form to other requires 42 KJ/mole energy which is readily available at room T. Thus all hydrogens of cyclohexane are equivalent.

SUBSTITUTED CYCLOHEXANES

Monosubstituted Cyclohexanes

Methyl cyclohexane can take up two chair conformations



- In one form, methyl group is in axial position
- In other form, methyl group is in equatorial position.

In axial form, there is flagpole interaction between methyl group and hydrogens on C – 3 and C – 5 . It increases the instability of axial form.

As a rule, conformation with more substituent in equatorial position is stable than conformation with more substituent in axial position.

Thus methyl cyclohexane with methyl group in equatorial position is more stable.

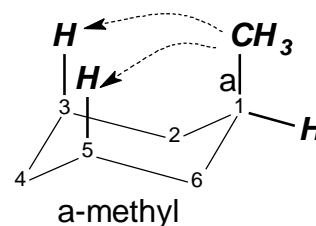
Di – Substituted Cyclohexanes

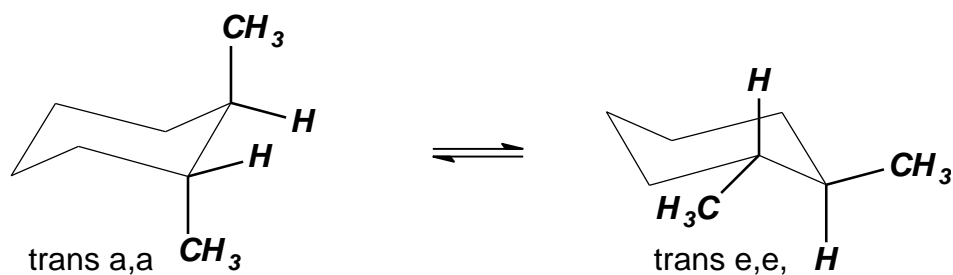
Dimethyl cyclohexanes has three possible structures

1,2 – Dimethyl Cyclohexane

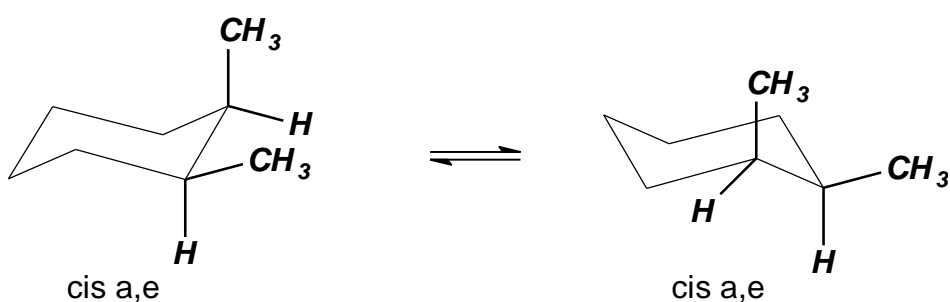
It can exist in two chair forms

- One form has both methyl groups in axial or equatorial positions (diaxial or diequatorial). It is called trans form.





- *2nd form with one methyl group in axial position and other in equatorial position. It is called cis form. For this form flipping of ring does not cause any difference. However, if one of the group is bulky, then it will preferably occupy equatorial position and methyl group will be axial for maximum*



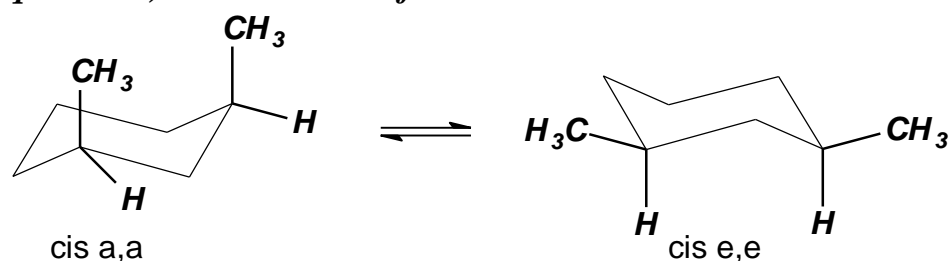
stability.

In 1,2 – dimethyl cyclohexane di – equatorial form is more stable than cis isomer by about 8 KJ/mol

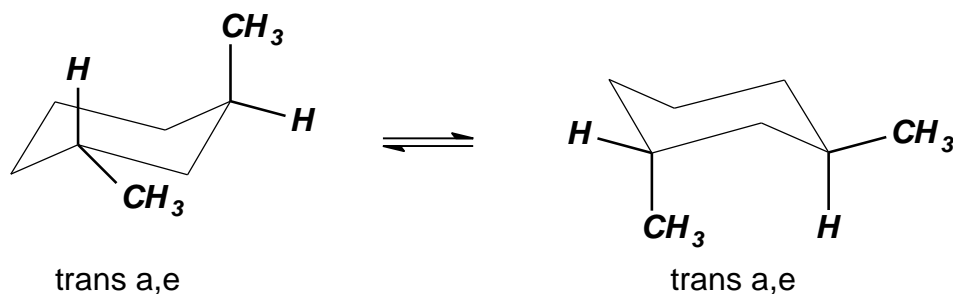
1,3 – Dimethyl Cyclohexane

It can exist in two chair forms

- *One form has both methyl group in axial or equatorial positions (diaxial or diequatorial). It is called cis form.*



- *2nd form with one methyl group in axial position and other in equatorial position. It is called trans form.*

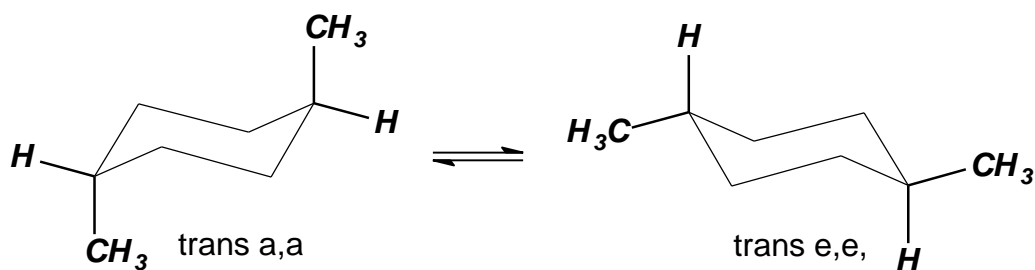


In 1,3 – dimethyl cyclohexane cis di – equatorial form is more stable than trans isomer by about 8 KJ/mol

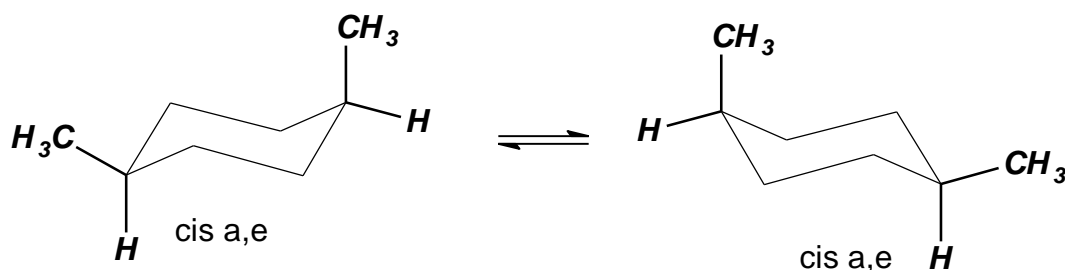
1,4 – Dimethyl Cyclohexane

It can exist in two chair forms

- *One form has both methyl group in axial or equatorial positions (diaxial or diequatorial). It is called trans form.*



- *2nd form with one methyl group in axial position and other in equatorial position. It is called cis form.*



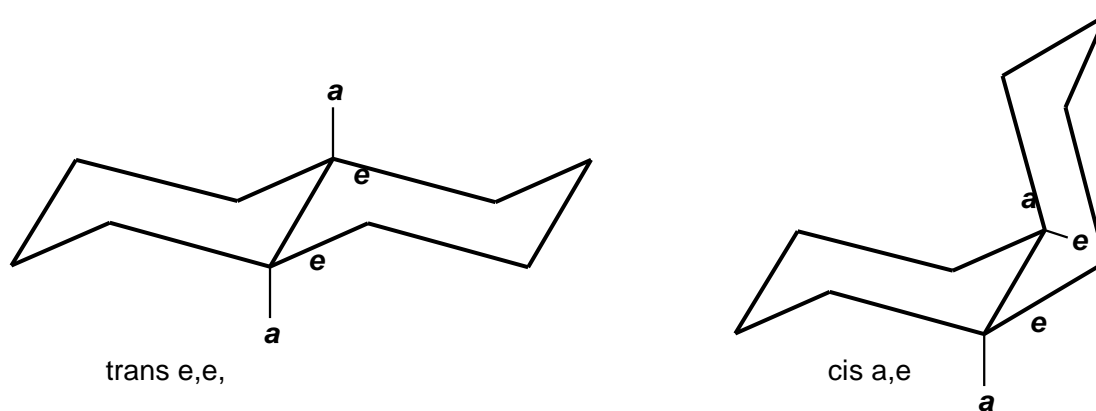
In 1,4 – dimethyl cyclohexane trans di – equatorial form is more stable than cis isomer by about 8.4 KJ/mol

CONFORMATIONAL ANALYSIS OF BICYCLIC COMPOUNDS

Most important bicyclic compounds is bicyclo [4, 4, 0] decane commonly called decalin.

In decalin, two cyclohexane ring are fused together at 1,2 – positions.

Decalin can be considered as 1,2 – disubstituted cyclohexane. Thus it exist in two form , cis and trans



In trans form, two rings are fused by two equatorial bonds. But in cis form, two rings are fused through one axial and one equatorial bond.

Thus trans isomer is more stable than cis isomer by about 10 KJ/mole.

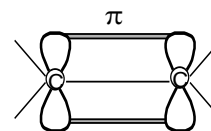
GEOMETRICAL ISOMERISM

The isomerism arises due to restricted rotation of different groups about a double bond, is called geometrical isomerism.

GEOMETRICAL ISOMERISM IN ALKENES

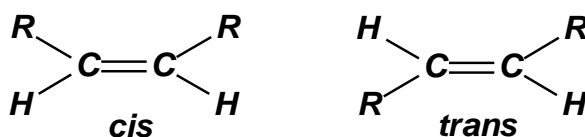
Alkenes are the most common organic compounds, which show geometrical isomerism.

In alkenes, double bond is formed by one σ – bond and one π – bond.

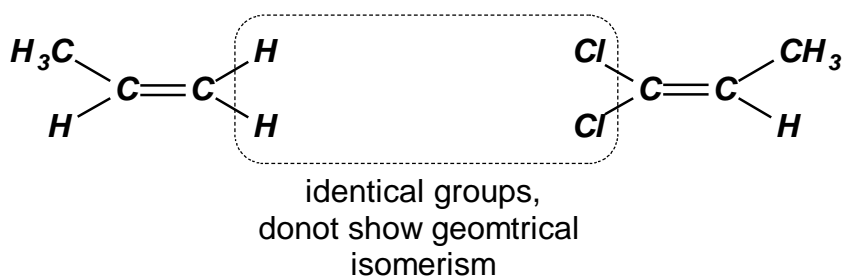


Each carbon of double bond is sp^2 – hybridized. Thus it can form three σ – bonds. Double bonded carbon atoms and group attached to them are all coplanar. Each carbon of double bond also have a p – orbital perpendicular to the plane of atoms. These two orbitals overlap sideways to give a π – bond.

The π – bond fixes the position of two doubly bonded carbon atoms as well as four groups attached to them. Thus rotation around the double bond is not possible as it would break the π – bond. Rotation about double bond require 250 KJ/mol of energy. This energy is not available at room T. Hence a compounds of type $R - CH = CH - R$, can exist in two geometrical isomeric forms.



Another condition for geometrical isomerism is that, each carbon of double bond must have two different groups attached to it.



Hence for a compound to show geometrical isomerism

- It must have double bond and
- It must have tow different groups attached to each carbon of double bond.

Nomenclature

Two designations are commonly used for geometrical isomers.

- cis – trans designation
- Z, E – designation

- cis – trans Designation

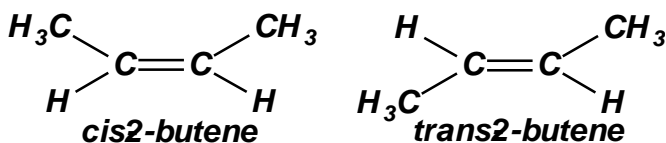
It is applied, when both carbon atoms of double bond have identical set of two different groups.

According to this system

- ⇒ If two similar groups are present on the same side of double bond, it is called cis isomer.

⇒ If two similar groups are present on the opposite side of double bond, it is called *trans* – isomer.

Example



• Z, E – Designation

It is applied, when both carbon atoms of double bond have non-identical set of two different groups.

In this system, both groups of each carbon are given priority separately.

The priority is given to the groups on the basis of Chan, Ingold, Prelog system.

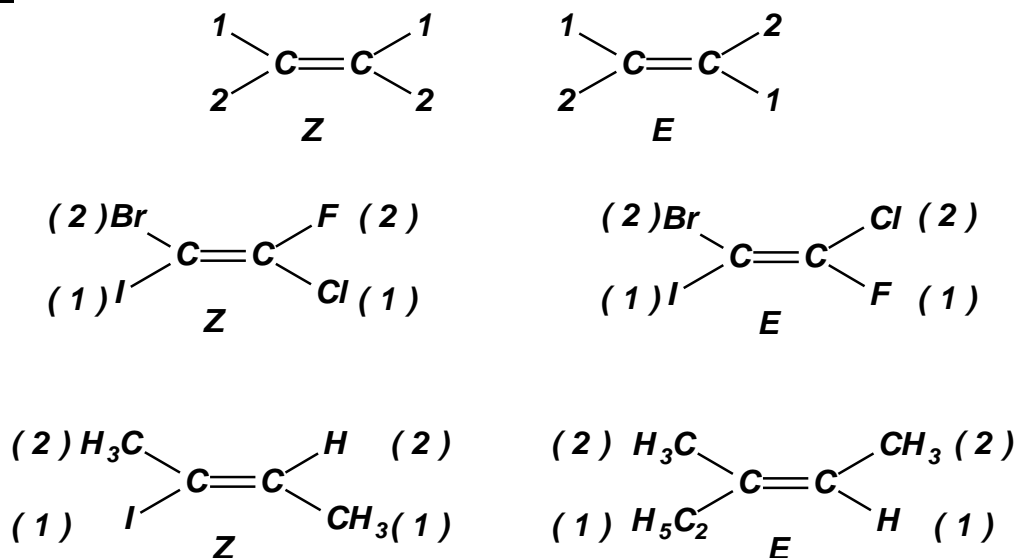
This system was initially developed for optical isomers.

According to this system

⇒ If highest priority groups are present on the same side it is called *Z*

⇒ If highest priority groups are present on the opposite side it is called *E*

Examples



GEOMETRICAL ISOMERISM OF OXIMES AND AZO COMPOUNDS

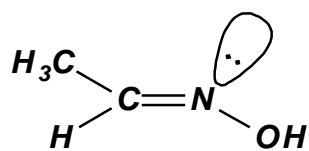
Oximes and azo compounds have $\text{C} = \text{N}$ and $\text{N} = \text{N}$, bonds respectively. These bonds can also give rise to geometrical isomerism

The $\text{C} = \text{N}$ and $\text{N} = \text{N}$ bond consist of one σ and one π – bond. Nitrogen in these compounds are sp^2 – hybridized. Nitrogen uses its two sp^2 hybrid orbitals, to form σ – bond while third sp^2 – hybrid orbital is occupied by a lone pair of electron. In addition, N also form a π – bond by parallel overlapping of unhybridized p – orbital. Thus there is restricted rotation about $\text{C} = \text{N}$ and $\text{N} = \text{N}$ bonds, which give rise to geometric isomerism.

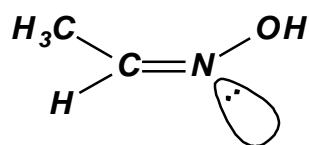
To designate geometrical isomers of oximes and azo compounds, syn – anti system is used

⇒ In aldoxime, if H and OH are present on the same side, it is called syn aldoxime.

While If H and OH are present on opposite side, it is called anti aldoxime.

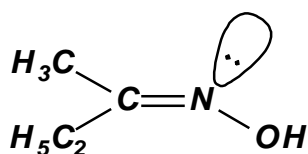
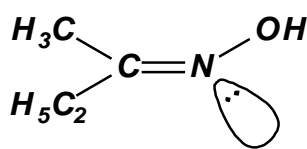


syn-acetaldehyde oxime



anti-acetaldehyde oxime

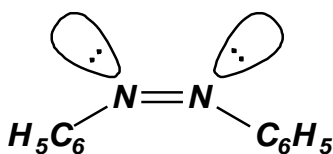
⇒ In ketoxime, if OH and first – named of the two groups on the carbon atoms are present on the same side, it is called syn ketoxime, but if these are present on opposite side, it is called anti-ketoxime.

syn-ethylmethyl ketoxime
or
anti-methylethyl ketoximesyn-methylethyl ketoxime
or
anti-ethylmethyl ketoxime

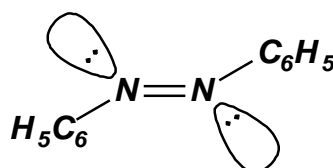
⇒ In azobenzene, if two groups on two nitrogen are present on same side, it is called syn azo compound.

But

If present on opposite side, it is called anti azo compound.



syn-azobenzene



anti-azobenzene

GEOMETRICAL ISOMERISM IN ALICYCLIC COMPOUNDS

In alicyclic compounds, there is restricted rotation about C – C single bond. Due to this, disubstituted derivatives of alicyclic compound can also show geometrical isomerism.

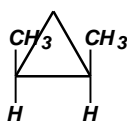
The basic condition is that

Two carbon of alicyclic ring must have two different groups attached to them

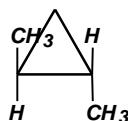
In alicyclic compounds due to restricted rotation around C – C single bond, groups present above and below the plane of ring have fixed position.

Thus for 1,2 – dimethyl cyclopropane following two isomers are possible

Similarly, cyclobutane – 1,2 – dicarboxylic acid have following geometrical isomers.

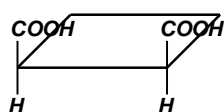


cis-1,2-dimethyl cyclopropane

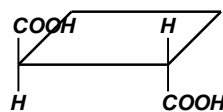


trans-1,2-dimethyl cyclopropane

EXPERIMENTAL DETERMINATION OF CONFIGURATION OF GEOMETRICAL ISOMERS



cis-cyclobutane-1,2-dicarboxylic acid



trans-cyclobutane-1,2-dicarboxylic acid

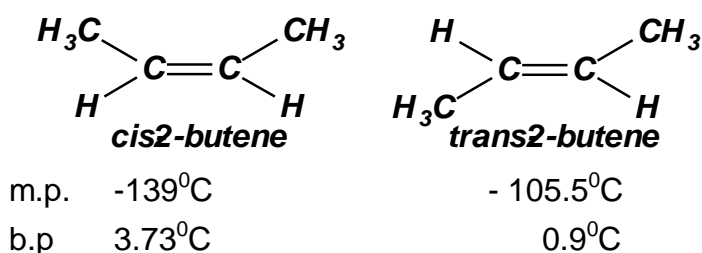
Following methods are commonly used for the determination of configuration of geometrical isomers.

Physical Methods**1. Determination Physical Constants**

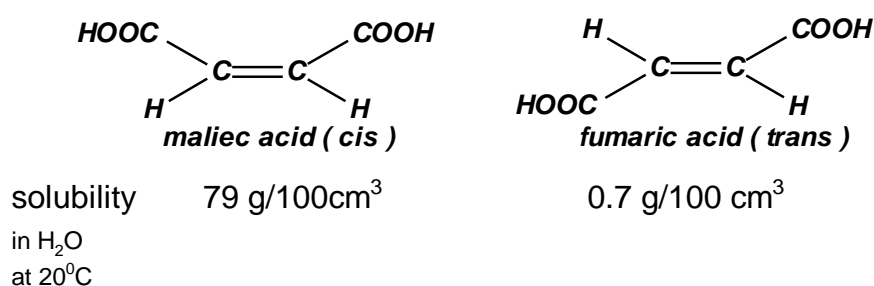
Following are some generalizations

\Rightarrow *cis isomer has lower m.p. than trans isomer*

\Rightarrow *cis isomer has higher b.p. than trans isomer*



\Rightarrow *cis isomer has higher solubility than trans isomer*

**2. Determination Of Dipole Moment**

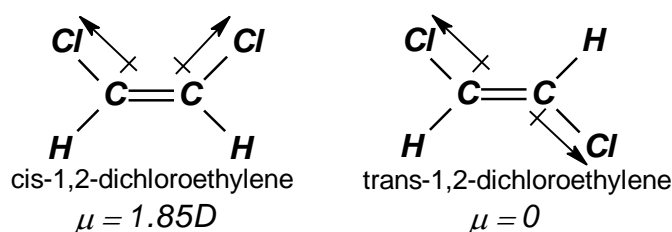
cis isomer has higher dipole moment than trans isomer

Trans isomer have symmetrical structure, thus individual bond moments have subtractive effect

While

cis isomer do not have symmetrical structure, thus individual bond moments have additive effect

Hence dipole moment of cis isomer is greater than trans isomer.

**3. Spectroscopic Measurements**

\Rightarrow *IR spectra of trans isomer is different from cis isomer. Thus both can be identified*

\Rightarrow *In NMR spectra both cis and trans isomers have different coupling constant by which these can be identified.*

Chemical Method**1. Formation Of Cyclic Compounds**

In cis isomer, similar groups are on same side. Thus it can easily form cyclic structure

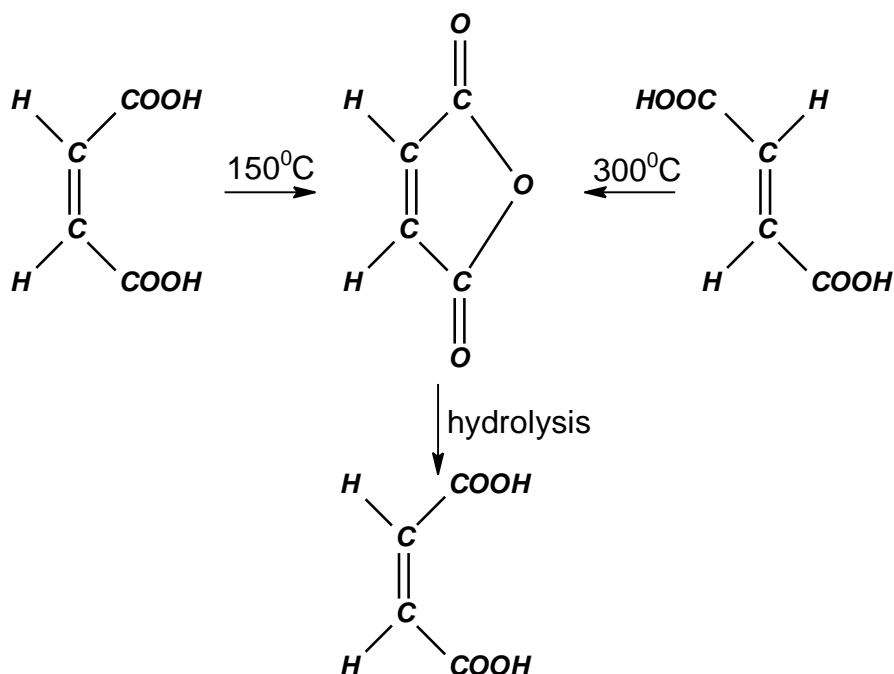
While

Trans isomer usually requires vigorous conditions to form cyclic compounds.

Example

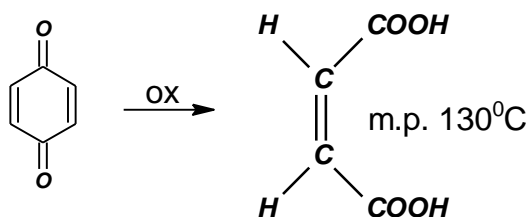
Fumaric acid and Maleic acid are geometrical isomers. Maleic acid has cis structure while fumaric acid has trans structure.

Thus Maleic acid (cis) form cyclic compound at 140⁰C while fumaric acid (trans) needs a much higher T of 300⁰C.



2. **Formation Of Geometrical Isomers From Cyclic Compounds**

If 1,4 – benzoquinone is oxidised, it gives an unsaturated dicarboxylic acid of m.p. 130⁰C. This m.p. is identical with maleic acid.



Structure of quinone shows that maleic acid must have two carboxyl group on same side and it must be a cis isomer.

Thus , other isomer fumaric acid must have trans structure.

3. **Chemical Correlation Method**

In this method, a compound of unknown configuration is changed chemically into a compound of known configuration, under controlled conditions. Thus a relationship can be established between a compound of known and unknown configuration.

Generally, configuration (cis, trans) of unknown compound is like that of known compound.

Example

Deamination of a particular o –aminocinnamic acid give cis cinnamic acid. Thus this particular o – amino cinnamic acid must have cis-configuration.



Similarly trans – amino cinnamic acid gives trans cinnamic acid

INTERCONVERSION OF CIS TRANS ISOMERS

Two important methods for interconversion are

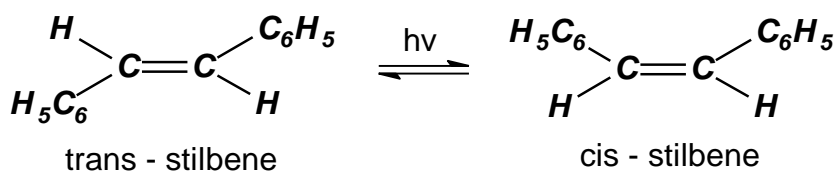
1. *Photochemical method*
2. *Acidic isomerization*

1. Photochemical Method

When a molecule absorb light, it is excited and there develops somewhat single bond character in its double bond. Hence, due to free rotation about single bond, one isomer is converted to other.

Example

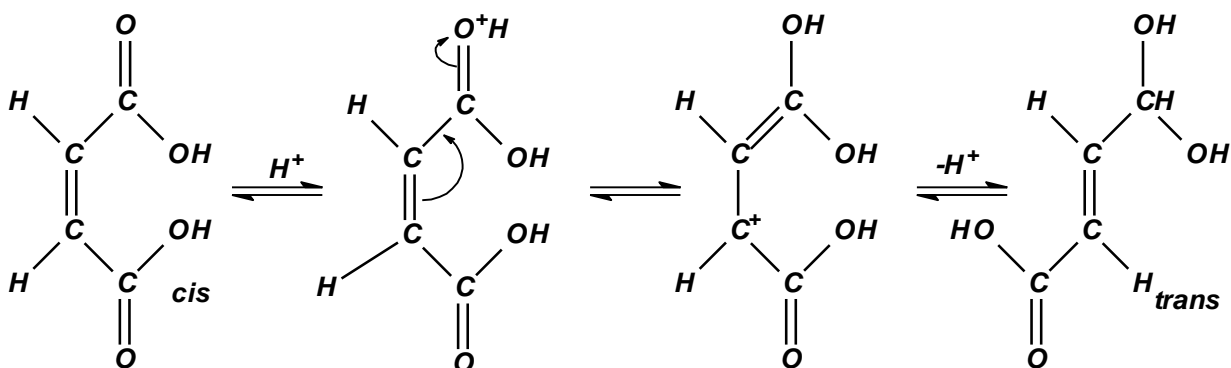
Irradiation of trans – stilbene by UV light gives cis – stilbene.

2. Acidic Isomerization

Under acidic isomerization condition, alkene undergo isomerization

Example

A solution of Maleic acid in HCl is isomerized to fumaric acid on heating.

Note

All the interconversion methods generally gives an equilibrium mixture of two isomers. The %age of isomers in equilibrium mixture depends upon their thermodynamic stability.