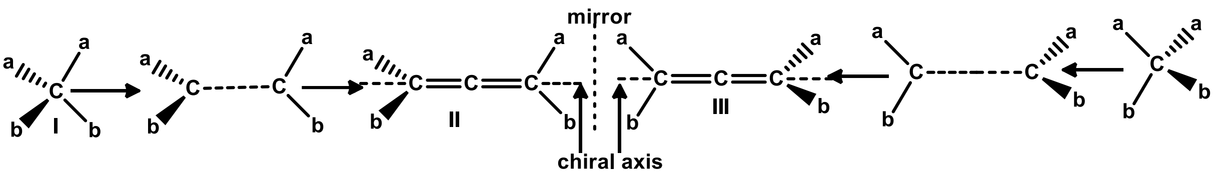
STEREOCHEMISTRY

Chirality arising out of stereo axis

AXIAL CHIRALITY:

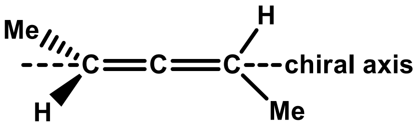
There are some molecules where different atoms or groups are arranged in two different planes along a common axis and there is no vertical plane of symmetry, then the molecule becomes chiral, i.e the mirror image of the molecule becomes non-superimposable. The molecule may exist as enantiomeric pair and becomes optically active. The common axis of the above said two planes is known as chiral axis. So the existence of chiral axis in a molecule may also lead to optical activity of the molecule.

A regular tetrahedron with four distinguishable vertices (attached with four different groups) represents a three-dimensional chiral simplex. The centre of the tetrahedron which is usually occupied by a tetracoordinate atom, e.g., C in Cabcd is a stereocentre. If this centre is replaced by a linear grouping such as C—C or C=C=C, the tetrahedron becomes elongated (extended) along the axis of the grouping as shown in II and illustrated by an allene, abC=C=Cab. Such an elongated tetrahedron with pairs of vertices around the two ends of the axis need to be distinguished (i.e. a≠b) to make it chiral. The structure (II) thus becomes three-dimensionally chiral and is enantiomorphous with its mirror image (III). The axis along which the tetrahedron is elongated (shown by the dotted lines) is called the **chiral axis or the stereoaxis**, exchange of ligands at either of the terminal atoms across the axis reverses the chirality

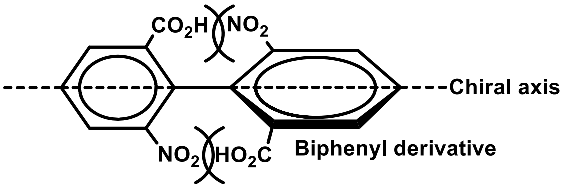


Thus in case of molecule with chiral axis— **when two groups are different around the chiral axis the molecule becomes chiral and optically active.**

Chiral axis: An axis about which a set of ligands is rigidly held in a spatial arrangement which is not superimposable on its mirror image is known as chiral axis.



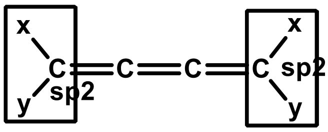
1,3-dimethyl allene



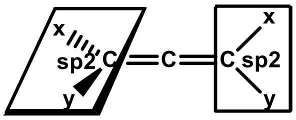
Biphenyl derivative

Molecules with chiral axis:

1. Cumulated polyenes : Polyenes containing cumulated double bonds have two sp2 hybridised terminal carbon atoms.



groups attached with two terminal sp2 C-are on the same plane, the molecule is planar

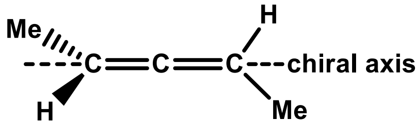


groups attached with two terminal sp2 C- are perpendicular, the molecule is not planarmolecule has chiral axis when x ≠ y

(a) Cumulenes with even number of double bonds exhibit enantiornerism if each of the terminal sp2 carbon atoms contains non-identical substituents (x≠y). Because the molecule has a chiral axis along the C=C=C bond and it has no σ-plane or inversion centre (*i*) or S_n axis of symmetry.

Cumulenes with even number of double bonds **cannot show *cis-/trans-*** isomerism as the terminal groups are not planar. Thus interchange of groups on any terminal sp2 carbon does not produce a diastereomers.

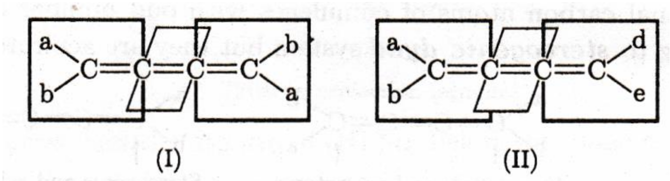
Example:



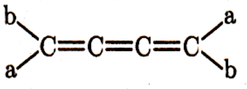
1,3-dimethyl allene ,

(b) Cumulenes with odd number of double bonds never exhibit enantiomerism irrespective of the nature of the substituents on the terminal carbons, This is due to the fact that, in cumulenes with odd number of double bonds, the terminal carbon atoms along with their substituents lie in the same plane and **such cumulenes have always a σ-plane** irrespective of the nature of the substituents. So they are optically inactive and achiral.

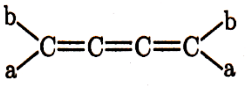
As the terminal groups remain in the same plane, the molecule exhibits *cis-trans* diastereomerism.



(I) and (II) are achiral as they possess plane of symmetry



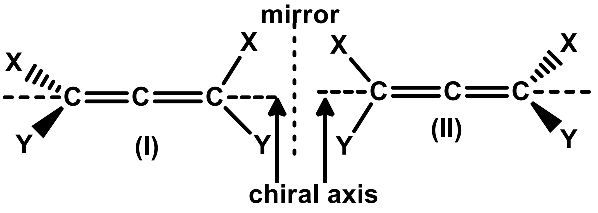
Trans isomer



Cis isomer

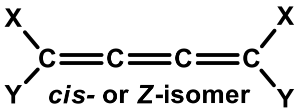
Q 1.9. Explain the nature of stereoisomerism exhibited by the compounds of the formula X YC=(C=)$_n$ CXY where n=1 and 2 2 **C.U. 2006**

Ans: When n=1, the molecule has even number (two) of double bonds so the two terminal groups are mutually perpendicular the molecule has a chiral axis along the C=C=C bond. The molecules has no σ-plane, inversion centre and S_n axis. **Thus the molecule exhibit enantiornerism when (x≠y).** It has two enantiomers as follows—

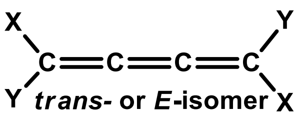


(I) and (II) are enantiomers

When n=2 i.e. the molecule has odd (three) number of double bond. In this molecule, the terminal carbon atoms along with their substituents lie in the same plane and such cumulene has always a σ-plane irrespective of the nature of the substituents. So it is optically inactive and achiral. **But it exhibits diastereomerism.** It has ***cis-/trans-* or *E/Z*** isomers.



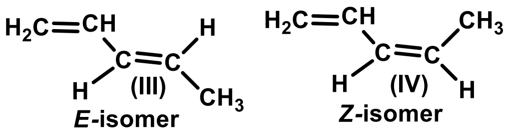
cis- or *Z*-isomer



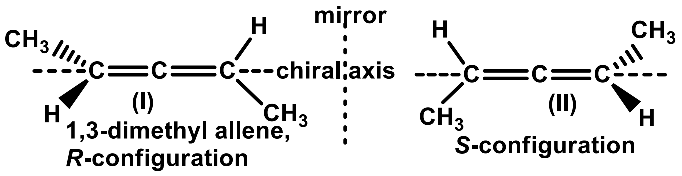
trans- or *E*-isomer

Q 1.4. Draw structures of two isomeric organic molecules of molecular formula C_5H_8 where one shows geometrical isomerism and the other diastereomerism (geometrical isomerism as well). 3 **C.U. 1991**

Ans:

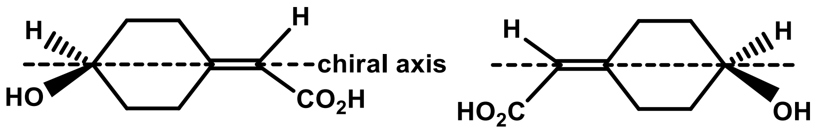


(III) and (IV) are geometrical isomers and diastereomers



(I) and (II) are geometrical isomers as well as enantiomers

2. Some alkylidene cycloalkanes exhibit axial chirality:

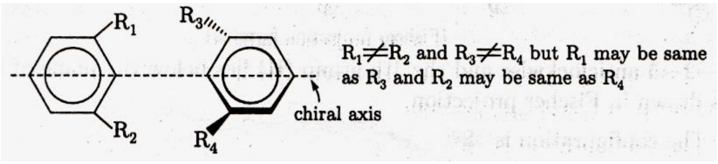


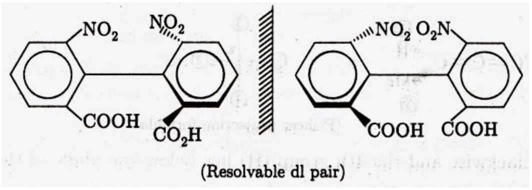
3. Some Biphenyl system exhibit axial chirality:

Substituted biphenyls (biaryls precisely) have restricted rotation about C_{sp2}—C_{sp2} bond (a bond) joining the two rings. Stereoisomerism of the compounds having restricted rotation about a σ-bond is specifically known as atropisomerism or conformational chirality. Stereoisomerism of biaryls is also due to presence of chiral axis in them.

A number of appropriately substituted biphenyls can have a chiral axis when steric (van der Waals repulsive) interactions between the ortho- substituents are sufficient to prevent rotation of aromatic rings relative to each other about the sigma bond joining them. This sigma bond is also called pivotal bond.

In this situation, the preferred conformations are those in which the aromatic rings are almost orthogonal (lie in perpendicular planes) provided the substitution is of the type in structure 6,6´-dinitro biphenyl—2,2´-dicarboxylic acid (6,6´-dinitro diphenic acid), then the minimum energy conformers are enantiomeric and the isomers can be isolated under ambient conditions.



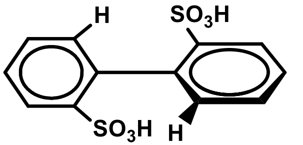


Atropisomerism **(Conformational Chirality):** Stereoisomerism due to restricted rotation about single bond where the isomers can actually be isolated under usual experimental conditions is known as atropisomerism.

Atropisomers: A type of conformers, which can be isolated as a separate chemical compound and which arise from restricted rotation about a single bond within the concerned molecule.

Atropisomers are also known as torsional isomers about single bonds.

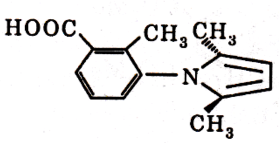
Examples:



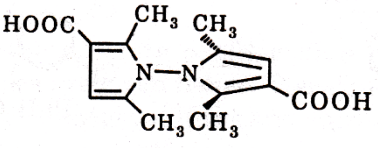
Biphenyl-2,2'-disulphonic
chiral, optically active and resolvable

Other examples of atropisomerism around sp2-sp2 sigma bond without biphenyl system:

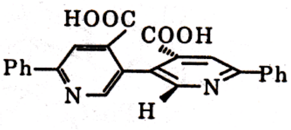
The following compounds have **chiral axis**. So they are **chiral and optically active**. As they have restricted rotation around C─C, they cannot change their conformations rapidly, as a result two conformational isomers of these compounds can easily be separated. i.e. they are resolvable.



(Resolvable)

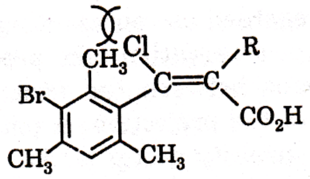


(Resolvable)

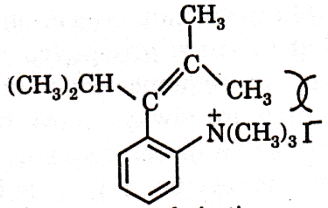


(Resolvable)

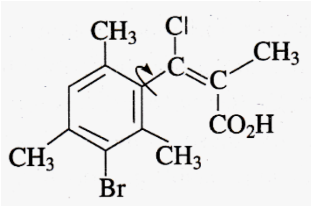
Following styrenes are found to be resolvable due to restricted rotation about sp2-sp2 a-bond. Due to overcrowding of the groups in planar conformation, the molecules become distorted and chiral.

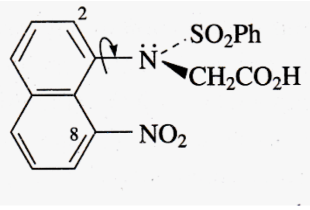


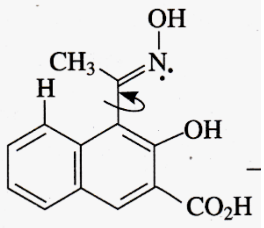
styrene derivative
E-Z isomers possible
(Resolvable)

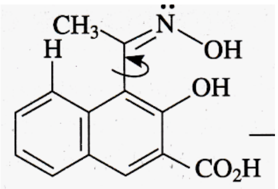


styrene derivative
E-Z isomers not possible
(Resolvable)



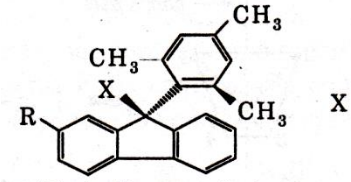






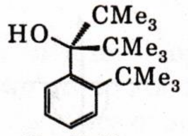
Atropisomerism around sp2-sp3 single bond:

Certain 9-mesityifluorenes were resolvable when the C -9-(sp3) position also contains a substituent.

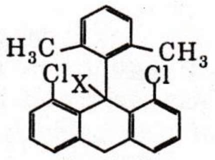


X = H , Cl , OH , etc.

9-Mesitylfluorene derivatives



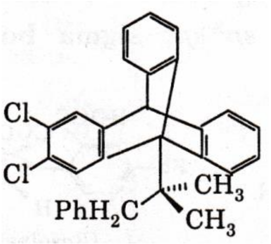
Resolvable

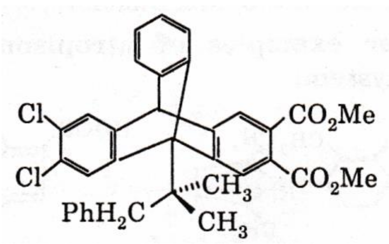


X = H , OH , etc.

Resolvable

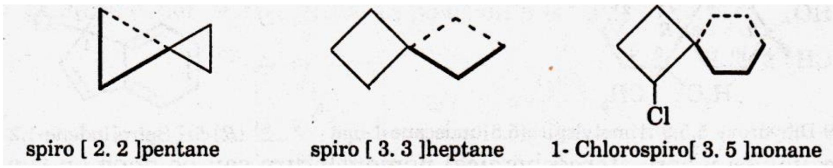
Atropisomerism around sp3-sp3 single bonds:





Stereoisomerism of Spiro compounds:

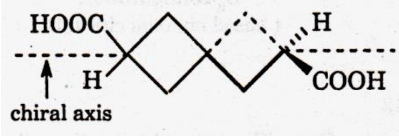
Spiro compounds are those compounds where two or more rings are joined by common tetrahedral carbon or other atoms. Spiro compounds are non-planar and this structural characteristic is primarily responsible for their chirality. A few spiro-compounds are shown below—

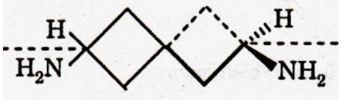


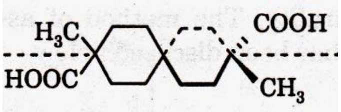
spiro [2. 2]pentane   spiro [3. 3]heptane   1- Chlorospiro[3. 5]nonane

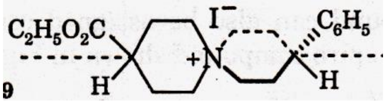
Chiral spiranes with axial chirality:

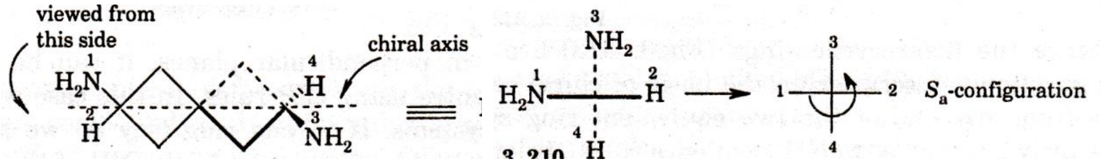
Since the two rings in spirans are perpendicular to each other, suitable substitution may produce molecules with no elements of symmetry except C (n> 1), thereby giving rise to molecular chirality. This chirality is due to chiral axis. Following are examples of a few resolvable spiranes with chiral axis.

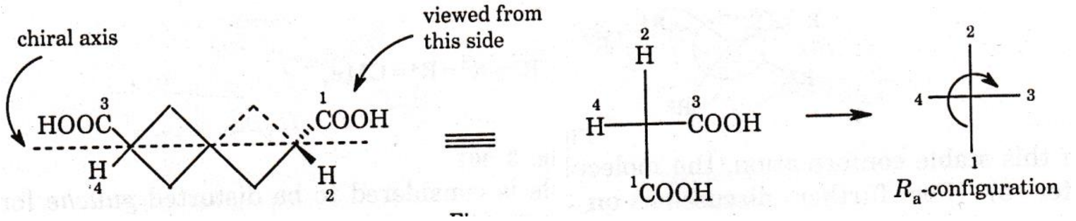


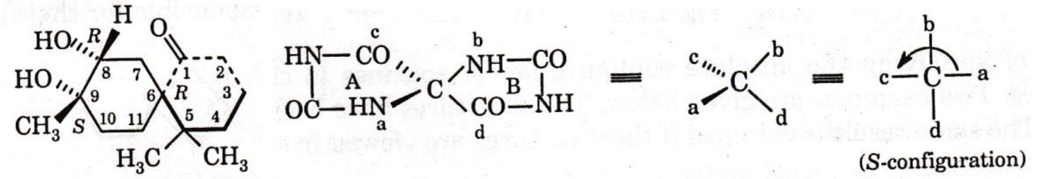


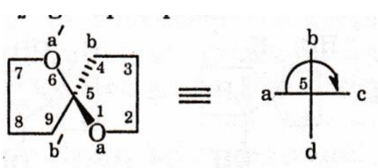




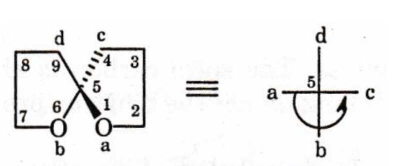




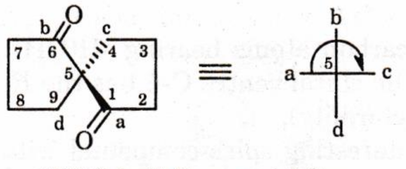




(5*R*)-1,6-Dioxaspiro[4.4]nonane



(5*S*)-1,6-Dioxaspiro[4.4]nonane



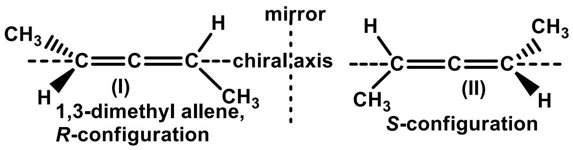
(5*R*)-Spiro[4.4]nonane-1,6-dione

Q **1.1. Indicate whether the following compounds would be resolvable? Explain.**

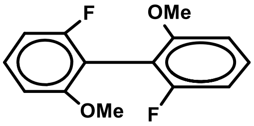
$CH_2=C=CMe_2$, $CH_3CH=C=CHCH_3$ 2 **C.U. 1989**

Ans: The compound $CH_2=C=CMe_2$ has two σ-planes, So the molecule is optically inactive and non resolvable.

The molecule $CH_3CH=C=CHCH_3$, has no σ-planes, inversion centre and S_n-axis. The molecule has a chiral axis and around this axis two groups are different (Me and H). Thus the molecule is optically active and it has two different configurational enantiomers separated by high energy barrier so they are resolvable.



Another example: In a biphenyl system when the two pair of ortho groups are not sufficiently large to undergo steric repulsion; the rotation of the phenyl ring around pivotal bond is rapid. The molecule remains in a nonresolvable pairs of enantiomers. The molecule is chiral as it has a chiral axis with two different groups around the axis.

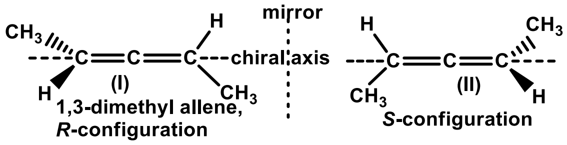


F and –OMe groups are smaller group the molecule undergoes rapid rotation around pivotal bonds.

Q1.2. What are the necessary and sufficient conditions for an allene and biphenyl to exhibit optical activity? Give one example in each case. 2+2 **C.U. 1990**

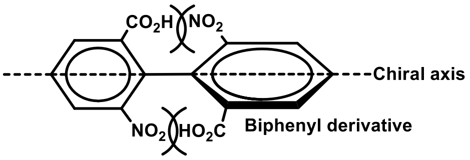
Q1.5. What is the necessary and sufficient condition for an allene and a biphenyl to exhibit optical activity. Give one example in each case. 3 **C.U. 1992**

Ans: Allene and biphenyls are axially chiral molecules. The necessary and sufficient condition for an allene to exhibit optical activity is— the two groups around the chiral axis should be different.
Example: 1,3-dimethylallene, where two groups around the axis are different Me ≠ H.

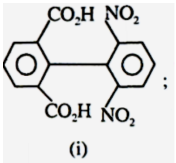


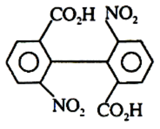
In case of biphenyls the two pair of ortho substituents should be large enough to make the molecule non-planar and the two groups around the chiral axis should be different.

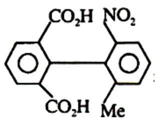
Example:

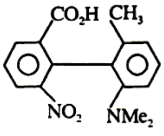


Q 1.2. Comment on the chirality of the following compounds: 2 **C.U. 2015**


(i)


(ii)


(iii)


(iv)

Ans: The molecule (i) has two **σ-planes** containing the plane of each benzene ring so it is **achiral and optically inactive.**

The molecule (ii) has a **chiral axis** and the groups around the axis are different so the **molecule is chiral and optically active.**

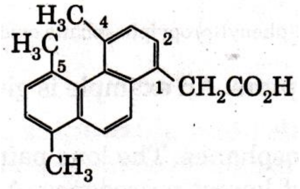
The molecule (iii) has one **σ-planes** passing through the plane of benzene ring bearing –NO_2 and Me-groups so it is **achiral and optically inactive.**

The molecule (iv) has a **chiral axis** and the groups around the axis are different so the **molecule is chiral and optically active.**

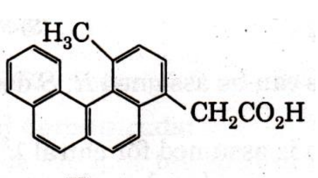
Compounds with chirality planes due to intramolecular overcrowding:

It has been found that, in general non-bonded carbon atoms cannot approach closure to each other than about 3.0Å. Thus, the geometry of the molecule is such as to produce 'intramolecular overcrowding', the molecule becomes distorted. This type of distortions of the structure has been observed in case of substituted polynuclear compounds.

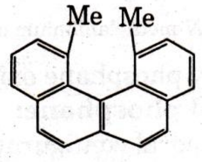
An example of this type is 4,5,8-trimethyl-1-phenanthrylacetic acid (I). The phenanthrene nucleus is planar. But when there are fairly large groups in positions 4 and 5, then there will not be enough space to accommodate both groups in the molecule keeping the planarity undisturbed. Strain is developed due to steric interaction and to release that strain, the molecule has to take up a non-planar distorted geometry and consequently the property of molecular asymmetry and helicity is developed due to the appearance of chiral plane and the system becomes optically active. To identify this class of chiral molecules, Newman introduced the term 'molecular chirality. Examples are given below.



(I)



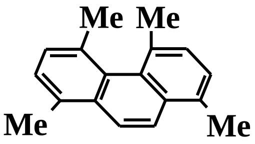
(II)

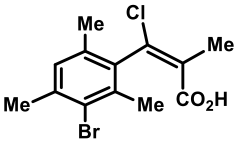


(III)

[up to this Out of syllabus]

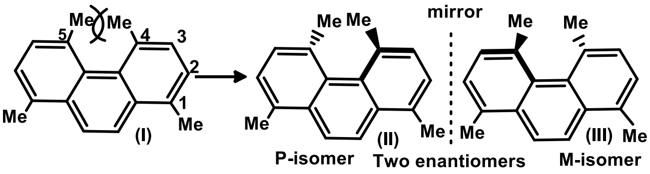
Q 1.6. Explain whether the following compounds show optical activity. 3 **C.U. 1997**

(i) 

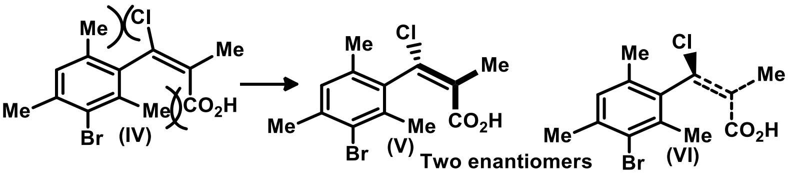
(ii) 

Ans: (i)

The molecule (I) is normally expected to be planar but there is severe steric interaction between two Me-groups at C-4 and C-5. To release such molecular overcrowding the ring structure assume a helical shape (in II and III) where the terminal rings and the substituents Me-groups are remain in different planes. Consequently the property of molecular asymmetry is developed due to the apperance of chiral plane and the molecule becomes chiral and optically active.

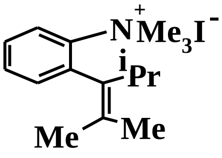


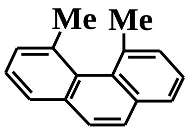
(ii)



Due to steric interaction in the molecule (IV) it becomes non planar (V) and (VI). The molecule has a chiral axis and it shows atropisomerism. Thus the molecule is chiral and optically active

Q 1.7. Determine with brief reasoning the chiral/achiral nature of the following compounds:

(i) 

(ii) 

2 **C.U. 1998**

Ans: (i) Similar to Q 3.5 (ii)

Ans: (ii) Similar to Q 3.5 (i)

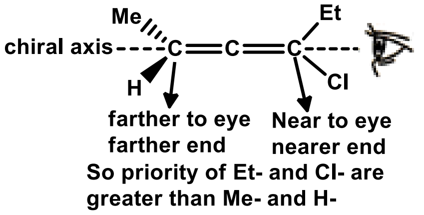
R_a,S_a description of molecules with chiral axis (Allene, biphenyls, spiro-compounds etc.)

(i) In this case we have to look at the molecule along chiral axis form either side of the chiral axis.

(ii) Priority of nearer end groups (near to eye of observer) are higher than farther end groups. In this case we should apply the Sub rule (0).

Sub rule (0): Nearer end or side of a chiral axis (or a chiral plane) precedes the farther end or side (this is called proximity rule).

(iii) Bonds between near groups and the C-atom are represented by thick lines. And the farther bonds are represented by simple line. The two end groups remain in two mutually perpendicular planes.



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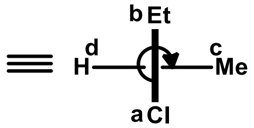
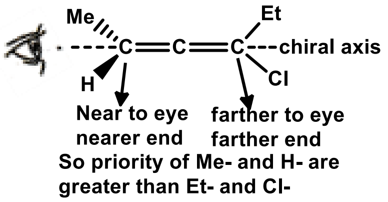


Priority order Cl > Et > Me > H
Movement of a to b to c is clockwise
So the configuration is "*R*" or "R_a" (a= axial)

This is not a Fischer projection formula so "very good" rule is not applicable here. Movement of a to b to c will give the correct descriptor irrespective of the position of d-group.

If we look from other side of the chiral axis the configuration of the molecule (***R**$_a$*) will be same.



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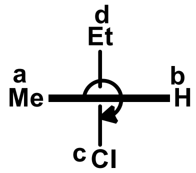
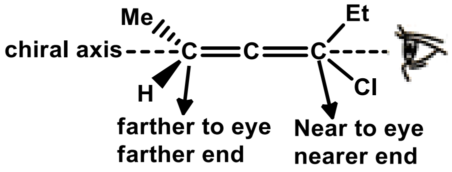


Priority order Me > H> Cl > Et
Movement of a to b to c is clockwise
So the configuration is "*R*" or "R_a"
(a= axial)

The bonds of the four groups are also represented by simple line (—) for nearer groups and dotted line (………) for farther groups.



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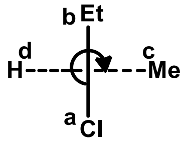
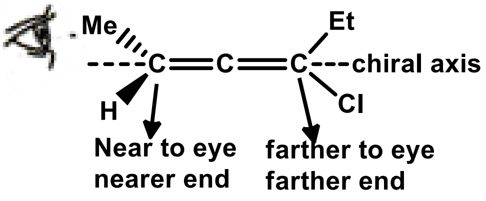


Priority order Cl > Et > Me > H
Movement of a to b to c is clockwise
So the configuration is "*R*" or "R_a" (a= axial)



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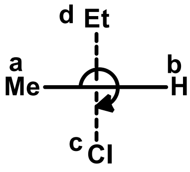
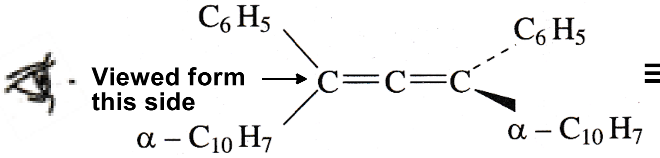


Priority order Me > H> Cl > Et
Movement of a to b to c is clockwise
So the configuration is "*R*" or "R_a"
(a= axial)

Some Example:



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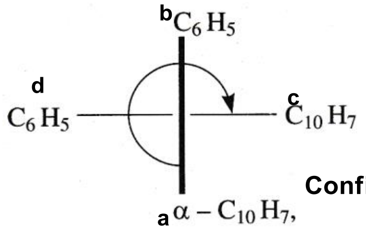
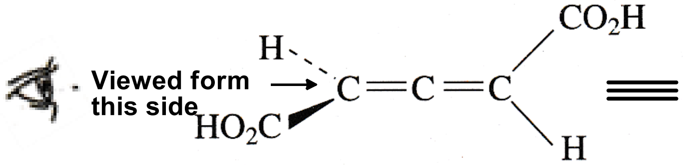


Configuration R_a



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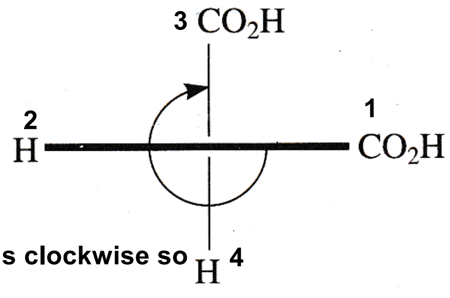
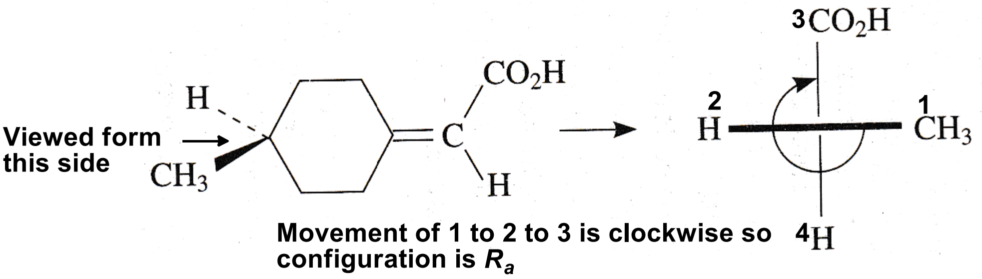
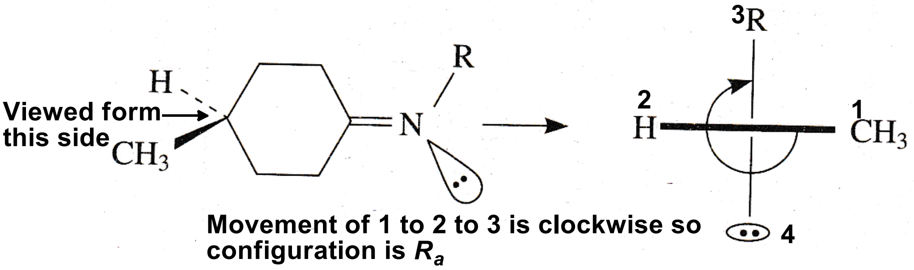


Movement of 1 to 2 to 3 is clockwise so configuration is R_a

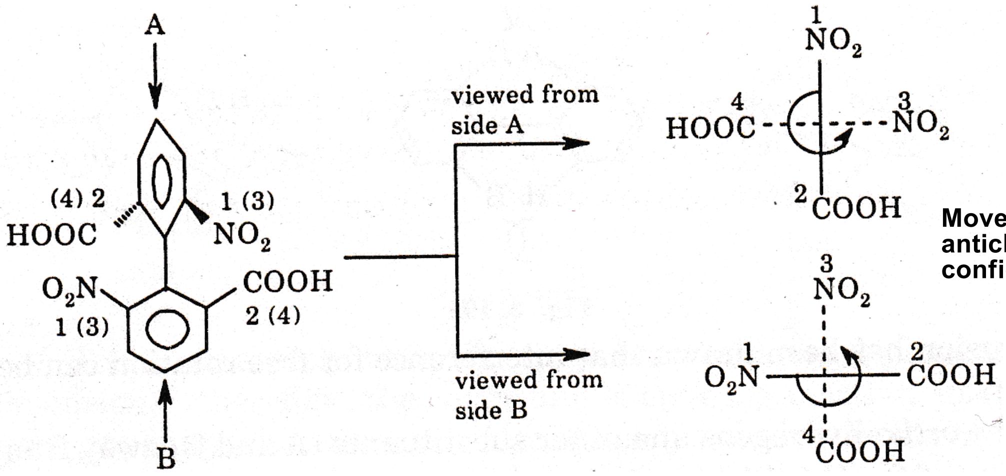


Movement of 1 to 2 to 3 is clockwise so configuration is R_a

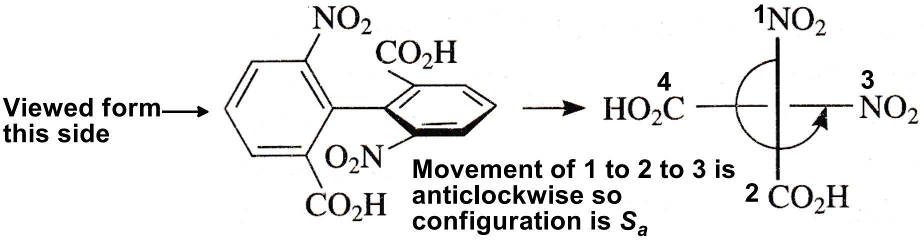


Movement of 1 to 2 to 3 is clockwise so configuration is R_a

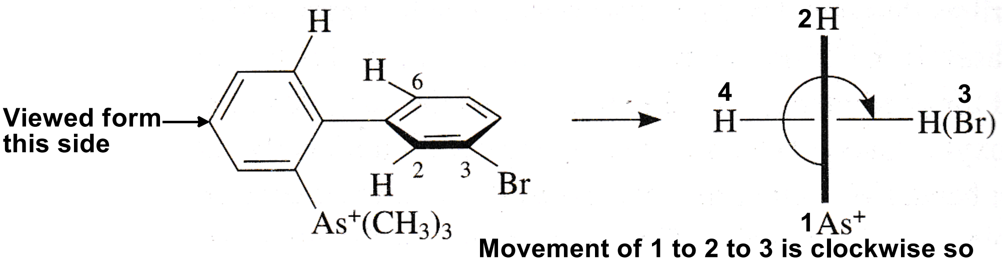
This method is applicable for biphenyl system:



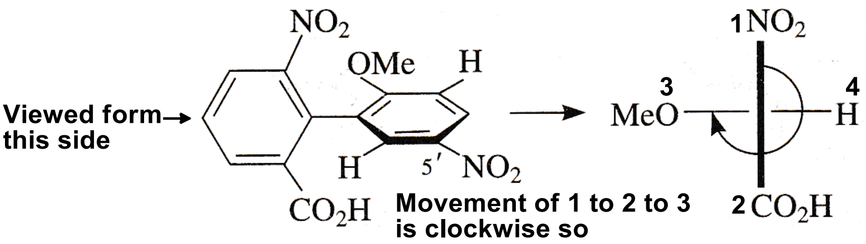
Movement of 1 to 2 to 3 is anticlockwise so configuration is S_a



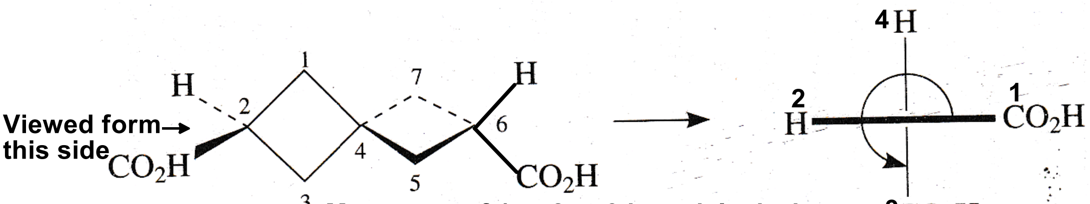
Movement of 1 to 2 to 3 is anticlockwise so configuration is S_a



Movement of 1 to 2 to 3 is clockwise so configuration is R_a

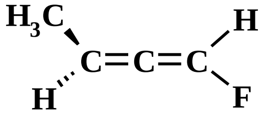


Movement of 1 to 2 to 3 is clockwise so configuration is R_a



Movement of 1 to 2 to 3 is anticlockwise so configuration is S_a

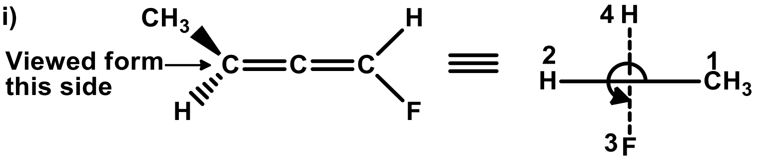
Q 1.14. Assign R/S descriptor to the following compounds. 1×3 C.U. 2011



(iii)

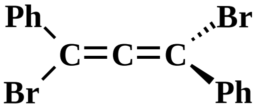
Ans:

(ii)

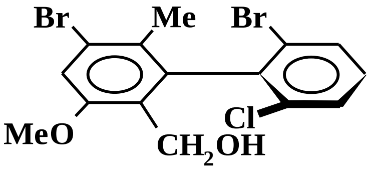


Movement of 1 to 2 to 3 is anticlockwise so configuration is S_a

Q 1.14. Assign R/S configuration to the following molecules: 2 C.U. 2010



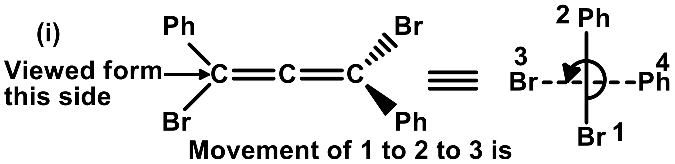
(iv)



(v)

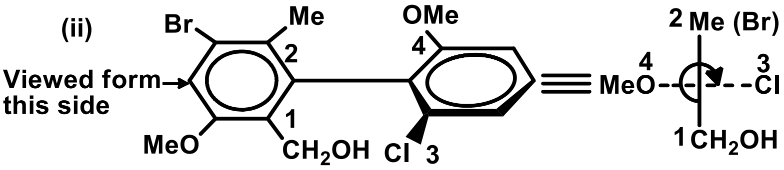
Ans:

(i)

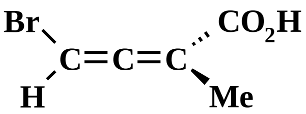


Movement of 1 to 2 to 3 is anticlockwise so configuration is S_a

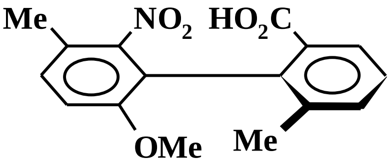
(ii)



Q 1.14. Find out the absolute (*R*,*S*) configuration of the following compounds: 1+1 C.U. 2011



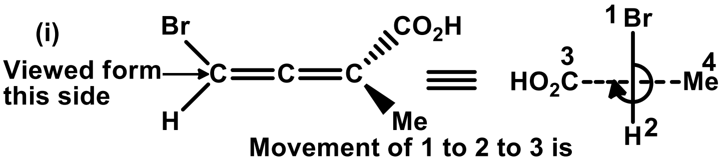
(vi)



(vii)

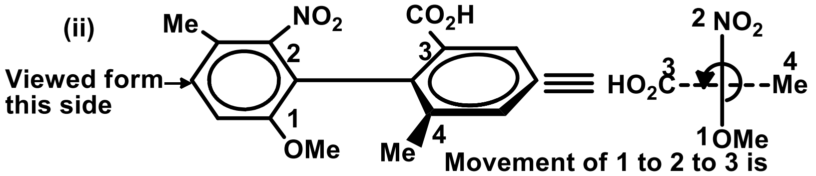
Ans:

(i)



Movement of 1 to 2 to 3 is ckwise so configuration is R_a

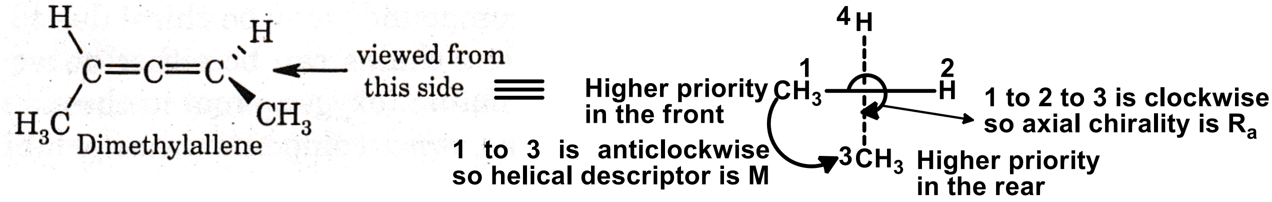
(ii)



Movement of 1 to 2 to 3 is anticlockwise so configuration is S_a

NB: **P,M-descriptor of molecule with axial/helical chirality:**

The molecules with chiral axes can also be treated as helices and their configurations may be expressed **as P or M,**. For this designation, only the ligands of highest priority in front and in the back of the framework are considered. If the turn from the priority front ligand marked as ‘1’ to the priority rear ligand numbered ‘3’ is clockwise, the configuration **is P**, if the turn is anticlockwise it is **M**. A few examples are given below.

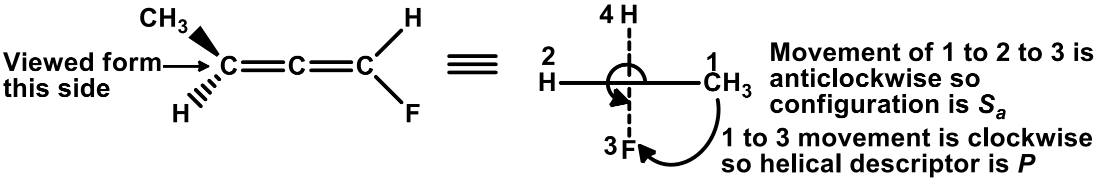


Higher priority in the front

1 to 2 to 3 is clockwise so axial chirality is R_a

1 to 3 is anticlockwise so helical descriptor is M

Higher priority in the rear



Movement of 1 to 2 to 3 is anticlockwise so configuration is S_a

1 to 3 movement is clockwise so helical descriptor is P