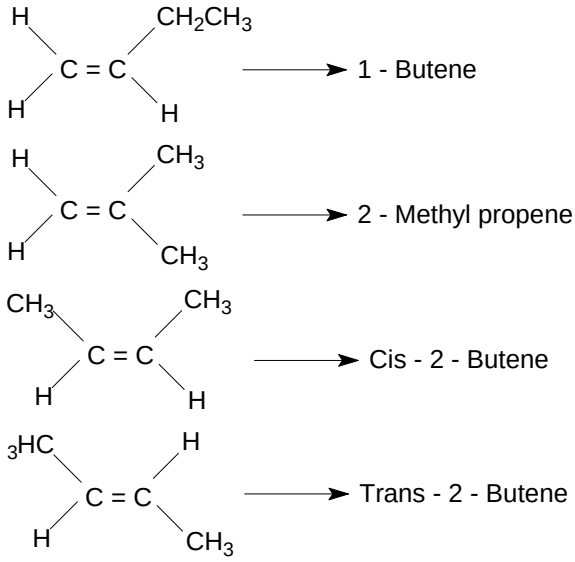
13. ORGANIC CHEMISTRY

VI) STEREO ISOMERISM

- Stereochemistry deals with the spatial arrangements of atoms (or) groups of atoms in molecules in three dimensions.
- Because of the tetrahedral arrangement of bonds to carbon, the given two compounds with the same structure may be different when the arrangement of their atoms in space is different.
- Molecules that have the same constitution but differ in the spatial arrangement of their atoms or groups of atoms are called Stereoisomers and the phenomenon is called **Stereoisomerism**.
- Stereoisomers are of two types. They are
  (1) Configurational isomers
  (2) Conformational isomers.
- Configurational isomers differ from conformations.
- In configurational isomers type the isomers posses certain types of rigity in the molecules and these can be interconverted by bond breaking and reforming of covalent bonds.
- In conformational isomers type the isomers are simply inter converted by rotation about 'σ' bonds.
- Configurational isomers are stereoisomers and they can be classified in to two types. They are
  (1) Geometrical isomers (2) Optical isomers.

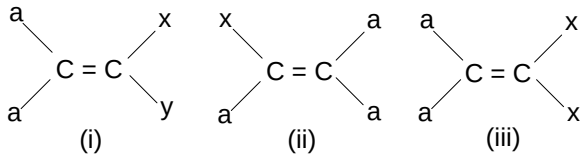
Geometrical Isomers – Geometrical isomerism :

- Ethene is an alkene which contains only two carbons with molecular formula C_2H_4.
- Propene is three carbon alkene with molecular formula C_3H_6.
- C_4H_8 is a four carbon alkene which has 4 different structures. They are



- 1 – Butene and Cis – 2- Butene differ in the position of double bond and they are position isomers.
- 1 – Butene and 2 – Methyl propene differ in the carbon chain length and they are chain isomers.
- These position isomers and chain isomers are called structural isomers because their atoms are bonded in different structures.

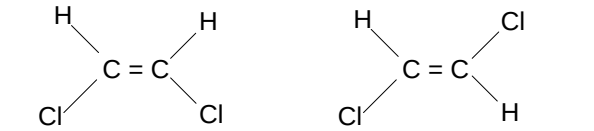
- Cis – 2 – Butene and Trans – 2 – Butene have an unbranched carbon chain with a double bond between C – 2 and C – 3 and their atoms are bonded in the same structure.
- The isomer which has both of its methyl groups on the same side of the double bond and it is called cis-isomer. i.e. Cis – 2 – Butene.
- The isomer which has its methyl groups opposite sides of the double bond is called trans-isomer. i.e. trans – 2 – Butene.
- Therefore Cis-2-Butene and Trans-2-Butene are stereoisomers because they have same constitution (or) structure but they differ by arrangement of their atoms (or) groups in space.
- Stereoisomers of the cis-trans type are also called as geometrical isomers and this phenomenon is called geometrical isomerism (or) cis-trans isomerism.
- Geometrical isomerism is due to fixed geometry around C = C.
- This geometrical isomerism is not possible in alkenes if one of the doubly bonded carbon bears two identical substituents.
  i.e. 1 – Butene and 2 – Methyl propene.
- Due to restricted rotation of C = C π bond which requires high activation energy i.e. 250 kJ/mole for rotation, two possible arrangements of groups attached to the doubly bonded carbon atoms are possible which results cis-trans isomers.
- Geometrical isomerism requires the two groups attached to the same carbon to be different.
- Alkenes of the type,
  abC = Cab
  abC = Ccd
  abC = Cax
  abC = Cbx shows this type of isomerism.
- Compounds of the following type will not show geometrical isomerism.



(i) (ii) (iii)

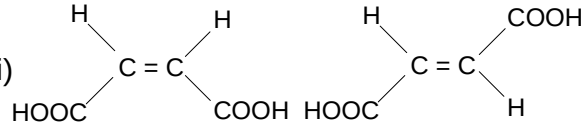
- Some examples of the molecules showing geometrical isomerism are,

(i)



Cis-1, 2-dichloroethene Trans-1, 2 dichloro ethene

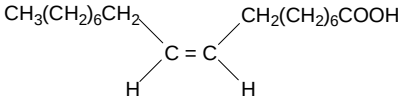
(ii)



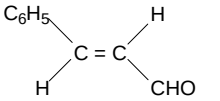
Maleic acid (Cis isomer) Fumaric acid (Trans isomer)

Naming of Stereoisomeric alkenes by the E – Z notational system :

- When the substituents on either end of the double bond are the same (or) structurally same it is easier to describe the configuration of molecules as cis (or) trans.

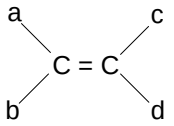


Cis-oleic acid



Trans-cinnamal-dehyde

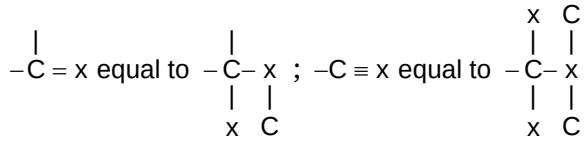
- When three (or) four different groups attached to the carbon atoms of a double bond E – Z system is followed



- E – Z system is based on atomic number ranking method.
- According to this when atoms of higher atomic number are on the same side of the double bond is called as "Z" configuration ["Zusammen" which means together].
- When the atoms of higher atomic number are on opposite sides of the double bond it is said to be called as "E" configuration. ["Entgegen" which means opposite]

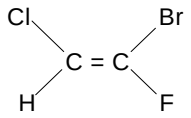
Rules for the priorities of atoms (or) groups :

- If the four atoms attached to the double bonded carbon atoms are different priority depends on the atomic number. i.e. the atom with higher atomic number gets high priority.
  Example : I > Br > Cl > F
- If two isotopes of same element are present, the isotope of higher mass number gets the higher priority.
  Example : Deuterium gets priority over hydrogen.
- If two atoms are identical, the atomic numbers of the next atoms are considered for priority.
  Example : If CH_3 and C_2H_5 are attached C_2H_5 gets higher priority because atoms attached to first carbon are C, H and H where as in CH_3 group atoms attached are H, H and H only.
- When there is a double bond (or) triple bond, both atoms are considered to be duplicated (or) triplicated. Example :



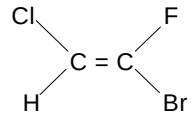
Some examples :

(1) This is 'Z' configuration because $_{17}Cl$ and $_{35}Br$ with higher atomic number are on the same side of the double bond compared to $_1H$ and $_9F$ at carbons.



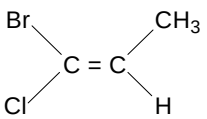
'Z' configuration

- This is 'E' configuration because higher atomic groups $_{17}Cl$ and $_{35}Br$ are on opposite sides of the double bond.



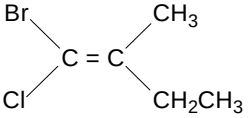
'E' configuration

(2) This is 'Z' configuration because $_{35}Br$ has first priority than $_{17}Cl$ and $_6C$ of methyl has higher priority than $_1H$. Therefore higher priority groups $_{35}Br$ and $_6C$ of CH_3 are on same side.



'Z' configuration

(3) This is 'E' configuration because $_{35}Br$ has higher priority than $_{17}Cl$ and ethyl [C(C, H, H)] has higher priority than methyl [C(H, H, H)].



'E' configuration

$\therefore$ Higher priority groups are opposite side.

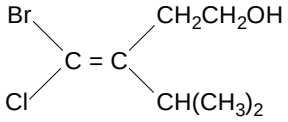
Order of priority of some groups.

$\rightarrow C_2H_5 > CH_3$

$\rightarrow C(CH_3)_3 > CH(CH_3)_2 > CH_2CH_3$

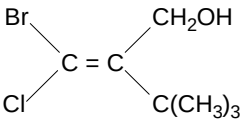
$\rightarrow C(C, C, C) > C(C, C, H) > C(C, H, H)$

(4) In this structure $_{35}Br$ has higher priority than $_{17}Cl$ and $-CH(CH_3)_2$ [C(C, C, H)] has higher priority than $-CH_2CH_2OH$ [–C(C, H, H)]. It is 'E' configuration because higher priority groups are opposite side of carbon atoms.



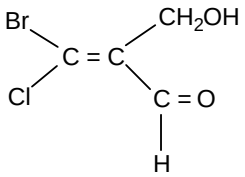
'E' configuration

(5) In this structure $_{35}Br$ has higher priority than $_{17}Cl$ and CH_2OH [–C(O, H, H)] has higher priority than $C(CH_3)_3$ [–C(C, C, C)]. It is 'Z' configuration because higher priority groups are on same side of carbon atoms.



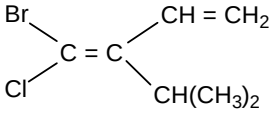
'Z' configuration

(6) In this structure $_{35}Br$ has higher priority than $_{17}Cl$ and $-\underset{\underset{H}{|}}{C=O}$ [–C(O, O, H)] has higher priority group than $-CH_2OH$[–C(O,H, H)]. It is 'E' configuration because higher priority group are opposite side of carbon atoms.



'E' Configuration

(7) In this structure $_{35}Br$ has higher priority than $_{17}Cl$ and vinyl (–CH = CH_2) $\left[\begin{array}{l} C-C \\ | \\ -C-C \\ | \\ H \end{array}\right]$ has higher priority than isopropyl $-CH(CH_3)_2$



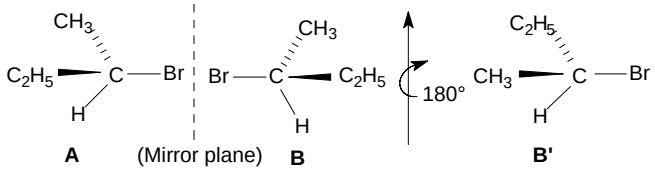
'Z' Configuration

$\left[\begin{array}{l} C(H,H,H) \\ | \\ -C-C(H,H,H) \\ | \\ H \end{array}\right]$. It is 'Z' configuration because higher priority groups are on same side of carbon atoms.

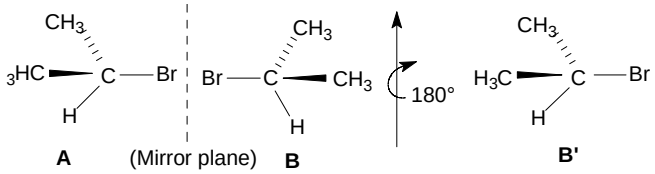
OPTICAL ISOMERISM :

- The compounds having same molecular formula and almost having the same physical and chemical properties but differ in the rotation of plane polarized light are called optical isomers and the phenomenon is called optical isomerism.
- A molecule which is non superimposable on its mirror image is "Chiral" (or) dissymmetric.
- A molecule which is super imposable on its mirror image is "Achiral".
- To exhibit optical isomerism the compound must contain one asymmetric carbon.

- According to Van't Hoff an organic molecule is asymmetric if one of the carbon atoms has four different groups around it.
- In 2-Bromobutane carbon atom contains four different groups (or) atoms H, Br, CH_3 and C_2H_5.



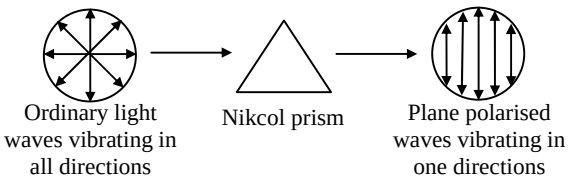
- The mirror image of A is B. If B is reoriented by rotating through 180° B′ is formed.
- If A and B′ are compared in A ethyl group is pointing towards the observer while in B′ the ethyl group is pointing away. Hence A and B′ are non-superimposable and this molecule is a chiral molecule.
- The stereoisomers that are related as an object and it is non-superimposable mirror image are called enantiomers.
- Therefore in the above structures A and B′ are enantiomers.
- Bromo chlorofluoro methane molecule is also an example of a chiral molecule.
- In 2-Bromopropane carbon atom contains H, Br, CH_3 and CH_3.



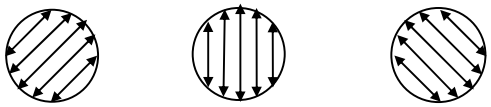
- A and B are mirror image forms of 2-Bromo propane.
- If B is reoriented by rotating through 180°C B′ is formed.
- A and B′ are super imposable because the substituents at C–2 are same. They are CH_3 and CH_3. Hence it is achiral molecule.
- Enantiomers (or) non super imposable mirror images posses same physical properties like M.P., B.P., refractive index but differ in their action towards plane of polarised light.

Plane polarised light and optical activity :

- An ordinary light is an electromagnetic wave has its photons vibrating in all the directions perpendicular to the path of its propagation.
- If this ordinary light is passed through a Nicol prism the transmitted light photons posses vibrations only in one perpendicular direction to the path of propagation.
- This type of light which has its photons vibrating only one perpendicular direction to the path of propagation is called plane polarised light.
- A Nicol prism made from a special crystalline form of calcium carbonate. i.e. Calcite.



- Certain organic compounds, when their solutions are placed in the path of plane polarized light, they rotating its plane through a certain angle which may be either to the left or to the right.



Plane rotated to the right (Dextro rotation '+') | Plane polarized light | Plane rotated to the left (Laevo rotation '–')

- The property of a substance of rotating the plane polarized light is called optical activity.
- The substances which are possessing optical activity are called as optical active compounds.
- The observed rotation of the plane polarized light in polarimeter produced by a solution depends on
  (i) The amount of the substance in tube.
  (ii)On the length of the solution examined.
  (iii) The temperature of the experiment.
  (iv) The wavelength of the light used.
- For the measurement of optical rotations a term specific rotation is introduced.
- Specific rotation is a physical constant characteristic of a substance as much as the melting point, boiling point, density, refractive index etc.
- The number of degrees of rotation was observed when light is passed through 1 decimeter (10 centrimeters) of its solution having concentration 1 gram per millilitre is known as specific rotation.
- The specific rotation of a given substance can be calculated by using the following expression.
- $$[\alpha]_{\lambda}^{T} = \frac{\alpha(obs)}{\text{length of the tube} \times \text{concentration of solution } (gm.lit^{-1})}$$

  T = temperature

  λ = wavelength, their values to be mentioned

  (or) $[\alpha]_{D}^{t^\circ} = \frac{\alpha(obs)}{\ell \times C}$

  where $[\alpha]_{D}^{t^\circ}$ = stands for specific rotation determined at t°C and using D-line of sodium light.

  α(obs) = It is observed angle of rotation.

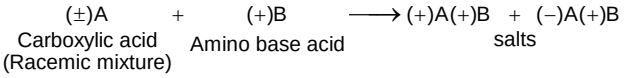
  ℓ = Length of the solution in decimetres.

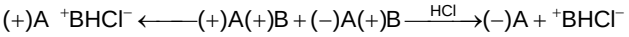
  C = Concentration of the active compound in grams per millilitre.
- Example 1 : The specific rotation of amyl alcohol (or) 2-methyl-1-butanol at 25°C for D-line of sodium light is $[\alpha]_{D}^{25^\circ C} = -5.756^\circ$.
- The sign attached with the angle of rotation signifies the direction of rotation. Negative (–) indicates that the rotation is toward the left i.e.Levo rotation.
- Example 2 : The specific rotation of chloroform is $[\alpha]_{D}^{25^\circ C} = +24.7^\circ$.
- Positive sign (+) indicates the direction of rotation is towards right i.e. Dextro rotation.
- The rotation may be different in different solvents. It must be mentioned while reporting the specific rotation.

Racemic mixture, Racemic modification :

- All the optically active substances can exists in 3 forms.

- Substances which are rotating the plane of polarized light to the left. This form is named as Laevorotatory (or) '–' form.
- Substances which are rotating the plane of polarized light to the right. This form is named as Dextro rotatory (or) '+' form.
- Substances which shows zero optical activity (or) which does not rotate the plane of polarized light at all. This is a mixture of equal amount of (+) dextro and (–) Laevo forms.
- A mixture of equal amounts of dextro (+) and Laevo (–) forms is named (±) – mixture (or) Racemic mixture (or) Racemic modification.
- The process of convertion of an enantiomer into a Racemic mixture is called Racemisation.
- An asymmetric molecule should not posses any element of symmetry such as centre of symmetry, axis of symmetry, alternating axis of symmetry (or) plane of symmetry.
- The process of separating Dextro and Laevo forms from Racemic mixture is called resolution.
- The isomers which are not mirror images and non super imposable are called diastereomers.
- Resolution of a Racemic mixture with an enantiomer of some other compound gives diastereomers.
- Diastereomers have different melting points, boiling points and solubility etc.
- Example : Racemic mixture of carboxylic acid (±) A is treated with an amino acid base (+B) enantiomer giving (+)A (+)B, (–)A (+)B two salts which are diastereomers. These are separated by treating with conc.HCl. So that, we will get (+)A, (–)A. It can be represented as follows.





(+) A → Dextro form

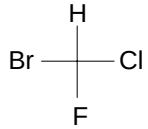
(–) A → Laevo form

- These diastereomers differ from physical properties, rate of formation, easyness of crystallisation, solubility etc.

Fischer projection formulae :

- To represent three dimentional structures on a two dimentional surface Fischer projection formulae were proposed.
- In Fischer projection formulae the molecule is oriented in such a way that
  (i) The vertical bonds at the stereogenic center are directed away form the viewer horizontal bonds point towards him.
  (ii)If the carbon chain is more than one carbon atom, the chain is written vertically.
  (iii) The stereogenic carbon (or) other carbon atoms of the chain are the centre of crosses and are not shown through symbols but understood.

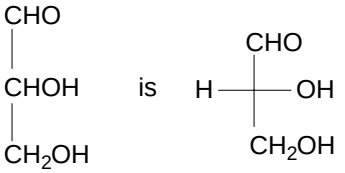
  Ex1: Bromo chloro fluoromethane is shown as



Fischer projection formula

Ex2.

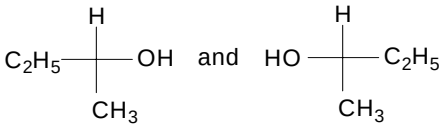
- Fischer projection formula for glyceraldehyde



- In this formula the horizontal bonds i.e. C – OH and C – H projects towards us out of the plane of the paper, where as the vertical bonds i.e.C – CHO and C – CH_2OH project away from us.

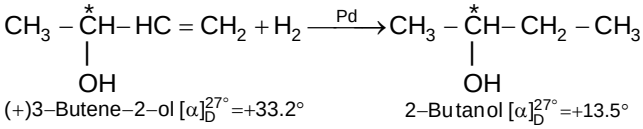
Absolute and relative configurations :

- The three dimentional arrangement of atoms or groups at asymmetric carbon atom is called its absolute configuration.
- Neither the sign nor the magnitude of rotation by itself provides any information about absolute configuration of a substance.



- absolute configurations of 2-Butanol.
- These absolute configurations cannot give any additional information about them. i.e. Whether it is (+) 2 Butanol (or) (–) 2-Butanol.
- But we will know some information about the above molecule experimentally through chemical inter conversion.

  Ex. When (+) 3-Butene-2-ol is hydrogenated the product formed is 2-Butanol.



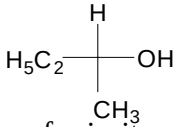
In this conversion same sign of identical configuration is known.

- In some conversions the same relative configuration could have opposite sign of optical rotation.
- Ex. $CH_3 - CH_2 - \underset{\displaystyle CH_3}{\underset{|}{CH}} - CH_2OH + HBr \rightarrow CH_3 - CH_2 - \underset{\displaystyle CH_3}{\underset{|}{CH}} - CH_2Br + H_2O$

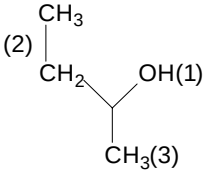
  2-Methyl-1-Butanol $[\alpha]_D^{25^\circ} = -5.8^\circ$ 1-Bromo-2-methyl butane $[\alpha]_D^{25^\circ} = +4.0^\circ$

- After the determination of absolute configuration of (+) tartaric acid the absolute configurations of all compounds whose configurations had been similar to (+) tartaric acid were established.

The Cahn-Ingold-Prelog-R-S notational system :

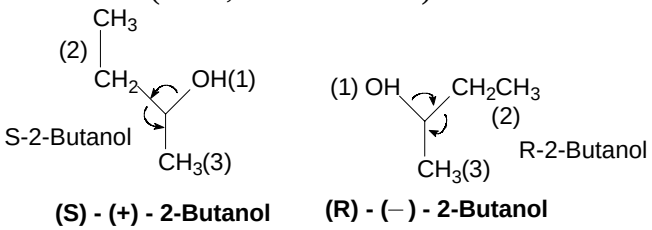
- This is newer and more systematic method of specifying absolute configuration to optically active compounds.
- This system is based on actual three dimentional (or) tetrahedral structure of the compound. It has certain rules.
- Identify the substituents at asymmetric carbon and arrange them in order of priority i.e. from highest atomic number to lowest atomic number.
- Ex. 

(+) 2-Butanol



- Order of priority of groups is :
  – OH > – CH_2CH_3 > – CH_3 > H

- The molecule is oriented so that the lowest priority group is far away from the viewer. i.e. 'H' atom.
- The remaining three higher priority groups are written as they appear to the viewer with lowest priority group far away.
- If the eye while moving from 1 → 2 → 3 travels in a clockwise direction (or) right hand direction then the absolute configuration is 'R'(Latin, Rectus=right)
- If the eye while moving from 1 → 2 → 3 travels in clockwise (or) left-hand direction the configuration is designated as 'S' (Latin, Sinister = Left)



(S) - (+) - 2-Butanol **(R) - (−) - 2-Butanol**

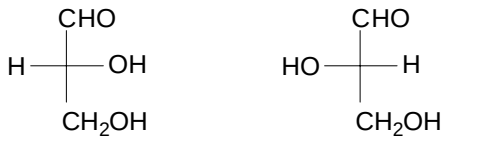
D and L system :

- The sign of rotation of plane polarized light by an enantiomer cannot be easily related to either its absolute or relative configuration.
- Compounds with similar configuration at the asymmetric carbon atom may have opposite sign of rotations and compounds with different configuration may have same sign of rotation.
- Ex. d-lactic acid with specific rotation +3.82° gives L-methyl lactate with a specific rotation –8.25°, although the configuration (or) arrangement or groups about the asymmetric carbon atom remains the same during the change.



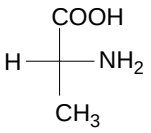
d-lactic acid (+ 3.82°) l -methyl lactate (−8.25°)

- From this we found that no relation between configuration and sign of rotation. Therefore D, L system is used to specify the configuration at the asymmetric carbon.
- In this system the configuration of an enantiomer is related to a standard compound, glyceraldehyde.
- The two forms of glyceraldehyde are as follows :

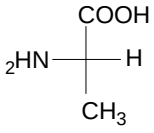


D-(+) glyceraldehyde (D configuration) L(−) glyceraldehyde (L configuration)

- If the configuration at the asymmetric carbon atom of a compound is related to D-glyceraldehyde it belongs to D-series.
- If the configuration at the asymmetric carbon atom of a compound is related to L-glyceradehyde it belongs to L-series.
- Ex. Natural alanine (2-amino propanoic acid)



D- (+) 2-amino propanoic acid
(D series)



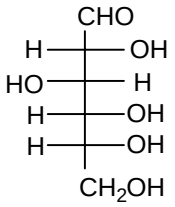
L(−) 2-amino propanoic acid
(L series)

Note :

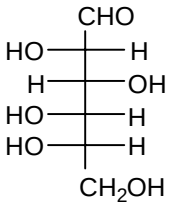
For α-amino acid compounds NH_2 – COOH, R and H groups at asymmetric carbon atom are related to OH, CHO, CH_2OH and H respectively of glyceraldehyde.

- **Some other examples :**

1) Glucose :

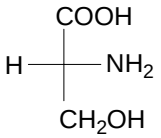


D(+)-glucose
(D series)

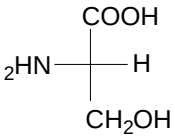


L(−)-glucose
(L series)

2) Serine :



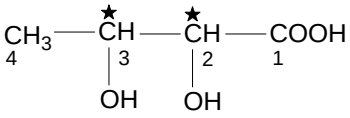
D(+)-Serine
(D series)



L(−)-Serine
(L series)

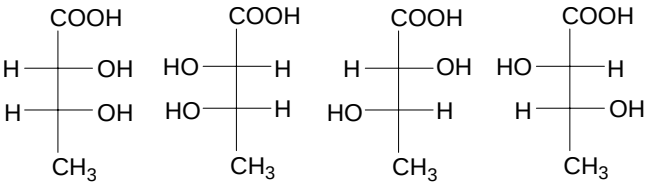
Optical Isomerism in compounds with more than one chiral centres (or) asymmetric carbon atom :

- A molecule with a chiral carbon atom has two enantiomers.
- A molecule with two asymmetric carbon atoms forms 4 stereoisomers.
- In general for a molecule with 'n' asymmetric carbons there can be maximum of 2^n stereoisomers.
- Ex. 2, 3 – dihydroxybutanoic acid



2, 3 carbon atoms are asymmetric.

- This molecule forms 4 stereoisomers as follows :

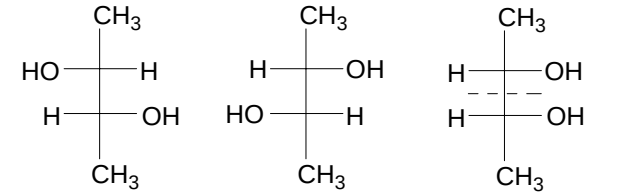


(i) (ii) (iii) (iv)

- 'i' and 'iv' structures have same constitution but differ in the arrangement of atoms (or) groups.
  - i and ii are enantiomers.
  - iii and iv are enantiomers.
  - i and iii are diastereomers.
  - ii and iv are diastereomers.
  - i and iv are diastereomers.
  - ii and iii are diastereomers.
- If like substituents are on the same side of the Fischer projection formula that isomer is called Erythro diastereomer.
- If like substituents are on the opposite side that isomer is called threodiastereomer.
- In above structures
  i and ii are Erythrodiastereomers.
  iii and iv are Threodiastereomers.

Chiral molecules with two stereogenic centres :

- Suppose if we take 2, 3-butanediol we have only three stereoisomers but not four isomers. They are



- (2R, 3R) –2, 3 butane diol and (2S, 3S) –2, 3 butane diol forms are enantiomers. They are equal but have optical rotations.
- The third configuration (2R, 3S) however has an achiral structure and it is super imposable on its (2S, 3R) mirror image.
- The third configuration has achiral structure and it is optically inactive.
- The achiral molecules that have stereogenic centres are called mesoforms.
- In structure iii dotted line represents plane of symmetry.
- A meso compound is an optically inactive stereoisomer which is achiral due to the presence of an internal plane of symmetry.
- A meso compound is inactive due to its one half is dextrorotary and other half is laevorotatory. So that its optical activity was cancelled.
- When two optically inactive compounds react no optical active compound is formed.
- When two optically inactive compounds react in the presence of a catalyst which is optically active an optical active compound is formed.

Applications :

- Stereochemistry plays an important role in studying biological processes and chemical reactions.
- It helps in deciding the physiological properties of compounds.
- Ex. (1) (+) Nicotine is less toxic than (–) Nicotine.

(2) (+) Adrenaline is very active in the construction of blood vessels than (–) Adrenaline.