Mirror Images and Enantiomers

A left hand is not identical with its mirror image, which is a right hand.
A left hand cannot be superimposed, point for point, on a right hand.
Molecular structures that cannot be superimposed on their mirror images are called enantiomers.
Superimposition requires a point-by-point, 3-dimensional correspondence.

sp\(^3\) Carbons and Enantiomerism

A CH\(_2\)X molecule cannot exist as enantiomers.

A CH\(_2\)XY molecule cannot exist as enantiomers.

A CH\(_3\)X molecule cannot exist as enantiomers.

A CH\(_3\)XY molecule cannot exist as enantiomers.

A CH\(_3\)XYZ (or CWXYZ) molecule must exist as enantiomers.
The molecule as a whole is chiral.

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**Chiral And Achiral Cyclic Compounds; Chirality Centers**

![Molecules Diagram](image)

- **CH**
  - Chirality center
  - The molecule as a whole is chiral.

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**Plane Polarized Light**

Unpolarized light passes through a polarizing filter. Wave oscillations in all planes except one are absorbed.

The oscillation in the transmitted plane is **plane polarized light**.

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**The Polarimeter**

Organic molecules within the polarimeter tube rotate the plane of the plane polarized light.

The ability to rotate the plane of plane polarized light is known as **optical activity**.
Qualitative - Direction of Rotation

Dextrorotation - If the chiral molecule rotates the plane clockwise as you view the analyzing filter, the enantiomer is dextrorotatory. Dextrorotatory $2\text{-bromobutane}$ is $\alpha\text{-2-bromobutane}$ or $(+)-2\text{-bromobutane}$.

Levorotation - If rotation is counterclockwise the enantiomer is levorotatory. Levorotatory $2\text{-bromobutane}$ is $\beta\text{-2-bromobutane}$ or $(-)-2\text{-bromobutane}$.

Specific Rotations of Organic Compounds

<table>
<thead>
<tr>
<th>Compound</th>
<th>$[\alpha]_D$ (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propyl alcohol</td>
<td>$+53.3$</td>
</tr>
<tr>
<td>Sodium bromide</td>
<td>$+66.1$</td>
</tr>
<tr>
<td>Cyclohexane</td>
<td>$+44.35$</td>
</tr>
<tr>
<td>Methylamine</td>
<td>$-25.5$</td>
</tr>
</tbody>
</table>

Quantitative - Extent of Rotation

To express optical rotations in a meaningful way so that comparisons can be made, we have to choose standard conditions. The specific rotation, $[\alpha]_D$, of a compound is defined as the observed rotation when the sample pathlength is 1 decimeter (1 dm = 10 cm), the sample concentration $C$ is 1 g/mL, and light of 589 nanometer (nm) wavelength is used. (Light of 589 nm, the so-called sodium D line, is the yellow light emitted from common sodium street lamps; 1 nm $= 10^{-9}$ m.)

$$[\alpha]_D = \frac{\text{Observed rotation (degrees)}}{1 \text{ dm} \times \text{Concentration, C (g/mL)}} \times \frac{\text{Pathlength, (cm)}}{10}$$

Each chiral molecule that interacts with the plane polarized light adds to the rotation of the plane. This is reflected in the equation for specific rotation.


Rule 1 Look at the four atoms directly attached to the chirality center, and assign priorities in order of decreasing atomic number. The atom with highest atomic number is ranked first, the atom with lowest atomic number (usually hydrogen) is ranked fourth.

Rule 2 If a decision about priority can't be reached by applying rule 1, compare atomic numbers of the second atoms in each substituent, continuing as necessary through the third and fourth atoms until the first point of difference is reached.

Rule 3 Multiple-bonded atoms are equivalent to the same number of single-bonded atoms. For example:

- $\text{C=O} \equiv \text{C} \equiv \text{C}$
- $\text{C=O} \equiv \text{C} \equiv \text{C}$

Assign rankings to the 4 substituents WXYZ.

Absolute Configuration - The R,S Rules - Part 2: 1$\rightarrow$2$\rightarrow$3

With rank 4 behind the chiral carbon, determine if 1$\rightarrow$2$\rightarrow$3 is clockwise (R) or counterclockwise (S).
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What’s The R,S Designation?

(R)-2-Bromobutane

What’s The R,S Designation?

?
What’s the R,S designation?

(R)-2-bromobutane

(S)-2-butanol

2-bromobutane

In the structure shown above, there’s no information about configuration.
What’s The R,S Designation?

(R)-2-bromobutane

What’s The R,S Designation?

(S)-2-butanol

What’s The R,S Designation?

Absolute Configuration and Specific Rotation

Q: Is (S)-2-butanol dextrorotatory or levorotatory?
A: There’s no way to tell unless we go into the laboratory and observe its specific rotation.
All we know: Whatever the direction of rotation of any chiral compound, its enantiomer will rotate in the opposite direction.
Other than this, there’s no correlation between absolute configuration and specific rotation.

Enantiomers, Diastereomers, and Meso Compounds

Consider butanes that are substituted at the 2 and 3 positions . . .

Enantiomers
Diastereomers

Diastereomers are stereoisomers that are not mirror images of each other. Diastereomers must contain two or more chirality centers. Diastereomers have opposite configurations at some but not all of their chirality centers.

Meso Compounds

Compounds that are achiral, yet contain chirality centers, are called meso compounds (meso).

Three 2,3-dibromobutanes
Two of these form an enantiomeric pair.
The meso structure is a diastereomer of each of the two enantiomers.

Meso Compound

Cholesterol, with 8 chirality centers, could exist as $2^8$ = 256 stereoisomers.
Only 1 cholesterol exists in natural sources.
Physical Properties of Stereoisomers

Enantiomers differ only in their direction of rotation of plane polarized light. Diastereomers, including meso compounds, differ in all their physical properties. Racemates differ from their individual enantiomers in physical properties.

<table>
<thead>
<tr>
<th>Stereoisomer</th>
<th>Melting point (°C)</th>
<th>[α]D (degrees)</th>
<th>Density (g/cm³)</th>
<th>Solubility at 20°C (g/100 ml H₂O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(+)</td>
<td>108–110</td>
<td>+12</td>
<td>1.7768</td>
<td>1.30</td>
</tr>
<tr>
<td>(-)</td>
<td>158–170</td>
<td>-12</td>
<td>1.7768</td>
<td>1.30</td>
</tr>
<tr>
<td>Meso</td>
<td>146–148</td>
<td>0</td>
<td>1.6660</td>
<td>1.25</td>
</tr>
</tbody>
</table>

The Resolution of Racemates

A racemate, or racemic mixture, is a mixture of equal amounts of two enantiomers. A racemate is indicated by d,l or by (±). Racemic 2-butanol is d,l-2-butanol or (±)-2-butanol. The separation of a racemate into its component isomers is called the resolution of the racemate.

The Fischer Projection

Align the perspective projection so that the carbon chain is vertical and lies behind the chiral carbon, much like a spinal column. This places the other two substituents on a horizontal line in front of the chiral carbon, much like ribs. Draw intersecting lines connecting the vertical and the horizontal substituents, with the chiral carbon at the intersection.

From Fischer to R,S

Is this Fischer projection R or S?
1) Redraw the Fischer projection in a perspective format.

Label the substituents in order of Cahn-Ingold priority.
From Fischer to R,S
Is this Fischer projection R or S?
1) Redraw the Fischer projection in a perspective format
2) Label the substituents in order of Cahn-Inglold priority
3) Is the priority R or S?

Fischer: 180° Rotation Permitted
180° Rotation of the Fischer projection in the plane of the paper is permitted. The ribs and the backbone maintain their relative orientations.

Fischer: 90° Rotation Forbidden
90° Rotation in the plane of the paper causes an interchange of the ribs and backbone. 90° Rotation is prohibited.

Back to Enantiomers
Four 2-bromo-3-chlorobutanes
Molecular structures that cannot be superimposed on their mirror images are called enantiomers.
2-Bromo-3-chlorobutane exists as two pairs of enantiomers.
Enantiomers: Fischer

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Back to Diastereomers

Four 2-bromo-3-chlorobutanes
Stereoisomers that are not mirror images are diastereomers.

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Diastereomers: Fischer

Four 2-bromo-3-chlorobutanes.
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Back to Meso Compound

Three 2,3-dibromobutanes
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Meso Compound: Fischer

Three 2,3-dibromobutanes
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Inactive Reagents Produce Inactive Products

Even though they may generate products containing chirality centers, the reactions of optically inactive reagents produce optically inactive products.
The 2-bromobutane produced here is racemic.
The Planar Carbocation

Attack by the nucleophile can occur from either side with equal probability.
The result is a racemic product.

Bromination Of *cis*-2-Butene
Produces A Racemic Product

Bromination Of *trans*-2-Butene
Produces A Meso Product

Chirality In Nature

End

Stereochemistry