Organic Chemistry I, CHM 3140, Dr. Laurie S. Starkey, Cal Poly Pomona
Chapter 5 (Klein) Stereochemistry

Chapter 5 Outline

I) Stereoisomerism (5.1) and Chirality (5.2, 5.8, 5.9)
II) Nomenclature (*R* and *S* configurations) (5.3)
III) Fischer Projections (5.7)
IV) Molecules with Multiple Chiral Centers (5.5, 5.6)
V) Optical Activity and other physical properties (5.4)
VI) Mixtures of Enantiomers (5.4, 5.10)
VII) Alkene Nomenclature (*E* and *Z* configurations) (5.11)

skip SkillBuilder 5.4, calculation of specific rotation [α]

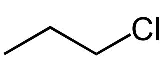
Different compounds with the same molecular formula are called:

[ ]

Constitutional Isomers (4.3)

→ different connectivity (different IUPAC names)
→ use DU/HDI to avoid counting H atoms

Examples:



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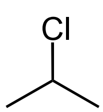
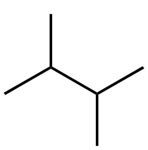


1-chloropropane 2-chloropropane



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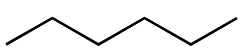
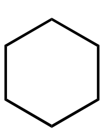


2,3-dimethylbutane hexane



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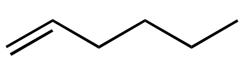


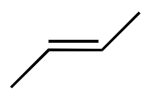
cyclohexane 1-hexene

Stereoisomers (4.14, 5.1)

→ same connectivity (same IUPAC name!)
→ differ only by spacial arrangement (3D shape)

Examples:

Alkenes



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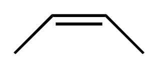
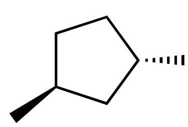
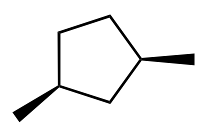


trans-2-butene *cis*-2-butene

Cycloalkanes

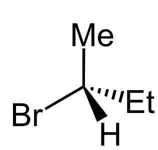


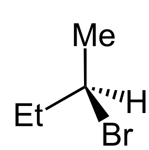


trans-1,3-dimethylcyclopentane *cis*-1,3-dimethylcyclopentane

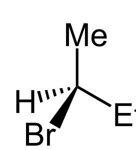
and...Chiral Centers!

(*R*)-2-bromobutane





(*S*)-2-bromobutane



I. Definition of Chirality (5.2, 5.8, 5.9)

Stereoisomerism is possible when a tetrahedral carbon has four different groups attached. This is called a chiral center (or chirality center or asymmetric carbon) and is denoted with (*). A *molecule* can also be described as chiral or not chiral (achiral), based on its symmetry.

Chiral objects have no internal planes of symmetry.
Achiral objects have one or more planes of symmetry (one half is the mirror image of other half).
(there are rare exceptions, if a point of symmetry present - a center of inversion, then it is achiral)

ACHIRAL Things	**CHIRAL Things**

All **chiral** objects have non-superimposable mirror images. (e.g., a student desk)

Every chiral molecule has an ________________________

All **achiral** objects are exactly the same as their mirror images. (e.g., a chair without arms)

An achiral molecule does / does not have an enantiomer.

try SkillBuilders 5.1, 5.2

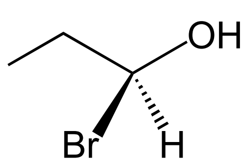
II. *R/S* Nomenclature of Chiral Centers (5.3, Cahn-Ingold-Prelog Rules)

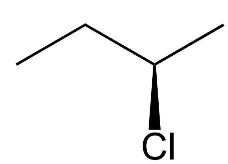
The stereochemistry of each chirality center (tetrahedral carbon with four different groups attached) is designated as either *R* or *S* configuration.

1. Assign priorities to the four groups: #1 has highest atomic number, #4 has lowest atomic number
   - if there is a tie, move away one atom at a time until you find a difference
   - a double bond can be treated as two single bonds

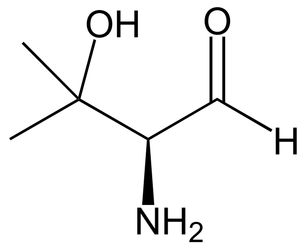
2. With the lowest priority group (#4) pointing **away** from you, move from #1 → #2 → #3

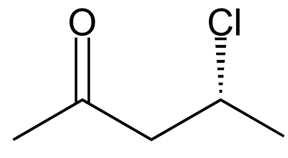
3. if rotation is **clockwise**, then (*R*) (Latin rectus/right-handed)
   if rotation is **counterclockwise**, then (*S*) (Latin sinister/left)

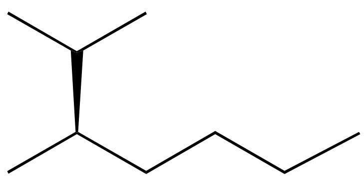


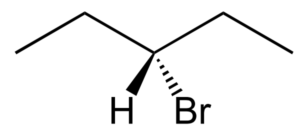


Determine the configuration of each chiral center:









try SkillBuilder 5.3

Draw (*S*)-2-bromopentane.

To draw the enantiomer of (*S*)-2-bromopentane, there are two methods that work:

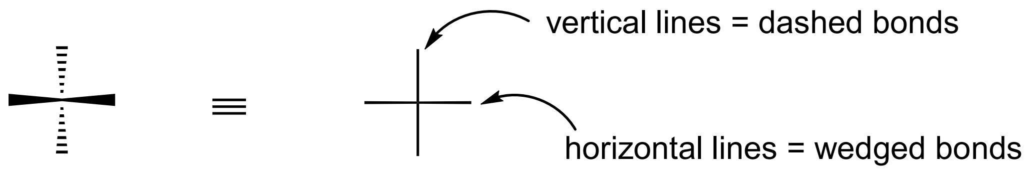
1. Draw its mirror image.

2. Invert ALL chiral centers.
(invert = swap any two groups, e.g. dash/wedge)

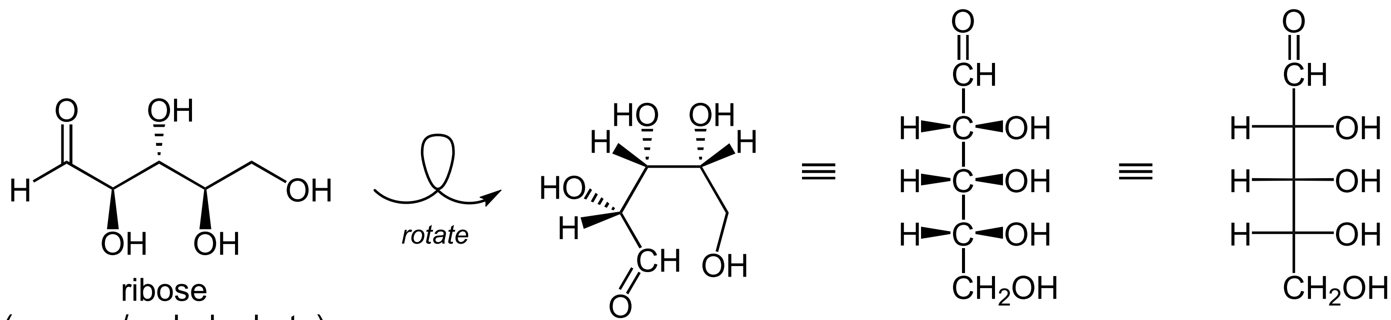
III. Fischer Projections (5.7)

A short-hand way to draw chiral centers.

definition:



tetrahedral carbon ≡ tetrahedral carbon!

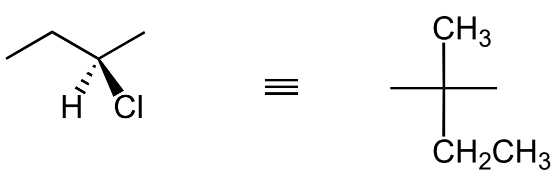


ribose (a sugar/carbohydrate)

view so that groups on L/R are pointing toward you

Fischer projection

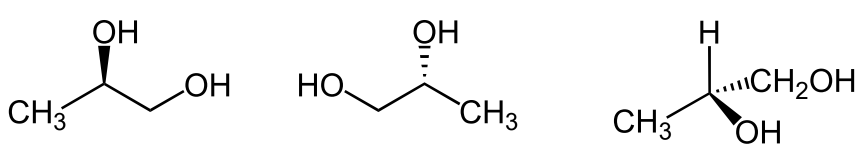
Draw the given compound as a Fischer projection:



(*R*)-2-chlorobutane

try SkillBuilder 5.8

II. Revisited: assigning *R/S* configuration if group #4 is *in the plane* (5.3).

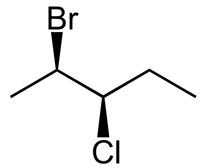


#4 is dashed so 1→2→3 = (*R*)

#4 is wedged so 3→2→1 = (*R*)

#4 is planar so change POV!

IV. Molecules with 2 chiral centers (5.5, 5.6)

A 

Enantiomer of **A** =

(,   )-2-bromo-3-chloropentane

Other stereoisomers?

How many stereoisomers are possible?

Relationship between **A** and **B**?

Relationship between **C** and **D**?

Relationship between **A** and **C**?

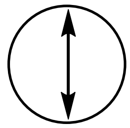
Example: draw all stereoisomers of 2,3-dichlorobutane

try SkillBuilders 5.6, 5.7

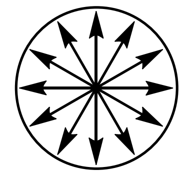
V. Optical Activity and other physical properties (5.4)

**Chiral molecules rotate a plane of polarized light.

Angle of rotation (α) is measured by a polarimeter. Polarized light has oscillations of electromagnetic field occur in a single plane, as shown.



polarized light

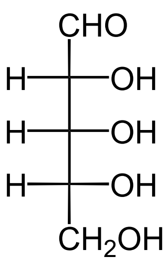


view looking into a beam of ordinary light

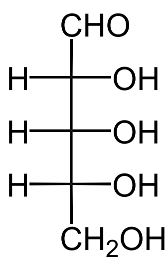
**Achiral species are NOT optically active (i.e., they are optically inactive). α =

**Enantiomers have identical physical properties (bp, mp, solubility, IR, etc.) *except* they have equal and opposite optical rotations [α] (also called specific rotation).

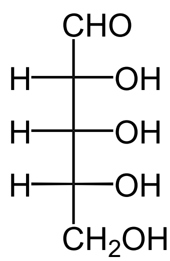
**Diastereomers have different everything! (bp, mp, solubility, IR, [α], etc.).



(2*R*, 3*R*, 4*R*)
(–)-ribose
$[\alpha]_D^{20}$ -19°
mp 88°C



(2 , 3 , 4)



(2 , 3 , 4)

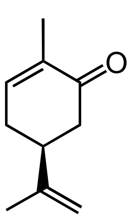
**Note: there is no relationship between R and S and +/- (d/l). Can't predict; must measure.*

When do enantiomers behave differently? When interacting with other chiral molecules, or when they are in a chiral environment.

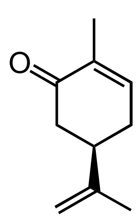
R/L hand + coffee mug ⟶

R/L hand + right-handed glove ⟶

+/– molecule + chiral receptor ⟶



(*S*)-carvone



(*R*)-carvone

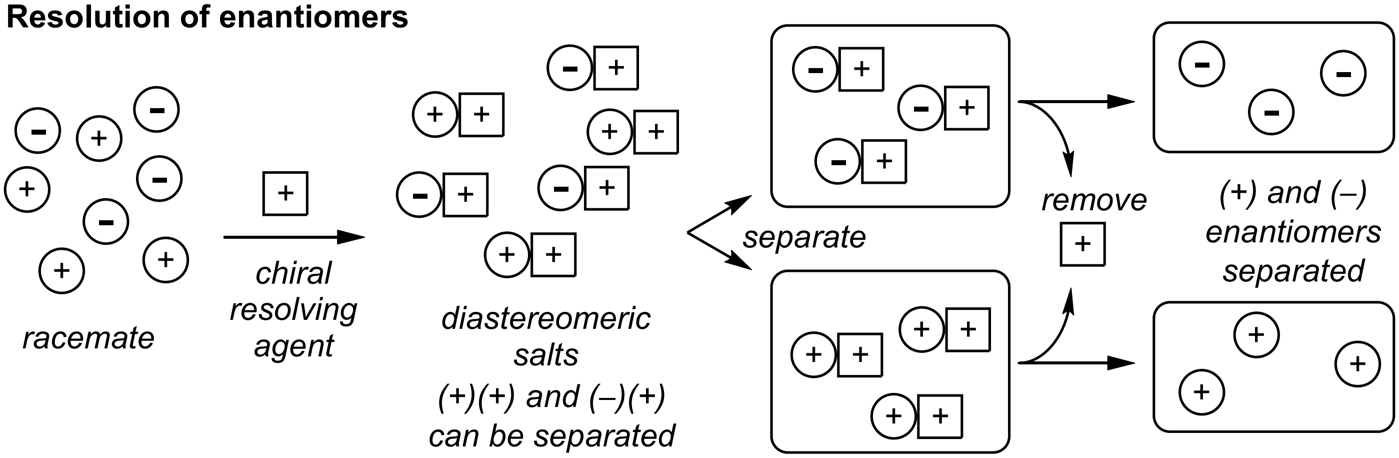
(*R*)-carvone smells/tastes like spearmint, and (*S*)-carvone like caraway seeds (used in rye bread). What does that tell you about the odor receptors in your nose and taste receptors in your mouth?

VI. Racemic Mixtures (5.4)

Nature synthesizes every chiral compound as a single enantiomer, but synthesis in a laboratory produces both enantiomers in equal amounts. This is called a **racemic mixture**, or a **racemate**:

- a 1:1 mixture of enantiomers
- a racemate is optically active / inactive
- can be separated by a procedure called an optical resolution
- most chiral drugs are sold as racemates, but often each enantiomer has different biological activity (*e.g.*, thalidomide)

Resolution of enantiomers



VI. Mixtures of enantiomers (5.10)

1:1 mixture of enantiomers is called a ______________________________.

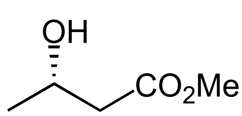
An unequal mixture of enantiomers is described by its **enantiomeric excess** (ee).

$$ee = \frac{\text{measured } [\alpha]}{\text{pure } [\alpha]} \times 100\%$$

$$ee = (\%\text{ major enantiomer}) - (\%\text{ minor enant.})$$

100% ee means ______________________________ (ee = 100% - 0%)

0% ee means ______________________________ (ee = 50% - 50%)



(*S*)-alcohol

pure (*S*) [α] = +20°

pure (*R*) [α] =

racemic [α] =

any other mixture?

if a sample of the alcohol has [α] = +10°

$$\text{then ee} = \frac{+10^\circ}{+20^\circ} \times 100\% =$$

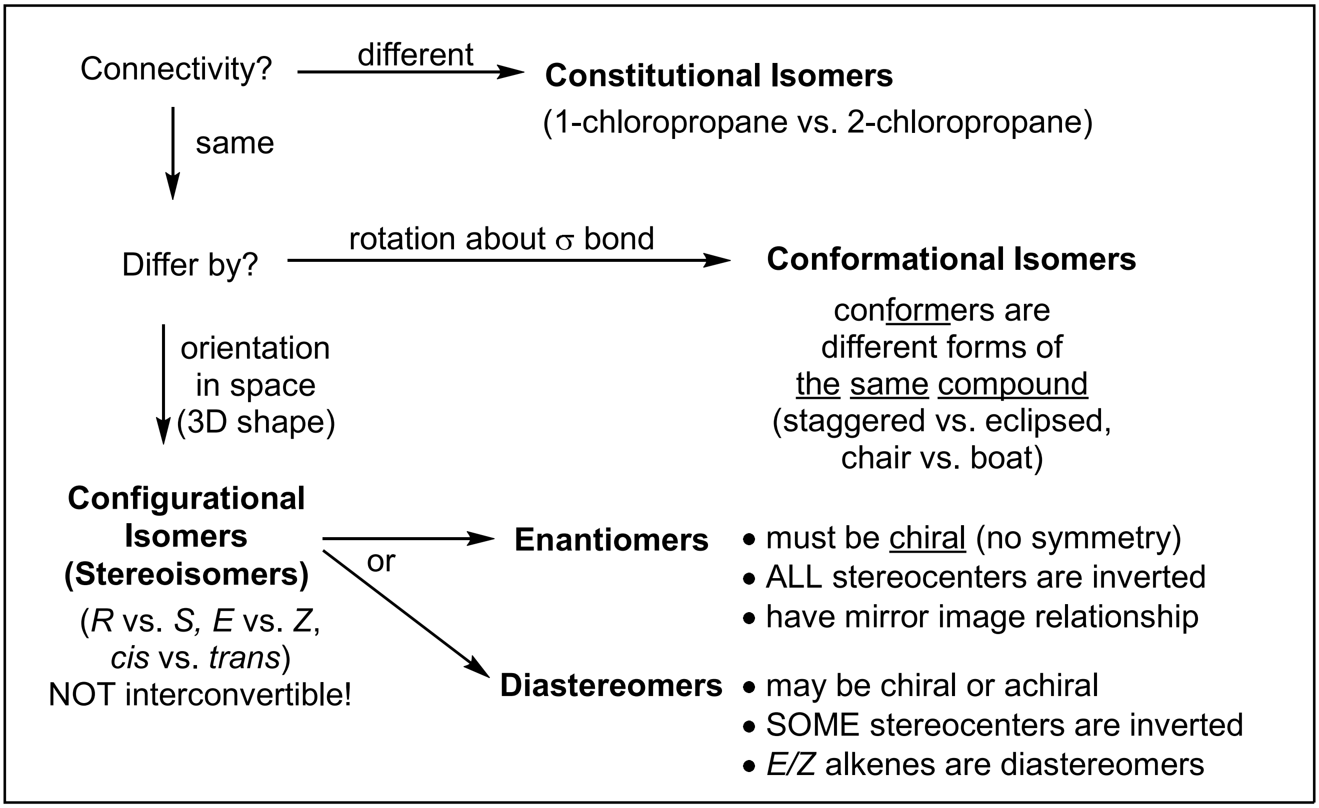
the mixture contains mostly *S* but some *R*

75% (+) and 25% (–) (50% ee = 75% - 25%)

What is the percent composition of a sample with 90% ee?

try SkillBuilder 5.5

All <u>isomers</u> have the same molecular formula.



A molecule is **chiral** if it contains no planes of symmetry. Every chiral molecule has a non-superimposable mirror image (**enantiomer**). Only chiral molecules have enantiomers. Achiral molecules have identical (superimposable) mirror images.

An **achiral** molecule has symmetry. If its plane of symmetry reflects one **chiral carbon** onto another, the molecule is called a **meso** compound.

Chiral substances are called **optically active** because they will rotate a plane of polarized light by a certain angle, α. The plane is either rotated counterclockwise (levorotatory, $\alpha < 0°$) or clockwise (dextrorotatory, $\alpha > 0°$). Enantiomers have equal but opposite **specific rotations** ([α] values).

A **racemic mixture** (or **racemate**) contains equal amounts of two enantiomers. Since the + and – rotations "cancel," such a mixture has $\alpha = 0°$, is not optically active. Because enantiomers have identical physical properties, they can only be separated by performing a **resolution** (also called an optical resolution). The "optical purity" of a nonracemic sample of a chiral compound is described by its **enantiomeric excess** (ee).

Suggested textbook problems: 1-71, but you can skip [α] calcs: 11-14, 42, 43, 49, 56.

California State Polytechnic University, Pomona
CHM 3140 Organic Chemistry I, Dr. Laurie S. Starkey
Chapter 5 Summary (Klein 4th ed. textbook): Stereochemistry

I. Stereoisomerism (5.1) and Chirality (5.2, 5.8, 5.9) SkillBuilders 5.1, 5.2
  A) chiral center = tetrahedral carbon with four different groups attached
  B) chiral object
    i) has no plane of symmetry (rare exceptions)
    ii) has a non-superimposable mirror image (called its enantiomer)
  C) achiral object
    i) has a plane of symmetry
    ii) is identical (superimposable) with its mirror image
    iii) has no enantiomer

II. Nomenclature (5.3) SkillBuilder 5.3
  A) assign priorities to groups
  B) determine (R) or (S) configuration
  C) be able to draw a compound, given its name

III. Fischer Projections (5.7) SkillBuilder 5.8
  A) definition
  B) gaining the proper perspective to convert a line drawing to a Fischer Projection
  C) using Fischer Projections to help determine R/S if group #4 is in the plane

IV. Molecules with Multiple Chiral Carbons (5.5, 5.6) SkillBuilders 5.6, 5.7
  A) diastereomers
  B) maximum of 2n stereoisomers possible
  C) achiral molecules which contain chiral carbons are called meso (5.6)
  D) determining the relationship between two compounds

V. Optical Activity and other Physical Properties (5.4)
  A) plane polarized light; polarimeter
  B) levorotatory ($-\alpha$, counterclockwise) and dextrorotatory ($+\alpha$, clockwise) rotations
  C) enantiomers have equal and opposite specific rotations [α]
  D) diastereomers have different physical properties

VI. Mixtures of Enantiomers
  A) Racemic mixtures, racemates (5.5)
    i) 1:1 mixture of enantiomers
    ii) optically inactive ($\alpha = 0°$)
    iii) can be separated by a resolution (5.10)
  B) unequal mixtures (5.4) SkillBuilder 5.5
    i) enantiomeric excess (e.e.), optical purity

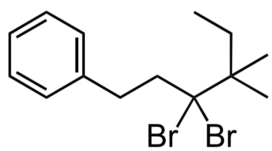
VII. Stereochemistry Designation of Alkenes (5.11) SkillBuilder 5.9
  A) cis, trans, E, Z

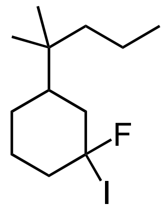
Skip SkillBuilder 5.4

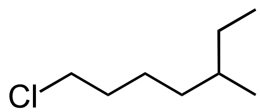
Extra Stereochemistry Practice: Quizzes in Canvas

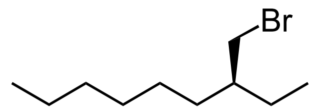
- Two drill-type quizzes available: R/S, Compare
- Questions are different every time you take the quiz, take as many as you'd like!
- Click on any Attempt number to see your results and to read the feedback for each question
- 3 course points for each quiz with a score of at least 50% (highest attempt is saved)

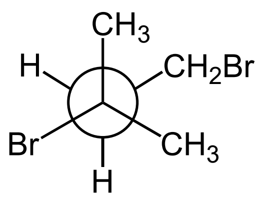
CHM 3140, Dr. Laurie S. Starkey, Exam II Nomenclature Practice Problems

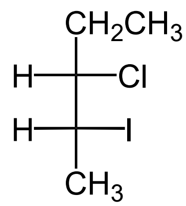


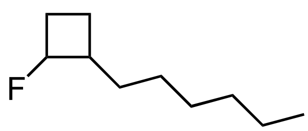


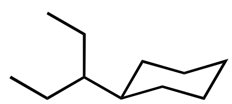


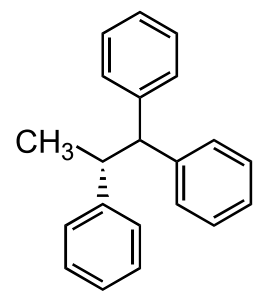












Draw and provide the correct IUPAC name:

2-*tert*-butyloctane

6-chloro-7-(1-ethylpropyl)heptane

(*R*)-3-ethyl-5-methyl-4-propylhexane

1-phenyl-5-(2-methylbutyl)cyclopentane

(2*S*)-3-bromo-2-isobutylpropane