Chapter 15 The Three-Dimensional Shape of Molecules

Solutions to In-Chapter Problems

15.1 Constitutional isomers differ in the way the atoms are connected to one another. Stereoisomers differ only in the three-dimensional arrangement of atoms.

a. \( \text{CH}_3\text{CH}_2\text{CHCH}_3 \) and \( \text{CH}_3\text{CHCH}_2\text{CH}_3 \)
   different connection of atoms constitutional isomers

b. \( \text{CH}_3\text{CH}_2\text{C}==\text{CH}_3 \) and \( \text{CH}_3\text{CH}_2\text{C}==\text{CH}_3 \)
   cis and trans stereoisomers

c. \( \text{CH}_3\text{CH=CHCH}_3 \) and \( \text{CH}_2\text{CH}_2\text{CH}==\text{CH}_3 \)
   identical

d. \( \text{CH}_3\text{CH}=\text{CHCH}_3 \) and \( \text{CH}_3\text{CHCH}=\text{CH}_3 \)
   different connection of atoms constitutional isomers

15.2 Draw the isomers of trans-2-hexene.

\[ \begin{align*}
\text{trans-2-hexene} & \quad \text{cis-2-hexene stereoisomer} \\
a. & \quad \begin{array}{c}
\text{CH}_3 \\
\text{H} \\
\text{C}==\text{C} \\
\text{CH}_2\text{CH}_3 \\
\text{CH}_2\text{CH}_3
\end{array} & \quad \begin{array}{c}
\text{CH}_3 \\
\text{H} \\
\text{C}==\text{C} \\
\text{CH}_2\text{CH}_3 \\
\text{CH}_2\text{CH}_3
\end{array}
\end{align*} \]

c. \( \begin{array}{c}
\text{OH} \\
\text{H} \\
\text{C}==\text{C} \\
\text{C}==\text{C} \\
\text{CH}_3 \\
\text{CH}_3 \\
\text{CH}_3
\end{array} \)

d. \( \begin{array}{c}
\text{OH} \\
\text{Br} \\
\text{H} \\
\text{C}==\text{C} \\
\text{C}==\text{C} \\
\text{CH}_3 \\
\text{CH}_3 \\
\text{CH}_3
\end{array} \)

different connection of atoms constitutional isomer
different connection of atoms constitutional isomer

different connection of atoms constitutional isomer

different connection of atoms constitutional isomer

15.3 A molecule (or object) that is not superimposable on its mirror image is said to be chiral. A molecule (or object) that is superimposable on its mirror image is said to be achiral.

a. nail—achiral
b. screw—chiral
c. glove—chiral
d. pencil—achiral

15.4 A molecule that is chiral is not superimposable on its mirror image. A chirality center is a carbon with four different groups bonded to it.

15.5 To locate the chirality centers, look at each C individually and eliminate those C’s that can’t be chirality centers. Thus, omit all CH\(_2\) and CH\(_3\) groups and all multiply bonded C’s. Check all remaining C’s to see if they are bonded to four different groups, as in Example 15.1.

a. \( \begin{array}{c}
\text{H} \\
\text{CH}_3 \\
\text{C}==\text{C} \\
\text{CHCH}_3 \\
\text{CHCH}_2\text{CH}_3
\end{array} \)

b. \( (\text{CH}_3)_3\text{CH} \)

none

c. \( \begin{array}{c}
\text{H} \\
\text{CH}_3 \\
\text{CH}_2\text{CH}==\text{CHCH}_3 \\
\text{CH}_3 \\
\text{OH}
\end{array} \)

d. \( \begin{array}{c}
\text{H} \\
\text{CH}_3 \\
\text{C}==\text{C} \\
\text{C}==\text{C} \\
\text{CH}_3 \\
\text{CH}_3 \\
\text{CH}_3 \\
\text{Br}
\end{array} \)

15.6 Label each chirality center, as in Example 15.1.

a. \( \begin{array}{c}
\text{Br} \\
\text{H} \\
\text{N} \\
\text{C}==\text{C} \\
\text{CH}_2\text{CH}_2\text{N(CH}_3)_2
\end{array} \)

b. \( \begin{array}{c}
\text{H} \\
\text{C}==\text{O} \\
\text{CH}_3 \\
\text{CH}_2\text{CH}_2\text{NHCH}_3
\end{array} \)

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15.7 Label each chirality center, as in Example 15.1.

a. CH₃CH₂CH₂–C=CH₃

b. CH₃CH₂C=CH₂

c. CH₃CH₂C=CH₂

15.8 Label the two chirality centers in vitamin K.

15.9 To draw both enantiomers:

[1] Draw one enantiomer by arbitrarily placing the four different groups on the bonds to the chirality center.

[2] Draw a mirror plane and arrange the substituents in the mirror image so that they are a reflection of the groups in the first molecule.

15.10 Locate the chirality centers in each compound.

a. OH

b. CH₂CH₃

c. Cl

All C's are part of multiple bonds or are bonded to two or three H's.
15.11 Label the two chirality centers.

\[ \text{CH}_3\text{NH} \quad \text{Cl} \quad \text{Cl} \]

15.12 Answer each question about propranolol.

\[ \text{chirality center} \quad \text{OCH}_2\text{CHCH}_2\text{NCH(CH}_3)_2\text{OH} \]

a. 

\[ \text{enantiomers} \]

b. 

c. 

This enantiomer fits the receptor.

This enantiomer does not fit the receptor.

15.13 Convert each molecule to a Fisher projection formula by replacing the chirality center with a cross.

a. 

b. 

15.14 Work backwards to draw a structure with wedges (horizontal bonds) and dashes (vertical bonds).

a. 

b. 

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15.15 Convert each molecule to a Fisher projection formula as in Example 15.2.
- Draw the tetrahedron of one enantiomer with the horizontal bonds on wedges and the vertical bonds on dashed lines. Arrange the four groups on the chirality center arbitrarily in the first enantiomer.
- Draw the second enantiomer by arranging the substituents in the mirror image so they are a reflection of the groups in the first molecule.
- Replace the chirality center with a cross to draw the Fischer projections.

\[ \text{CH}_3\text{CHCH}_2\text{CH}_2\text{CH}_3 \]

Draw the compound. Then, draw the mirror image.

\[ \text{CH}_3\text{CH}_2\text{CH}_2\text{OH} \]

Fischer projection of one enantiomer

\[ \text{CH}_3\text{CH}_2\text{CH}_2\text{Cl} \]

Draw the compound. Then, draw the mirror image.

\[ \text{CH}_3\text{CH}_2\text{CH}_2\text{Cl} \]

Fischer projection of one enantiomer

15.16 A chiral compound is optically active and an achiral compound is optically inactive.

\[ \text{CH}_3(\text{CH}_2)_5\text{CH}_3 \]

achiral optically inactive

\[ \text{CH}_3\text{CH}(\text{CH}_3)\text{OH} \]

chiral optically active

\[ \text{CH}_3\text{CH}_2\text{OH} \]

achiral optically inactive

\[ \text{CH}_3\text{CH}(\text{CH}_3)\text{OH} \]

achiral optically inactive
15.17 Because two enantiomers rotate the plane of polarized light to an equal extent but in opposite directions, the rotation of one enantiomer is cancelled by the rotation of the other enantiomer and the sample is optically inactive.

15.18 Answer the questions about cholesterol as in Sample Problem 15.3.
   a. The specific rotation of cholesterol is a negative value, so cholesterol is levorotatory.
   b. The specific rotation of the enantiomer has the same value, but is opposite in sign—that is, +32.

15.19 Answer each question about alanine, as in Sample Problem 15.3.
   a. \[
   \begin{align*}
   (R)-\text{alanine} & , \\
   \text{COO}^- & \\
   \text{H}_3\text{N}^- & \text{CH}_3
   \end{align*}
   \]
   b. Two enantiomers have the same melting point, so the melting point of \((R)\)-alanine is 297°C.
   c. The specific rotation of \((R)\)-alanine is –8.5.

15.20 Enantiomers are stereoisomers that are nonsuperimposable mirror images of each other.
Look for two compounds that when placed side-by-side have the groups on both chirality centers drawn as a reflection of each other. A given compound has only one possible enantiomer.
Diastereomers are stereoisomers that are not mirror images of each other.

- a. W and Z are enantiomers.
- b. X and Y are enantiomers.
- c. Z and W are diastereomers of Y.
- d. X and Y are diastereomers of Z.

15.21 Convert each structure to a Fischer projection by replacing each chirality center with a cross.
15.22 Identify the chirality center and draw the enantiomers.

\[
\begin{align*}
\text{CH}_3 & \text{CH}_2\text{C}=\text{CH}_2 \quad \text{CH}_2\text{C}=\text{CH}_2 \quad \text{CH}_3 \\
\text{CH}_3 & \quad \text{CH}_2\text{C}=\text{CH}_2 \quad \text{CH}_3 \\
\text{CH}_3 & \quad \text{CH}_3
\end{align*}
\]

Solutions to End-of-Chapter Problems

15.23 Use the definitions in Answer 15.3 to label each object as chiral or achiral.

- a. chalk—achiral
- b. shoe—chiral
- c. baseball glove—chiral
- d. soccer ball—achiral

15.24 Use the definitions in Answer 15.3 to label each object as chiral or achiral.

- a. boot—chiral
- b. index card—achiral
- c. scissors—chiral
- d. drinking glass—achiral

15.25 All objects and molecules have a mirror image. Butane does not have an enantiomer since the molecule and its mirror image are superimposable, so they are identical.

15.26 The human body is chiral because it is not superimposable on its mirror image.

15.27 Draw the mirror image for each compound.

- a. \begin{align*}
\text{CF}_3 & \quad \text{Br} \quad \text{Cl} \quad \text{H} \\
\text{H} & \quad \text{H} \quad \text{Cl} \quad \text{Cl}
\end{align*}

- b. \begin{align*}
\text{CF}_3 & \quad \text{Cl} \quad \text{H} \quad \text{Br} \\
\text{H} & \quad \text{H} \quad \text{Br} \quad \text{Cl}
\end{align*}

15.28 Draw the mirror image for each compound.

- a. \begin{align*}
\text{CH}_3\text{CH}_2\text{O}\text{CH}_2\text{CH}_3 & \quad \text{CH}_3\text{CH}_2\text{O}\text{CH}_2\text{CH}_3 \\
\text{CH}_3\text{CH}_2\text{O}\text{CH}_2\text{CH}_3 & \quad \text{CH}_3\text{CH}_2\text{O}\text{CH}_2\text{CH}_3
\end{align*}

- b. \begin{align*}
\text{CH}_2\text{OH} & \quad \text{H} \quad \text{O} \\
\text{HO} & \quad \text{H} \quad \text{CH}_2\text{OH}
\end{align*}
15.29 A and B are mirror images of each other—enantiomers. A and C are superimposable and identical.

[Diagrams showing A, B, and C with labels]

15.30 D and E are superimposable and identical. D and F are mirror images of each other—enantiomers.

15.31 To locate the chirality centers, look at each C individually and eliminate those C’s that can’t be chirality centers. Thus, omit all CH₂ and CH₃ groups and all multiply bonded C’s. Check all remaining C’s to see if they are bonded to four different groups, as in Example 15.1.

a. CH₃CH₂CHCl 
   
   two Cl's bonded to end C  
   no chirality center

b. CH₂CHClCH₂CH₃ 
   
   four different groups bonded to C

c. CH₃CH₂CH₃ 
   
   two CH₃'s bonded to middle C  
   no chirality center

d. CH₃C₂H₂CH₂CH₃ 
   
   four different groups bonded to C

15.32 To locate the chirality centers, look at each C individually and eliminate those C’s that can’t be chirality centers. Thus, omit all CH₂ and CH₃ groups and all multiply bonded C’s. Check all remaining C’s to see if they are bonded to four different groups, as in Example 15.1.

a. CH₃CH₂CH₂CH₃ 
   
   no chirality center

b. CH₃CH₂CH₂CH₃ 
   
   four different groups bonded to C

c. CH₃CHO 
   
   two CH₂'s bonded to middle C  
   no chirality center

d. CH₂CH₂CHO 
   
   four different groups bonded to C

15.33 Label each chirality center.

a. none  

b. none

c. none  

d. none

15.34 Label each chirality center.

a. none 

b. none

c. none 

d. none
15.35 Draw a compound to fit each description.

a. \( \text{CH}_3\text{CH}_2\text{C}-\text{CH}_2\text{CH}_2\text{CH}_3 \)
   b. \( \text{OH} \)

   \( \text{C}_7\text{H}_{16} \)
   one chirality center

   \( \text{C}_6\text{H}_5\text{O} \)
   one chirality center

15.36 Draw a compound to fit each description.

a. \( \text{CH}_3\text{CH}_2\text{C}-\text{CH}_3 \)
   b. \( \text{OH} \text{OH} \)

   \( \text{C}_4\text{H}_9\text{Br} \)
   one chirality center

   \( \text{C}_9\text{H}_{12}\text{O}_2 \)
   two chirality centers

15.37 A chirality center must have a carbon bonded to four groups and a carbonyl carbon has only three groups. Therefore, a carbonyl carbon can never be a chirality center.

15.38 A chirality center must have a carbon bonded to four groups and a carbon atom that is part of a triple bond has only two groups. Therefore, a carbon atom that is part of a triple bond can never be a chirality center.

15.39 Locate the chirality centers in each compound.

a. \[
\begin{array}{c}
\text{N} \\
\text{H} \\
\text{CH}_3
\end{array}
\]

b. \[
\begin{array}{c}
\text{NH}_2 \\
\text{CO}_2\text{CH}_3 \\
\text{O}
\end{array}
\]

15.40 Locate the chirality centers in each compound.

a. \[
\begin{array}{c}
\text{O} \\
\text{CH}_3 \\
\text{CH}_2\text{CO}_2\text{H}
\end{array}
\]

b. \[
\begin{array}{c}
\text{N} \\
\text{CH} \\
\text{CO}_2\text{CH}_3
\end{array}
\]

15.41 Locate the chirality center and draw the enantiomers.

Draw the bonds:

Add the groups:

\[
\begin{array}{c}
\text{mirror} \\
\text{enantiomers}
\end{array}
\]
15.42 Locate the chirality center and draw the enantiomers.

Add the groups:

Enantiomers are stereoisomers that are nonsuperimposable mirror images of each other.

a. \( \text{CH}_3 - \text{C} - \text{CH}_3 \) and \( \text{CH}_3 - \text{C} - \text{H} \)
   The central C is bonded to two CH\(_3\) groups.
   There is no chirality center.
   identical molecules

b. \( \text{CH}_3 - \text{C} - \text{CO}_2\text{H} \) and \( \text{HO}_2\text{C} - \text{C} - \text{CH}_3 \)
   The central C is bonded to four different groups.
   The compounds are nonsuperimposable mirror images.
   enantiomers

c. \( \text{Br} - \text{C} - \text{Cl} \) and \( \text{Cl} - \text{C} - \text{CH}_3 \)
   The central C is bonded to four different groups.
   The compounds are nonsuperimposable mirror images.
   enantiomers
15.44 Enantiomers are stereoisomers that are nonsuperimposable mirror images of each other.

a. \[
\begin{align*}
\text{CH}_3\text{CH}_2\text{C} & \text{ Br} \quad \text{and} \quad \text{CH}_3\text{CH}_2\text{C} \text{ Br} \\
\text{The central C is bonded to four different groups.} \\
\text{The compounds are nonsuperimposable mirror images.} \\
\text{enantiomers}
\end{align*}
\]

b. \[
\begin{align*}
\text{HOOH} & \text{C} \quad \text{OH} \quad \text{and} \quad \text{OH} \quad \text{C} \text{CH}_2\text{OH} \\
\text{The central C is bonded to four different groups.} \\
\text{The compounds are nonsuperimposable mirror images.} \\
\text{enantiomers}
\end{align*}
\]

c. \[
\begin{align*}
\text{CH}_3\text{O} & \quad \text{CHO} \quad \text{and} \quad \text{OH} \quad \text{C} \text{CH}_3 \text{O} \text{CH}_3 \\
\text{The central C is bonded to two OCH}_3 \text{ groups.} \\
\text{There is no chirality center.} \\
\text{identical molecules}
\end{align*}
\]

15.45 Enantiomers are stereoisomers that are nonsuperimposable mirror images of each other. Diasteromers are stereoisomers that are *not* mirror images of each other.

a. \[
\begin{align*}
\text{CH}_3\text{CH}_2\text{CH}_2\text{OCH}_3 \quad \text{and} \quad \text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3 \\
\text{different connectivity} \\
\text{constitutional isomers}
\end{align*}
\]

b. \[
\begin{align*}
\text{CH}_3 \quad \text{OH} \quad \text{and} \quad \text{HO} \quad \text{CH}_3 \\
\text{mirror images} \\
\text{enantiomers}
\end{align*}
\]

c. \[
\begin{align*}
\text{CH}_3\text{CH}_2\text{CH}_2\text{C} & \text{CH}_3 \quad \text{and} \quad \text{CH}_3\text{C} \text{CH}_2\text{CH}_2\text{CH}_3 \\
\text{There is no chirality center.} \\
\text{identical molecules}
\end{align*}
\]

d. \[
\begin{align*}
\text{CH}_3 \quad \text{Cl} \quad \text{H} \quad \text{and} \quad \text{Cl} \quad \text{H} \quad \text{CH}_2\text{CH}_3 \\
\text{two chirality centers} \\
\text{not mirror images} \\
\text{diastereomers}
\end{align*}
\]
**15.46** Enantiomers are stereoisomers that are nonsuperimposable mirror images of each other. Diastereomers are stereoisomers that are *not* mirror images of each other.

- a. \( \text{mirror images enantiomers} \)
  \[
  \begin{align*}
  \text{a. } & \quad \text{CH}_3\text{CH}_2\text{C(OH)CO}_2\text{H} \quad \text{and} \quad \text{HO}_2\text{C}–\text{CH}_2\text{CH}_3 \\
  \text{b. } & \quad \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \quad \text{and} \quad \text{CH}_3\text{CH}_2\text{OCH}(\text{CH}_3)_2
  \end{align*}
  \]
- b. \( \text{different connectivity constitutional isomers} \)
  \[
  \begin{align*}
  \text{c. } & \quad \text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3 \quad \text{and} \quad \text{HO}_2\text{C}–\text{CH}_2\text{CH}_3 \\
  \text{d. } & \quad \text{CH}_3\text{CH}_2\text{C(OH)CO}_2\text{H} \quad \text{and} \quad \text{HO}_2\text{C}–\text{CH}_2\text{CH}_3
  \end{align*}
  \]

**15.47** Answer each question with a compound of molecular formula C\(5\)H\(10\)O\(2\).

- a. \( \text{CH}_3\text{CH}_2\text{C(OH)CO}_2\text{H} \quad \text{no chirality center} \quad \text{same molecular formula constitutional isomer} \)
- b. \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \quad \text{no chirality center} \quad \text{same molecular formula constitutional isomer} \)
- c. \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \quad \text{no chirality center} \quad \text{same molecular formula constitutional isomer} \)

**15.48** Answer each question with a compound of molecular formula C\(5\)H\(12\)O.

- a. \( \text{CH}_3\text{CH}_2\text{C(OH)CO}_2\text{H} \quad \text{no chirality center} \quad \text{same molecular formula constitutional isomer} \)
- b. \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \quad \text{no chirality center} \quad \text{same molecular formula constitutional isomer} \)
- c. \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \quad \text{no chirality center} \quad \text{same molecular formula constitutional isomer} \)

**15.49** Draw the constitutional isomers and then label the chirality centers.

- a. \( \text{CHO} \quad \text{CHO} \quad \text{CHO} \quad \text{CHO} \quad \text{CHO} \quad \text{CHO} \)
- b. \( \text{CH}_3\text{CH}_2\text{H} \quad \text{CH}_3\text{CH}_2\text{H} \quad \text{CH}_3\text{CH}_2\text{H} \quad \text{CH}_3\text{CH}_2\text{H} \quad \text{CH}_3\text{CH}_2\text{H} \quad \text{CH}_3\text{CH}_2\text{H} \)
- c. \( \text{CH}_3\text{CH}_2\text{H} \quad \text{CH}_3\text{CH}_2\text{H} \quad \text{CH}_3\text{CH}_2\text{H} \quad \text{CH}_3\text{CH}_2\text{H} \quad \text{CH}_3\text{CH}_2\text{H} \quad \text{CH}_3\text{CH}_2\text{H} \)

**15.50** Draw the enantiomers in three dimensions.
15.51 Convert the given ball-and-stick model to a Fischer projection by replacing the chirality center with a cross.

![Fischer projection](image)

15.52 Convert the given ball-and-stick model to a Fischer projection by replacing the chirality center with a cross.

![Fischer projection](image)

15.53 Convert each molecule to a Fisher projection formula by replacing the chirality center with a cross.

![Fischer projection](image)

15.54 Convert each molecule to a Fisher projection formula by replacing the chirality center with a cross.

![Fischer projection](image)

15.55 Work backwards to draw three-dimensional representations from the Fischer projections.

![Fischer projection](image)
15.56 Work backwards to draw three-dimensional representations from the Fischer projections.

![Fischer projection examples](image)

15.57 Enantiomers are stereoisomers that are nonsuperimposable mirror images of each other.

![Enantiomer examples](image)

15.58 Enantiomers are stereoisomers that are nonsuperimposable mirror images of each other.

![Enantiomer examples](image)

15.59

a. An optically active compound rotates the plane of polarized light. An optically inactive compound does not rotate the plane of polarized light.

b. One possibility: CH₃CH₂CH₂CH₂OH is achiral and optically inactive.

c. One possibility:

![Chiral and optically active example](image)
15.60

a. \( \text{C}_2\text{H}_4\text{O} \)
   optically inactive

b. \( \text{C}_6\text{H}_{12}\text{O} \)
   optically active

15.61 A chiral compound is optically active and an achiral compound is optically inactive.

a. \( \text{CH}_3 \text{Br} \)
   chiral
   optically active

b. \( \text{CH}_2\text{OH} \)
   achiral
   optically inactive

c. \( \text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \)
   achiral
   optically inactive

15.62 A chiral compound is optically active and an achiral compound is optically inactive.

a. \( \text{(CH}_3)_2\text{CHCH}_2\text{CHO} \)
   achiral
   optically inactive

b. \( \text{C}_5\text{H}_10\text{O} \)
   achiral
   optically inactive

c. \( \text{H}_3\text{C} \)
   chiral
   optically active

15.63

a. Lactose is dextrorotatory.

b. The specific rotation of two enantiomers is the same numerical value, but opposite in sign.
   Therefore, the specific rotation of the enantiomer of lactose is \(-52\).

c. Two enantiomers have identical physical properties except for their interaction with plane-
   polarized light, and therefore, \(22\) g of the enantiomer of lactose dissolves in \(100\) mL of water.

15.64

a. The specific rotation of two enantiomers is the same numerical value, but opposite in sign.
   Therefore, the specific rotation of the enantiomer of taxol is \(+49\).

b. Two enantiomers have identical physical properties except for their interaction with plane-
   polarized light, so the boiling points of taxol and its enantiomer are identical.

c. Two enantiomers have identical physical properties except for their interaction with plane-
   polarized light, so the solubility properties of taxol and its enantiomer are identical.

15.65 Enantiomers are stereoisomers that are nonsuperimposable mirror images of one another, whereas
diastereomers are stereoisomers that are \textit{not} mirror images of one another.
15.66 The two major types of stereoisomers are enantiomers and diastereomers. Enantiomers are stereoisomers that are nonsuperimposable mirror images of one another, whereas diastereomers are stereoisomers that are not mirror images of one another.

enantiomers  diastereomers

15.67 Enantiomers are stereoisomers that are nonsuperimposable mirror images of each other. Look for two compounds that when placed side-by-side have the groups on both chirality centers drawn as a reflection of each other. A given compound has only one possible enantiomer. Diastereomers are stereoisomers that are not mirror images of each other.

The figure above shows the enantiomers. All other relationships are diastereomers.


15.68 Enantiomers are stereoisomers that are nonsuperimposable mirror images of each other. Look for two compounds that when placed side-by-side have the groups on both chirality centers drawn as a reflection of each other. A given compound has only one possible enantiomer. Diastereomers are stereoisomers that are not mirror images of each other.

The figure above shows the enantiomers. All other relationships are diastereomers.

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b. \[
\begin{align*}
\text{CHO} \\
\text{H} &\text{C}\text{OH} \\
\text{H} &\text{C}\text{OH} \\
\text{H} &\text{C}\text{OH} \\
\text{CH}_2\text{OH}
\end{align*}
\]

15.69 Enantiomers are stereoisomers that are mirror images. \textit{cis}-2-Butene and \textit{trans}-2-butene are diastereomers because they are stereoisomers that are not mirror images of one another.

\[
\begin{align*}
\text{cis} &\quad \text{not mirror images} \\
\text{diastereomers}
\end{align*}
\]

15.70 \textit{cis}-2-Butene and \textit{trans}-2-butene are achiral because four different groups are needed for a chiral center. Since two of the carbons in each compound share a double bond, the molecules are achiral.

15.71 Answer each question about lactic acid.

a. \[
\text{CH}_3\text{CHCO}_2\text{H} \quad \text{chirality center}
\]

b. \[
\text{CH}_3\text{C}\text{COOH} \quad \text{HOOC}\text{C}\text{CH}_3 \quad \text{enantiomers}
\]

c. \[
\begin{align*}
\text{CH}_3 &\text{COOH} \\
\text{HOOC} &\text{CH}_3
\end{align*}
\]

15.72 Locate the chirality centers in vitamin E and vitamin C.

a. \[
\begin{align*}
\text{HO} &\text{CH}_3 \quad \text{chirality centers} \\
\text{H}_3\text{C} &\text{CH}_3 \\
\text{chirality center}
\end{align*}
\]

b. \[
\begin{align*}
\text{HOCH}_2\text{CH} &\text{O} \quad \text{chirality centers} \\
\text{OH} &\text{OH}
\end{align*}
\]
15.73 Answer each question about hydroxydihydrocitronellal.

a. \[ \text{CH}_3\text{CCH}_2\text{CH}_2\text{CH} = \text{CH}_2\text{CHO} \]

b. \[ \text{HO} \quad \text{CH}_3 \quad \text{CH} \quad \text{CH}_2\text{CHO} \quad \text{OH} \]

c. \[ \text{HO} \quad \text{CH}_3 \quad \text{CH}_2\text{CHO} \quad \text{OH} \]

15.74 Answer the questions for L-Leucine.

a. \[ \text{H}_2\text{N} \quad \text{COOH} \quad \text{CH}_3\text{CH}(\text{CH}_3)_2 \]

b. \[ \text{H}_2\text{N} \quad \text{COOH} \quad \text{CH}_2\text{CH}(\text{CH}_3)_2 \quad \text{and} \quad \text{H}_2\text{N} \quad \text{COOH} \quad \text{CH}_2\text{CH}(\text{CH}_3)_2 \quad \text{NH}_2 \]

c. \[ \text{H}_2\text{N} \quad \text{COOH} \quad \text{CH}_2\text{CH}(\text{CH}_3)_2 \quad \text{NH}_2 \]
15.75 Answer each question about Darvon.

![Chemical structures](image)

(Novrad is Darvon spelled backwards.)

15.76 Answer the questions about Plavix.

![Chemical structures](image)
15.77 Each chirality center in sucrose is labeled with a star.

15.78 Each chirality center in nandrolone is labeled with a star.