5

Stereoisomerism

Chapter Summary

Stereoisomers have the same atom connectivities but different arrangements of the atoms in space. They may be **chiral** or **achiral**. A stereoisomer is chiral if its mirror image is not identical or superimposable on the original molecule. It is achiral if the molecule and its mirror image are identical or superimposable. **Enantiomers** are a pair of molecules related as nonsuperimposable mirror images.

A carbon atom with four different groups attached is called a **stereogenic center** *because it gives rise to stereoisomers*. Any molecule with a **plane of symmetry** is achiral. **Configuration** refers to the arrangement of groups attached to a stereogenic center. Enantiomers have opposite configurations. Configuration can be designated by the ***R–S* convention**. Groups attached to the stereogenic center are ranked in a priority order according to decreasing atomic number. When the stereogenic center is viewed from the side *opposite* the lowest-priority group, the center is said to be *R* if the other three groups, in decreasing priority order, form a *clockwise* array. If the three-group array is counterclockwise, the configuration is *S*. A similar convention (*E–Z*) has been applied to alkene *cis–trans* isomers.

Chiral molecules are **optically active**. They rotate a beam of plane-polarized light. They are **dextrorotatory** (+) or **levorotatory** (-), depending on whether they rotate the beam to the right or left, respectively. The rotations are measured with a **polarimeter** and are expressed as **specific rotations**, defined as

$$[\alpha]_{\lambda}^{t} = \frac{\alpha}{l \times c} \quad \text{(solvent)}$$

where α = observed rotation, l = length of sample tube in decimeters, c = concentration in g/mL, and the measurement conditions of temperature (t), wavelength of polarized light (λ), and solvent are given. Achiral molecules are **optically inactive**.

Pasteur showed that optical activity was related to molecular right- or left-handedness (chirality). Later, van't Hoff and LeBel proposed that the four valences of carbon are directed toward the corners of a tetrahedron. If the four attached groups are different, two arrangements are possible and are related as an object and its nonsuperimposable mirror image. Enantiomers differ *only* in chiral (or handed) properties, such as the *direction* of rotation of plane-polarized light. They have identical **achiral properties**, such as melting and boiling points.

Fischer projection formulas show three-dimensional structures in two dimensions. In such formulas, horizontal groups project toward the viewer, and vertical groups project away from the viewer.

Diastereomers are stereoisomers that are not mirror images of one another. They may differ in all types of properties, and may be chiral or achiral.

Compounds with *n* different stereogenic centers may exist in a maximum of 2^n forms. Of these, there will be $2^n/2$ pairs of enantiomers. Compounds from different enantiomeric pairs are diastereomers. If two (or more) of the stereogenic centers are identical, certain isomers will be achiral. A **meso form** is an optically inactive, achiral form of a compound with stereogenic centers. **Tartaric acid**, which has two identical stereogenic centers, exists in three forms: the *R,R* and *S,S* forms (a pair of enantiomers) and the achiral *meso* form.

Stereoisomers may be classified as conformational or configurational, chiral or achiral, and enantiomers or diastereoisomers.

The stereochemistry of organic reactions depends on the nature of the reactants. Achiral molecules can react to give a chiral product. In such reactions, both enantiomers of the product will always be formed in equal amounts. When chiral molecules react with achiral reagents to create a new stereogenic center, diastereoisomers are formed in unequal amounts.

A **racemic form** is 50:50 mixture of enantiomers. It is optically inactive. A racemic mixture of configurational isomers cannot be separated (resolved) by ordinary chemical means (distillation, crystallization, chromatography) unless the reagent is chiral. One way to separate a pair of enantiomers is to first convert them to diastereomers by reaction with a chiral reagent, then separate the diastereomers and regenerate the (now separate) enantiomers.

Learning Objectives

1. Know the meaning of: chiral, achiral, enantiomers, plane of symmetry, superimposable and nonsuperimposable mirror images, racemic mixture.
2. Know the meaning of: stereogenic carbon atom, stereogenic center, *R–S* convention, priority order, *E–Z* convention, Fischer projection.
3. Know the meaning of: diastereomer, *meso* compound, lactic acid, tartaric acid, resolution.
4. Know the meaning of: plane-polarized light, polarimeter, optically active or optically inactive, observed rotation, specific rotation, dextrorotatory, levorotatory.
5. Given the concentration of an optically active compound, length of the polarimeter tube, and observed rotation, calculate the specific rotation. Given any three of the four quantities mentioned, calculate the fourth.
6. Given a structural formula, draw it in three dimensions and locate any plane of symmetry.
7. Given the structure of a compound, determine if any stereogenic centers are present.
8. Given the structure or name of a compound, tell whether it is capable of optical activity.
9. Know the rules for establishing priority orders of groups in the *R–S* convention.

10. Given a compound with a stereogenic center, assign the priority order of groups attached to it.
11. Given a stereogenic center in a molecule, assign the *R* or S configuration to it.
12. Draw the three-dimensional formula of a molecule with a particular configuration, *R* or *S*.
13. Given a pair of *cis–trans* isomers, assign the *E* or *Z* configuration.
14. Draw the formula of an alkene with a particular configuration, *E* or *Z*.
15. Given a structure with one or more stereogenic centers, draw a Fischer projection.
16. Given Fischer projections of two isomers, tell their relationship (for example, same structure, enantiomers, diastereomers).
17. Assign *R* or *S* configuration to each stereogenic center in a Fischer projection.
18. Given a structure with more than one stereogenic center, tell how many stereoisomers are possible and draw the structure of each. Tell what relationship the stereoisomers have to one another (for example, enantiomeric, diastereomeric).
19. Tell whether a particular structure can exist as a *meso* form.
20. Given a structure with two or more identical stereogenic centers, draw the structure of the *meso* form.
21. Given a pair of stereoisomers, classify them as configurational or conformational, chiral or achiral, and enantiomers or diastereomers.
22. Given a chemical reaction that gives a chiral product, tell the stereochemistry of the products.

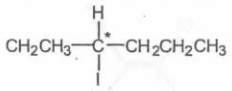
ANSWERS TO PROBLEMS

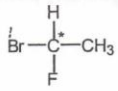
Problems Within the Chapter

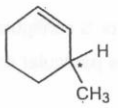
5.1 a. chiral b. achiral c. achiral d. chiral
e. achiral f. chiral g. chiral h. achiral

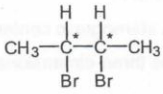
The achiral objects (teacup, football, tennis racket, and pencil) can be used with equal ease by right- or left-handed persons. Their mirror images are superimposable on the objects themselves. On the other hand, a golf club must be either left- or right-handed and is chiral; a shoe will fit a left or a right foot; a corkscrew may have a right- or left-handed spiral. These objects, as well as a portrait, have mirror images that are *not* identical with the objects themselves, and thus they are chiral.

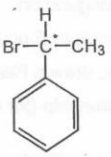
5.2 The stereogenic centers are marked with an asterisk. Note that each stereogenic center has four different groups attached.

a. 

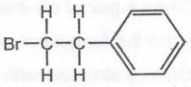
b. 

c. 

d. 

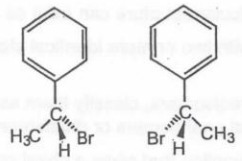
5.3 a. 

chiral

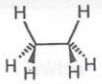
b. 

no stereogenic centers; achiral

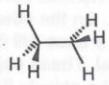
5.4 Note that if the right structure is rotated 180° about the carbon-phenyl bond, the methyl and phenyl groups can be superimposed on those of the left structure, but the positions of the hydrogen and bromine will be interchanged.



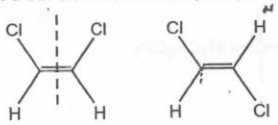
5.5 The planes of symmetry are (a) the three planes that pass through any pair of eclipsed hydrogens and (b) the perpendicular bisector of the C–C bond. Ethane in this conformation is achiral.



5.6 There are three planes of symmetry that pass through any pair of anti-hydrogens. Ethane in this conformation is achiral.



5.7 *cis*-1,2-Dichloroethene has a plane of symmetry that bisects the double bond. The molecular plane is also a symmetry plane. *trans*-1,2-Dichloroethene is planar. That plane is a symmetry plane. Both *cis*- and *trans*-1,2-dichloroethene are achiral.



5.8 In each case, proceed from high to low priority.

a. $-NH_2 > -CH(CH_3)_2 > -CH_3 > -H$

b. $-F > -OH > CH_2OH > -CH_3$

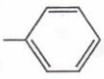
c. $-OCH_3 > -OH > -NHCH_3 > -CH_2NH_2$

The oxygen in the methoxy group ($-OCH_3$) is bonded to carbon, whereas the hydroxyl oxygen (–OH) is bonded only to hydrogen.

d. $-C(CH_3)_3 > -CH(CH_3)_2 > -CH_2CH_2CH_3 > -CH_2CH_3$

5.9 a. $-C{\equiv}CH \; > \; -CH{=}CH_2$

The acetylenic carbon (–C≡) is treated as though it is bonded to three carbons, while the olefinic carbon (–CH=) is treated as though it is bonded to two carbons and a hydrogen (see Sec. 5.3).

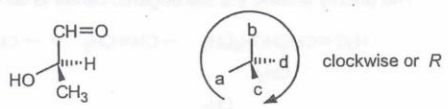
b.  $> -CH{=}CH_2$

The phenyl carbon is treated as though it is bonded to three carbons.

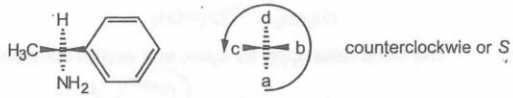
c. $-CH{=}O \; > \; -CH_2OH \; > \; -CH{=}CH_2 \; > \; -CH_2CH_3$

The aldehyde carbon is treated as though it is bonded to two oxygens.

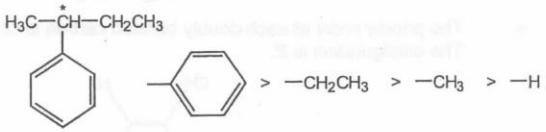
5.10 a. Priority order: OH > CH=O > CH_3 > H. Configuration is *R*.



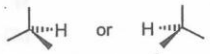
b. Priority order: $NH_2 > -C_6H_5 > CH_3 > H$. The configuration is *S*.



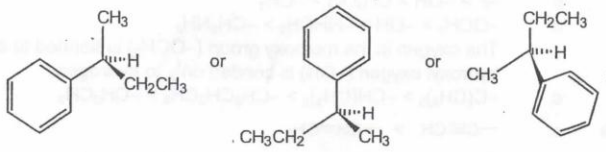
5.11 a. The priority of groups around the stereogenic center is as follows:



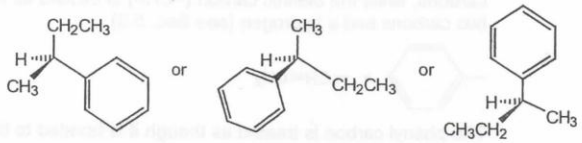
First, draw the lowest-priority group pointing away from you:



Then fill in the groups in priority order, counterclockwise (*S*),

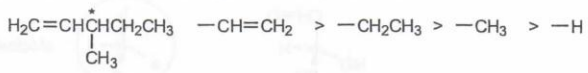


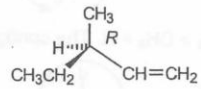
Similarly,



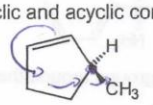
As you can see, there are many ways to write the correct answer. In subsequent problems, only one correct way will be shown. Work with models if you have difficulty.

b. The priority around the stereogenic center is as follows:

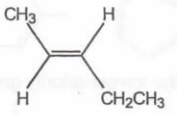




c. The same rules apply for cyclic and acyclic compounds.

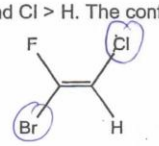


5.12 a. The priority order at each doubly bonded carbon is CH_3 > H and CH_3CH_2 > H. The configuration is *E*.



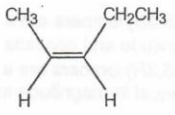
(*E*)-2-pentene

b. The priority order is Br > F and Cl > H. The configuration is *E*.



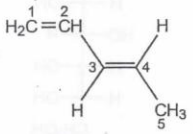
(*E*)-1-bromo-2-chloro-1-fluoroethene

5.13 a. The two highest-priority groups, CH_3 and CH_3CH_2, are *zusammen*, or together.



(*Z*)-2-pentene

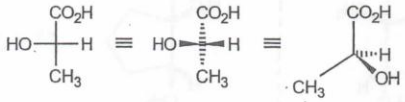
b. The priorities are $CH_2{=}C{-}$ > H and $CH_3{-}$ > H. The two highest-priority groups, $CH_2{=}CH{-}$ and $CH_3{-}$, are *entgegen* (opposite).



(*E*)-1,3-pentadiene

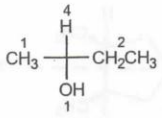
5.14 $$[\alpha]_D^{20} = \frac{+0.66}{0.5 \times \frac{1.5}{50}} = 44^\circ \quad \text{(ethanol)}$$

5.15



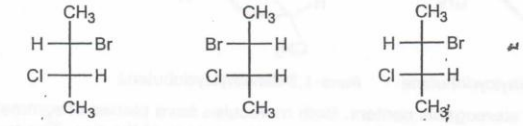
(*S*)-lactic acid

5.16 There are several ways to approach this problem. Here's one. Assign priorities to the four groups.



If the lowest priority group is in a vertical position, determine whether the sequence of the remaining three groups (1→2→3) is clockwise (*R*) or counterclockwise (*S*). In this case, it is clockwise and the Fischer projection represents (*S*)-2-butanol.

5.17



(2*S*,3*S*)-2-bromo-3-chlorobutane

(2*R*,3*S*)-2-bromo-3-chlorobutane

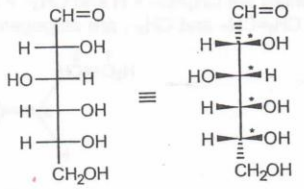
(2*S*,3*R*)-2-bromo-3-chlorobutane

These compounds are enantiomers.

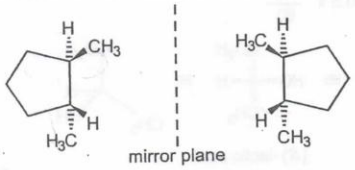
This is the enantiomer of (2*R*,3*R*)-2-bromo-3chlorobutane (Fig. 5.12)

5.18 The (2*R*,3*R*) and (2*S*,3*S*) isomers are a pair of enantiomers. Their specific rotations will be equal in magnitude and opposite in sign.
The (2*R*,3*R*) and (2*S*,3*R*) isomers are a pair of diastereomers. Their specific rotations will be unequal in magnitude and may or may not differ in sign.

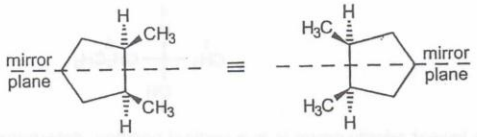
5.19 There are *four* different stereogenic centers, marked below with asterisks. There are, therefore, $2^4 = 16$ possible stereoisomers.



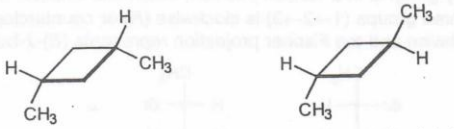
5.20 When the three CH_2 groups are superimposed, the methyl groups of one mirror image are superimposed on the hydrogens of the other mirror image. The mirror images are nonsuperimposable and are therefore enantiomers.



5.21 *cis*-1,2-Dimethylcyclopentane is achiral. It has a mirror plane of symmetry and is a *meso* compound.



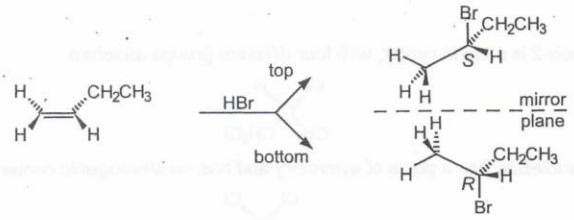
5.22



cis-1,3-dimethylcyclobutane *trans*-1,3-dimethylcyclobutane

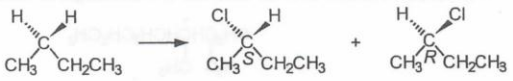
There are *no* stereogenic centers. Both molecules have planes of symmetry. The *cis* isomer has two such planes, through opposite corners of the ring. The *trans* isomer has one such plane, through the opposite methyl-bearing corners. Both compounds are optically inactive and achiral. They are not *meso* compounds because there are no chiral centers. To summarize, the two isomers are configurational, achiral and diastereomers.

5.23



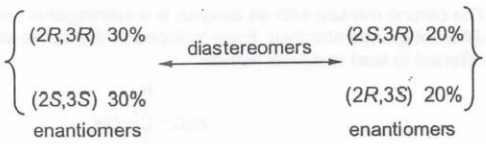
One-step addition of H–Br to the top face of the double bond gives (*S*)-2-bromobutane. Addition of H–Br to the bottom face gives (*R*)-2-bromobutane. Since 1-butene is achiral, the probability of addition to either face of the double bond is equal, and the product will be racemic (an equal mixture of enantiomers).

5.24 If we draw the structure in three dimensions, we see that either hydrogen at C-2 can be replaced with equal probability:



Thus a 50:50 mixture of the two enantiomers is obtained.

5.25 (*S*)-3-chloro-1-butene is the enantiomer of (*R*)-3-chloro-1-butene, and it will react with HBr to give the enantiomers of the products shown in eq. 5.7 [(2*S*, 3*S*)- and (2*R*, 3*S*)-2-bromo-3-chlorobutane], in the same 60:40 ratio. Therefore a racemic mixture of 3-chloro-1-butene will react with HBr to give the following mixture of 2-bromo-3-chlorobutanes:



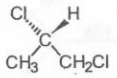
In other words, a 60:40 mixture of the two diastereomeric products will be obtained, each as a racemic mixture.

ADDITIONAL PROBLEMS

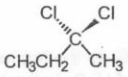
5.26 Each of these definitions can be found explicitly or implicitly in the following sections of the text:

a.	5.2	b.	5.1	c.	5.1	d.	5.5
e.	5.5	f.	5.8	g.	5.2	h.	5.9
i.	5.6	j.	5.12				

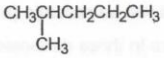
5.27 a. Carbon-2 is a chiral center, with four different groups attached.



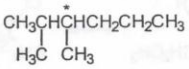
b. The molecule has a plane of symmetry and has no stereogenic centers.



c. None of the carbon atoms has four different groups attached.

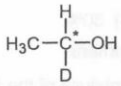


d. The carbon marked with an asterisk is a stereogenic center.

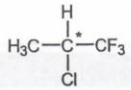


e. This molecule has a plane of symmetry perpendicular to the four-membered ring, through carbon-1 and carbon-3.

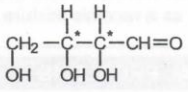
f. The carbon marked with an asterisk is a stereogenic center, with four different groups attached. Even isotopes of the same element are sufficiently different to lead to optical activity.



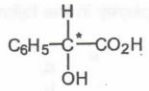
5.28 a.



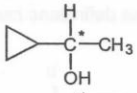
b.



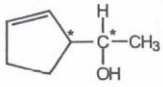
c.



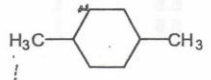
d.



e.



f.



no stereogenic centers

5.29 In each case the *observed* rotation would be doubled, but the specific rotation would remain constant. For example, if c is doubled, α will also double, but the fraction α/c in the formula for specific rotation will remain constant.

5.30 $[\alpha]_D^{25} = \dfrac{1.33}{0.5 \times \frac{1}{100}} = 66.5^\circ$ (water)

5.31 a. enantiomers b. identical

5.32 The following are examples. There may be other possibilities.

a. $CH_3\overset{*}{C}HCH_2CH_2CH_2CH_3$ (Cl)

b. $CH_3\overset{*}{C}HCH_2CH_3$ (OH)

c. $CH_3CH_2\overset{*}{C}HCH_2CH_2CH_3$ (CH_3)

d. $CH_3CH_2\overset{*}{C}HCH_2OH$ (OH)

In each case the stereogenic carbon atom is marked with an asterisk.

5.33 All structures must contain only one double bond and no rings because if the monovalent bromine were replaced by a hydrogen, we would have C_5H_{10}, corresponding to the general formula C_nH_{2n} (a molecule with one double bond or one ring). Since the bromide is described as unsaturated, there can be no ring present.

a. $CH_2=CHCH_2CH_2CH_2Br$ or $(CH_3)_2=CHCH_2Br$

b. $CH_3CH=\overset{CH_3}{\overset{|}{C}}CH_2Br$ or $CH_3CH_2CH=CHCH_2Br$ or $CH_3CH_2CH_2CH=CHBr$

c. $H_2C=CH\overset{*}{C}HCH_2CH_3$ (Br) or $H_2C=CHCH_2\overset{*}{C}HCH_3$ (Br)

d. $CH_3CH=CH\overset{*}{C}HCH_3$ (Br)

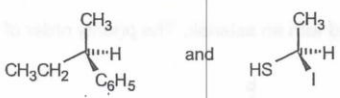
5.34 The rules for priority order are given in Sec. 5.3.

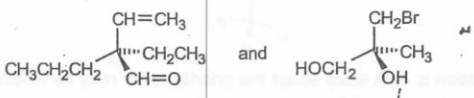
a. $C_6H_5- > CH_3CH_2- > CH_3- > H-$

b. $I- > HS- > CH_3- > H-$

c. $-CH=O > CH_2=CH- > CH_3CH_2CH_2- > CH_3CH_2-$

d. $HO- > BrCH_2- > HOCH_2- > CH$

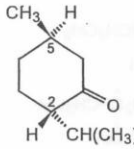
5.35 a. 

b. 

There are many ways to write these structures. They have been drawn here by putting the lowest-priority group receding away from the viewer and the remaining three groups in a clockwise (a) or counterclockwise (b) array, with the highest-priority group at the lower right extending toward the viewer.

5.36 In each case, write down the groups in the proper priority order. Then view the stereogenic center from the face opposite the lowest-priority group and determine whether the remaining array is clockwise (*R*) or counterclockwise (*S*). If you have difficulty, construct and examine molecular models.

a.



Carbon-5

$-CH_2C(=O)- > -CH_2CH_2 > -CH_3 > -H$

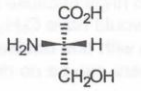
therefore *R*

Carbon-2

$-C(=O)- > -CH(CH_3)_2 > -CH_2 > -H$

therefore *S*

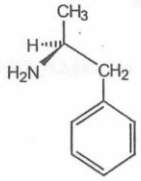
b.



$-NH_2 > -CO_2H > -CH_2OH > -H$

therefore *S*

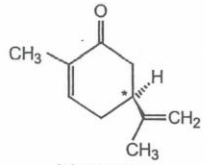
c.



$-NH_2 > -CH_2C_6H_5 > -CH_3 > -H$

therefore *S*

5.37

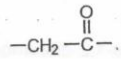


(+)-carvone

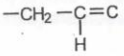
The stereogenic center is marked with an asterisk. The priority order of groups at this center is

and the configuration is *S*. A word about the priority order may be helpful. The

group has three bonds from the attached carbon atom to the next atoms "out" and is therefore of the highest priority. The remaining groups both begin with $-CH_2$, so we must proceed further. One group is



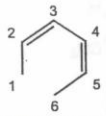
and the other is



Of these, the group with C=O has the higher priority because oxygen has a higher atomic number than carbon.

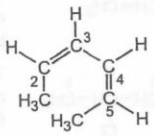
5.38 The priority of the four groups is Br > Cl > F > H. The structure of the *R* enantiomer is:

5.39 a.



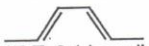
(*Z*,*Z*)-2,4-hexadiene or more precisely, (2*Z*,4*Z*)-2,4-hexadiene

If you have difficulty, draw the full structure:



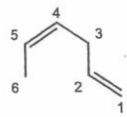
At the double bond between C-2 and C-3, the priority order is CH_3 > H and $CH_3CH{=}CH{-}$ > H. The two high-priority groups, CH_3 and $CH_3CH{=}CH{-}$, are *Z* or *zusammen*. The same is true at the double bond between C-4 and C-5.

b.



(*E*,*E*)-2,4-hexadiene

c.



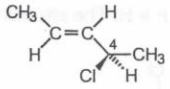
(*Z*)-1,4-hexadiene; there is no stereochemistry at the double bond joining C-1 and C-2 because both substituents at C-1 are identical (=CH_2).

d.

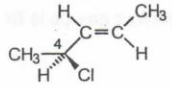
There is no stereochemistry at either double bond. The IUPAC name is 1,5-hexadiene.

5.40 *Trans*-1,2-dibromoethene and *cis*-1,2-dibromoethene are configurational isomers (they can only be interconverted by breaking and remaking a bond, in this case the pi–bond of the alkene), they are both achiral (their mirror images are identical to themselves), and they are diastereomers (although they are stereoisomers, they are not enantiomers).

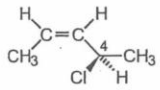
5.41 The structure has one double bond and one stereogenic center (C-4). Four isomers are possible (*R* or *S* at C-4 and *E* or *Z* at the double bond).



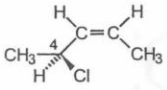
(*R*,*E*)



(*S*,*E*)



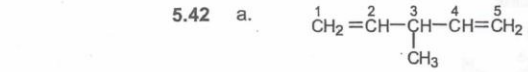
(*R*,*Z*)



(*S*,*Z*)

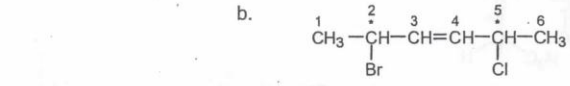
The upper and lower sets form two pairs of enantiomers.

5.42 a.



There are no stereogenic centers and no *cis–trans* possibilities at either double bond. Only one structure is possible.

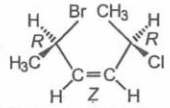
b.



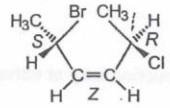
There are two stereogenic centers, marked with asterisks. Each can be either *R* or *S*. Also, the double bond joining C-3 and C-4 can be *E* or *Z*. Thus eight isomers are possible:

R, *Z*, *R*	*S*, *Z*, *R*
R, *Z*, *S*	*S*, *Z*, *S*
R, *E*, *R*	*S*, *E*, *R*
R, *E*, *S*	*S*, *E*, *S*

The first of these is shown below:

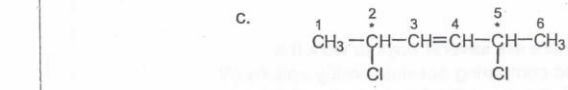


The other seven isomers can be drawn by interchanging one or more groups, using this structure as a guide. For example, the *S*, *Z*, *R* isomer is



and so on.

c.



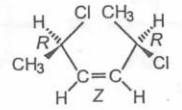
Compare with part b. In this case both stereogenic centers are identical. Therefore, two *meso* forms are possible, and the total number of isomers is reduced to six:

R, *Z*, *R*
R, *Z*, *S* (meso)
R, *E*, *R*
R, *E*, *S* (*meso*)
S, *Z*, *S*
S, *E*, *S*

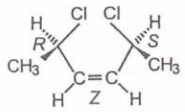
There are two sets of enantiomers:

R, *Z*, *R* and *S*, *Z*, *S*
R, *E*, *R* and *S*, *E*, *S*

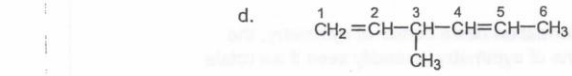
And there are two optically inactive, *meso* forms: *R*, *Z*, *S* and *R*, *E*, *S*. The *R*, *Z*, *R* isomer is shown below.



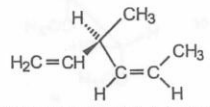
The other five structures can be derived from this one by interchanging groups. For example, the *R*, *Z*, *S meso* form is:



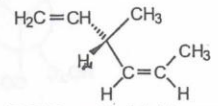
d.



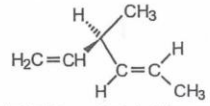
Carbon-3 is a stereogenic center, and *cis–trans* isomers are possible at the double bond between C-4 and C-5. Therefore, four structures are possible (*R* or *S* at C-3, and *E* or *Z* at the double bond).



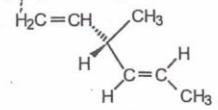
(*R*,*Z*)-3-methyl-1,4-hexadiene



(*S*,*Z*)-3-methyl-1,4-hexadiene



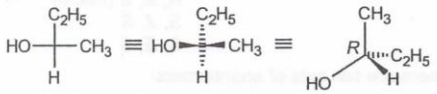
(*R*,*E*)-3-methyl-1,4-hexadiene



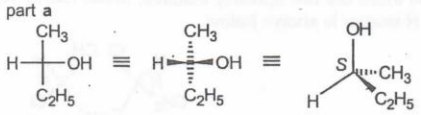
(*S*,*E*)-3-methyl-1,4-hexadiene

5.43 a. The projections are enantiomers. There are several ways to work this problem. One involves assigning and comparing absolute configurations (*R* or *S*) at each stereogenic carbon. First convert Fischer projection **A** into a wedge-dash drawing that depicts the arrangement of groups at the stereogenic carbon (use Figure 5.11 as a guide). Next, assign a priority order to the four groups (OH > C_2H_5 > CH_3 > H) and determine the arrangement of the three top-priority groups (clockwise or counterclockwise). In this case, they are clockwise, so the configuration is *R*.

A

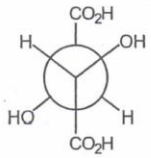


Manipulate the Fischer projection in part **a** in the same manner. In this case, the configuration is *S*.

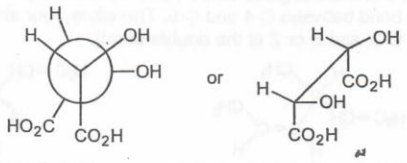


b. enantiomers
c. enantiomers

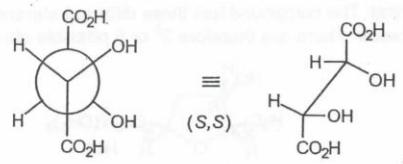
5.44

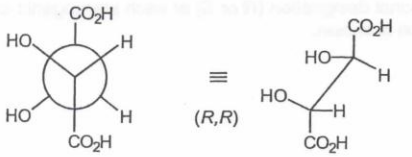


This is the *meso* form. As drawn, this conformation has a center of symmetry, the midpoint of the central C–C bond. The plane of symmetry is readily seen if we rotate the "rear" carbon 180°:



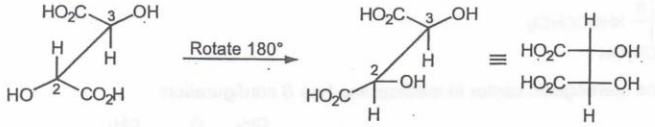
The remaining two structures correspond to the *S,S* and *R,R* isomers, respectively:





The priority order at each stereogenic center is OH > CO_2H > $CH(OH)CO_2H$ > H.

5.45



Rotate around the C2-C3 bond to give an eclipsed sawhorse projection. This can be converted into a Fischer projection. Remember that vertical lines project behind the plane of the page and horizontal lines project out of the page. There are several correct Fischer projections in this case. The plane of symmetry, which is easily seen in the projection shown above, shows that this is *meso*-tartaric acid.

5.46 The structures are conformational isomers. Both are achiral. They are diastereomers (stereoisomers but not mirror images).

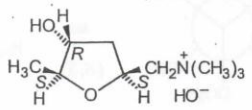
5.47 For three different stereogenic carbons, $2^3 = 8$. The possibilities are as follows:

R–R–R	*S–R–R*
R–R–S	*S–R–S*
R–S–R	*S–S–R*
R–S–S	*S–S–S*

For four different stereogenic carbons, $2^4 = 16$. The possibilities are as follows:

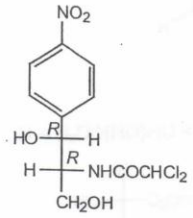
R–R–R–R	*R–S–R–R*	*S–R–R–R*	*S–S–R–R*
R–R–R–S	*R–S–R–S*	*S–R–R–S*	*S–S–R–S*
R–R–S–R	*R–S–S–R*	*S–R–S–R*	*S–S–S–R*
R–R–S–S	*R–S–S–S*	*S–R–S–S*	*S–S–S–S*

5.48 Muscarine is chiral. The compound has three different stereogenic centers, indicated in the formula below. There are therefore 2^3 or 8 possible stereoisomers.

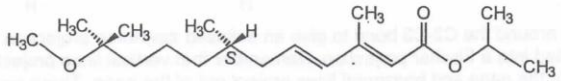


The configurational designation (*R* or *S*) at each stereogenic center in the naturally occurring poison is shown.

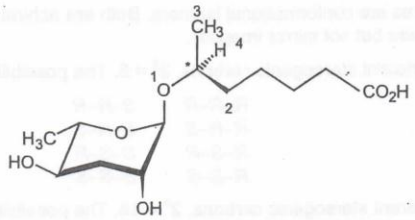
5.49



5.50 The one stereogenic center in methoprene has *S* configuration:

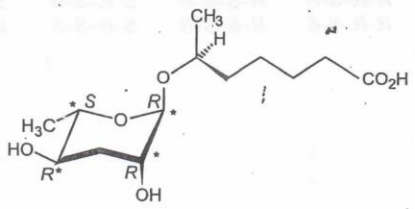


5.51 a. The stereogenic center is marked with an esterisk and the priorities of the 4 groups are:

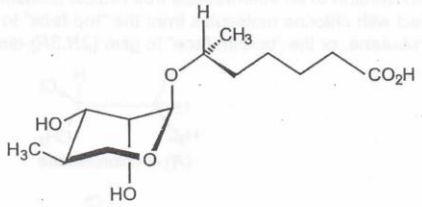


so the absolute configuration is *S*.

b. The additional stereogenic carbons, and their configuration, in daumone are:

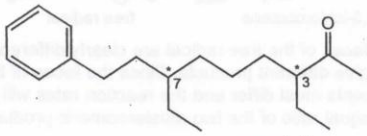


c. The easiest way is to switch two of the groups attached to each of the 5 stereogenic centers, and then confirm by assigning the configuration for each center.



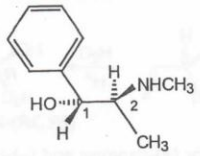
d. The enantiomers will probably not induce hibernation. Enzymes are chiral, and the active site of the enzyme will interact with one enantiomers selectively.

5.52 a. There are two stereogenic centers, one at C-3 and one at C-7.



b. Since there are two stereogenic centers, there are $2^2 = 4$ possible stereoisomers (two pairs of enantiomers). These would be the (3*R*,7*R*), (3*S*,7*R*), (3*R*,7*S*) and (3*S*,7*R*) stereoisomers.

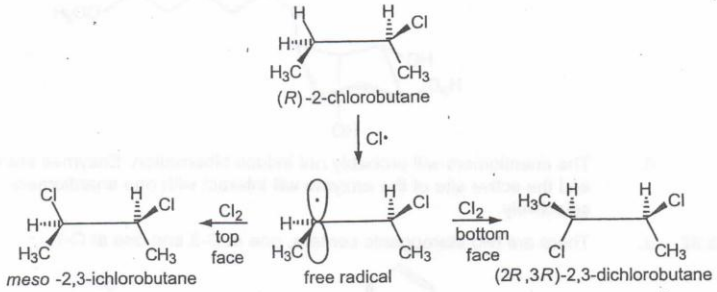
5.53 a. The absolute configuration at C-1 is *R* (OH > $CH(NHCH_3)CH_3$ > C_6H_5 > H). The absolute configuration at C-2 is *S* ($NHCH_3$ > $CH(OH)(C_6H_5)$ > CH_3 > H).



b. Ephedrine has two stereogenic centers so there are $2^2 = 4$ possible stereoisomers (including ephedrine itself).

c. The aromatic units in (–)-ephedrine and (–)-epinephrine are slightly different and (–)-epinephrine lacks the C-2 stereogenic center present in (–)-ephedrine. They both have the same configuration at C-1.

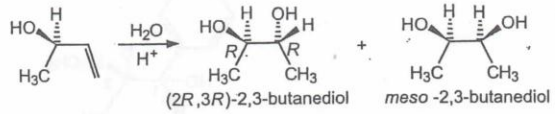
5.54 The reaction of (*R*)-2-chlorobutane with chlorine to give 2,3-dichlorobutane involves initial conversion to an intermediate free radical (consult Sec. 2.13). This free radical can react with chlorine molecules from the "top face" to give *meso*-2,3-dichlorobutane, or the "bottom face" to give (2*R*,3*R*)-dichlorobutane.



The two faces of the free radical are clearly different because their reactions with chlorine give different products. Since the faces of the radical differ, the steric environments must differ and the reaction rates will differ. This will lead to formation of an unequal ratio of the two diastereomeric products.

5.55 a. In this reaction, a *chiral* product is formed from *achiral* reactants, so both enantiomers (of 1-phenylethanol) will be formed in equal amounts (see Sec. 5.11).

b. In this reaction, a compound with one stereogenic center is converted to a compound with two stereogenic centers. The new stereogenic center can be either *R* or *S* and the latter is a *meso* compound.



5.56 The receptor site for (+)-carvone and (–)-carvone must be chiral such that the complex of the (+) and (–) isomers with the receptor are diastereomers. Therefore (+)-carvone and (–)-carvone have different odors.