

Learning from Molecular Models III - Enantiomers and Diastereomers

Textbook Reference - Klein, Chapter 5

Overview

This work sheet introduces the concepts of chirality, enantiomerism, and diastereomerism through the construction of models of molecules that contain chirality centers.

Definitions

Chirality Center. A tetrahedral atom that has four different groups bonded to it is called a **chirality center**. (Other commonly used terms to be discouraged are, "chiral center", "asymmetric atom", "stereocenter", and "tetrahedral stereogenic center".)

Plane of Symmetry. Any object that consists of two halves that are mirror images of each other is said to possess a **plane of symmetry**. For example, a human nose, a fork, a baseball bat, and a basketball all possess mirror planes (neglecting small imperfections and markings on the objects). Examples of objects that do not have a plane of symmetry are; a human hand, a pair of scissors, a golf club, and a bowling ball,

Chiral. Chiral objects possess a "handedness". In other words, they exist as two different mirror-image forms, a "right-handed" and a "left-handed" form. Any object that is not identical to its mirror image is chiral.

Achiral. Achiral objects do not possess a "handedness". They do not exist as two different mirror-image forms. Any object that is identical to its mirror image is achiral.

Superimposable. This is the criterion we use to decide if molecules/models are identical to each other. If by turning a model around in space and/or rotating single bonds you can make it into a form that will superimpose atom for atom on a second model, that means the two models are identical. **Superimposable models are identical.**

Stereoisomers. Stereoisomers are isomers that have all of the atoms bonded to each other in the same manner (i.e., the same connectivity). The only difference is the 3-D arrangement of the atoms. Examples of stereoisomers are cis/trans isomers, enantiomers, and diastereomers.

Enantiomers. The two mirror-image forms of a chiral molecule are called **enantiomers**. Enantiomers are isomers that are mirror images of each other. Please note, in order to be isomers the structures must be non-identical. Hence, enantiomers are often defined as non-superimposable mirror images.

Diastereomers. **Diastereomers** are stereoisomers that are **not** mirror images of each other.

PROCEDURES

Draw wedge/dash representations of each molecule and/or pair of molecules as you study them.

CHIRALITY CENTERS AND SYMMETRY

Make a model in which a tetrahedral carbon atom has four different color balls bonded to it. Observe it carefully. Does the model possess a plane of symmetry? _____

This model can be used to represent any molecule that contains one chirality center. As an example consider 3-methylhexane. Draw the structure of 3-methylhexane and use an asterisk to label the chirality center and name the four different groups attached to it.

Note that the model with four different color balls can be used to represent 3-methylhexane by simply stipulating that each ball represents one of these four groups.

Does 3-methylhexane possess a plane of symmetry? _____

For further practice in finding chirality centers, draw structures of each of the following and mark any chirality centers present in each with an asterisk:

3-methylpentane

4-ethyloctane

2,5-dimethylhexane

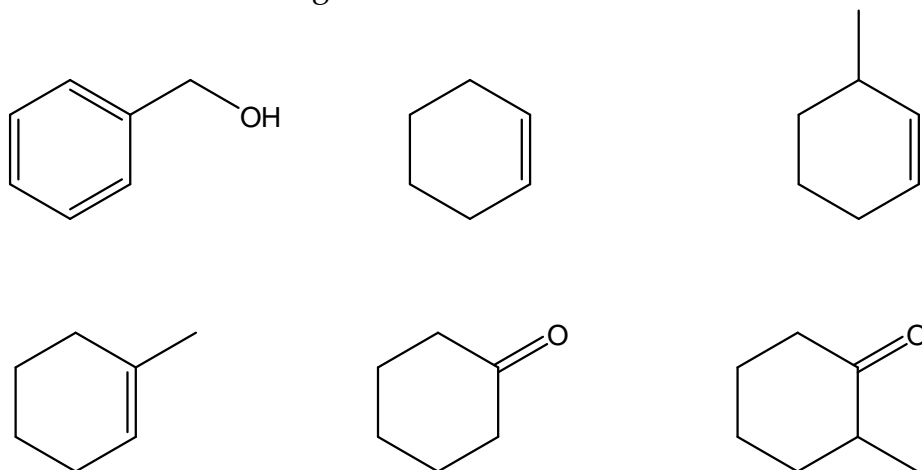
2,4-dimethylhexane

CHIRALITY AND ENANTIOMERS

As you have just seen, the presence of one chirality center in a molecule causes it to not have a plane of symmetry. Objects that lack a plane of symmetry are usually **chiral**. (The only exceptions are when they possess other symmetry elements such as a center or axis of symmetry.) Which of the following objects are chiral? a baseball hat, a baseball glove, a baseball bat, a baseball, a baseball pitcher, a baseball diamond, a screw, a nail, a spiral staircase.

Go back to the bottom of the previous page and indicate which of the four compounds there are chiral.

Which of the following molecules are chiral?



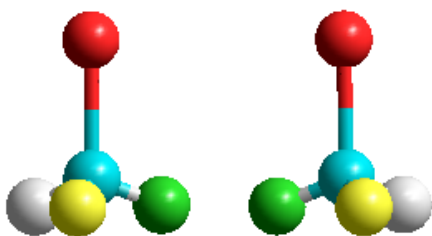
Go back to your original model (4 different colors) and make a second identical model of it. Make sure the two models are identical by trying to superimpose them; all of the atoms on one should superimpose on atoms of the same color in the other.

Now switch any two balls on one of the models and answer the following questions.

Are the models still superimposable? _____ Are they identical? _____

What is the word for non-identical structures that have the same molecular formula?

Place the two models side-by-side on the desktop so that they both have the same color ball pointing up. Keep that atom pointing up and rotate the models so that one of the other colors is closest to the ball of the same color on the other model. (Like the picture below.)



You should now be able to observe that the models are mirror images of each other. At the same time, they are not identical (not superimposable). Hence, the two models represent **enantiomers** of each other.

All molecules that possess one (and only one) chirality center lack a plane of symmetry, are chiral, and exist as a pair of enantiomers.

Again, switch any two balls on one of the models and then answer the following questions.

Are the models still mirror images of each other? _____

Are the models superimposable? _____

Do the models represent identical or different structures? _____

Do the models represent enantiomers? Why or why not?

Note that switching any two groups on a chirality center creates the enantiomer of the molecule you started with. Another way of saying this is that **it inverts the configuration of the chirality center.**

ACHIRAL MOLECULES

Now replace the red ball on each of the models with a second white ball.

Are the models mirror images of each other? _____

Does either possess a plane of symmetry? _____

Are the models superimposable? _____

Do the models represent identical or different structures? _____

Do the models represent enantiomers? Why or why not?

Now switch any two balls on one of the models. Does this change anything in terms of the answers to the questions in the preceding paragraph?

Objects that possess a plane of symmetry are never chiral. Explain why.

When a tetrahedral atom has two identical groups attached there will almost always be a plane of symmetry cutting between the two identical groups. (The only exception is when one of the other two groups contains a chirality center.) Therefore, molecules represented by the models used in this last part of the lab are not capable of existing as enantiomers and are “**achiral**”. Achiral molecules have mirror images that are identical to each other.

MOLECULES WITH TWO CHIRALITY CENTERS

Two Chirality Centers with Same 4 Groups

Remake the first model of the lab (4 different colors around a central carbon atom) and again make a second identical model of it. Make sure the two models are identical by superimposing them. Now remove the red ball from each and connect the two carbons to each other. How many chirality centers does this molecule possess?

Does the molecule represented by the model possess a plane of symmetry in any of its conformations? _____

Construct a new model that is the mirror image of the previously examined one. Are the two models identical or different? _____

What term should be used to describe the relationship between the two models?

Is this molecule chiral or achiral? _____

Take one of the previous models and interchange any two groups on one of the carbons. Do the same with the other model. Notice that both of these models have a conformation that possesses a plane of symmetry. Draw this conformation (use a wedge/dash formula) and indicate the location of the mirror plane.

Are the two models identical or different?

Are the models mirror images of each other?

Do the models represent stereoisomers of each other?

Do the models represent enantiomers of each other?

Is this molecule chiral or achiral?

The two models just examined represent an example of a **meso** compound. The simplest meso compounds are compounds that contain two chirality centers but are still achiral because the two chirality centers are mirror images of each other leading to a plane of symmetry being present. A meso compound is only possible if the two chirality centers have the same four groups attached.

Which of these compounds can exist as an achiral *meso* form?

2,3-dimethylbutane

3,4-dimethylhexane

2,3-dimethylpentane

2,4-dimethylpentane

The four models just looked at prove that a compound with two chirality centers, each with the same groups attached, can exist as three stereoisomers; a pair of enantiomers and a *meso* compound.

Think about what the relationship is between one of the enantiomers (one of the first two models in this part) and the *meso* form.

Are they enantiomers of each other? _____

Are they identical to each other? _____

What is the relationship? (See definitions.) _____

Two Chirality Centers with Different Groups

Now replace one of the balls on one of the models with a different color ball. Replace a same color ball on the other model so that you end up with mirror-image structures. Are the two models identical or enantiomers?

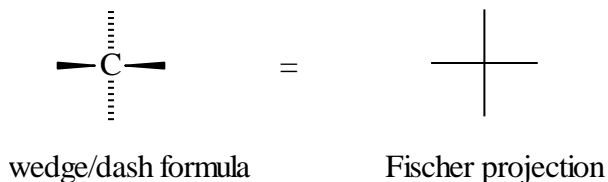
How many stereoisomers exist for a compound such as this with two chirality centers that do not have the same groups attached? Explain and check your answer with the instructor.

REPRESENTING MOLECULES WITH CHIRALITY CENTERS

The great German chemist, Emil Fischer, often worked with compounds with multiple chirality centers. In order to make representing these structures on paper easier, he devised the structural convention known as a Fischer projection.

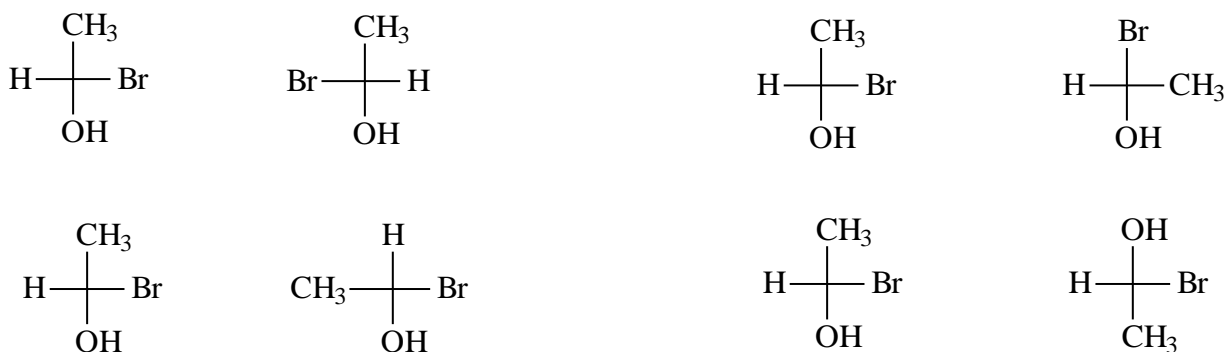
Go back to a simple model with a central carbon atom and four different colors attached. Hold the model so that two of the bonds are parallel to the floor and pointing straight at you. The other two bonds should be pointing away from you and be

perpendicular to the floor. Verify that the molecule in this orientation is represented by wedge/dash representation shown at left below.



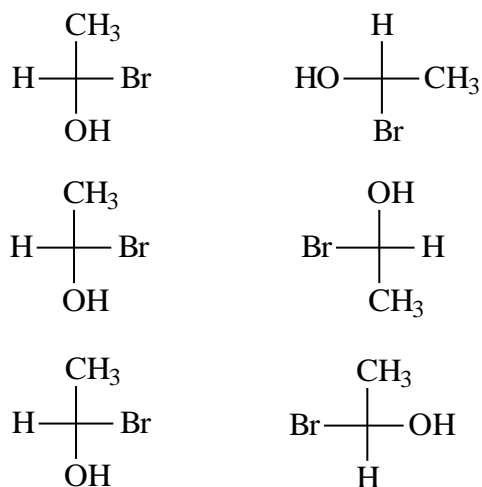
A Fischer projection (or "cross formula") uses a simple cross to represent this orientation of a chirality center.

Make models of each pair of molecules and use the models to decide if they are enantiomers or identical structures.



Note that all of the above examples involve switching two groups on a Fischer projection. When the only difference between two Fischer projections is that two groups have been switched then the relationship between those two structures is what?

Make models of each pair of molecules below and decide if they are enantiomers or identical structures.

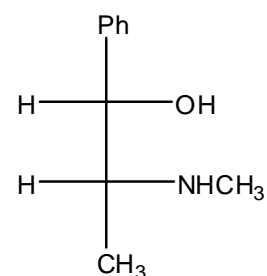
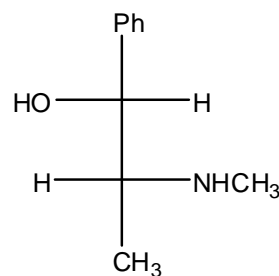
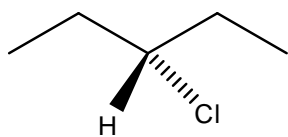
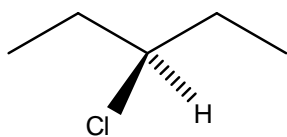
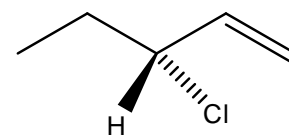
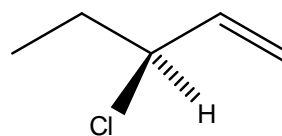
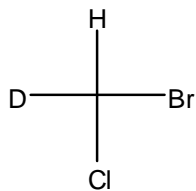
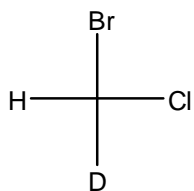
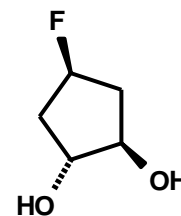
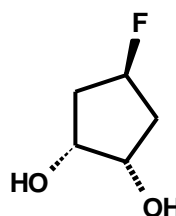
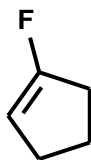
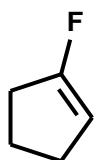
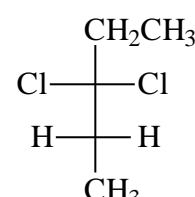
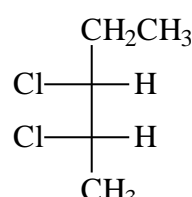
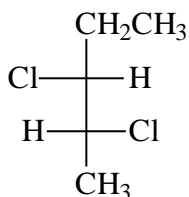
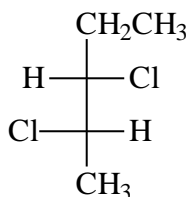
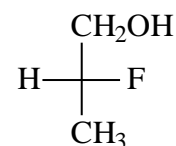
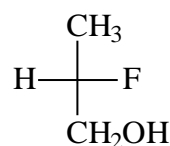
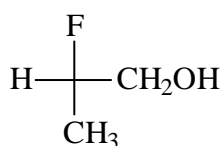
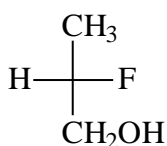


Use the above three examples to complete the sentences.

1. When the only difference between two Fischer projections is that the projection appears to have rotated 90° then the relationship between the structures is _____.
2. When the only difference between two Fischer projections is that the projection appears to have rotated 180° then the relationship between the structures is _____.
3. When the only difference between two Fischer projections is that three of the attached groups have rotated then the relationship between the structures is _____.

As a test of your understanding of the concepts and definitions covered to this points, determine the relationship between the compounds in each pair of structures shown below. Choose from the following choices.

A. enantiomers B. diastereomers C. constitutional isomers D. same compound



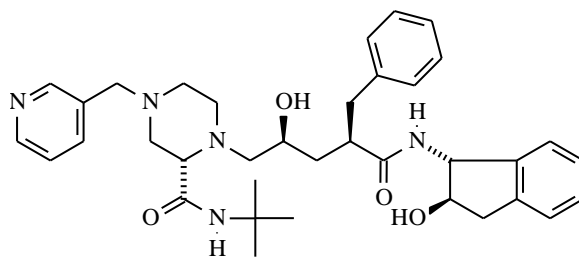
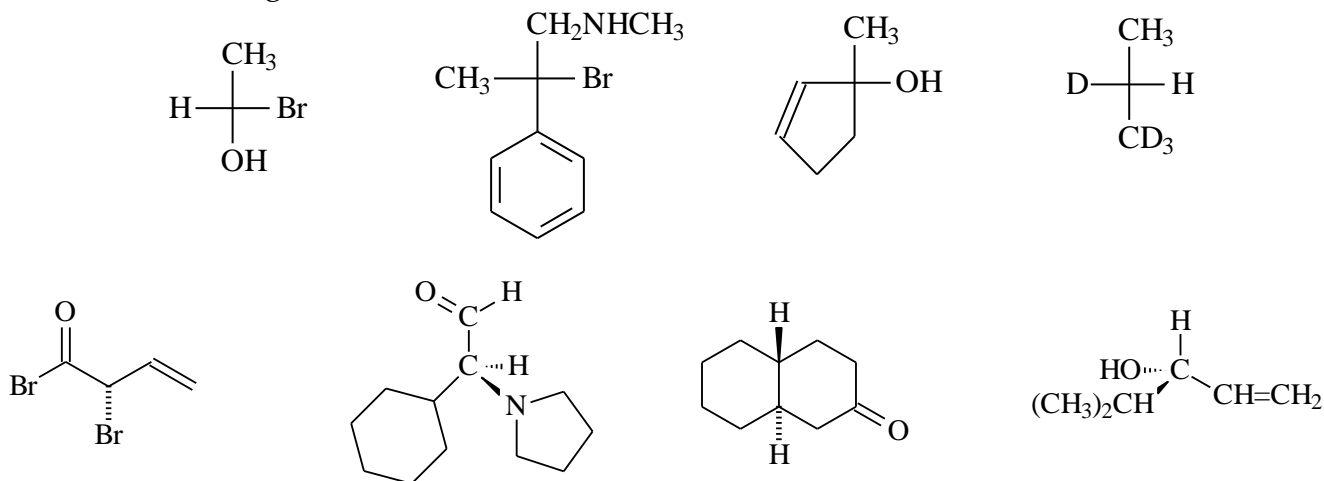
NAMING ENANTIOMERIC STRUCTURES - THE R AND S CONVENTION

A way to refer to the specific configuration around a chirality center is obviously needed. In other words, one needs to be able to specify which enantiomer is being referred to without drawing it. The rules for doing so were developed by Cahn, Ingold and Prelog and formally adopted by IUPAC and are summarized in the table (taken from Klein, *Organic Chemistry*) below

A REVIEW OF CAHN-INGOLD-PRELOG RULES: ASSIGNING THE CONFIGURATION OF A CHIRALITY CENTER

| STEP 1 | STEP 2 | STEP 3 | STEP 4 | STEP 5 |
|--|---|---|--|---|
| Identify the four atoms directly attached to the chirality center. | Assign a priority to each atom based on its atomic number. The highest atomic number receives priority 1, and the lowest atomic number (often a hydrogen atom) receives priority 4. | If two atoms have the same atomic number, move away from the chirality center looking for the first point of difference. When constructing lists to compare, remember that a double bond is treated as two separate single bonds. | Rotate the molecule so that the fourth priority is on a dash (going behind the plane of the page). | Determine whether the sequence 1-2-3 follows a clockwise order (<i>R</i>) or a counterclockwise order (<i>S</i>). |

Make models if necessary to determine the R/S designation of all chirality centers in each of the following.



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