Isomers Lab

Teacher's Guide

The reactions and structures of isomers are studied in organic chemistry, inorganic chemistry, biology, medicine, and physics. Since an undertaking of a full exploration of isomerism in introductory chemistry would be be too time consuming, we present lab procedures which utilize a dichotomous key to be used, along with some models to study organic isomers only.

For more detailed background information consult the Ryler Enterprises “Organic Stereochem-Large Set” kit available on the Ryler Enterprises website: www.rylerenterprises.com. Click on “Instructions and Quizzes,” locate the **Organic Chemistry** section, then click on Organic Stereochem-Large Set (ORG-3).

Also, visit the Ryler Enterprises “Chemistry of Sugars” kit available on the Ryler Enterprises website: www.rylerenterprises.com. Click on “Instructions and Quizzes,” locate the **Biochemistry** section, then click on Chemistry of Sugars (SUG-1).

General Instructions

Hand out the dichotomous key (found below), and then use the teaching set of molecules to demonstrate the use of the key. The color of the atom in the model identifies the element and, therefore, the number of bonds the atom should make with other atoms. Omit hydrogen atoms from the models in order to simplify building and identification.

Color	Element	# Bonds
Black	Carbon	4
Blue	Nitrogen	3
Red	Oxygen	2
Green	Halogen	1

These are not isomers since they have different formulas.

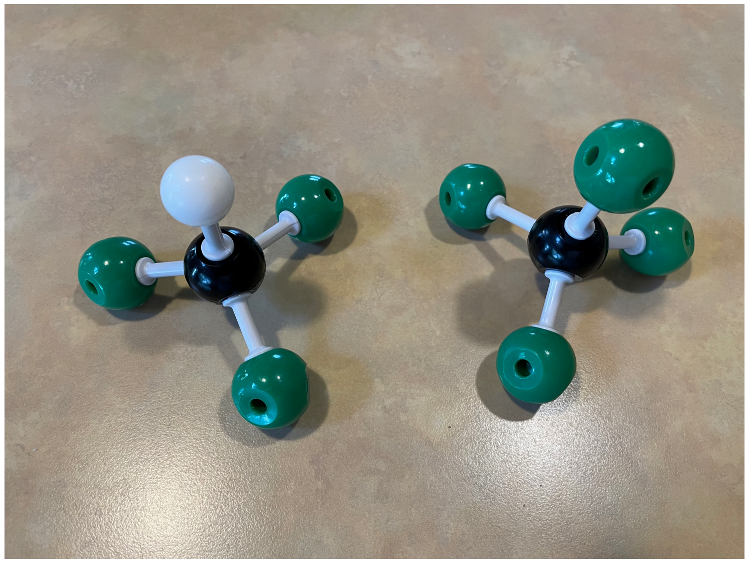


FIg. 1 Chloroform (left) and carbon tetrachloride (right) are not isomers.

Molecules in Fig. 2 are *a* the ketone, acetone, and *b* the aldehyde, propanal (propionaldehyde). The two compounds are constitutional isomers with the same formulas but different properties and connectivities of atoms.

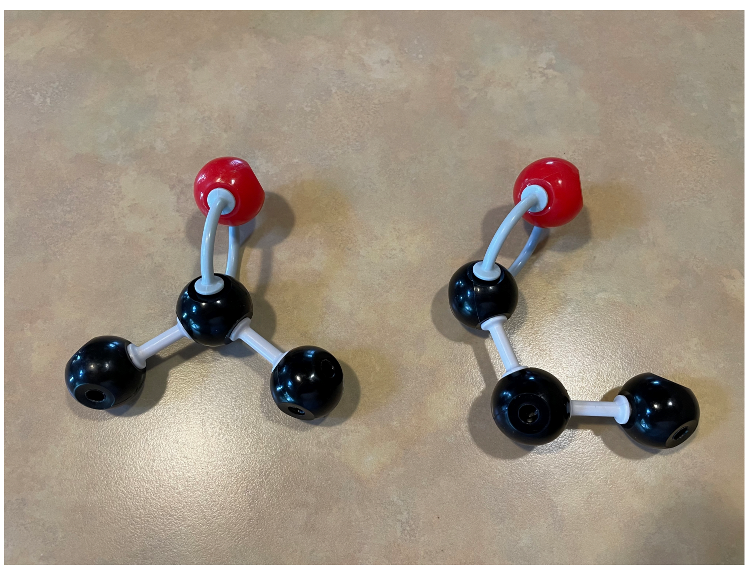


Fig. 2. A ketone (left) and an aldehyde (right)

Fig. 3 shows two different shapes (conformation) of the same molecule. (Configurations have different attachments of the same kinds of atoms in 3-d space. To make one configuration into another, bonds must be broken and different bonds must be made.) One conformation is converted into the other by rotation. Hence these are rotamers.

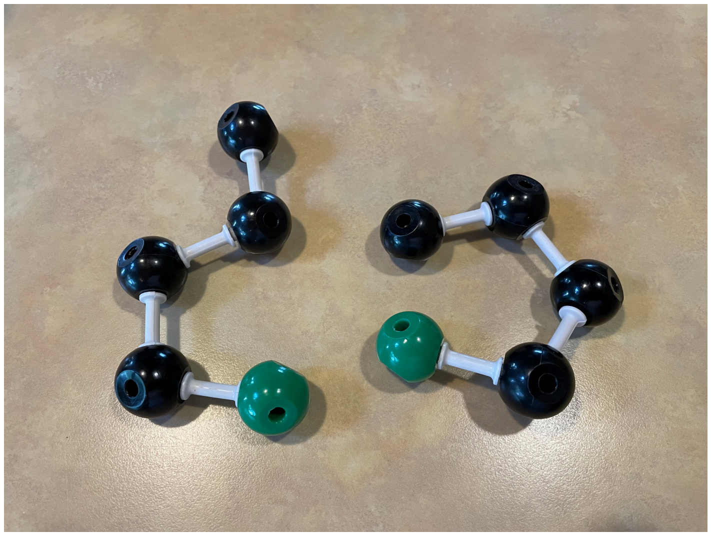
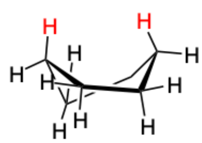


Fig. 3. Twisting the model on the left can result in the second model.

Rotation around a single bond in a molecule depends upon the energy difference between the two participating conformations. It is possible for some molecules to have more than two rotamers as in the following four conformations of cyclohexane. A chair shape is also a common arrangement other molecules such as ice and diamond.

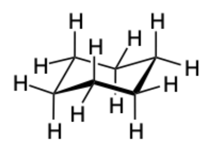


twist boat conformation

slight angle strain

small eclipsing strain

small steric strain

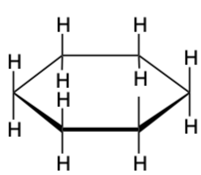


chair conformation

no angle strain

no eclipsing strain

small steric strain

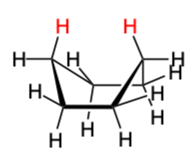


planar structure

severe angle strain (120°)

severe eclipsing strain (all bonds)

small steric strain



boat conformation

slight angle strain

eclipsing strain at two bonds

steric crowding of two hydrogens

In Fig. 5, the bottom molecule is the *trans* isomer, and the top molecule is the *cis* isomer. Due to the presence of the double bond, rotation around the carbon atoms in the double bond is not possible. One of the isomers cannot be converted into the other, without breaking and making new bonds, and each has its own unique properties.

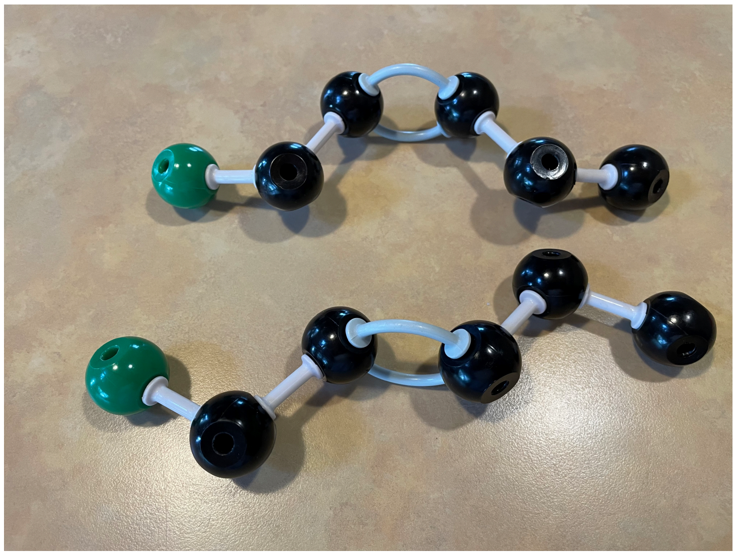
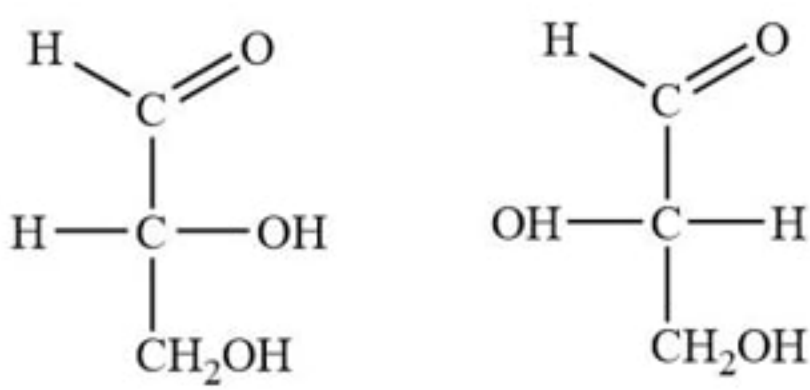


Fig. 5 A cis (top) and trans (bottom) isomer

The two sugar molecules in Fig. 6 are mirror images that are not superimposable, so they are enantiomers (also called optical isomers). Molecule *a* is L-glyceraldehyde, and *b* is D-glyceraldehyde. Place *b* on top of *a* to see if all of the atoms in both molecules align. Only carbons 1 and 2 and the pegs (which should be bonded to hydrogens) on carbon 2 will



D-Glyceraldehyde L-Glyceraldehyde

Fig. 6

align. Now we can do rotation around single bonds to make a better fit. Rotate carbon 1 of model b so the double bonded oxygens overlap. Rotate carbon 2 of model b so that carbon 3 and its oxygen will be in register with the same atoms in model a. Notice that the oxygens on a and b, as well as the pegs on the number 2 carbons are not in register. Models a and b are like a left and right hand: mirror images which are not superimposable. The D form of gyceraldehyde (the simplest sugar) is used by living things, but its enantiomer is not found in nature. The prefix L is for *laevo* (Latin for left), and D is for *dexter* (Latin for right). The labels L and D are usually only used for sugars and amino acids. (S) which stands for *sinister* (left) in Latin and (R) which stands for *rectus* (right) in Latin, are used for other organic compounds; **Λ** (the Greek letter, lambda) and **Δ** (the Greek letter, delta) are used for complex-ion enantiomers.

This type of isomerism is very common to biochemicals and drugs.

Two sugars found in nature will be used to illustrate a pair of diastereomers. *a* has the same connectivity of atoms as *b,* but their arrangements in space are different. They are not mirror images of each other, and they are not superimposable. In Fig. 7, molecule *a* is D-threose, and *b* is D-erythrose.

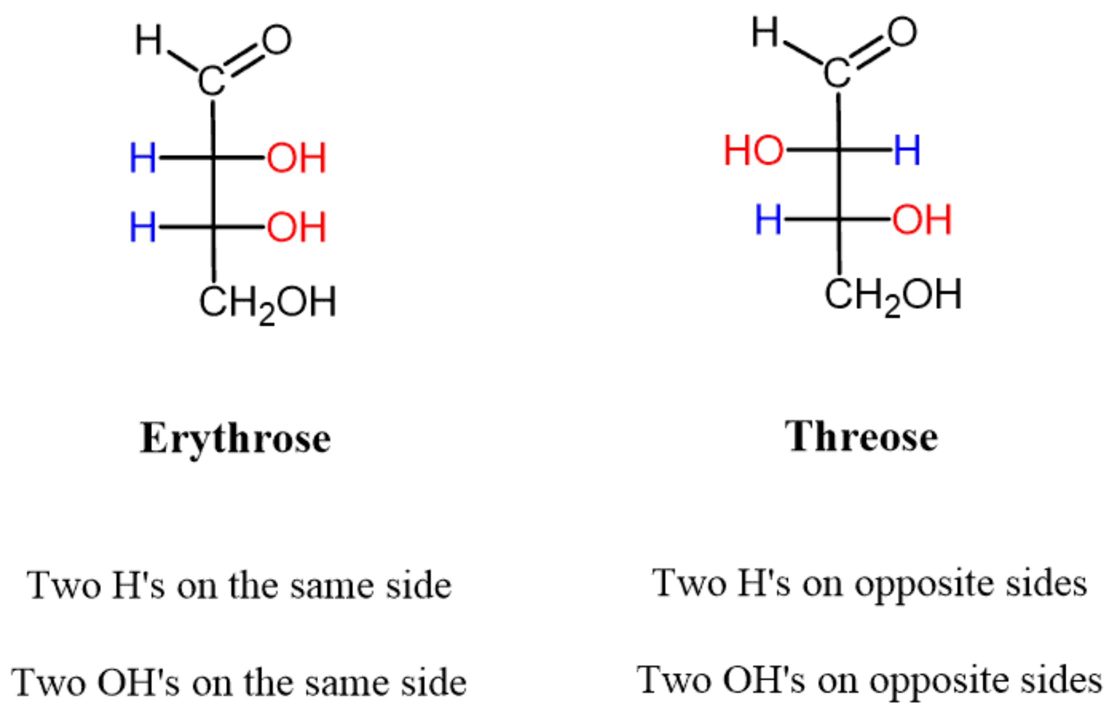


Fig. 7

The final pair of molecules to use to test your students' observational skills is the simplest alpha (α) amino acid, glycine, which has no isomer. In Fig. 8, *a* and *b* are mirror images,

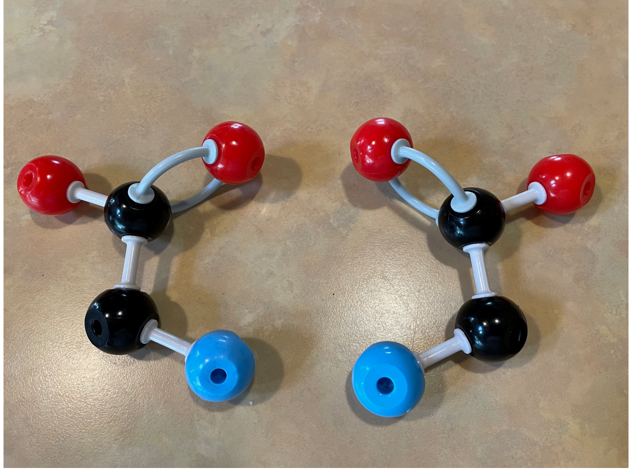


Fig. 8

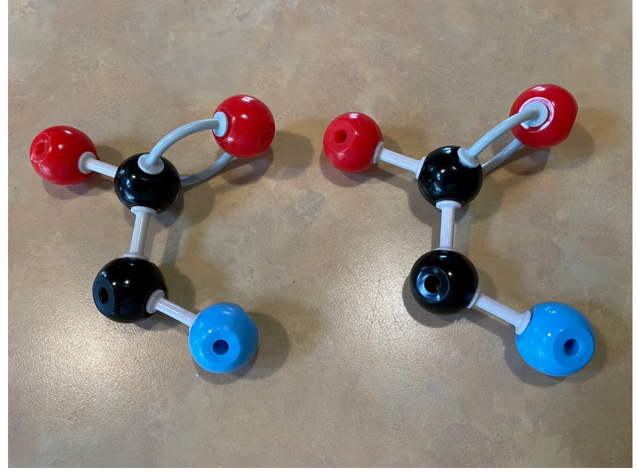


Fig. 9

but they are exactly the same molecule (figure 9). For a carbon atom to have a mirror image which is not superimposable, the atom must have four different atoms or groups of atoms bonded to it. Notice that the α carbon (the bottom carbon) has two unused holes for bonding to two hydrogen atoms. After bonding the two hydrogens, it can be seen that the α carbon only has three different kinds of groups.

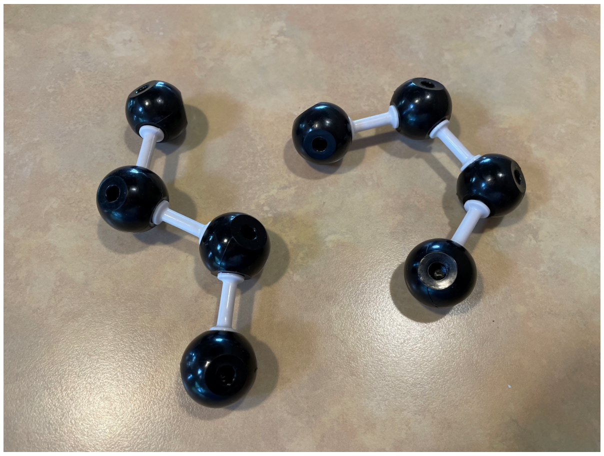
Lab procedure:

1. Students make the pairs of molecules (1-6 pictured below) and fill out the table. There are not enough parts in one kit to make up all the molecules simultaneously.

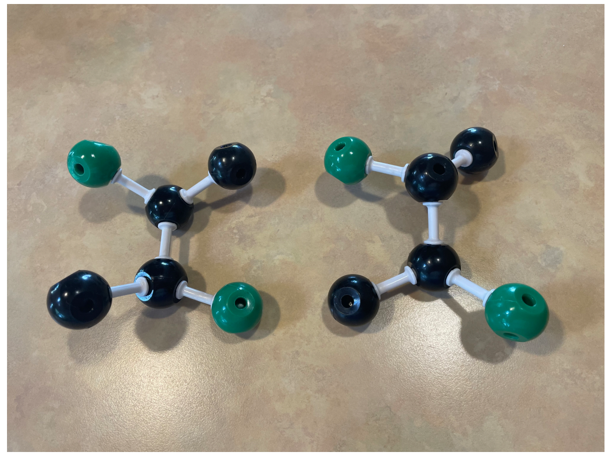
Answer Key:

Pair Number	Type of Isomer
1	rotamers
2	diasteromers
3	structural
4	rotamers
5	enantiomers
6	cis/trans

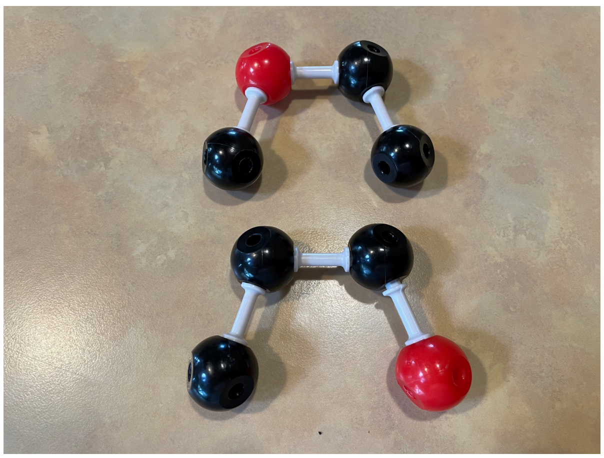
Students will make the following models:



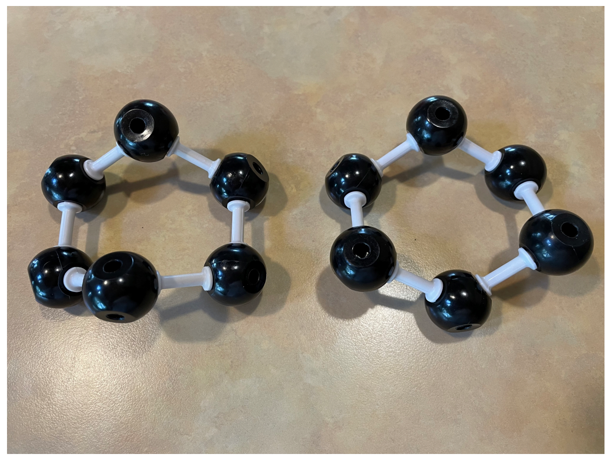
1



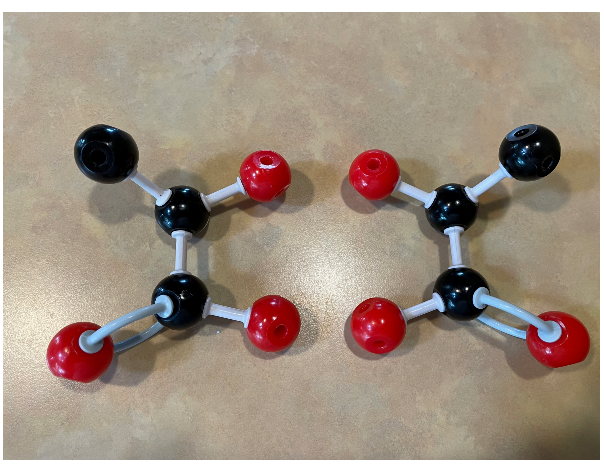
2



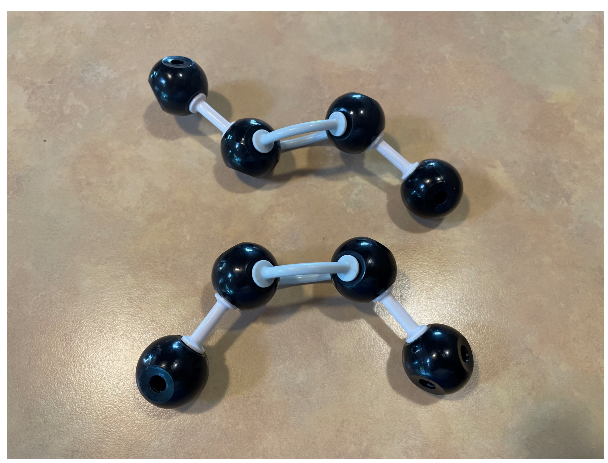
3



4



5



6

Isomers Lab

Objective: To compare and classify pairs of molecules as not isomers, or isomers.

To determine the type of isomers a pair of molecules present.

Materials: General Chemistry Model Kit, photos of models 1-6, dichotomous key to isomers

Student Procedure: Make the models pictured.

After making your determinations, fill in the following table.

Molecule Pair Number	Type of Isomer	Explain:
1		
2		
3		
4		
5		
6		

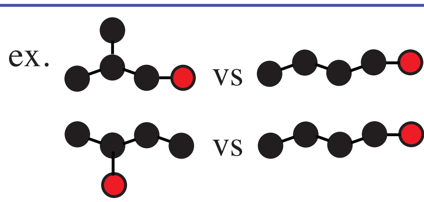
Dichotomous Key

Do the molecules have the same formula? (assuming the molecules are not identical)

- No → **Not isomers**
- Yes → **Isomers**: Molecules with the same chemical formula.

Do both molecules have the same kinds of atoms connected to the same kinds of atoms in the same order?

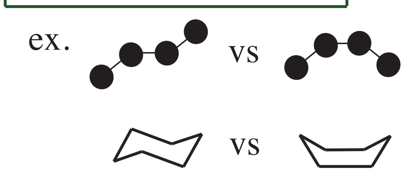
- No → **Structural (constitutional) isomers**: Different connectivity



- Yes → **Stereoisomers**: Same connectivity, Different spatial arrangement

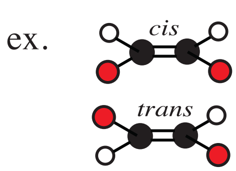
Can the molecules be interconverted by a rotation around a single bond?

- Yes → **Rotamers**: Rotating bond(s) in one molecule makes both molecules the same.



- No → Is the isomerism at a double bond?

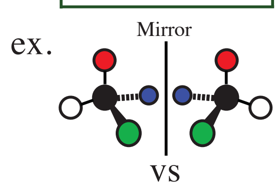
  - Yes → ***Cis/trans* (geometric) isomers**



  - No → **Optical isomers**:

Are the molecules mirror images of each other?

- Yes → **Enantiomers**: Mirror-image-isomers



- No → **Diastereomers**: Non-mirror-image-isomers