22.3 Isomers

Guide for Reading

Key Concepts
- How do the properties of structural isomers differ?
- What are the two types of stereoisomers?

Vocabulary
isomers  
structural isomers  
stereoisomers  
geometric isomers  
trans configuration  
cis configuration  
asymmetric carbon  
optical isomers

Reading Strategy
Building Vocabulary  
As you read, write definitions of the four types of isomers described. Be sure your definitions differentiate among the types.

Structural Isomers

You may have noticed that the structures of some hydrocarbons differ only in the positions of substituent groups or of multiple bonds in their molecules. Look at the structural formulas for butane and 2-methylpropane shown below and at their ball-and-stick models in Figure 22.7. Even though both compounds have the formula C₄H₁₀, their boiling points and other properties differ. Because their structures are different, they are different substances. Compounds that have the same molecular formula but different molecular structures are called isomers.

Butane and 2-methylpropane represent a category of isomers called structural isomers. Structural isomers are compounds that have the same molecular formula, but the atoms are joined together in a different order. Structural isomers differ in physical properties such as boiling point and melting point. They also have different chemical reactivities. In general, the more highly branched the hydrocarbon structure, the lower the boiling point of the isomer compared with less branched isomers. For example, 2-methylpropane has a lower boiling point than butane.

Figure 22.7  Both butane and 2-methylpropane have the molecular formula C₄H₁₀. But the atoms in their molecules are arranged in a different order. So these compounds are structural isomers.

- Butane (C₄H₁₀)  
  (bp = 0°C)
- 2-methylpropane (C₄H₁₀)  
  (bp = 10°C)

Butane 2-methylpropane

Figure 22.7  Both butane and 2-methylpropane have the molecular formula C₄H₁₀. But the atoms in their molecules are arranged in a different order. So these compounds are structural isomers.

Butane 2-methylpropane

Section Resources

Print
- Guided Reading and Study Workbook, Section 22.3
- Core Teaching Resources, Section 22.3 Review
- Transparencies, T257–T258
- Small-Scale Chemistry Laboratory Manual, Lab 37

Technology
- Interactive Textbook with ChemASAP, Simulation 28, Problem-Solving 22.18, Assessment 22.3
Stereoisomers

Remember that molecules are three-dimensional structures. So molecules with the same molecular formula and with atoms joined in exactly the same order may still be isomers. Stereoisomers are molecules in which the atoms are joined in the same order, but the positions of the atoms in space are different. Two types of stereoisomers are geometric isomers and optical isomers.

Geometric Isomers The first category of stereoisomers is based on the presence of a double bond in a molecule. A double bond between two carbon atoms prevents them from rotating with respect to each other. Because of this lack of rotation, groups on either side of the double bond can have different orientations in space. Geometric isomers have atoms joined in the same order, but differ in the orientation of groups around a double bond. Look at the models of 2-butene in Figure 22.8. Two arrangements are possible for the methyl groups with respect to the rigid double bond. In the trans configuration, the methyl groups are on opposite sides of the double bond. In the cis configuration, the methyl groups are on the same side of the double bond. Trans-2-butene and cis-2-butene have different physical and chemical properties. For example, the density of cis-2-butene is 0.616 g/cm³, and the density of trans-2-butene is 0.599 g/cm³. The groups attached to the carbons of the double bond do not need to be the same. Geometric isomerism is possible whenever each carbon of the double bond has at least one substituent.

Optical Isomers The second category of stereoisomers occurs whenever a carbon atom has four different atoms or groups attached. A carbon with four different atoms or groups attached is an asymmetric carbon. Look at the models in Figure 22.9. Because H, F, Cl, and Br atoms are attached to a single carbon atom, the carbon is asymmetric. The relationship between the molecules is similar to the relationship between right and left hands.

Think about an object placed in front of a mirror. If the object is symmetrical, like a ball, then its mirror image can be superimposed. That is, the appearance of the ball and its reflection are indistinguishable. By contrast, a pair of hands is distinguishable even though the hands consist of identical parts. The right hand reflects as a left hand and the left hand reflects as a right hand. The images cannot be superimposed. Many ordinary objects, such as ears, feet, shoes, and bird wings, are similarly related.

Figure 22.8 There is a trans and a cis configuration of 2-butene because a methyl group is attached to each carbon of the double bond. Comparing and Contrasting How are the trans and cis configurations different?

Figure 22.9 In these models, four different atoms are attached to the same carbon atom, making the carbon atom an asymmetric carbon.

Discuss

Point out that the number of possible structural isomers for an alkane increases dramatically with increasing numbers of carbon atoms. With more carbon atoms there are more ways to arrange the atoms in space. Remind students that each isomer has a unique set of physical and chemical properties. Name the three isomers of pentane. Have students name the five isomers of hexane they constructed in the Modeling Isomers class activity. Point out that the existence of isomers is a major reason that so many different organic compounds exist.

Stereoisomers

Discuss

Point out that the number of possible isomers for an alkene can be much greater than for an alkane. Draw the complete structural formulas of 1-butene, cis-2-butene, and trans-2-butene on the board to show the three possible isomers for butene (C₄H₈). Introduce the term geometric isomers and explain how cis-2-butene and trans-2-butene are different molecules due to the lack of free rotation about the carbon-carbon double bond.

TEACHER Demo

Optical Isomers

Purpose Students observe three-dimensional models of optical isomers.

Materials two ball-and-stick models of CHFClBr

Procedure Demonstrate how it is not possible to superimpose one model on the other.

Answers to...

Figure 22.8 The groups are on opposite sides of the double bond in the trans configuration; the groups are on the same side of the bond in the cis configuration.
CONCEPTUAL PROBLEM 22.3

Answers

18. a. 
\[
\begin{align*}
\text{CH}_3 & \quad \text{--}^*\text{C} \quad \text{--} \text{CHO} \\
\text{H} & \quad \text{Cl}
\end{align*}
\]

b. no asymmetric carbon

19. a. 
\[
\begin{align*}
\text{CH}_3\text{CH}_2 & \quad \text{--}^*\text{C} \quad \text{--} \text{Br} \\
\text{H} & \quad \text{F}
\end{align*}
\]

b. no asymmetric carbon

Quick LAB

Structural Isomers of Heptane

Objective After completing this activity, students will be able to:

• build ball-and-stick models of heptane isomers and name them.

Skills Focus Using models, observing, analyzing

Prep Time 5 minutes
Class Time 25 minutes
Expected Outcome Students will model and name nine structural isomers of heptane.

Analyze and Conclude

1. heptane, 2-methylhexane, 3-methylhexane, 2,3-dimethylpentane, 2,4-dimethylpentane, 2,2-dimethylpentane, 3,3-dimethylpentane, 3-ethylpentane, 2,2,3-trimethylbutane

2. 4

3. Each is a unique compound.

For Enrichment

Students can model, draw, and name the 18 structural isomers of octane.

CONCEPTUAL PROBLEM 22.4

Identifying Asymmetric Carbon Atoms

Compounds with the following formulas are alcohols. The alcohol represented by the formula in a. is the alcohol in rubbing alcohol. Which compound has an asymmetric carbon?

a. CH₃CHCH₂OH
b. CH₃CHCH₂CH₃

Analyze Identify the relevant concepts.

An asymmetric carbon atom has four different groups attached.

Solve Apply concepts to this situation.

Draw the structures in a more complete form to determine the presence of a carbon atom with four different groups attached.

a. The central carbon has two CH₃ groups attached. It is not asymmetric.
b. The central carbon has one H, one OH, one CH₃, and one CH₂CH₃ group attached. Because these four groups are different, the central carbon is asymmetric. In a structural formula, an asymmetric carbon is often marked with an asterisk.

Practice Problems

18. Identify the asymmetric carbon, if any, in each of the following structures.

a. CH₃CHCHO
b. CH₃CHOH

19. Identify the asymmetric carbon, if any, in each of the following structures.

a. CH₂Cl₂
b. CH₃Br

Facts and Figures

Mirror Images

Tell students that mirror images exist in nature. For example, 99% of the shells of some snails are right-handed spirals and 1% are left-handed spirals. The right- and left-handed spirals are mirror images. Other species have shells that are normally left-handed.
### Structural Isomers of Heptane

**Purpose**
To build ball-and-stick models and name the nine structural isomers of heptane (C\textsubscript{7}H\textsubscript{16}).

**Materials**
- ball-and-stick molecular model kit (Colors used to represent elements in the kit may not match colors used to represent elements in this book.)

**Procedure**
1. Build a model for the straight-chain isomer of C\textsubscript{7}H\textsubscript{16}. Draw the structural formula and write the IUPAC name for this isomer.
2. Move one carbon atom from the end of the chain and add a methyl substituent to the chain. Draw the structural formula and name this isomer.
3. Move the methyl group to a new position on the chain. Then draw and name this third isomer. Is there a third position that the methyl group can be moved to on the chain of six carbons to form yet another different isomer?
4. Make other structural isomers by shortening the longest straight chain and using the removed carbons as substituents. Draw the structural formulas and name each isomer.

**Heptane**

**Analyze and Conclude**
1. What are the names of the nine structural isomers of C\textsubscript{7}H\textsubscript{16}?
2. What is the shortest possible straight carbon chain in the isomers?
3. Why does each structural isomer have its own unique name?

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**22.3 Section Assessment**

20. **Key Concept** Explain why you would expect two structural isomers to have different boiling points.

21. **Key Concept** Name the two types of stereoisomers.

22. What structure must be present in a molecule for geometric isomers to exist?

23. **Key Concept** How can an asymmetric carbon be identified?

24. What is the relationship between two molecules that are optical isomers?

25. Draw structural formulas for the following alkenes. If a compound has geometric isomers, draw both the cis and trans forms.
   a. 1-pentene
   b. 2-hexene
   c. 2-methyl-2-hexene

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**Answers to...**

**Write instructions that could be used to decide whether two compounds are isomers and, if so, what type of isomers they might be.**

(1) How can you tell if two compounds are isomers?
(2) How can you tell if two compounds are structural isomers?
(3) How can you tell if two compounds can be geometric isomers?
(4) How can you tell if two compounds can be optical isomers?

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**Quick LAB**

**Purpose**
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3. Move the methyl group to a new position on the chain. Then draw and name this third isomer. Is there a third position that the methyl group can be moved to on the chain of six carbons to form yet another different isomer?
4. Make other structural isomers by shortening the longest straight chain and using the removed carbons as substituents. Draw the structural formulas and name each isomer.

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**Section 22.3 Assessment**

20. Structural isomers are different compounds with different physical properties.

21. geometric isomers and optical isomers

22. when each carbon in a double bond has at least one substituent

23. It has four different substituents.

24. The relationship is similar to the relationship between right and left hands, which can't be superimposed.

25. a. ![1-pentene](image)
   b. ![trans-2-hexene](image)
   c. ![cis-2-hexene](image)

**Checkpoint** The double bond prevents rotation around the carbon atoms, which allows for different spatial arrangements of substituents around the bond.
Hydrocarbons Isomers

**Objective** After completing this activity, students will be able to:
- write line-angle formulas for hydrocarbons.

**Prep Time** 5 minutes  
**Class Time** 20 minutes  

**Expected Outcome** Students will learn to write line-angle formulas for hydrocarbons.

**Analyze**

1. Students should draw formulas for pentane, 2-methylbutane, and 2,2-dimethylpropane.
2. Subtract from four the number of lines drawn to any point.

3. \[ \text{CH}_3(\text{CH}_2)_2\text{CH}_3 \text{ butane} \]

   \[ (\text{CH}_3)_2\text{CHCH}_3 \text{ methylpropane} \]

**For Enrichment**

There are eight isomers of \( \text{C}_7\text{H}_{16} \). Draw their line-angle formulas and name them.

- \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 \text{ pentane} \)
- \( \text{CH}_3\text{CHCHCH}_3 \text{ CH}_3 \text{ 2-methylbutane} \)
- \( \text{CH}_3\text{CHCH}_3\text{CH}_3 \text{ 2,2-dimethylpropane} \)

**You're the Chemist**

1. Gasoline contains isomers of hexane. Draw the line-angle formulas and name the five isomers of \( \text{C}_6\text{H}_{14} \). Make a model of one isomer and convert that model into the other four.

2. Gasoline also contains small amounts of the six isomers of pentene. Two of the isomers are cis and trans configurations of the same structural isomer. Experiment with your models to make these isomers. Use two toothpicks to represent a double bond. Draw structural formulas for the cis and trans isomers, and line-angle formulas for the others.