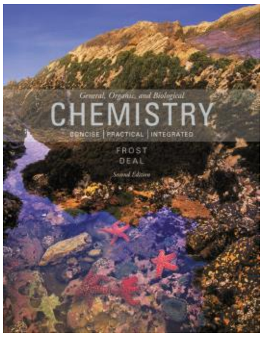

Lecture Presentation

Chapter 4

Introduction to Organic Compounds

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Outline

4.1 Alkanes: The Simplest Organic Compounds

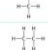
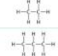
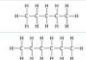
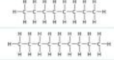
- **Alkanes** are structurally simple organic compounds made up solely of carbon and hydrogen.
- Alkanes are typically referred to as **saturated hydrocarbons**.
  - *Hydrocarbon* indicates that alkanes are made up entirely of hydrogen and carbon.
  - *Saturated* indicates that these compounds contain only single bonds.
  - Each carbon atom, in addition to being bonded to other carbon atoms, is bonded to the maximum number of hydrogen atoms (which saturate it).

4.1 Alkanes: The Simplest Organic Compounds

- **Straight-chain alkanes** are made up of carbon atoms joined to one another to form continuous, unbranched chains of varying length.
- Each compound is given a name that is based on the number of carbon atoms in its chain.
- **Cycloalkanes** are ring-form alkanes. The names of the cycloalkanes are formed by adding the prefix *cyclo-* to the alkane name for the compound containing the same number of carbon atoms.
- Rings of five and six carbon atoms are the most common in nature.

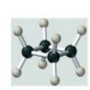
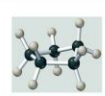
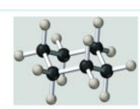
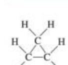
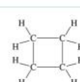
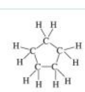
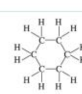
4.1 Alkanes: The Simplest Organic Compounds

TABLE 4.1 Names of the First 10 Straight-Chain Alkanes

Number of Carbon Atoms	Prefix	Name of Alkane	Molecular Formula	Lewis Structure
1	meth	Methane	CH_4	
2	eth	Ethane	C_2H_6	
3	prop	Propane	C_3H_8	
4	but	Butane	C_4H_{10}	
5	pent	Pentane	C_5H_{12}	
6	hex	Hexane	C_6H_{14}	
7	hept	Heptane	C_7H_{16}	
8	oct	Octane	C_8H_{18}	
9	non	Nonane	C_9H_{20}	
10	dec	Decane	$C_{10}H_{22}$	

4.1 Alkanes: The Simplest Organic Compounds

TABLE 4.2 Cycloalkanes: Names and Common Structures

Name			
Cyclopropane	Cyclobutane	Cyclopentane	Cyclohexane
Ball-and-Stick Models			
			
Lewis Structures			
			

4.1 Alkanes: The Simplest Organic Compounds

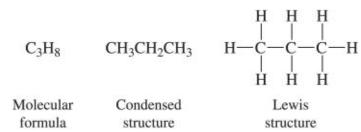
Alkanes Are Nonpolar Compounds

- The electronegativities of carbon and hydrogen are so similar that when these two elements form covalent bonds, the electrons are shared equally and the bond is nonpolar.
- Alkanes are composed solely of carbon and hydrogen, so regardless of their shape, alkanes are nonpolar.
- The nonpolar nature of alkanes affects the behavior of these compounds in aqueous systems. (Remember that water is polar.)

4.2 Representing Structures of Organic Compounds

Condensed Structural Formulas

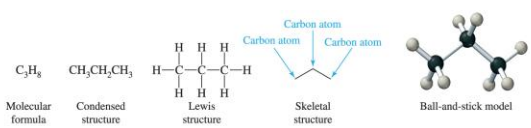
- These show all the atoms in a molecule, but as few bonds as possible.
- They are not useful for drawing cycloalkanes.
- The molecular formula shows only the number of each atom in the molecule.
- The Lewis structure shows complete connectivity—all atoms and all bonds.



4.2 Representing Structures of Organic Compounds

Skeletal Structures

- These show only bonds.
- They are useful for drawing cycloalkanes.
- Each carbon atom is assumed to be saturated, but hydrogens bonded to carbon are only implied.



4.2 Representing Structures of Organic Compounds

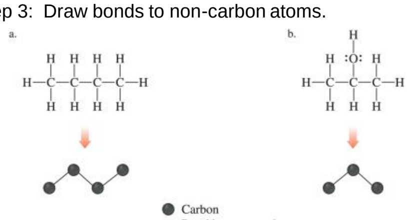
Rules for Drawing Skeletal Structures

- Only bonds to carbon are shown.
- Bonds between carbon and hydrogen are not shown, but are implied.
- Other elements bonded to carbon are drawn at the end of the bond using their symbol.
  - If these atoms have hydrogens bonded to them, these hydrogens are shown.
  - Lone pairs of electrons on these elements are not shown.

4.2 Representing Structures of Organic Compounds

Rules for Drawing Skeletal Structures

- Step 1: Determine the number of carbons connected end to end
- Step 2: Draw the carbon skeleton.
- Step 3: Draw bonds to non-carbon atoms.



4.3 Families of Compounds—Functional Groups

- Elements other than carbon and hydrogen that are present in an organic compound are called **heteroatoms**.
- A group of atoms bonded in a particular way is called a **functional group**.
- Each functional group has specific properties and chemical reactivity.
- Organic compounds that contain the same functional group behave similarly.

4.3 Families of Compounds—Functional Groups

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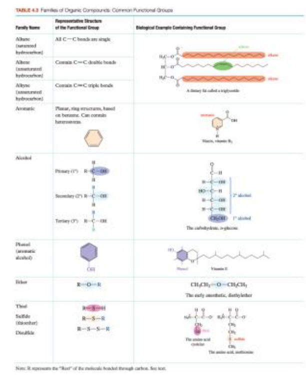
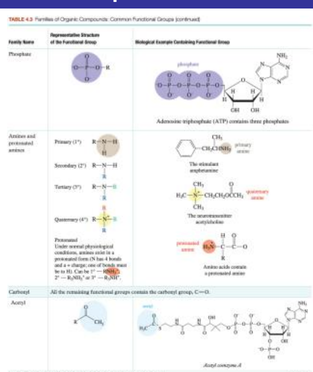
- A group of atoms bonded in a particular way is called a **functional group**.
- Each functional group has specific properties and chemical reactivity.
- Organic compounds that contain the same functional group behave similarly.
- The C=O group found in several families is called a **carbonyl**.

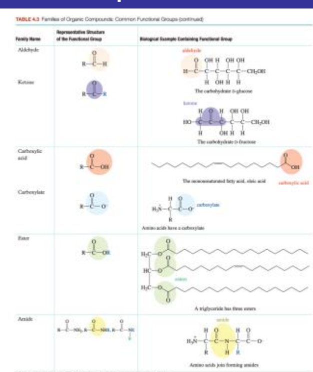
4.3 Families of Compounds—Functional Groups



4.3 Families of Compounds—Functional Groups



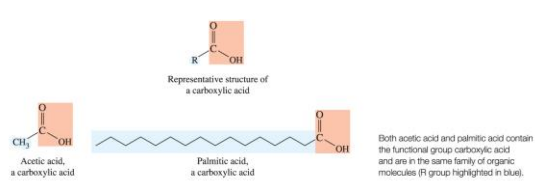
4.3 Families of Compounds—Functional Groups



4.3 Families of Compounds—Functional Groups

- The functional group is the reactive part of an organic molecule.
- To keep the focus on the functional group, an *R* is often used to represent the *R*est of the molecule.
- The use of *R* allows us to simplify a structure and highlight just the functional group of interest.
- *R* can represent anything from one carbon to a more complex group containing many carbons.

4.3 Families of Compounds—Functional Groups

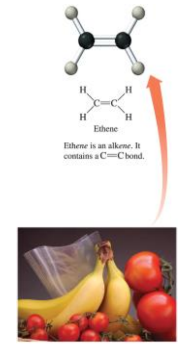


4.3 Families of Compounds—Functional Groups

- **Unsaturated Hydrocarbons—Alkenes**
  - A carbon–carbon double bond is an unsaturated hydrocarbon functional group in the **alkene** family.
  - Alkenes are considered **unsaturated hydrocarbons** because they have more than one bond between two carbon atoms.
  - A double bond is shorter and stronger than a single bond.
  - When alkenes react in an addition reaction, the second bond of the double bond is broken, but the carbon atoms remain joined together by the single bond.
  - Alkenes are more reactive than alkanes.

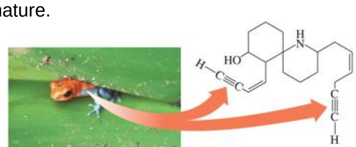
4.3 Families of Compounds—Functional Groups

- **Unsaturated Hydrocarbons—Alkenes**
  - Alkenes are also found in **terpenes**.
  - These compounds contain a multiple of 5 carbons (5, 10, 15, 20, and so on).
  - Some common terpenes are β-carotene, D-limonene, and α-pinene.
  - Cholesterol, testosterone, and estrogen are synthesized from terpenes.



4.3 Families of Compounds—Functional Groups

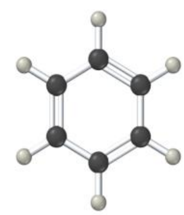
- **Unsaturated Hydrocarbons—Alkynes**
  - Compounds that contain one or more carbon–carbon triple bonds are members of the **alkyne** family.
  - The triple bond is shorter and stronger than the alkene's double bond.
  - Alkynes are even more reactive than alkenes.
  - Because they are so reactive, alkynes are rare in nature.



Histrionicotoxin

4.3 Families of Compounds—Functional Groups

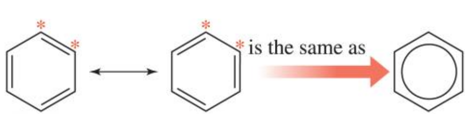
- **Unsaturated Hydrocarbons—Aromatics**
  - These compounds were originally dubbed "aromatic" because many have pleasant aromas.
  - **Aromatic compounds** have a cyclic structure like benzene (*phenyl* when part of a large molecule).
  - All the carbon–carbon bonds of benzene are the same length.
  - Benzene resists reactions that would break double bonds.



Benzene

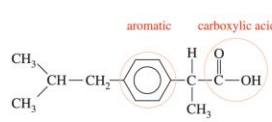
4.3 Families of Compounds—Functional Groups

- **Unsaturated Hydrocarbons—Aromatics**
  - The double bonds between adjacent carbon atoms are not static.
  - The electrons in the double bonds are shared evenly by all six carbons in a **resonance hybrid**.
  - Because these electrons are free to roam among the six carbons, they are much less likely to react with other molecules.

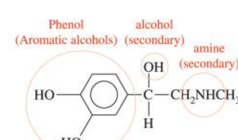


4.3 Families of Compounds—Functional Groups

- **Pharmaceuticals Are Organic Compounds**
  - Open the package of any prescription medication, and you will find an insert that includes a description and chemical structure.



Ibuprofen,
a nonsteroidal anti-inflammatory



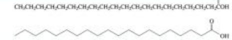
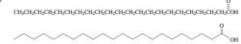
Epinephrine,
a stimulant and active ingredient in the EpiPen®

4.3 Families of Compounds—Functional Groups

- **Fatty Acids—Biological "Hydrocarbons"**
  - Fatty acids with one double bond are called **monounsaturated**.
  - Those with two or more double bonds are called **polyunsaturated**.
  - Saturated fatty acids belong to a class of biomolecules called **lipids**.
  - Fatty acids are long, straight-chain alkane-like compounds with a carboxylic acid group at one end.
  - The biologically most important fatty acids are compounds containing from 12 to 22 carbon atoms.
  - Most naturally occurring fatty acids have even numbers of carbon atoms.

4.3 Families of Compounds—Functional Groups

TABLE 4.4 Saturated Fatty Acids: Names and Structures

Name	Carbon Atoms	Source	Structures
Lauric acid	12	Coconut	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2\overset{O}{\overset{\|}{C}}OH$ 
Myristic acid	14	Nutmeg	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2\overset{O}{\overset{\|}{C}}OH$ 
Palmitic acid	16	Palm	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2\overset{O}{\overset{\|}{C}}OH$ 
Stearic acid	18	Animal fat	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2\overset{O}{\overset{\|}{C}}OH$ 
Arachidic acid	20	Peanut	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2\overset{O}{\overset{\|}{C}}OH$ 
Behenic acid	22	Canola	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2CH_2\overset{O}{\overset{\|}{C}}OH$ 

4.3 Families of Compounds—Functional Groups

- **Fatty Acids in Our Diets**
  - Fats play important roles as insulators and protective coverings for internal organs and nerve fibers.
  - The Food and Drug Administration (FDA) recommends a maximum of 30% of the calories in a normal diet from fatty acid–containing compounds, with a majority from foods containing mono- and poly-unsaturated fatty acids.

4.3 Families of Compounds—Functional Groups

TABLE 4.5 Fatty Acid Composition of Common Dietary Fats

	Saturated	Monounsaturated	Polyunsaturated
	%[a]	%[a]	%[a]
Butter	68	28	4
Canola oil	7	61	32
Coconut oil	91	7	2
Corn oil	13	28	59
Lard	43	47	10
Olive oil	15	73	12
Palm oil	49	40	11
Soybean oil	15	25	60
Sunflower oil	13	21	66

[a]Approximate percentages by weight of total fatty acids

4.4 Nomenclature of Simple Alkanes

- Alkanes that do not have their carbon atoms connected in a single continuous chain are called **branched-chain alkanes**.
- The IUPAC nomenclature rules provide a unique name for any organic compound and ensure that every compound has just one correct systematic name.
- All of the millions of organic compound names have three basic parts:

Substituents	+	Parent Name	+	Suffix
(Attachments)		*(Number of carbons in the longest continuous chain)*		*(Family name)*

4.4 Nomenclature of Simple Alkanes

Naming Branched-Chain Alkanes

- **Step 1:** Find the longest continuous chain of carbon atoms. This is the parent chain. Name the parent chain. (*Hint*: Count from each end to every other end to make sure you find the longest chain.)
- **Step 2:** Identify the groups bonded to the main chain but not included in the main chain. These **substituents** are called **alkyl groups.**
  - The name of each alkyl group is derived from the alkane with the same number of carbon atoms by changing *-ane* to *-yl*. Prop*ane* becomes prop*yl.*

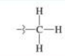
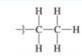
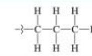
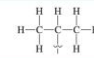
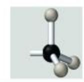
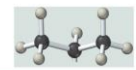
4.4 Nomenclature of Simple Alkanes

Naming Branched-Chain Alkanes

- **Step 3:** Number the parent chain starting at the end nearest to a substituent.
- **Step 4:** Assign a number to each substituent based on location, listing the substituents in alphabetical order at the beginning of the name. Separate numbers and words in the name by a dash.
  - If more than one of the same type of substituent is present in the compound, indicate this using Greek prefixes *di-*, *tri-, and tetra-,* but ignore these prefixes when alphabetizing.

4.4 Nomenclature of Simple Alkanes

TABLE 4.6 Four Simplest Alkyl Substituents

	Methyl	Ethyl	Propyl	Isopropyl
Lewis structure				
Condensed structure	$-CH_3$	$-CH_2CH_3$	$-CH_2CH_2CH_3$	CH_3CHCH_3
Line structure				
Ball-and-stick model				

4.4 Nomenclature of Simple Alkanes

Haloalkanes

- Halogens are common substituents on alkane chains. These are also called *alkyl halides*.
- The substituent names of the halogens are *fluoro-, chloro-, bromo-,* and *iodo-.*
- The rules for naming haloalkanes are the same as those for naming branched-chain alkanes with the halogen being the substituent.

4.4 Nomenclature of Simple Alkanes

Cycloalkanes

- The rules for determining the IUPAC names for cycloalkanes are the same as those for branched-chain alkanes with a couple of modifications:
  - **Step 1:** The ring serves as the parent name.
  - **Step 2:** Identify the substituents.
  - **Step 3:** Number the carbons in the ring. Carbon 1 will always have a substituent.
  - **Step 4:** Assign numbers to the substituents. On a ring bearing a single substituent, a 1 is implied and need not be listed. When more than one substituent is present, the ring should be numbered to give the lowest possible combination of numbers.

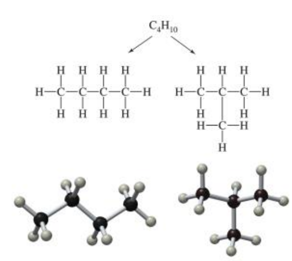
4.4 Nomenclature of Simple Alkanes

- Organic compounds with the same number of carbon atoms can have the carbons connected in many different ways.
- Molecules with the same molecular formula but different connectivity or arrangements of the atoms are called **isomers.**
- This is taken from the Greek *iso,* meaning "same," and *meros,* meaning "part."

4.5 Isomerism in Organic Compounds

Structural Isomers and Conformational Isomers

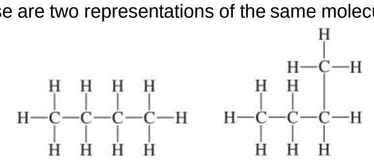
•When an organic compound has four or more carbons, there is more than one way that the carbons can be connected.



4.5 Isomerism in Organic Compounds

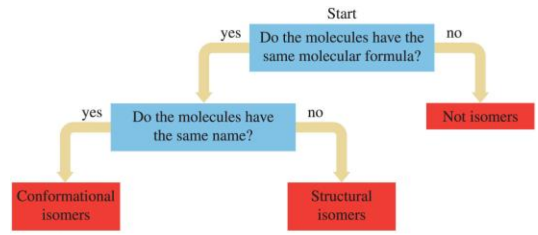
Structural Isomers and Conformational Isomers

- Because the connectivity of the carbons is the same, these are two representations of the same molecule:



- This type of isomer is a **conformational isomer** or **conformer**.
- These are not different compounds, but different arrangements of the same compound.

4.5 Isomerism in Organic Compounds

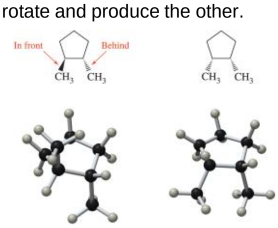


4.5 Isomerism in Organic Compounds

Cis–Trans Stereoisomers in Cycloalkanes and Alkenes

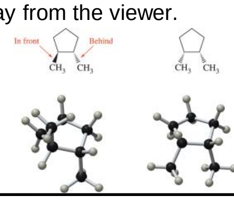
•If the following molecules were conformers, we could change one into the other without breaking any bonds.

•The ring of carbons makes it impossible for one of the molecules to rotate and produce the other.



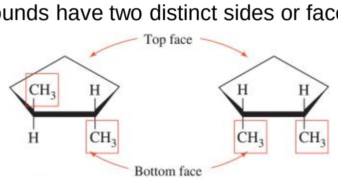
4.5 Isomerism in Organic Compounds

- Chemists draw wedge and dash bonds to show the three-dimensional nature of a molecule on the flat page.
- The wedge bond represents atoms that project out toward the viewer.
- The dash bond is used to represent atoms that project away from the viewer.



4.5 Isomerism in Organic Compounds

- Because of restricted rotation about the carbon–carbon bonds in cycloalkane rings, these compounds have two distinct sides or faces.



- When two molecules have the same molecular formula and the same attachments to the carbon skeleton but a different spatial arrangement, they are **stereoisomers.**

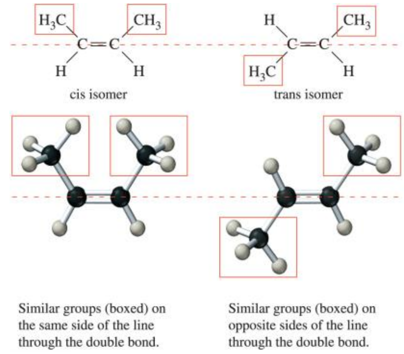
4.5 Isomerism in Organic Compounds

- *Cis*, *same side*. Notice all of the "s" sounds.
- *Trans* comes from the Latin, meaning "across."
- These prefixes, in italics, are included at the beginning of compound names to denote the arrangement of the substituents and give each compound a unique name.

4.5 Isomerism in Organic Compounds

- Cis–trans isomerism also can occur in alkenes.
- Double bonds will not allow two atoms to rotate independently of each other.
- Organic chemists say that the carbon–carbon double bond is rigid or has **restricted rotation**.
- A compound with similar groups on the same side of the double bond is the cis stereoisomer.
- A compound with similar groups on the opposite sides of the double bond is the trans stereoisomer.
- If one of the alkene carbons has two identical groups bonded to it, it cannot have cis–trans stereoisomers.

4.5 Isomerism in Organic Compounds



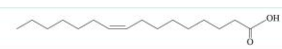
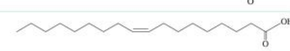
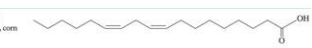
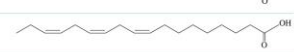
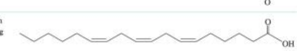
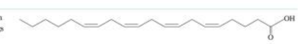
4.5 Isomerism in Organic Compounds

Unsaturated Fatty Acids Contain Cis Alkenes

- Omega (ω) designations are commonly used in nutrition literature.
- In this system, the carbon farthest from the carboxylic acid is numbered 1, the next carbon is 2, and so forth. The number indicates the carbon positioning of a double bond in the structure of the fatty acid.
- The polyunsaturated fatty acids linoleic and α-linolenic are considered **essential fatty acids**.
- Because our bodies cannot produce these compounds, they must be obtained from diet.

4.5 Isomerism in Organic Compounds

TABLE 4.7 Unsaturated Fatty Acids: Names and Structures

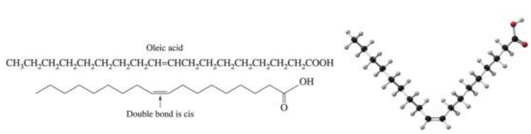
Name	Carbon Designation	Source	Structures
Monounsaturated Fatty Acids			
Palmitoleic acid	[16:1], ω-7	Butter	
Oleic acid	[18:1], ω-9	Olives, corn	
Polyunsaturated Fatty Acids			
Linoleic acid* (commonly called LA or Omega-6)	[18:2], ω-6	Soybean, safflower, corn	
α-Linolenic acid* (commonly called ALA or Omega-3)	[18:3], ω-3	Flaxseed, canola	
γ-Linolenic acid (commonly called GLA)	[18:3], ω-6	Formed from ALA, evening primrose, spirulina	
Arachidonic acid (commonly called AA)	[20:4], ω-6	Formed from LA, lard, eggs	

*Indicates essential fatty acid.

4.5 Isomerism in Organic Compounds

Stereoisomers—Chiral Molecules and Enantiomers

•The flavors of spearmint and caraway come from a pair of stereoisomers called the carvones.

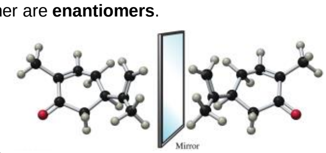


4.5 Isomerism in Organic Compounds

Stereoisomers—Chiral Molecules and Enantiomers

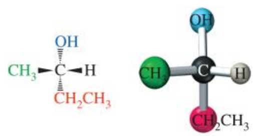
•Identical molecules are superimposable.

- The molecules are mirror images of each other.
- Compounds that are nonsuperimposable mirror images of each other are **enantiomers**.



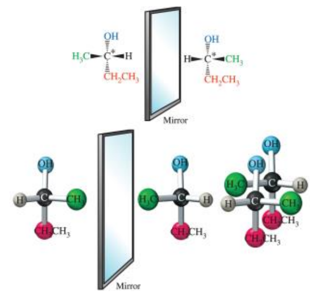
4.5 Isomerism in Organic Compounds

- A right-handed and a left-handed baseball glove are nonsuperimposable mirror images.
- Objects such as these are termed **chiral** (from the Greek *cheir,* meaning “the hand”).
- Most enantiomers contain a **chiral center**—a tetrahedral carbon atom bonded to four different atoms or groups of atoms.



4.5 Isomerism in Organic Compounds

- On paper, a chiral carbon is represented with an asterisk.



4.5 Isomerism in Organic Compounds

Identifying Chiral Carbons in a Molecule

- **Step 1: Locate the tetrahedral carbons** (carbons with four atoms bonded to them).
- **Step 2: Inspect the tetrahedral carbons.** Determine if the four groups attached to the tetrahedral carbons are different.
- **Step 3: Assign the chiral centers.** Typically, an asterisk is drawn next to the chiral carbon.

4.5 Isomerism in Organic Compounds

The Consequences of Chirality

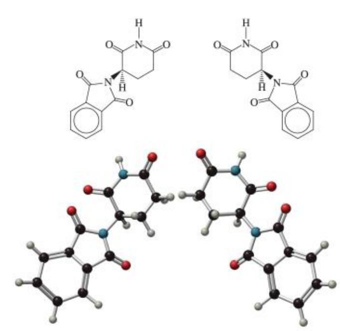
- Biological receptors are “handed.”
- A chiral molecule can fit only into a complementary receptor.
- In many pharmaceuticals, only a single enantiomer has biological activity.
- In some cases, one enantiomer of a drug can be beneficial and the other harmful.

4.5 Isomerism in Organic Compounds

The Consequences of Chirality

- This was the case with thalidomide.
- One enantiomer was effective in alleviating the symptoms of morning sickness.
- The mirror image was teratogenic.
- The drug was initially sold as a 50:50 mixture of the enantiomers; many mothers who took it later gave birth to babies with severe birth defects.

4.5 Isomerism in Organic Compounds



Thalidomide enantiomer used to treat morning sickness

Thalidomide enantiomer that causes birth defects

Chapter Four Summary

- **4.1 Alkanes: The Simplest Organic Compounds**
  - An organic compound is any compound that is composed primarily of carbon and hydrogen.
  - The simplest of these are the alkanes, containing *only* single-bonded carbon and hydrogen.
  - Alkanes can exist as straight-chain alkanes or as cycloalkanes.
  - Because carbon–hydrogen bonds are nonpolar, alkanes are nonpolar and not very reactive molecules.

Chapter Four Summary (continued)

- **4.2 Representing Structures of Organic Compounds**
  - Organic compounds can be represented with Lewis structures showing all atoms, bonds, and lone pairs of electrons.
  - Condensed structural formulas show all atoms in an organic molecule and their relative positioning, but they show bonds only when necessary for conveying the correct structure. Lone pairs may or may not be a part of a condensed structure.
  - Skeletal structures show the bonding "skeleton" of an organic molecule by showing all carbon-to-carbon bonds. Hydrogen atoms are not shown in skeletal structures, and carbon atoms are understood to exist at the corner formed when two bonds meet or at the termination of a bond. Non-carbon atoms and the hydrogens bonded to them are shown in skeletal structures.

Chapter Four Summary (continued)

- **4.3 Families of Compounds—Functional Groups**
  - Organic compounds are grouped into families based on the identity of the functional group(s) present.
  - A functional group is a common grouping of atoms bonded in a particular way.
  - Functional groups have specific properties and reactivity. Compounds with the same functional group behave similarly.
  - Since the functional group is the part of the molecule that is of interest, we typically represent the hydrocarbon portion as *R* (the *R*est of the molecule).
  - The hydrocarbon families the alkenes, alkynes, and aromatics are highlighted in this section.
  - Fatty acids are alkane-like biomolecules that are the primary components of dietary fats. Fatty acids with a carbon–carbon double bond in their structure are referred to as unsaturated, while those without a double bond are referred to as saturated.

Chapter Four Summary (continued)

- **4.4 Nomenclature of Simple Alkanes**
  - Alkanes, cycloalkanes, and haloalkanes can be named by following a simple set of rules developed by the IUPAC.
  - First find the longest continuous chain of carbons, then identify the substituents, then number the parent chain from the end closest to a substituent, and finally assign numbers to the substituents and alphabetize them in the name.

Substituents	+	Parent Name	+	Suffix
(Attachments)		*(Number of carbons in the longest continuous chain)*		*(Family name)*

Chapter Four Summary (continued)

- **4.5 Isomerism in Organic Compounds**
  - Structural isomers are two molecules with the same molecular formula, but a different connectivity.
  - Conformational isomers are different representations of the same compound.
  - Stereoisomers are two molecules with the same molecular formula and same connectivity but a different arrangement of the atoms in space.
  - Cis–trans stereoisomers can exist in cycloalkanes with two or more substituents and in alkenes. Naturally occurring unsaturated fatty acids contain cis-alkenes.
  - Organic compounds can also exist as stereoisomers if they contain a chiral center, which is a carbon atom bonded to four different atoms or groups of atoms.
  - Compounds with a single chiral center exist as a pair of stereoisomers called enantiomers. Enantiomers are related to each other as nonsuperimposable mirror images.
  - To distinguish between isomers and conformers, determine the correct name of each compound. Two isomers will have different names.

Chapter Four Study Guide

4.1 Alkanes: The Simplest Organic Compounds
- Distinguish between organic and inorganic compounds.
- Define the terms saturated and unsaturated hydrocarbon.
- Compare the molecular formulas of straight-chain alkanes and cycloalkanes.

4.2 Representing Structures of Organic Compounds
- Draw organic compounds as Lewis, condensed, and skeletal structures.

Chapter Four Study Guide (continued)

4.3 Families of Compounds—Functional Groups

- Identify common functional groups in organic molecules.
- Characterize the unsaturated hydrocarbons alkenes, alkynes, and aromatics.
- Draw saturated fatty acids in skeletal structure.

4.4 Nomenclature of Simple Alkanes

- Name branched-chain alkanes, haloalkanes, and cycloalkanes using IUPAC naming rules.

Chapter Four Study Guide

4.5 Isomerism in Organic Compounds

- Distinguish structural isomers from conformational isomers.
- Identify cis and trans isomers in cycloalkanes and alkenes.
- Draw unsaturated fatty acids in skeletal structure
- Locate chiral centers in organic molecules