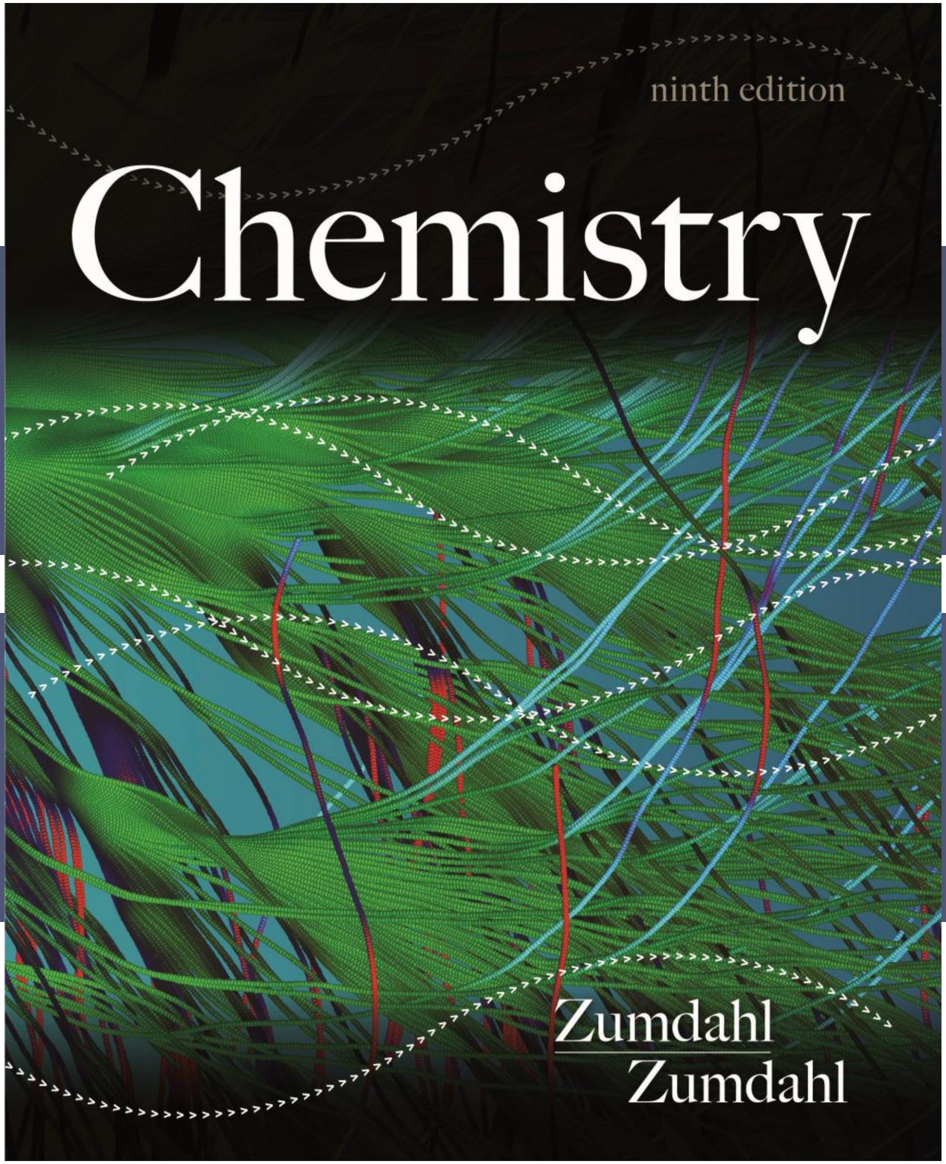


Chapter 22

Organic and Biological Molecules

Table of Contents

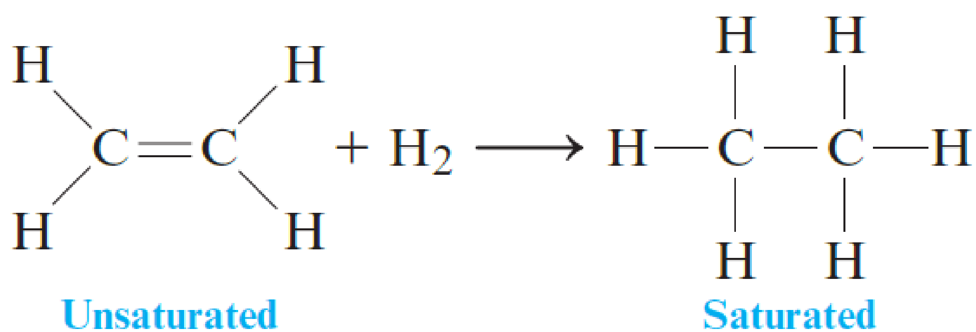
Organic Chemistry

- Study of carbon-containing compounds and their properties
  - Organic compounds contain chains or rings of carbon atoms
  - Helps understand living systems
- **Biomolecules**: Compounds that are responsible for the maintenance and reproduction of life

Hydrocarbons

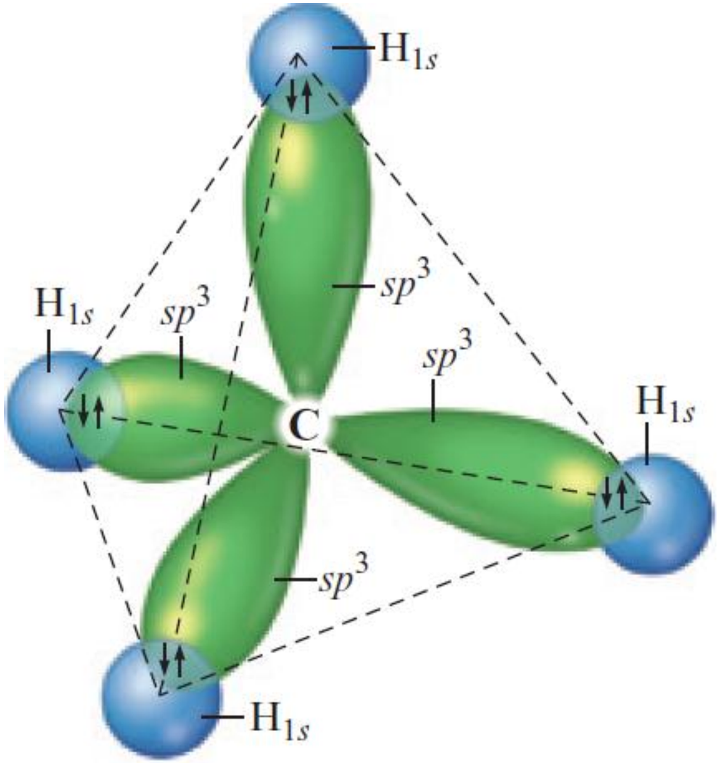
- Compounds composed of carbon and hydrogen
  - **Saturated hydrocarbons** (**Alkanes**): Compounds that contain carbon–carbon single bonds
  - **Unsaturated hydrocarbons**: Compounds that contain carbon–carbon multiple bonds

Addition of hydrogen to ethylene



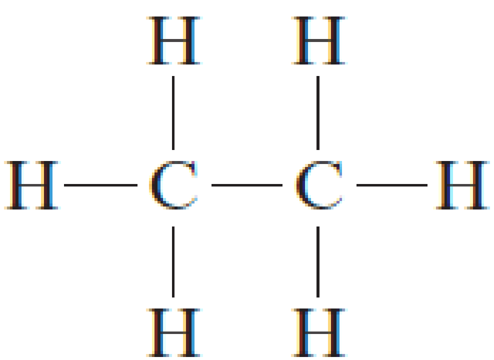
Saturated Hydrocarbons - Methane (CH_4)

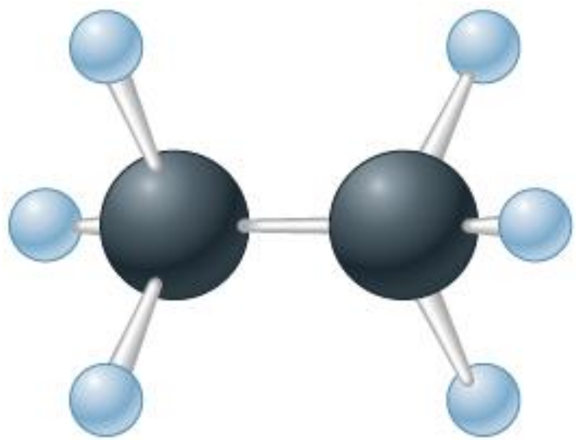
- Simplest member of saturated hydrocarbons
- Has a tetrahedral structure
  - Carbon atom uses sp^3 hybrid orbitals to bond to four hydrogen atoms

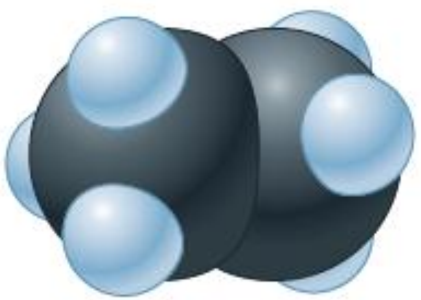


Saturated Hydrocarbons - Ethane (C_2H_6)

- Contains two carbon atoms
- Has a tetrahedral structure
- *sp*^{3} hybridized

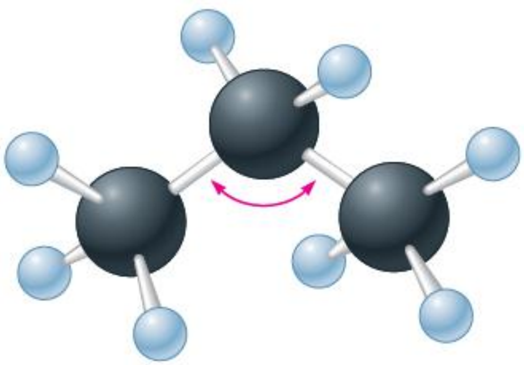




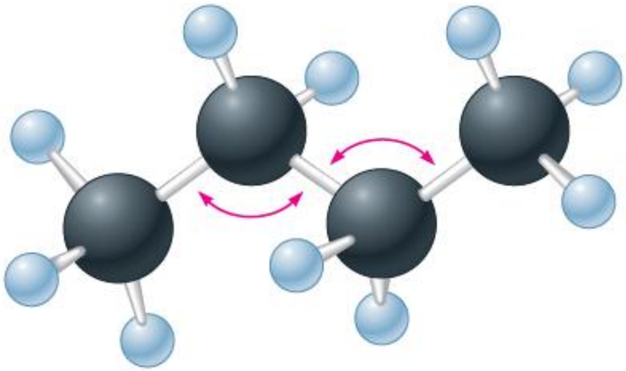


Saturated Hydrocarbons - Propane (C_3H_8) and Butane (C_4H_{10})

- Each carbon atom is bonded to four atoms
- *sp*^{3} hybridized



Propane



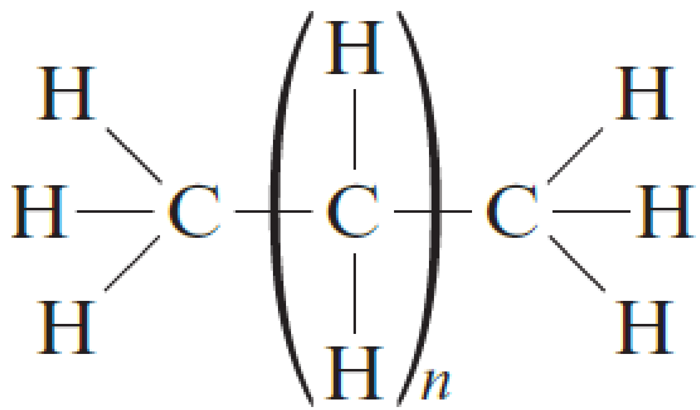
Butane

Unbranched Hydrocarbons

- Alkanes in which the carbon atoms form long strings or chains
  - Chains are zig-zag due to the tetrahedral C–C–C bond angle of 109.5°
- Known as **normal** or **straight-chain hydrocarbons**
- Example
  - Butane ($CH_3CH_2CH_2CH_3$) has a bond angle of 109.5°

Normal Alkanes

- Structure of a normal alkane, where *n* is an integer:



- Condensed general formula

$$CH_3 - (CH_2)_n - CH_3$$

Table 22.1 - Selected Properties of the First Ten Normal Alkanes

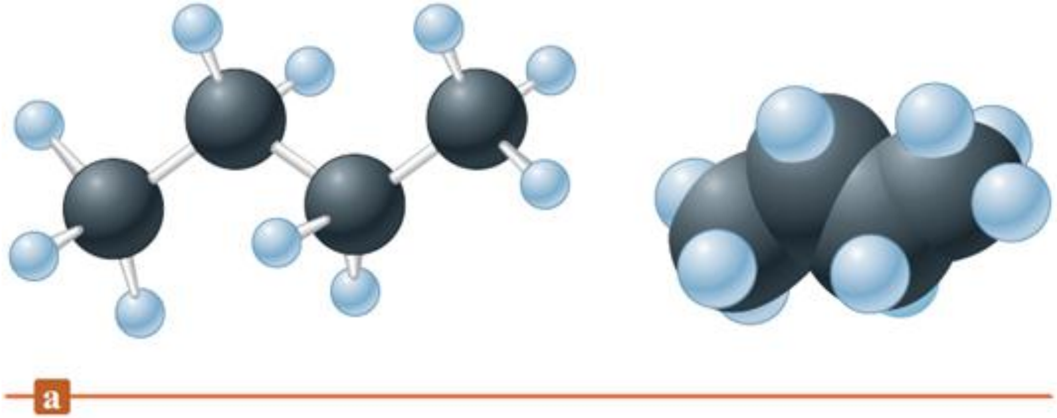
Name	Formula	Molar Mass	Melting Point (°C)	Boiling Point (°C)	Number of Structural Isomers
Methane	CH_4	16	−182	−162	1
Ethane	C_2H_6	30	−183	−89	1
Propane	C_3H_8	44	−187	−42	1
Butane	C_4H_{10}	58	−138	0	2
Pentane	C_5H_{12}	72	−130	36	3
Hexane	C_6H_{14}	86	−95	68	5
Heptane	C_7H_{16}	100	−91	98	9
Octane	C_8H_{18}	114	−57	126	18
Nonane	C_9H_{20}	128	−54	151	35
Decane	$C_{10}H_{22}$	142	−30	174	75

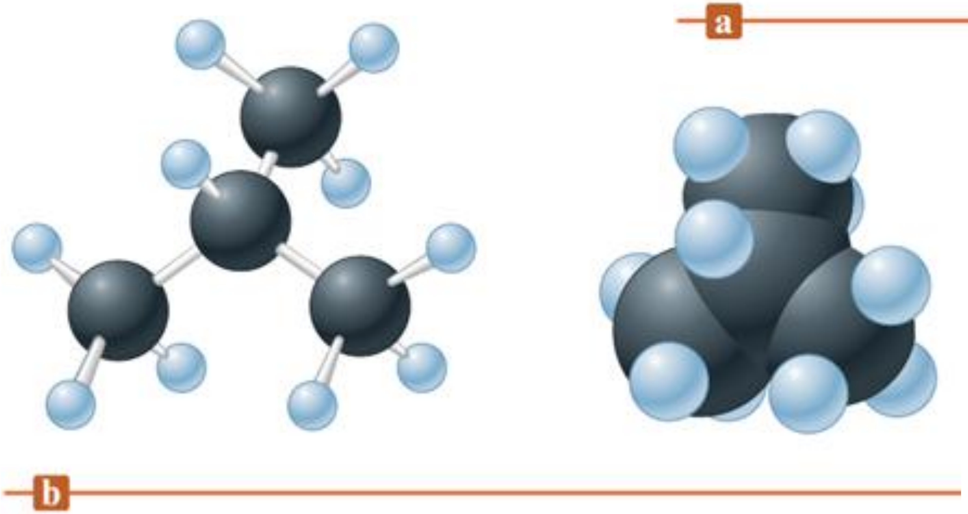
Isomerism in Alkanes

- **Structural isomerism**: Two molecules have the same atoms but different bonds
  - Example - Butane can exist as a straight chain structure (*n*-butane) or as a branched-chain structure (isobutane)
    - Different structures lead to different properties

Figure 22.4 - Structural Isomerism of Butane

Normal butane





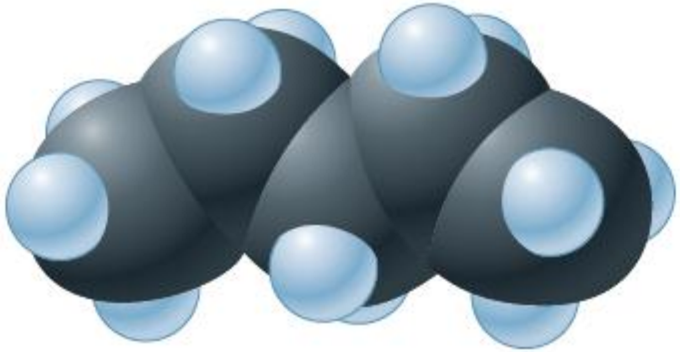
The branched isomer of butane

Example 22.1 - Structural Isomerism

- Draw the isomers of pentane

Example 22.1 - Solution

- Pentane (C_5H_{12}) has the following isomeric structures:
  - *n*-Pentane

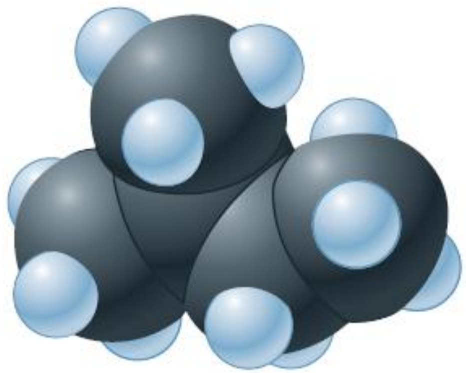


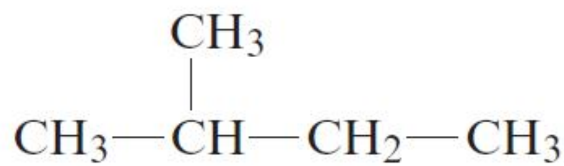
$CH_3—CH_2—CH_2—CH_2—CH_3$

***n*-Pentane**

Example 22.1 - Solution (Continued)

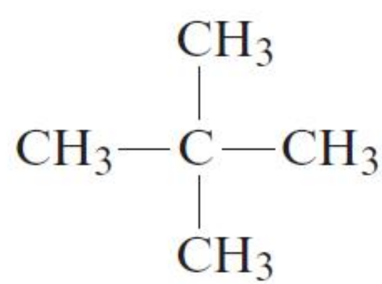
- Isopentane





Isopentane

- Neopentane



Neopentane

Rules for Naming Alkanes

1. For alkanes beyond butane, add -ane to the Greek root for the number of carbon atoms
   - For a branched hydrocarbon, the longest continuous chain of carbon atoms determines the root name
2. When alkane groups appear as substituents, drop the -ane and add -yl

Rules for Naming Alkanes (Continued 1)

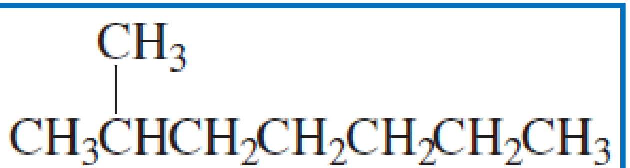
3. Positions of substituent groups are specified by numbering the longest chain of carbon atoms sequentially
   - Start at the end closest to the branching
   - Hyphen is written between the number and the substituent name

Rules for Naming Alkanes (Continued 2)

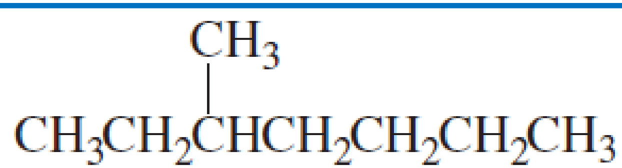
4. Location and name of each substituent are followed by the root alkane name
   - Substituents are listed in alphabetical order
   - Prefixes di-, tri-, and so on are used to indicate multiple, identical substituents

Exercise

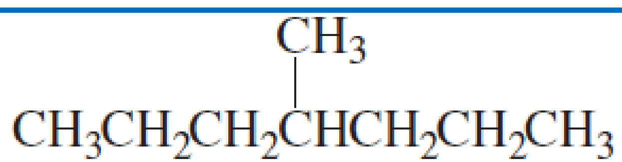
- Draw all the structural isomers for C_8H_{18} that have the root name (longest carbon chain) heptane
  - Name the structural isomers



2-methylheptane



3-methylheptane



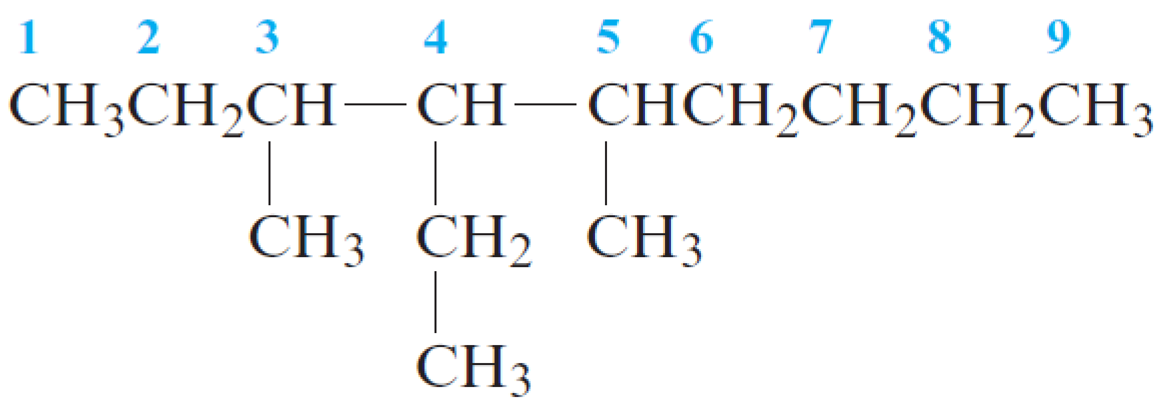
4-methylheptane

Interactive Example 22.3 - Structures from Names

- Determine the structure for each of the following compounds:
  a. 4-ethyl-3,5-dimethylnonane
  b. 4-*tert*-butylheptane

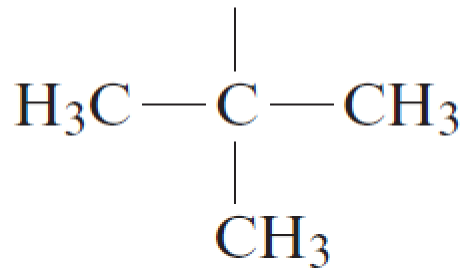
Interactive Example 22.3 - Solution (a)

- The root name nonane signifies a nine-carbon chain
  - Thus, we have

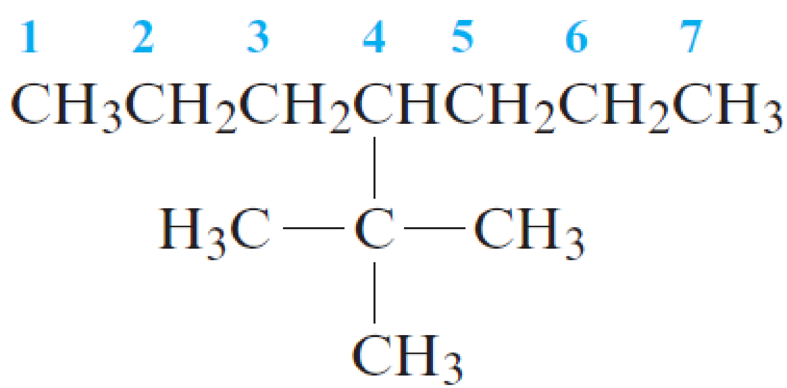


Interactive Example 22.3 - Solution (b)

- Heptane signifies a seven-carbon chain, and the *tert*-butyl group is



  - Thus, we have



Reactions of Alkanes

- Fairly unreactive
  - They are saturated compounds
  - The C—C and C—H bonds are strong
- Do not react with acids, bases, or strong oxidizing agents at 25° C
  - Makes them valuable lubricating materials and the backbone for structural materials

Combustion Reactions of Alkanes

- Alkanes react vigorously and exothermically with oxygen at high temperatures
  - Basis for use as fuels

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(g)$$

Substitution Reactions of Alkanes

- Occur primarily where halogen atoms replace hydrogen atoms
- Example - Chlorination of methane

$$CH_4 + Cl_2 \xrightarrow{h\nu} CH_3Cl + HCl$$

$$CH_3Cl + Cl_2 \xrightarrow{h\nu} CH_2Cl_2 + HCl$$

$$CH_2Cl_2 + Cl_2 \xrightarrow{h\nu} CHCl_3 + HCl$$

$$CHCl_3 + Cl_2 \xrightarrow{h\nu} CCl_4 + HCl$$

Dehydrogenation Reactions of Alkanes

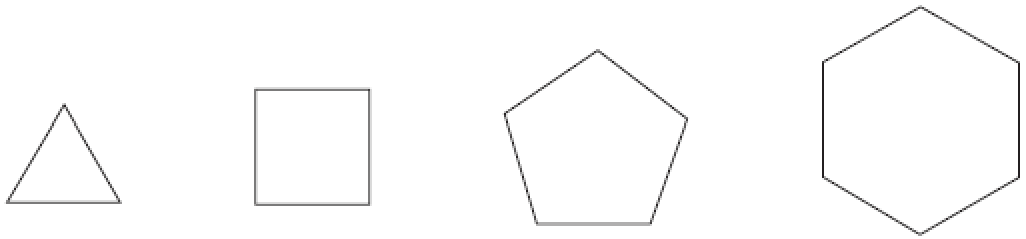
- Hydrogen atoms are removed
- Product is an unsaturated hydrocarbon
- Example - Dehydrogenation of ethane

$$CH_3CH_3 \xrightarrow[500°C]{Cr_2O_3} CH_2{=}CH_2 + H_2$$

Ethylene

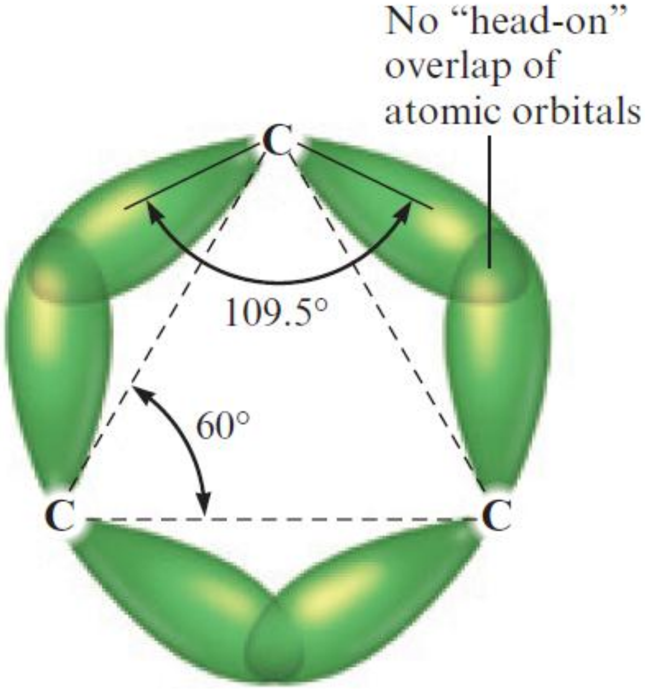
Cyclic Alkanes

- Carbon atoms can form rings containing only C—C single bonds
  - General formula - C_nH_{2n}
- Represented by the following figures for sake of simplicity:



Cyclopropane (C_3H_6)

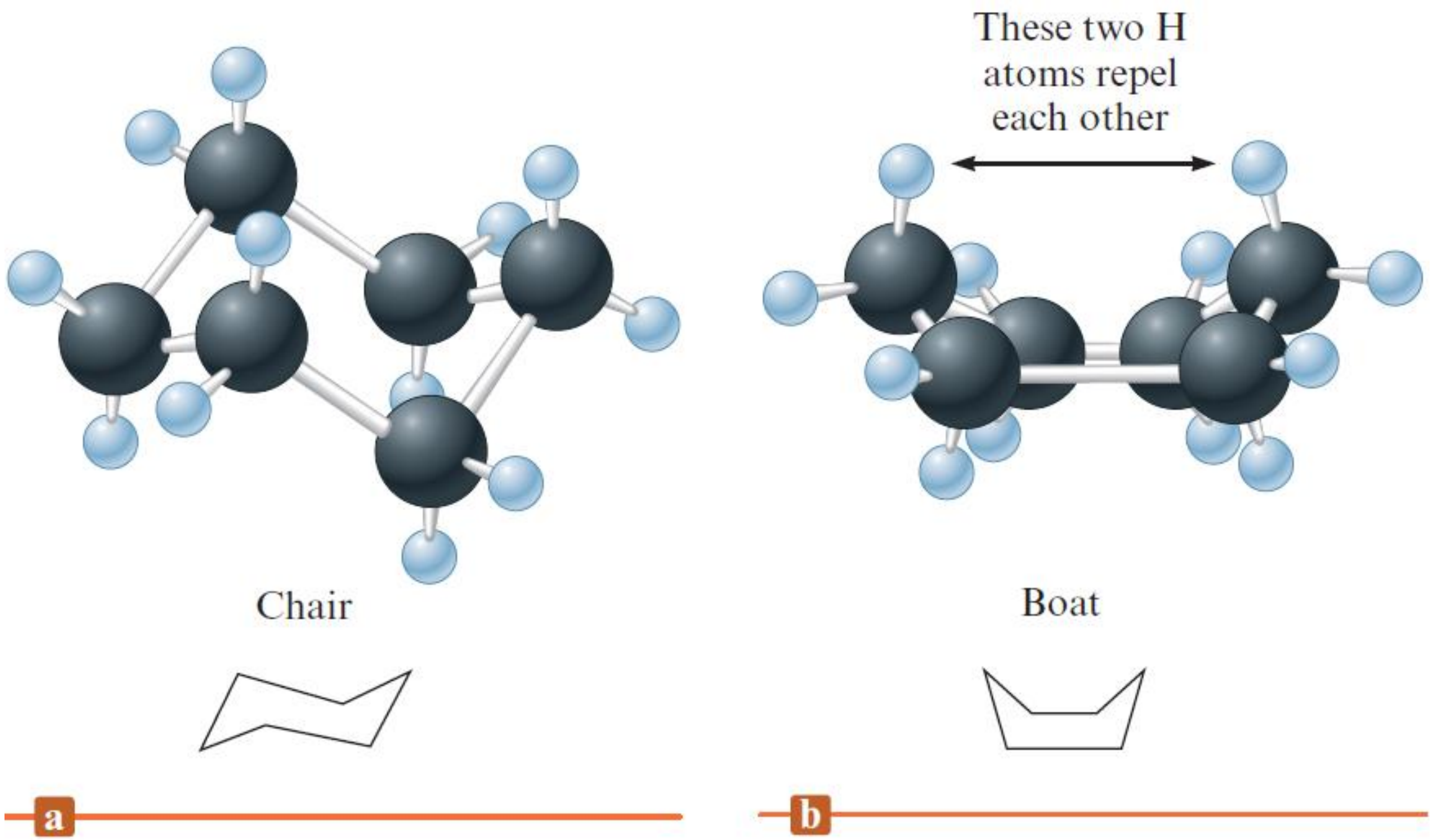
- Carbon atoms form an equilateral triangle with 60° bond angles
  - The sp^3 hybrid orbitals do not overlap
    - Results in weak or strained C—C bonds
- Highly reactive molecule



Cyclopentane (C_5H_{10}) and Cyclohexane (C_6H_{12})

- Rings have bond angles that are close to the tetrahedral angles
  - Permits *sp*^{3} hybrid orbitals on adjacent carbon atoms to overlap head-on and form normal C—C bonds
- Cyclohexane
  - Ring must become nonplanar to attain tetrahedral angles
  - Exists in the chair and the boat forms

Figure 22.6 - The Chair and Boat Forms of Cyclohexane



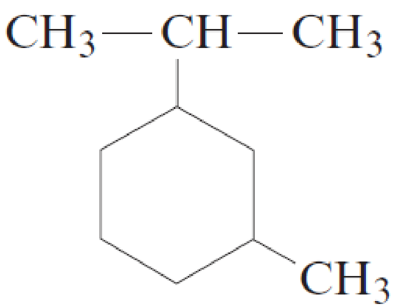
Nomenclature for Cycloalkanes

- Follows the same rules as those used in naming other alkanes
  - Exception - Root name is preceded by the prefix cyclo-
- Ring is numbered to yield the smallest substituent numbers possible

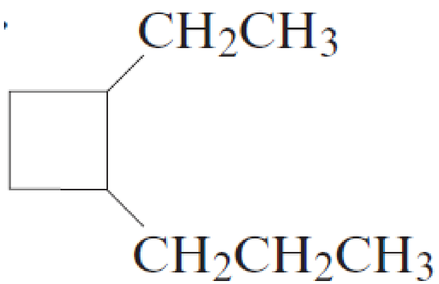
Interactive Example 22.4 - Naming Cyclic Alkanes

- Name each of the following cyclic alkanes:

a.

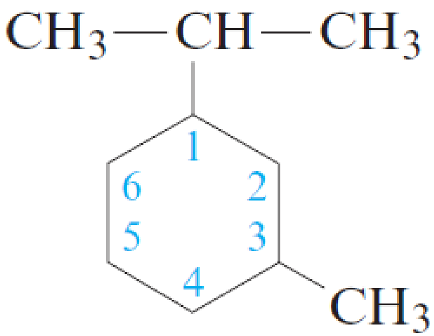


b.



Interactive Example 22.4 - Solution (a)

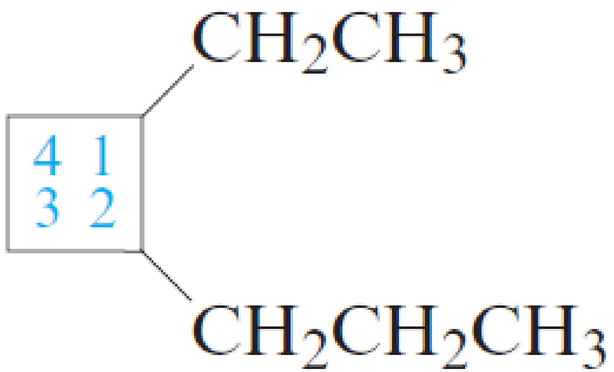
- The six-carbon cyclohexane ring is numbered as follows:



  - There is an isopropyl group at carbon 1 and a methyl group at carbon 3
  - The name is 1-isopropyl-3-methylcyclohexane, since the alkyl groups are named in alphabetical order

Interactive Example 22.4 - Solution (b)

- This is a cyclobutane ring, which is numbered as follows:

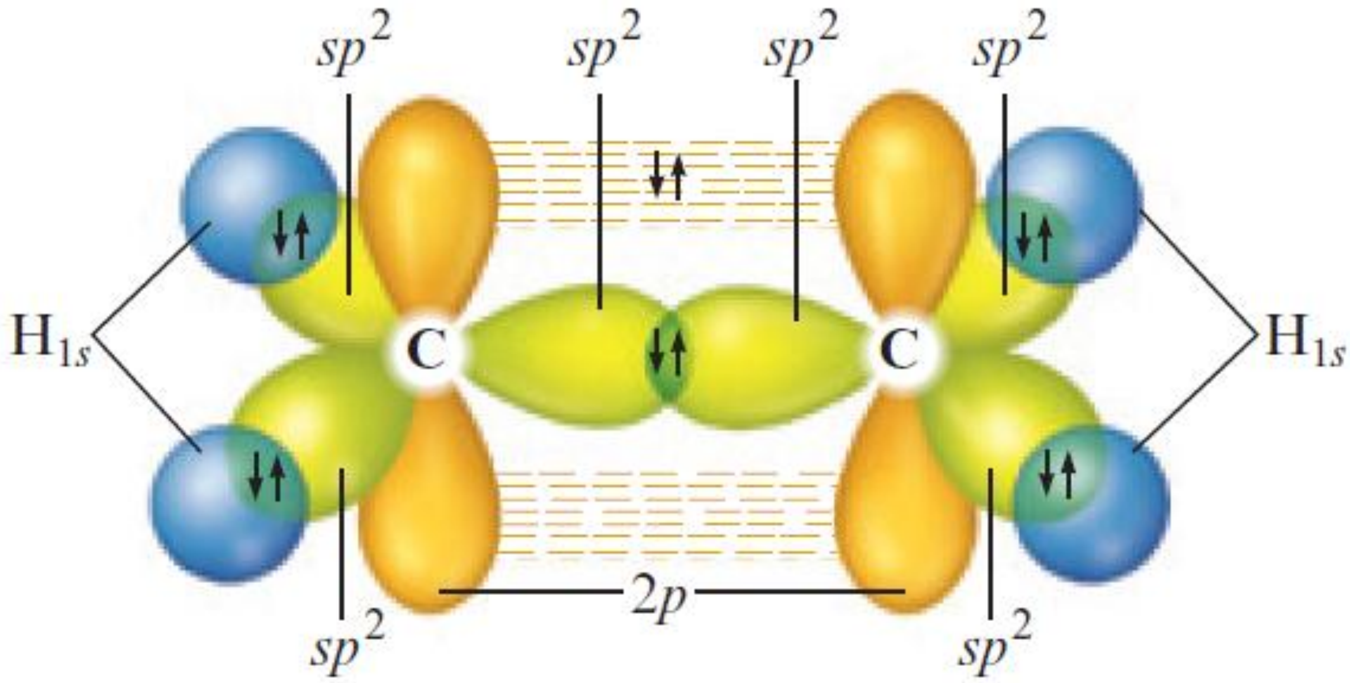


  - The name is 1-ethyl-2-propylcyclobutane

Alkenes

- Hydrocarbons that contain at least one carbon–carbon double bond
- General formula - C_nH_{2n}
- Simplest alkene - Ethylene (C_2H_4)
  - Each carbon atom is sp^2 hybridized
    - C—C σ bond is formed by sharing an electron pair between sp^2 orbitals
    - π bond is formed by sharing a pair of electrons between *p* orbitals

Figure 22.7 - The Bonding in Ethylene

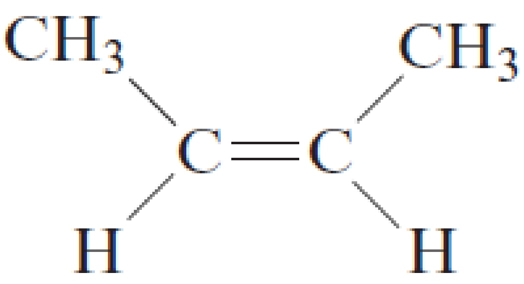


Rules for Naming Alkenes

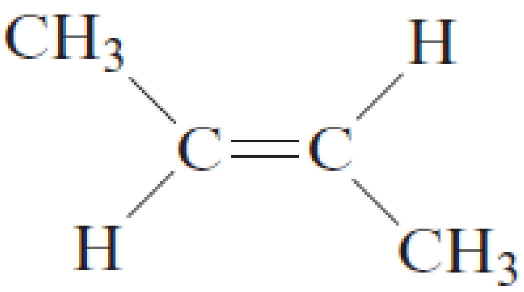
1. Root hydrocarbon name ends in -ene
2. In alkenes containing more than 3 carbon atoms, the location of the double bond is indicated by the lowest-numbered carbon atom in the bond

Isomerism of Alkenes

- Restricted rotation around double bonded carbon atoms implies that alkenes exhibit ***cis-trans* isomerism**
- Example - Stereoisomers of 2-butene



***Cis*-2-butene**

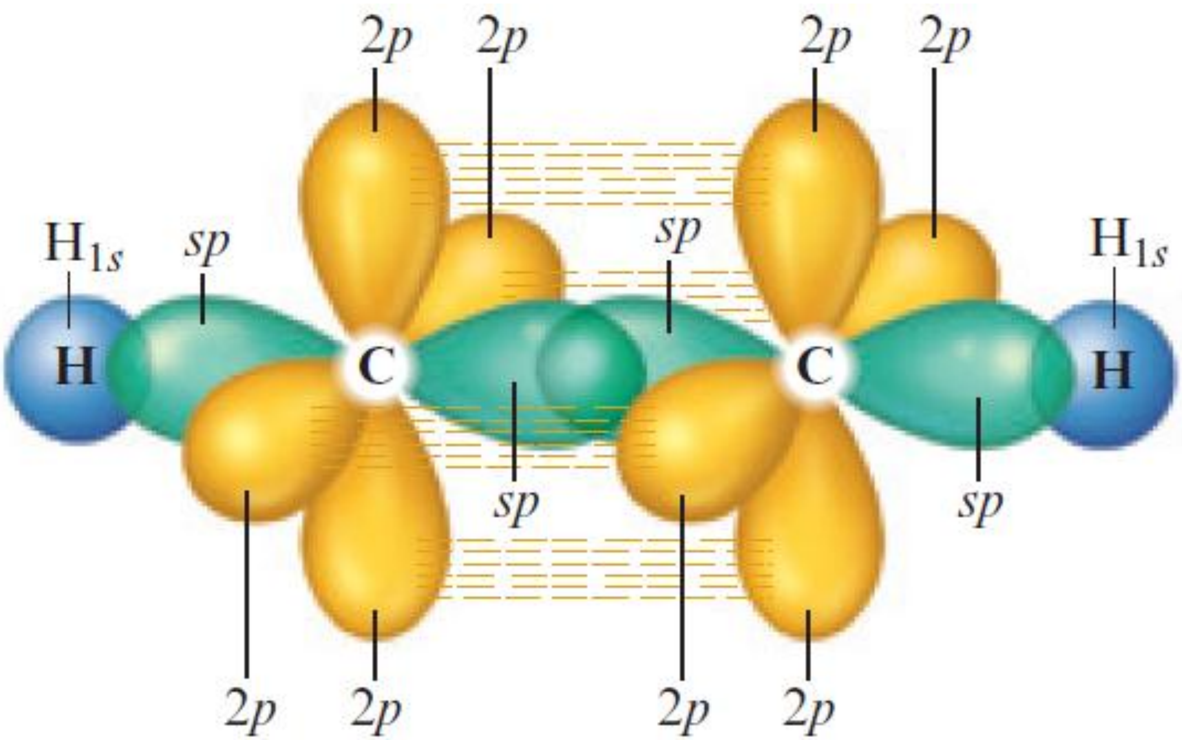


***Trans*-2-butene**

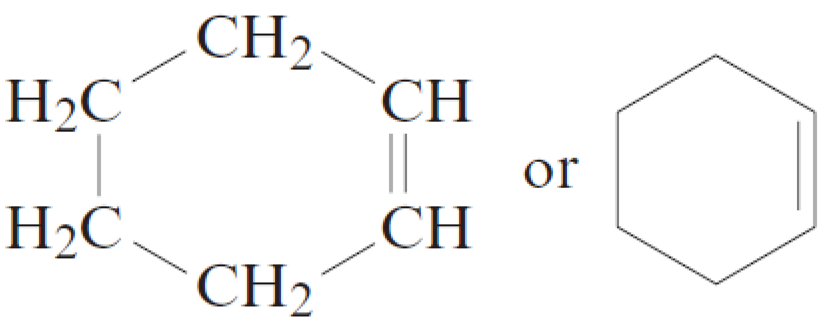
Alkynes

- Unsaturated hydrocarbons that contain at least one triple carbon–carbon bond
- Simplest alkyne - Acetylene or ethyne (C_2H_2)
- Nomenclature
  - -yne is used as a suffix to replace the -ane of the parent alkane

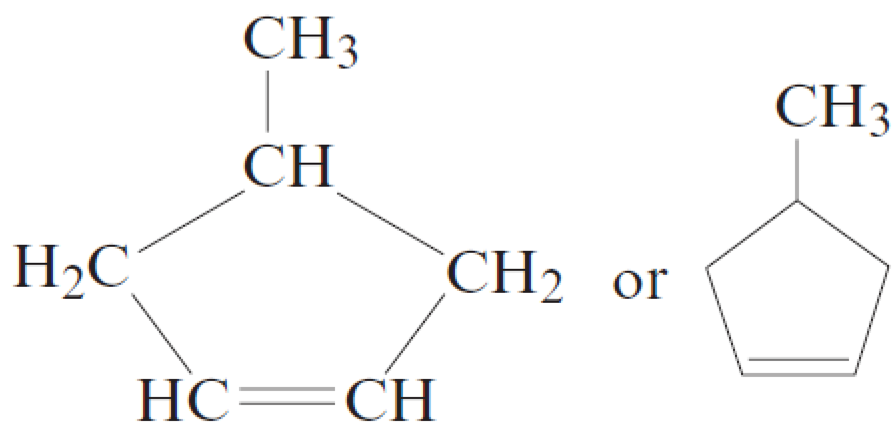
Figure 22.10 - The Bonding in Acetylene



Alkynes as Ringed Structures



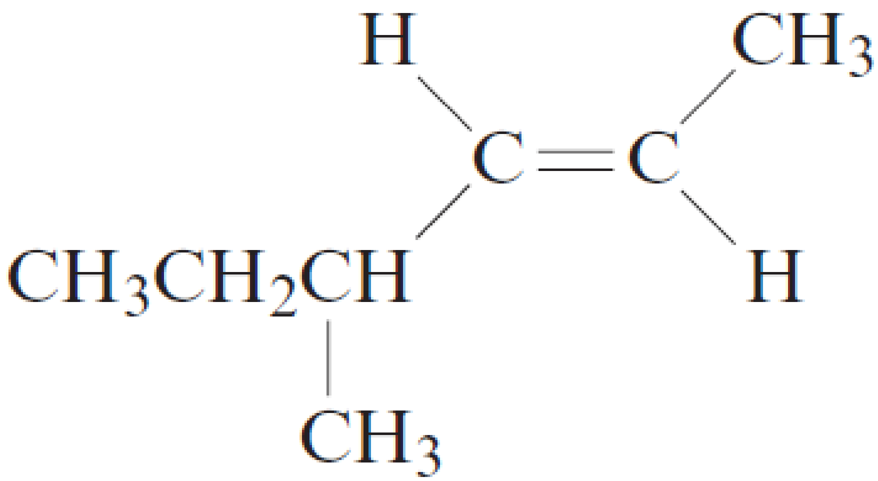
Cyclohexene



4-Methyl-cyclopentene

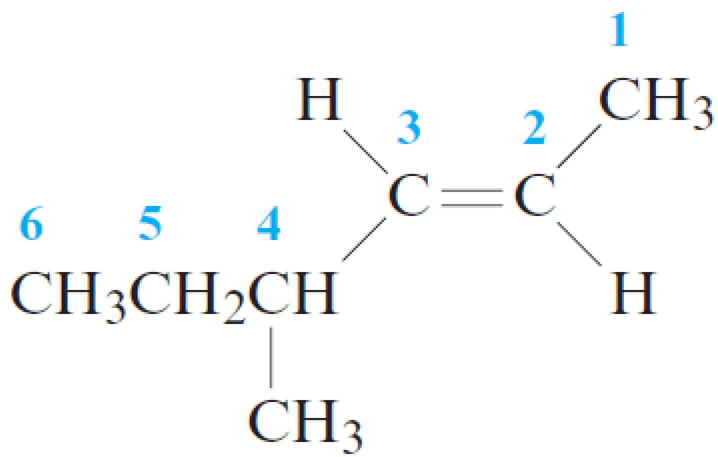
Interactive Example 22.5 - Naming Alkenes and Alkynes

- Name the following molecule:



Interactive Example 22.5 - Solution

- The longest chain, which contains six carbon atoms, is numbered as follows:



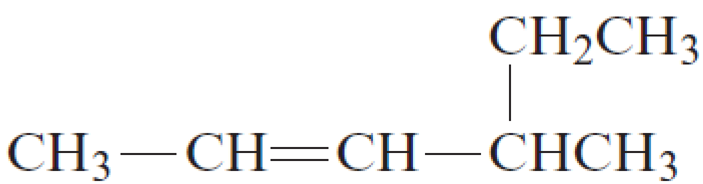
  - Thus, the hydrocarbon is a 2-hexene

Interactive Example 22.5 - Solution (Continued)

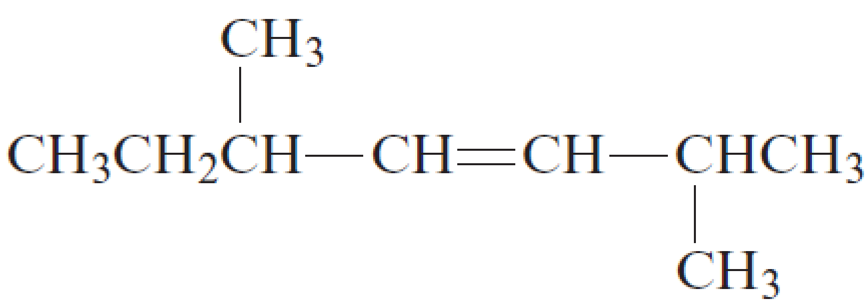
- Since the hydrogen atoms are located on opposite sides of the double bond, this molecule corresponds to the *trans* isomer
- The hydrocarbon is *trans*-4-methyl-2-hexene

Exercise

- Name each of the following alkenes:

a. 

4-methyl-2-hexene

b. 

2,5-dimethyl-3-heptene

Addition Reactions

- Involve breaking π bonds and forming new σ bonds
- Example
  - **Hydrogenation reaction**: Involves the addition of hydrogen atoms

$$CH_2{=}CHCH_3 + H_2 \xrightarrow{\text{Catalyst}} CH_3CH_2CH_3$$

1-Propene Propane

    - Nickel, palladium, or platinum acts as a catalyst for this reaction

Halogenation and Polymerization

- **Halogenation**: Involves the addition of halogen atoms

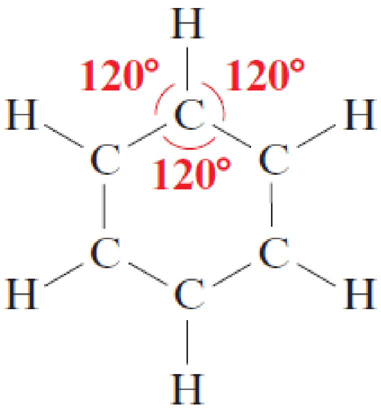
$$CH_2{=}CHCH_2CH_2CH_3 + Br_2 \rightarrow CH_2BrCHBrCH_2CH_2CH_3$$

1-Pentene 1,2-Dibromopentane

- **Polymerization**: Reaction that involves joining small molecules to form a large molecule

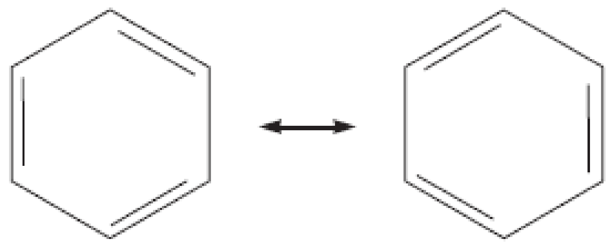
Aromatic Hydrocarbons - An Introduction

- A special class of cyclic unsaturated hydrocarbons
- Benzene (C_6H_6)
  - Simplest aromatic hydrocarbon
  - Has a planar ring structure

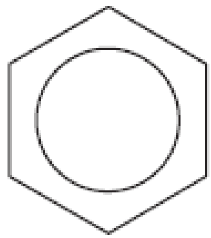


The structure of benzene with bond angles of 120°

Figure 22.11 - Resonance Structures and the Usual Representation of Benzene



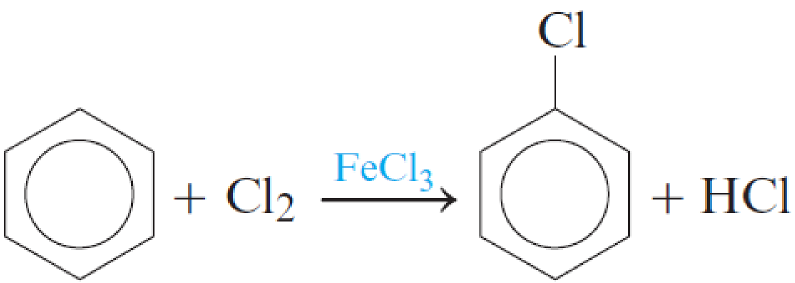
Two of the resonance structures of benzene



The usual representation of benzene

Benzene

- Delocalization of the π electrons makes the benzene ring behave differently from a typical unsaturated hydrocarbon
  - Benzene undergoes substitution reactions in which hydrogen atoms are replaced by other atoms



Benzene **Chlorobenzene**

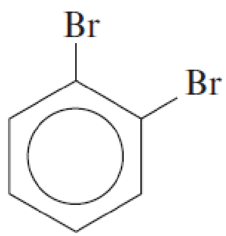
Benzene (Continued)

- Reacts more like a saturated hydrocarbon
  - Indicates the great stability of the delocalized π electron system
- **Phenyl group**: Benzene that is used as a substituent

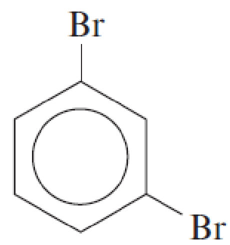
Nomenclature of Benzene Derivatives

- When there is more than one substituent, numbers are used to indicate their positions
- Alternate nomenclature system suggests the usage of the following prefixes:
  - Ortho- (o-) for two adjacent substituents
  - Meta- (m-) for two substituents with one carbon in between
  - Para- (p-) for two substituents that are opposite to each other

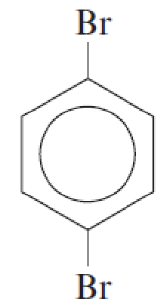
Figure 22.12 - Some Selected Substituted Benzenes



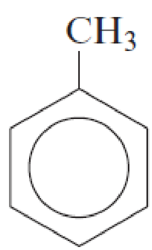
1,2-Dibromobenzene
(*o*-dibromobenzene)



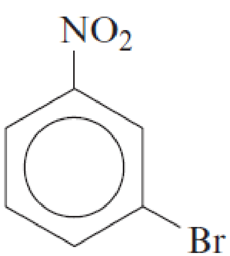
1,3-Dibromobenzene
(*m*-dibromobenzene)



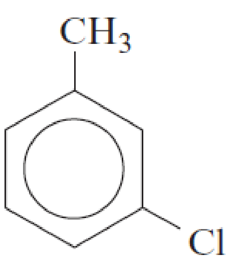
1,4-Dibromobenzene
(*p*-dibromobenzene)



Methylbenzene
(toluene)

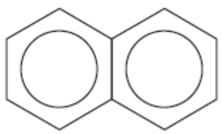
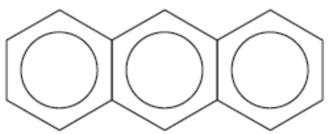
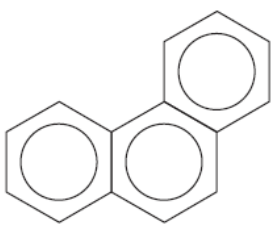
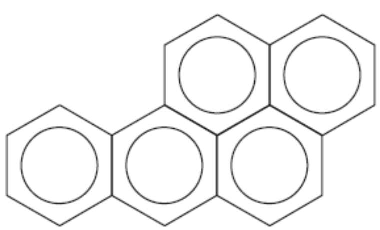


3-Bromonitrobenzene
(*m*-bromonitrobenzene)



3-Chlorotoluene
(*m*-chlorotoluene)

Table 22.3 - More Complex Aromatic Systems

Structural Formula	Name	Use of Effect
	Naphthalene	Formerly used in mothballs
	Anthracene	Dyes
	Phenanthrene	Dyes, explosives, and synthesis of drugs
	3,4-Benzpyrene	Active carcinogen found in smoke and smog

Hydrocarbon Derivatives - An Introduction

- Molecules that are fundamentally hydrocarbons but have functional groups
  - **Functional group**: An atom or group of atoms that contains elements in addition to carbon and hydrogen
    - Each group exhibits its own characteristic chemistry

Table 22.4 - The Common Functional Groups

Class	Functional Group	General Formula*	Example
Halohydrocarbons	—X (F, Cl, Br, I)	R—X	CH_3I Iodomethane (methyl iodide)
Alcohols	—OH	R—OH	CH_3OH Methanol (methyl alcohol)
Ethers	—O—	R—O—R′	CH_3OCH_3 Dimethyl ether
Aldehydes	$-\overset{\displaystyle O}{\overset{\|}{C}}-H$	$R-\overset{\displaystyle O}{\overset{\|}{C}}-H$	CH_2O Methanal (formaldehyde)

*R and R′ represent hydrocarbon fragments.

Table 22.4 - The Common Functional Groups (Continued)

Class	Functional Group	General Formula*	Example
Ketones	$-\overset{O}{\overset{\parallel}{C}}-$	$R-\overset{O}{\overset{\parallel}{C}}-R'$	CH_3COCH_3 Propanone (dimethyl ketone or acetone)
Carboxylic acids	$-\overset{O}{\overset{\parallel}{C}}-OH$	$R-\overset{O}{\overset{\parallel}{C}}-OH$	CH_3COOH Ethanoic acid (acetic acid)
Esters	$-\overset{O}{\overset{\parallel}{C}}-O-$	$R-\overset{O}{\overset{\parallel}{C}}-O-R'$	$CH_3COOCH_2CH_3$ Ethyl acetate
Amines	$-NH_2$	$R-NH_2$	CH_3NH_2 Aminomethane (methylamine)

*R and R′ represent hydrocarbon fragments.

Alcohols

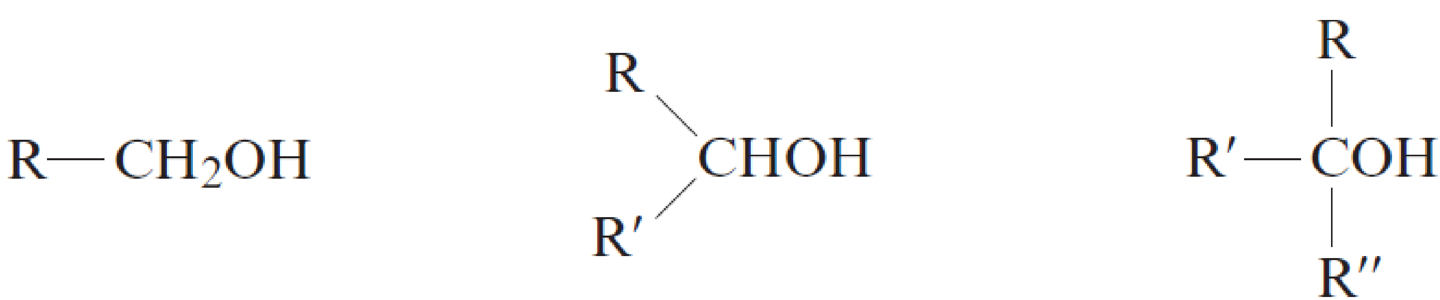
- Contain the hydroxyl group (—OH)
- Systematic nomenclature
  - Replace the final -e of the parent hydrocarbon with the -ol
  - Position of the —OH group is specified by a number
    - Chosen number is the smallest of the substituent numbers
- Have higher boiling points than what is expected from their molar masses

Alcohols - Boiling Point and Intermolecular Forces

- Higher boiling point is attributed to the types of intermolecular attractions in the liquids
  - Example - Methanol and ethane have a molar mass of 30
    - Boiling point of methanol is 65° C, and it exhibits hydrogen bonding
    - Boiling point of ethane is –89° C, and it exhibits weak London dispersion interactions

Classification of Alcohols

- Based on the number of hydrocarbon fragments that are bonded to the carbon where the —OH group is attached
  - R, R’, and R” represent hydrocarbon fragments



Primary alcohol (one R group) | *Secondary* alcohol (two R groups) | *Tertiary* alcohol (three R groups)

Table 22.5 - Some Common Alcohols

Formula	Systematic Name	Common Name
CH_3OH	Methanol	Methyl alcohol
CH_3CH_2OH	Ethanol	Ethyl alcohol
$CH_3CH_2CH_2OH$	1-Propanol	*n*-Propyl alcohol
$CH_3\underset{\underset{OH}{\vert}}{C}HCH_3$	2-Propanol	Isopropyl alcohol

Methanol

- Known as wood alcohol
  - Prepared by heating wood in the absence of air
- Industrial preparation
  - Hydrogenation of carbon monoxide

$$CO + 2H_2 \xrightarrow[ZnO/Cr_2O_3]{400°C} CH_3OH$$

Methanol (Continued)

- Uses
  - Starting material for the synthesis of acetic acid and for adhesives, fibers, and plastics
  - Motor fuel
- Highly toxic when ingested by humans
  - Leads to blindness and death

Ethanol

- Found in beer, wine, and whiskey
- Produced by the fermentation of glucose in grapes, corn, and barley

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \xrightarrow{\text{Yeast}} \underset{\text{Ethanol}}{2CH_3CH_2OH} + 2CO_2$$

  - When the alcohol content reaches 13%, the yeast can no longer survive, and the reaction stops
  - Beverages with higher alcohol content are made by distilling the fermentation mixture

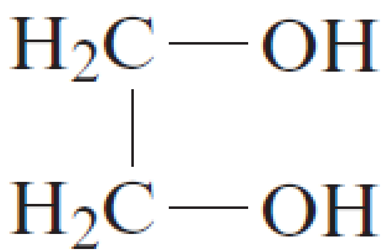
Ethanol (Continued)

- Uses
  - Can be burned in the internal combustion engine of an automobile
  - Used as a solvent and for the preparation of acetic acid
- Industrially produced by the reaction of water with ethylene

$$CH_2{=}CH_2 + H_2O \xrightarrow[\text{Catalyst}]{\text{Acid}} CH_3CH_2OH$$

Polyhydroxyl Alcohols

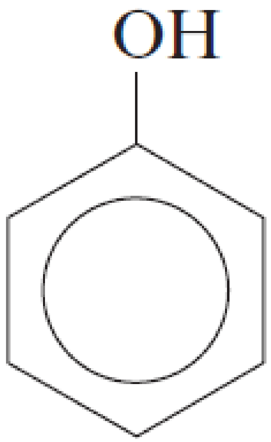
- Contain more than one hydroxyl group
- Example - 1,2-ethanediol (ethylene glycol)



  - Major constituent of automobile antifreeze solutions
  - Toxic in nature

Phenol

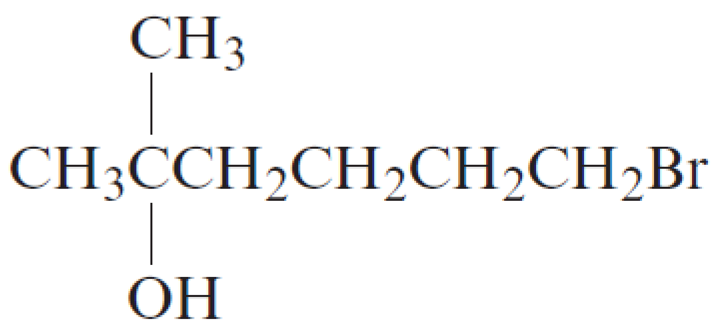
- Simplest aromatic compound with an attached —OH group



- Looks like an alcohol but has different properties

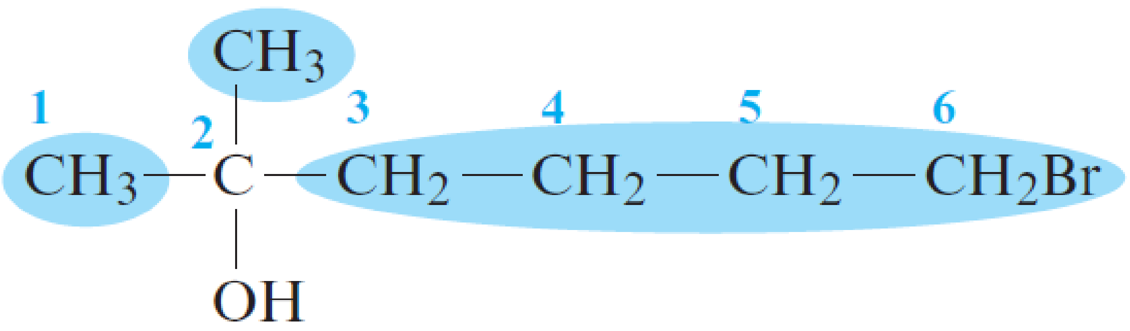
Interactive Example 22.6 - Naming and Classifying Alcohols

- For the following alcohol, give the systematic name and specify whether the alcohol is primary, secondary, or tertiary



Interactive Example 22.6 - Solution

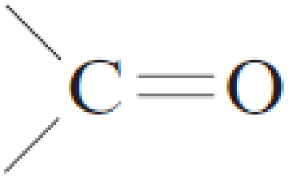
- The chain is numbered as follows:



- The name is 6-bromo-2-methyl-2-hexanol
  - This is a tertiary alcohol
    - The carbon where the —OH is attached also has three other R groups attached

Aldehydes and Ketones

- Contain the **carbonyl group**, which has the following structure:



  - **Ketones**: Carbonyl group is bonded to 2 carbon atoms
    - Example - Acetone
  - **Aldehydes**: Carbonyl group is bonded to at least 1 hydrogen atom
    - Example - Formaldehyde and acetaldehyde

Systematic Nomenclature of Aldehydes and Ketones

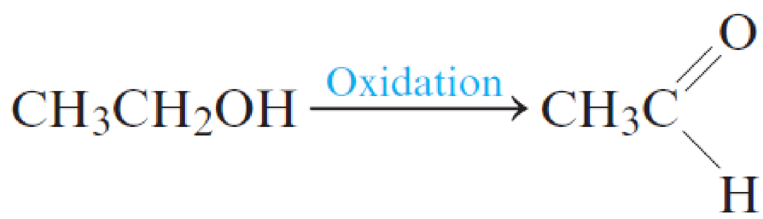
- Aldehydes
  - Name is obtained from the parent alkane by removing the final -e and adding -al
- Ketones
  - Replace the final -e with -one
  - Position of the carbonyl group is indicated by a number where necessary

Aldehydes and Ketones - Uses

- Ketones are useful solvents
- Aldehydes have strong odors
    - Examples
        - Vanillin is responsible for the sweet odor in vanilla beans
        - Cinammaldehyde produces the distinct odor of cinnamon
        - Butyraldehyde contributes to the unpleasant smell in rancid butter

Aldehydes and Ketones - Method of Preparation

- Prepared by the oxidation of alcohols
  - Aldehydes are prepared by oxidizing primary alcohols



  - Ketones are prepared by oxidizing secondary alcohols

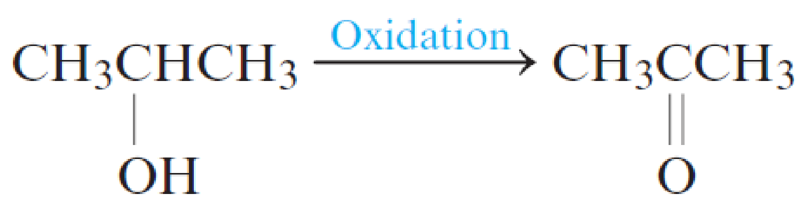
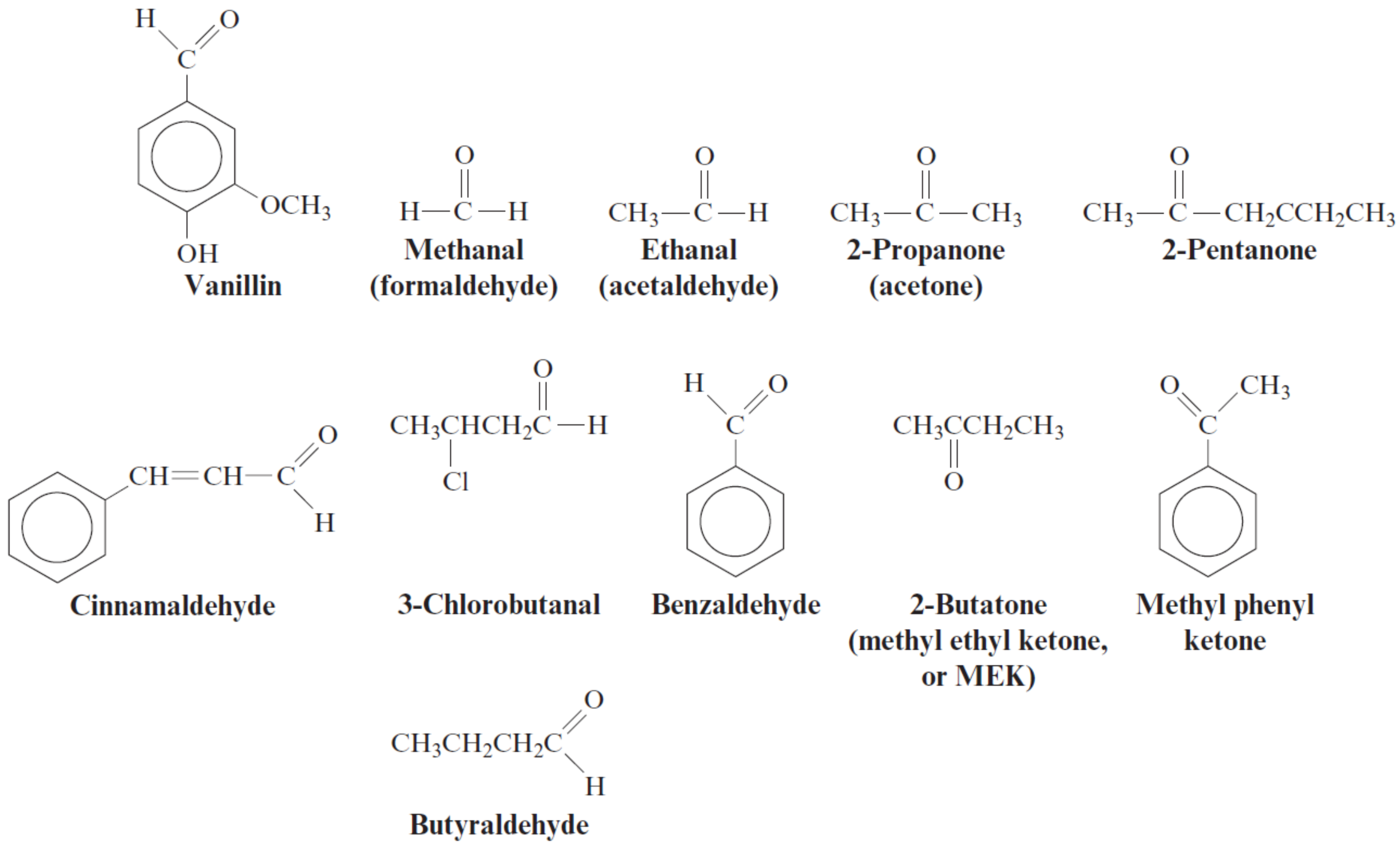
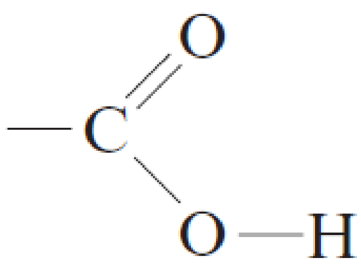


Figure 22.13 - Some Common Ketones and Aldehydes



Carboxylic Acids

- Contain the carboxyl group
  - **Carboxyl group**: Gives an acid the general formula RCOOH



  - Appear as weak acids in aqueous solutions
- Named from the parent alkane by dropping the final -e and adding -oic

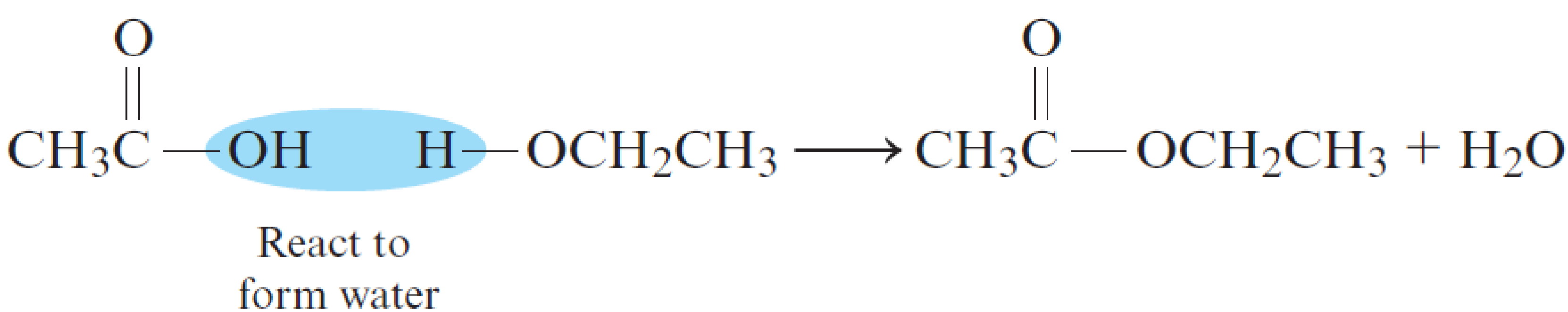
Carboxylic Acids - Synthesis

- Conducted by oxidation of primary alcohols with a strong oxidizing agent
- Example
  - Oxidation of ethanol in the presence of potassium permanganate to produce acetic acid

$$CH_3CH_2OH \xrightarrow{KMnO_4(aq)} CH_3COOH$$

Esters

- Carboxylic acid reacts with an alcohol to form an **ester** and a water molecule
- Example - Reaction of acetic acid with ethanol produces ethyl acetate and water

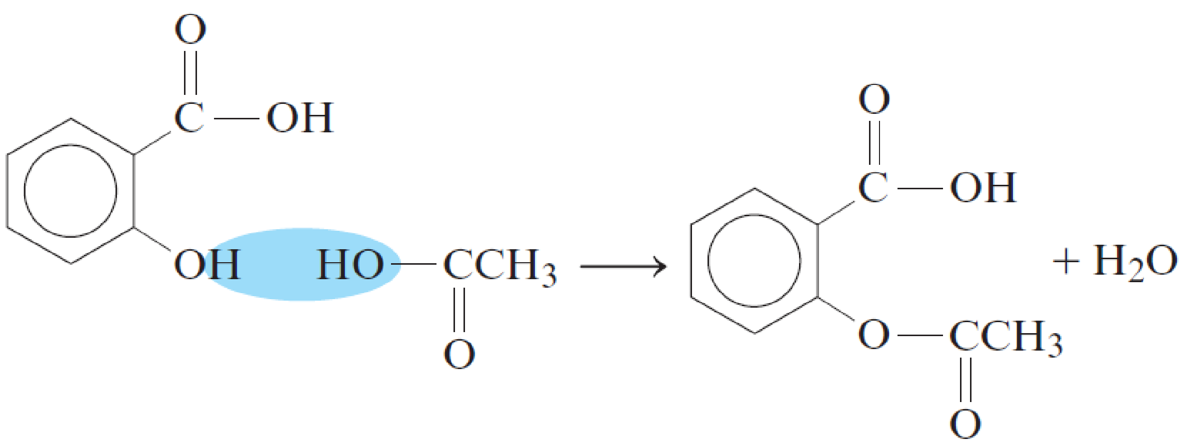


Esters (Continued)

- Have a sweet and fruity odor
  - Example - Smell of oranges is caused by *n*-octyl acetate
- Systematic nomenclature
  - Change the -oic ending in the parent acid to -oate
  - The parent alcohol chain is named first with a -yl ending

Aspirin - An Ester

- Acetylsalicylic acid is the product of the reaction between salicylic acid and acetic acid



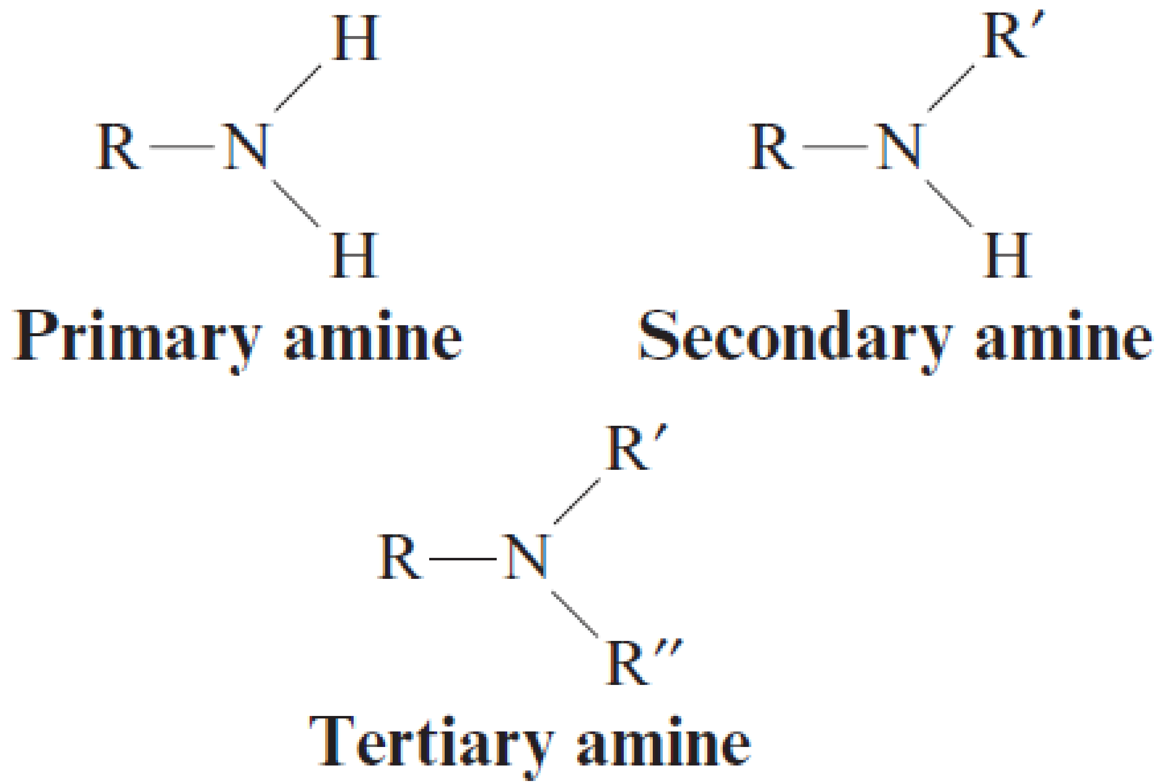
Salicylic acid   Acetic acid   Acetylsalicylic acid

- Used as an analgesic

Amines

- Derivatives of ammonia
  - One or more N—H bonds are replaced by N—C bonds
- Classification
  - Primary amines - One N—C bond exists
  - Secondary amines - Two N—C bonds exist
  - Tertiary amines - All three N—H bonds have been replaced by N—C bonds

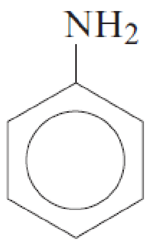
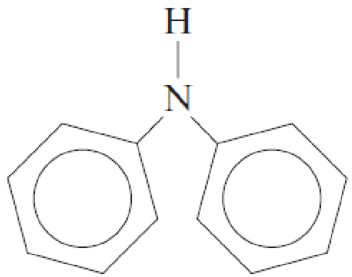
Figure 22.15 - The General Formulas for Primary, Secondary, and Tertiary Amines



Amines (Continued)

- Systematic nomenclature
  - Common names are used for simple amines
  - Complex molecules in the —NH_2 functional group are given the prefix amino-
- Have an unpleasant, fishlike odor
- Aromatic amines are used for making dyes

Table 22.6 - Some Common Amines

Formula	Common Name	Type
CH_3NH_2	Methylamine	Primary
$CH_3CH_2NH_2$	Ethylamine	Primary
$(CH_3)_2NH$	Dimethylamine	Secondary
$(CH_3)_3N$	Trimethylamine	Tertiary
	Aniline	Primary
	Diphenylamine	Secondary

Polymers - An Introduction

- Large, chainlike molecules that are built from small molecules called monomers
- Form the basis for:
  - Synthetic fibers
  - Plastics
  - Rubbers

Development of Polymers

- Christian Schoenbein
  - Found a new material that had surprising properties and was extremely flammable
- The first synthetic polymers were by-products of various organic reactions
  - Regarded as unwanted contaminants
- Leo H. Baekeland’s work resulted in the creation of Bakelite, a synthetic plastic
  - Used in telephones, insulators, and billiard balls

Development of Polymers (Continued 1)

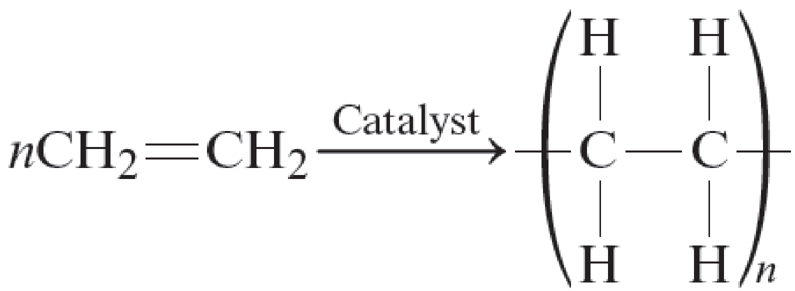
- **Thermoset polymer**: Substance that cannot be softened again after being molded into a certain shape under high temperature and pressure
  - Example - Bakelite
- **Thermoplastic polymer**: Substance that can be remelted or remolded
  - Example - Cellulose nitrate

Development of Polymers (Continued 2)

- Nylon - Prepared by Wallace H. Carothers
  - Julian Hill realized that nylon could be used as fibers
- **Crosslinking**: Existence of covalent bonds between adjacent chains
  - Contributes to the strength of polymers
- Charles Goodyear developed vulcanization
  - **Vulcanization**: Adding sulfur to rubber and heating the mixture to produce stronger, elastic rubber

Polyethylene

- Simplest polymer
- Constructed from ethylene monomers



  - *n* represents a large number
- Tough, flexible plastic

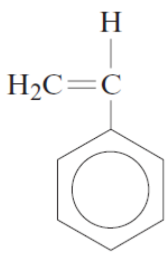
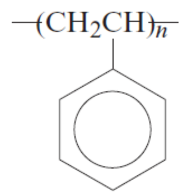
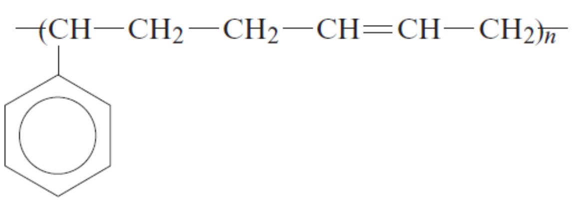
Polyethylene (Continued)

- Uses
  - Piping, bottles, electrical insulation, packaging films, and garbage bags
- Properties can be modified by using substituted ethylene monomers
  - Example - Teflon is obtained when the monomer is tetrafluoroethylene

Table 22.7 - Some Common Synthetic Polymers and Their Monomers and Applications

Monomer		Polymer		
Name	**Formula**	**Name**	**Formula**	**Uses**
Ethylene	$H_2C{=}CH_2$	Polyethylene	$-(CH_2-CH_2)_n-$	Plastic piping, bottles, electrical insulation, toys
Propylene	$H_2C{=}C(H)(CH_3)$	Polypropylene	$-(CH(CH_3)-CH_2-CH(CH_3)-CH_2)_n-$	Film for packaging, carpets, lab wares, toys
Vinyl chloride	$H_2C{=}C(H)(Cl)$	Polyvinyl chloride (PVC)	$-(CH_2-CH(Cl))_n-$	Piping, siding, floor tile, clothing, toys
Acrylonitrile	$H_2C{=}C(H)(CN)$	Polyacrylonitrile (PAN)	$-(CH_2-CH(CN))_n-$	Carpets, fabrics

Table 22.7 - Some Common Synthetic Polymers and Their Monomers and Applications (Continued)

Monomer		Polymer		
Name	**Formula**	**Name**	**Formula**	**Uses**
Tetrafluoro-ethylene	$F_2C{=}CF_2$	Teflon	$-(CF_2-CF_2)_n-$	Cooking utensils, electrical insulation, bearings
Styrene		Polystyrene		Containers, thermal insulation, toys
Butadiene	$H_2C{=}C(H)-C(H){=}CH_2$	Polybutadiene	$-(CH_2CH{=}CHCH_2)_n-$	Tire tread, coating resin
Butadiene and styrene	(See above.)	Styrene-butadiene rubber		Synthetic rubber

Types of Polymerization

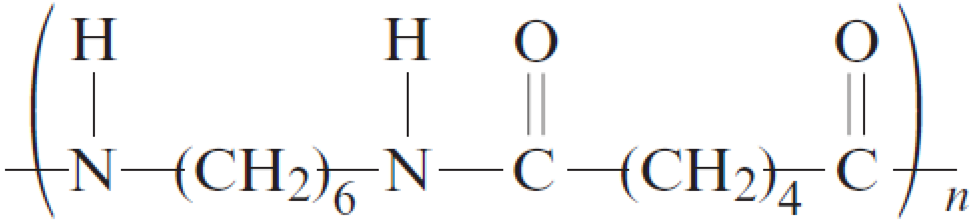
- Addition polymerization
  - Monomers add together to form the polymer
  - No other product is formed
  - Initiated by a free radical
    - **Free radical**: Species with an unpaired electron
    - Repeatedly attacks and breaks the π bonds to form a new free radical and to create a long-chain polymer

Types of Polymerization (Continued)

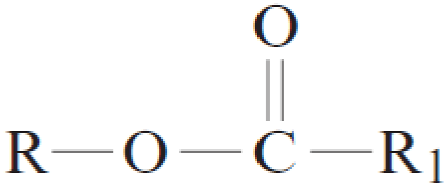
- **Condensation polymerization**
  - A small molecule is formed for each extension of the polymer chain
  - Used for the production of nylon
    - Nylon is a **copolymer** that contains two types of monomers that combine to form a chain
  - **Homopolymer**: Result of polymerizing a single type of monomer
  - **Dimer**: Two monomers joined

Structures of Nylon and Polyester

- Nylon

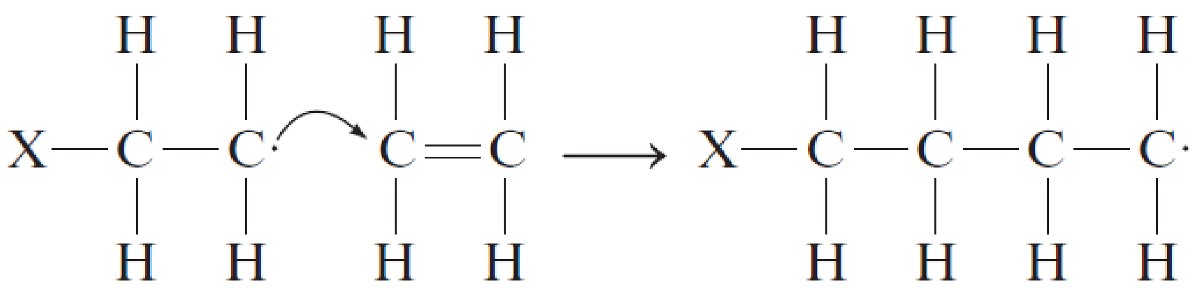


- **Polyester**
  - Example - Dacron



Polymers Based on Ethylene

- Ethylene undergoes addition polymerization after the double bond has been broken by an initiator



  - Process continues by adding new ethylene molecules to eventually give polyethylene

Forms of Polyethylene

- Low-density polyethylene (LDPE)
  - Contains branched chains
  - Manufactured under conditions of high temperature (500° C) and high pressure (≈20,000 psi)
    - Lower reaction pressures and temperatures have become possible through the use of catalysts
  - Used to manufacture transparent film that is used in packaging consumer goods

Forms of Polyethylene (Continued)

- High-density polyethylene (HDPE)
  - Comprises straight-chain molecules
  - Used for blow-molded products such as bottles
  - Linear low-density polyethylene
    - Product of the reaction between chromium(III) oxide and aluminosilicate catalyst
    - Similar to HDPE

Reason for the Usefulness of Polyethylene

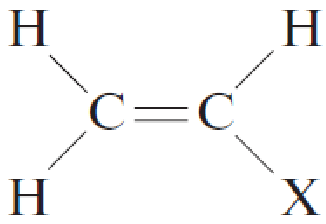
- Polyethylene has a high molecular weight (molecular mass)
  - Strengths of the interactions between points on the nonpolar chains are small
    - Length of the chains accumulate the attractions to a significant value, which help the chains stick together
    - Provides strength and toughness
  - As the molecular weight increases, polyethylene becomes more difficult to process

Polymer Properties That Are Not Influenced by Molecular Weight

- Resistance to chemical attack
- Color and refractive index
- Hardness
- Density
- Electrical conductivity

Methods to Alter the Strength of Polymeric Material

- Change in chain length
- Change in substituents
  - Properties of a polymer depend on the identity of the substituent
    - Example - If one uses the following monomer type, the resulting polymer will have properties based on the identity of X



Types of Chain Arrangements

- **Isotactic chain**: CH_3 groups arranged on the same side of the chain
- **Syndiotactic chain**: CH_3 groups arranged in an alternate fashion on the chain
- **Atactic chain**: CH_3 groups randomly distributed on the chain

Proteins

- Have molar masses that range from about 6000 to over 1,000,000 g/mol
- Constitute 15% of the human body
- **Fibrous proteins**
  - Provide structural integrity and strength for tissues
  - Main components of muscle, hair, and cartilage

Proteins (Continued)

- **Globular proteins**: Worker molecules of the human body
  - Roughly spherical in shape
  - Transport and store oxygen and nutrients
  - Act as catalysts
  - Fight invasion by foreign objects
  - Participate in the body's regulatory systems
  - Transport electrons in metabolism

α-Amino Acids

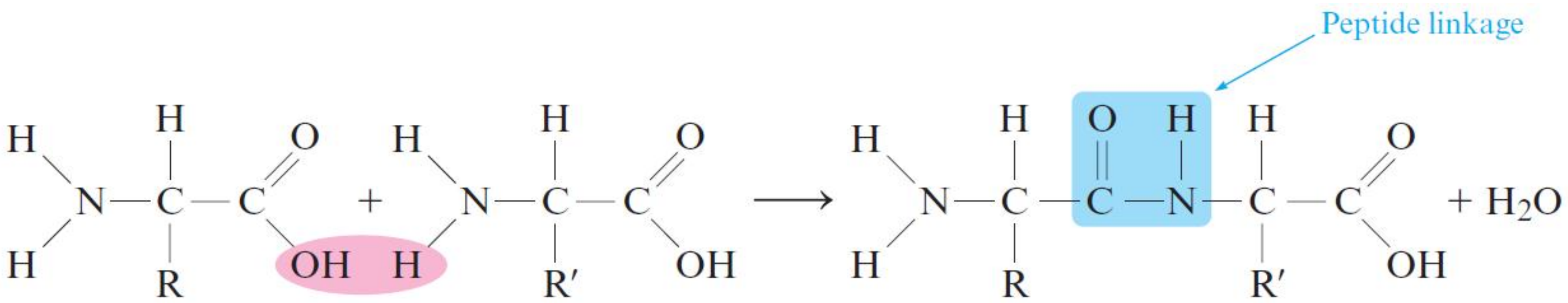
- Building blocks of all proteins
- R can represent H, CH_3, or a more complex substituent
- —NH_2 is always attached to the α-carbon
- 20 amino acids commonly found in proteins

α-Amino Acids (Continued)

- Amino acids are grouped into polar and nonpolar classes that are determined by the R groups or **side chains**
  - Polar side chains - Contain a large number of nitrogen and oxygen atoms
    - Hydrophilic (water-loving)
  - Nonpolar side chains - Composed of carbon and hydrogen atoms
    - Hydrophobic (water-fearing)

Bonding in Amino Acids

- Protein polymers are built by condensation reactions between amino acids
- Example - **Dipeptide**



Levels of Structure in Proteins

- Primary structure
- Secondary structure
- Pleated structure
- Tertiary structure

Primary Structure

- Sequence of amino acids in the protein chain
  - Indicated using three-letter codes for amino acids
    - Terminal carboxyl group is on the right, and the terminal amino group is on the left

cys—tyr—ile—gln—asn—cys—pro—leu—gly

a

cys—tyr—phe—gln—asn—cys—pro—arg—gly

b

The amino acid sequences in (a) oxytocin and (b) vasopressin
The differing amino acids are boxed

Interactive Example 22.7 - Tripeptide Sequences

- Write the sequences of all possible tripeptides composed of the amino acids tyrosine, histidine, and cysteine

Interactive Example 22.7 - Solution

- There are six possible sequences
  - tyr-his-cys
  - tyr-cys-his
  - his-tyr-cys
  - his-cys-tyr
  - cys-tyr-his
  - cys-his-tyr

Interactive Example 22.8 - Polypeptide Sequences

- What number of possible sequences exists for a polypeptide composed of 20 different amino acids?

Interactive Example 22.8 - Solution

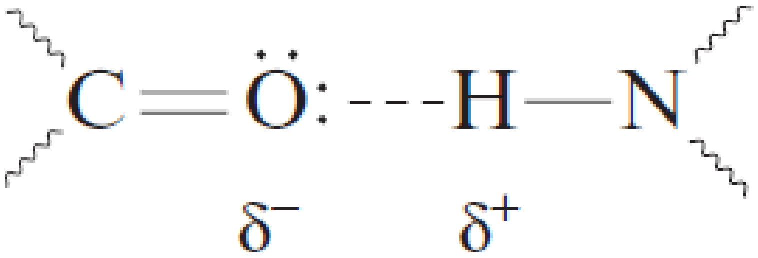
- The answer is 20!, or

$$20 \times 19 \times 18 \times 17 \times 16 \times . . . \times 5 \times 4 \times 3 \times 2 \times 1$$

$$= 2.43 \times 10^{18}$$

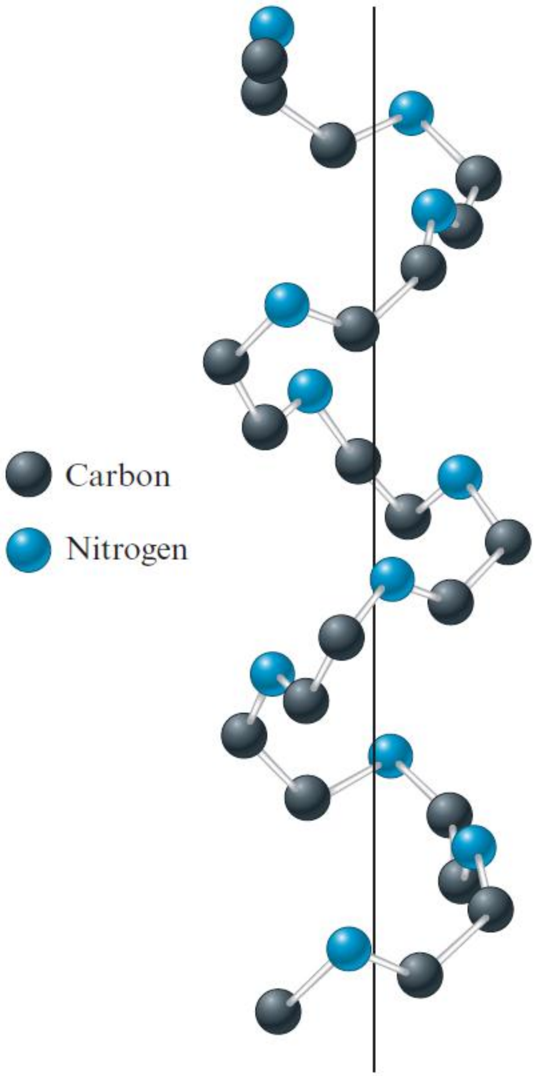
Secondary Structure

- Determined by hydrogen bonding between lone pairs on an oxygen atom in the carbonyl group of one amino acid and a hydrogen atom attached to a nitrogen of another amino acid



α-Helical Arrangement

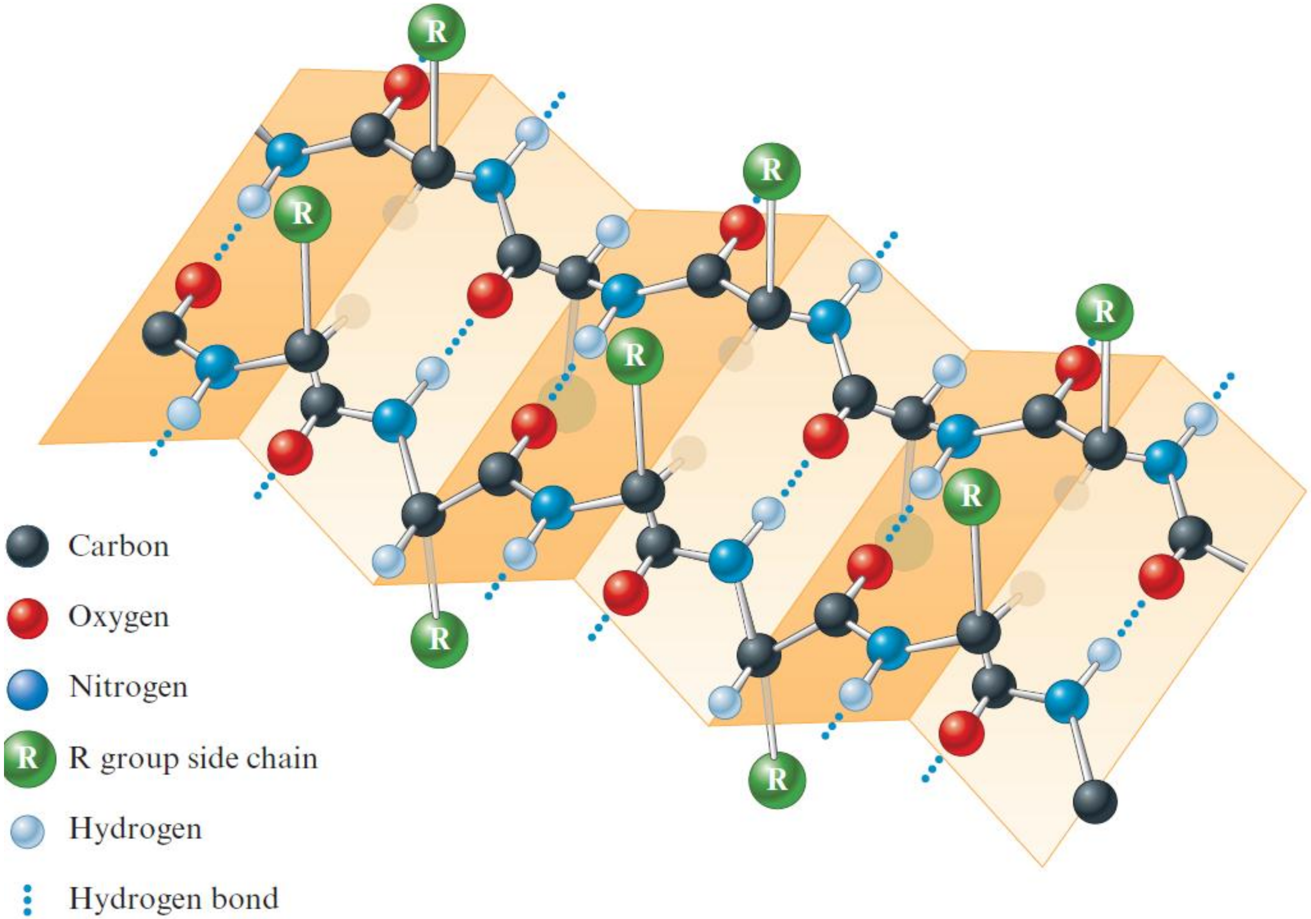
- **α-helix**: Result of intrachain hydrogen bonding
  - Occurs within a given protein chain
  - Provides the protein chain with its elasticity



Pleated Sheet Arrangement of Proteins

- Arrangement that results from interchain hydrogen bonding
  - Interchain - Bonding that occurs between different protein chains
- Found in:
  - Silk
  - Natural fibers
  - Muscle fibers

Figure 22.22 - Pleated Sheet Arrangement



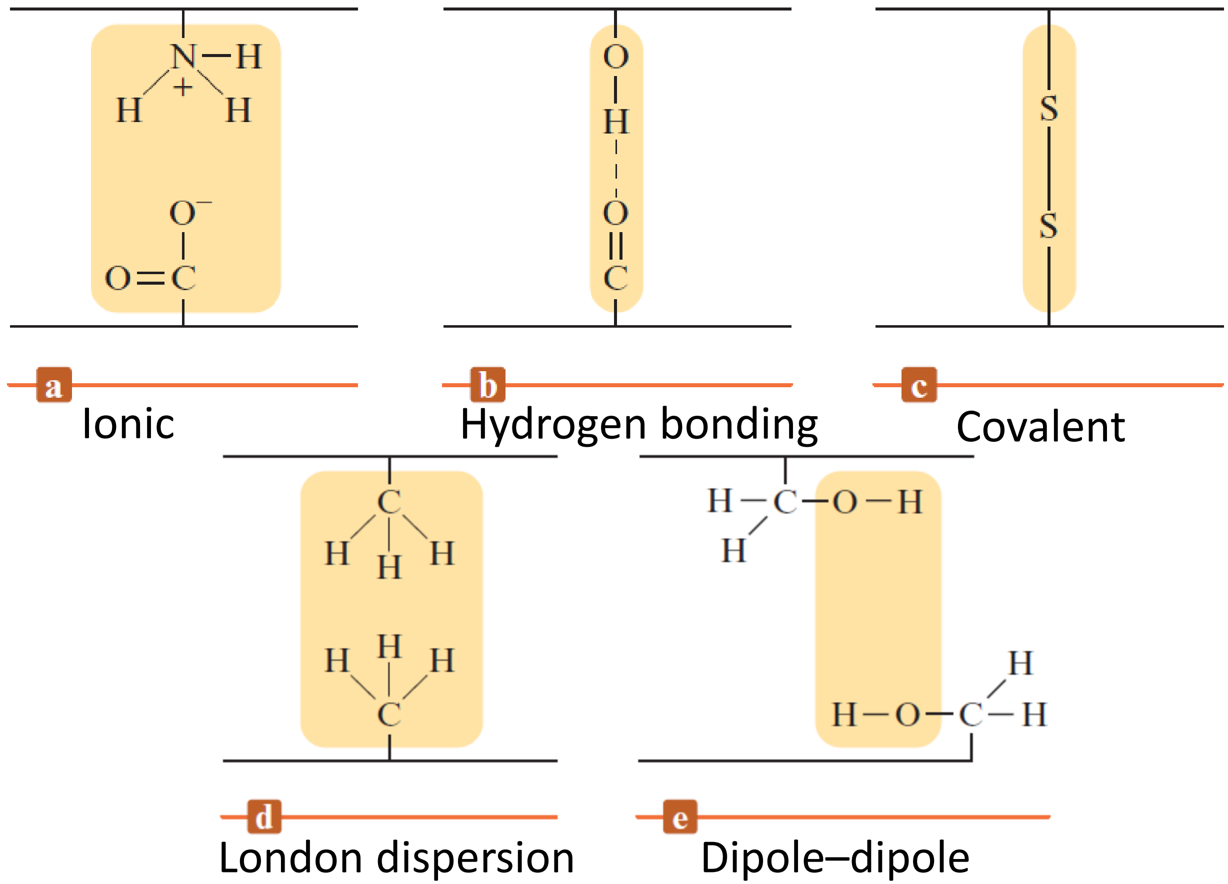
Random-Coil Arrangement of Proteins

- Structure that results from the breakage of the α-helix to provide a secondary configuration
  - Occurs in certain areas where the chain bends to give the protein a compact globular structure

Tertiary Structure

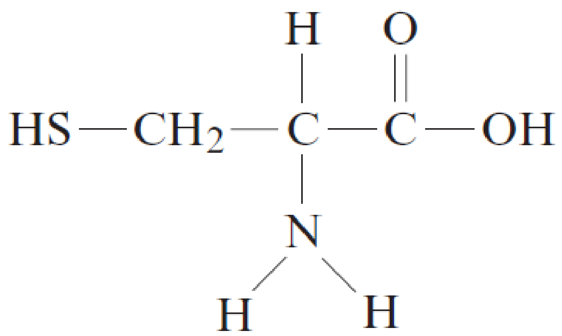
- Long and narrow or globular
- Maintained by several types of interactions
  - Hydrogen-bonding
  - Dipole–dipole interactions
  - Ionic bonds
  - Covalent bonds
  - London dispersion forces

Figure 22.24 - Summary of the Various Types of Interactions in the Tertiary Structure of a Protein



Tertiary Structure (Continued)

- Cysteine is an amino acid with the following structure:

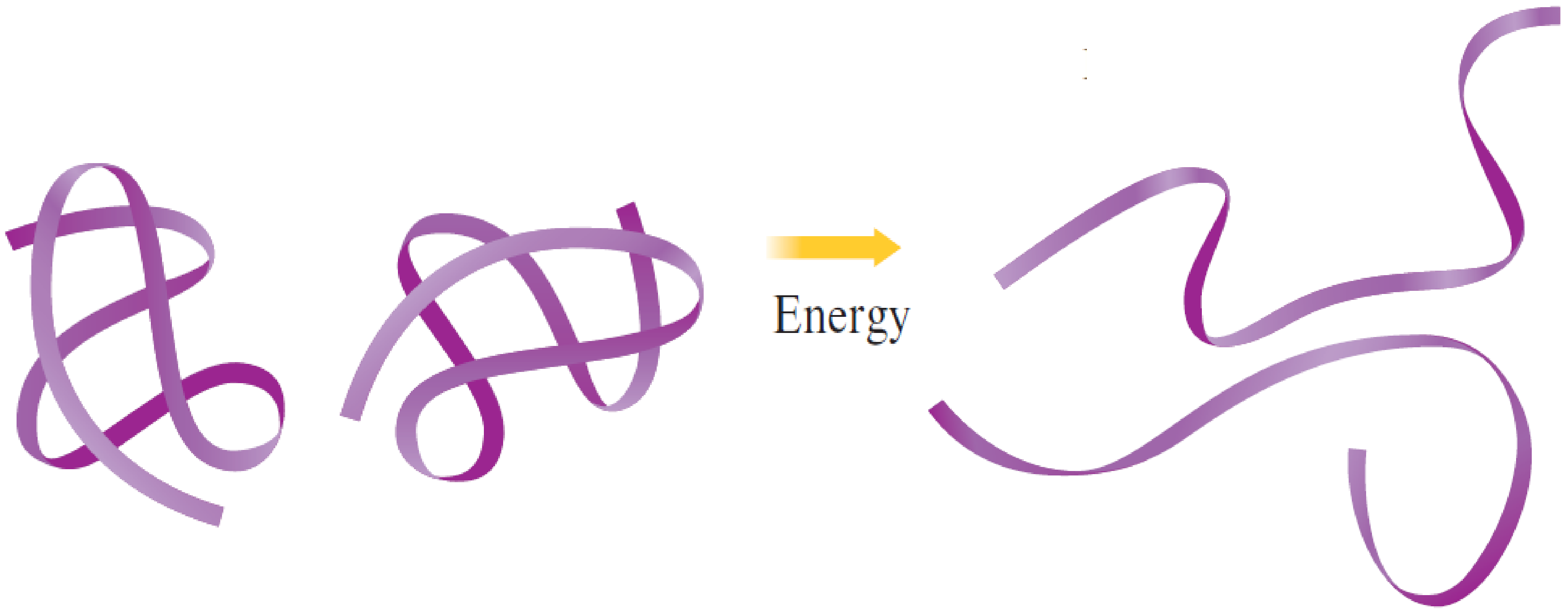


  - Plays a role in stabilizing the tertiary structure of proteins
    - —SH groups on two cysteines can react in the presence of an oxidizing agent to form a S—S bond called a **disulfide linkage**

Protein Damage

- **Denaturation**: Process of breaking down the three-dimensional structure of a protein
  - Initiated by any source of energy and is considered to be dangerous to living organisms
  - Caused by metals like lead and mercury by disrupting disulfide bonds between protein chains
- Can result from chemicals such as benzene, trichloroethane, and 1,2-dibromoethane

Figure 22.26 - Schematic Representation of the Thermal Denaturation of a Protein



Critical Thinking

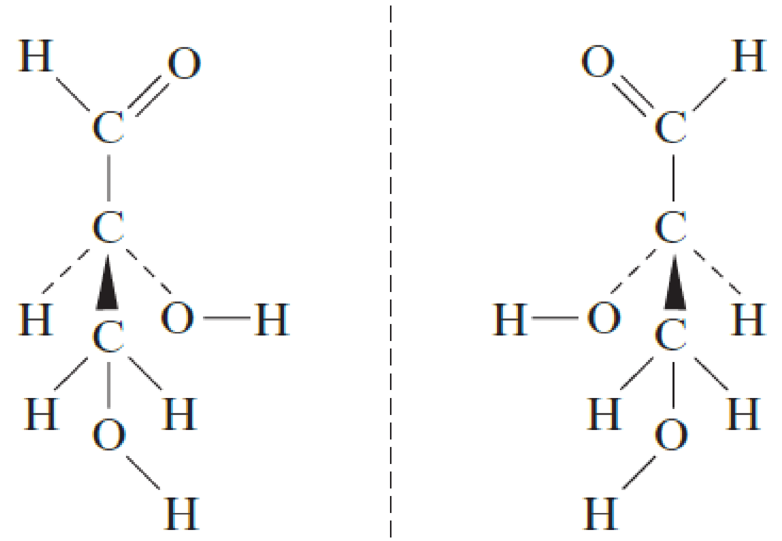
- What if you contracted a disease that prevents all hydrogen bonding in proteins?
  - Could you live with such a condition?

Carbohydrates

- Serve as a food source for most organisms and as structural material for plants
- Empirical formula - CH_2O
- **Monosaccharides** (**simple sugars**): Polyhydroxy ketone and aldehyde monomers
  - **Pentoses**: Contain five carbon atoms
  - **Hexoses**: Contain six carbon atoms

Optical Isomerism in Simple Sugars

- A carbon atom with four different groups bonded to it in a tetrahedral arrangement will always have a nonsuperimposable mirror image



The mirror image optical isomers of glyceraldehyde

Table 22.8 - Some Important Monosaccharides

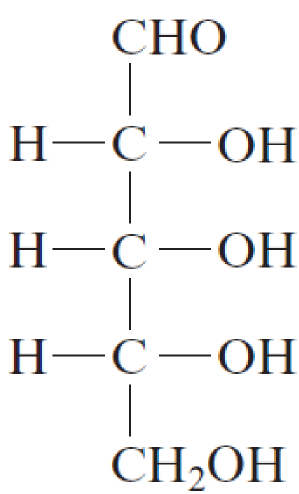
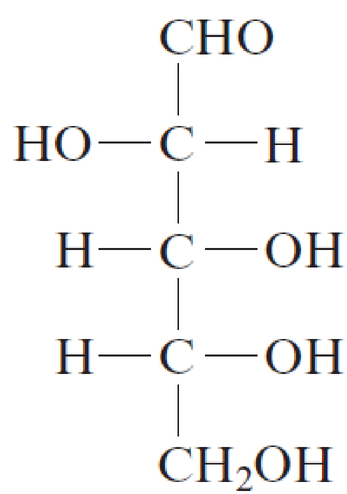
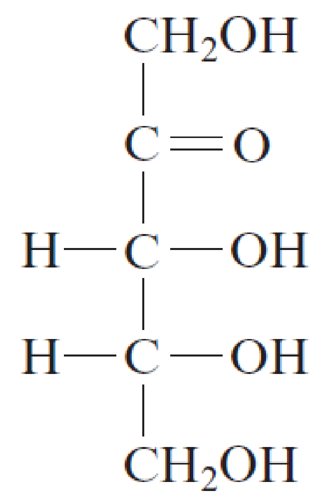
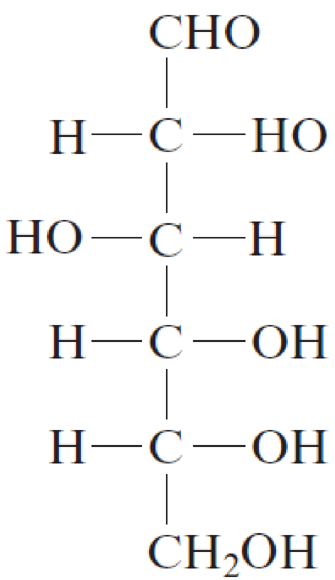
Pentoses		
D-Ribose	D-Arabinose	D-Ribulose
		

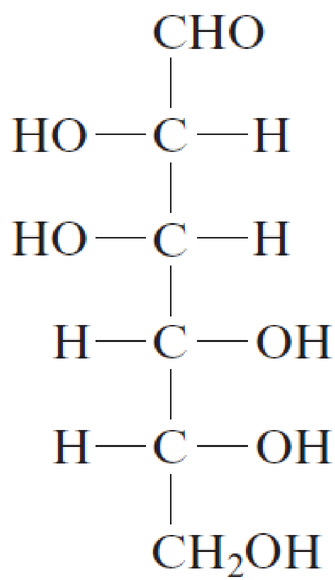
Table 22.8 - Some Important Monosaccharides (Continued)

Hexoses

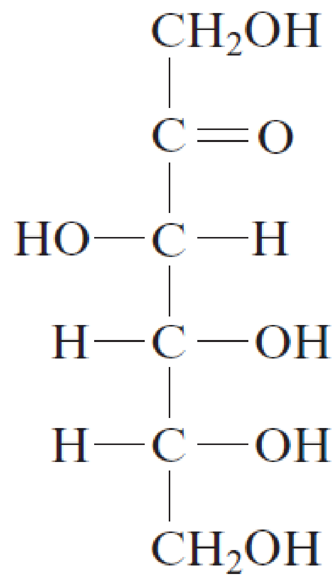
D-Glucose



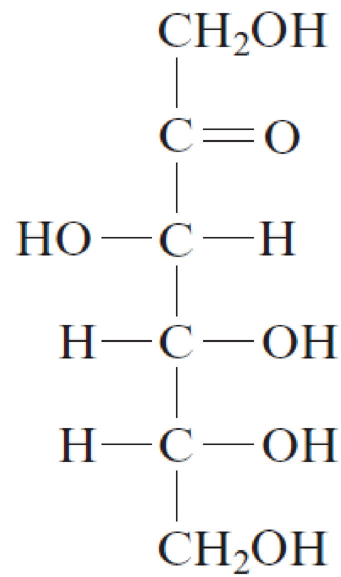
D-Mannose



D-Galactose

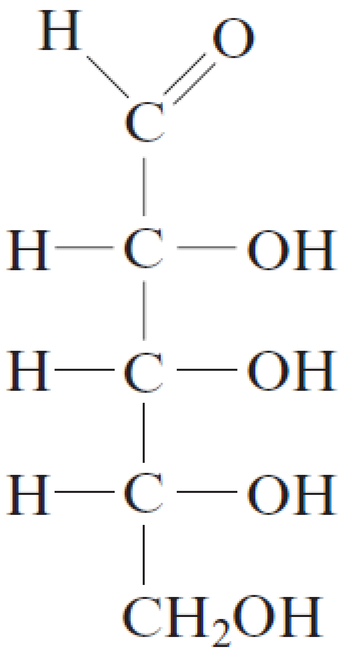


D-Fructose



Interactive Example 22.9 - Chiral Carbons in Carbohydrates

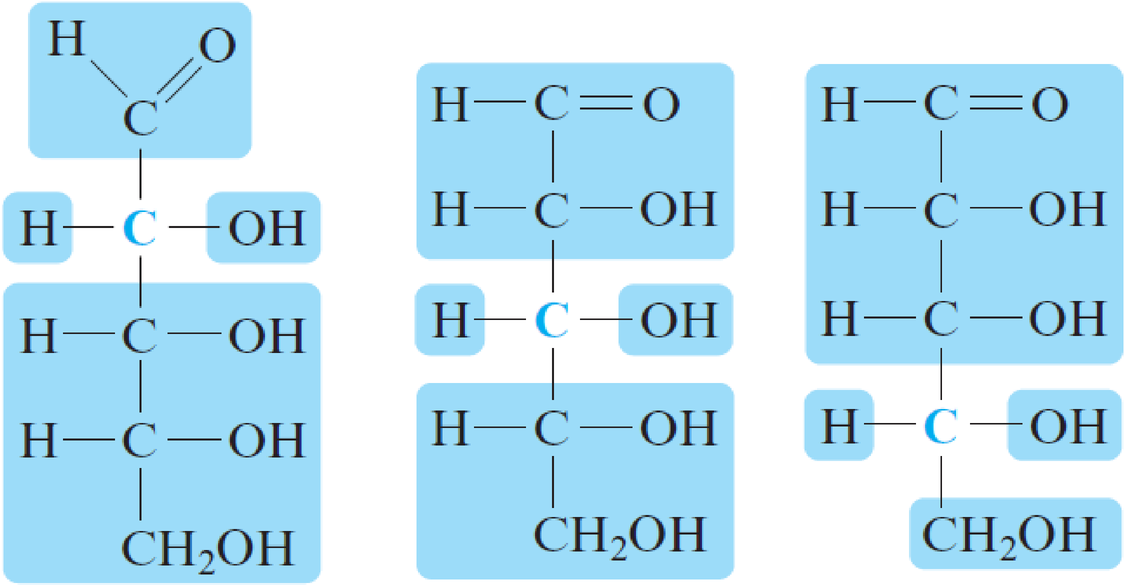
- Determine the number of chiral carbon atoms in the following pentose:



Interactive Example 22.9 - Solution

- We must look for carbon atoms that have four different substituents
  - The top carbon has only three substituents and thus cannot be chiral
  - The three carbon atoms (shown in blue) have four different groups attached to them

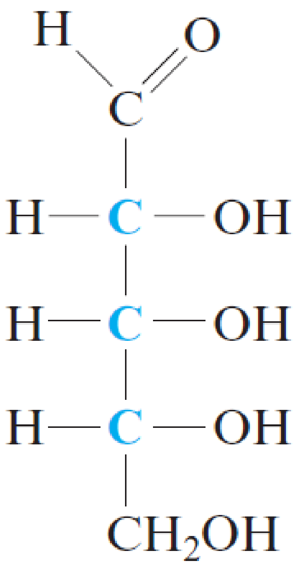
Interactive Example 22.9 - Solution (Continued 1)



- Since the fifth carbon atom has only three types of substituents (it has two hydrogen atoms), it is not chiral

Interactive Example 22.9 - Solution (Continued 2)

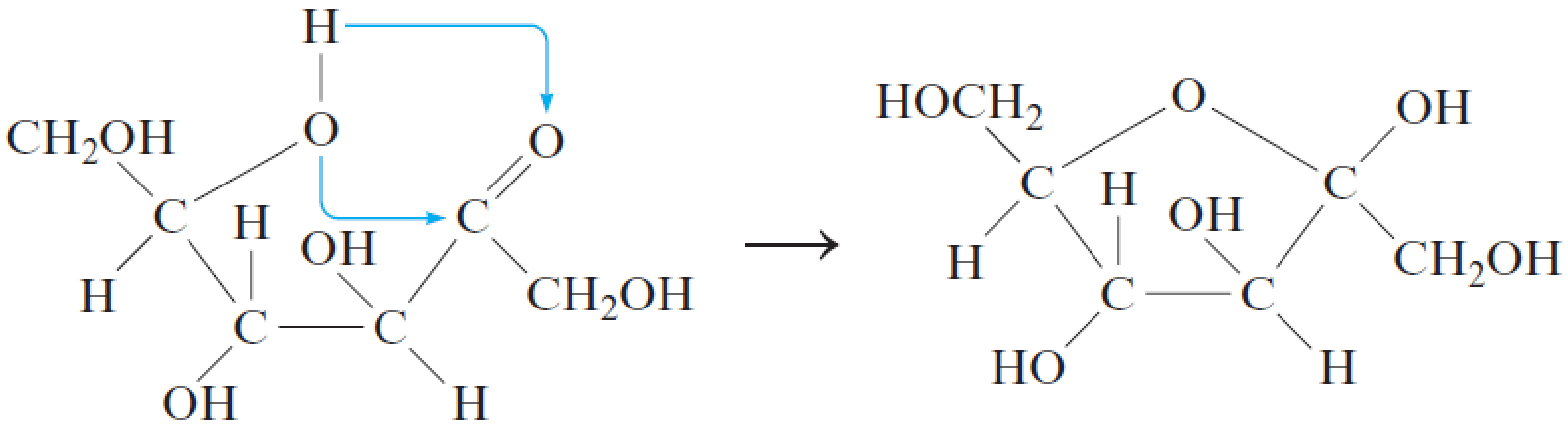
- Thus, the three chiral carbon atoms in this pentose are those shown in blue:



- Note that D-ribose and D-arabinose are two of the eight isomers of this pentose

Cyclic Structure of Monosaccharides

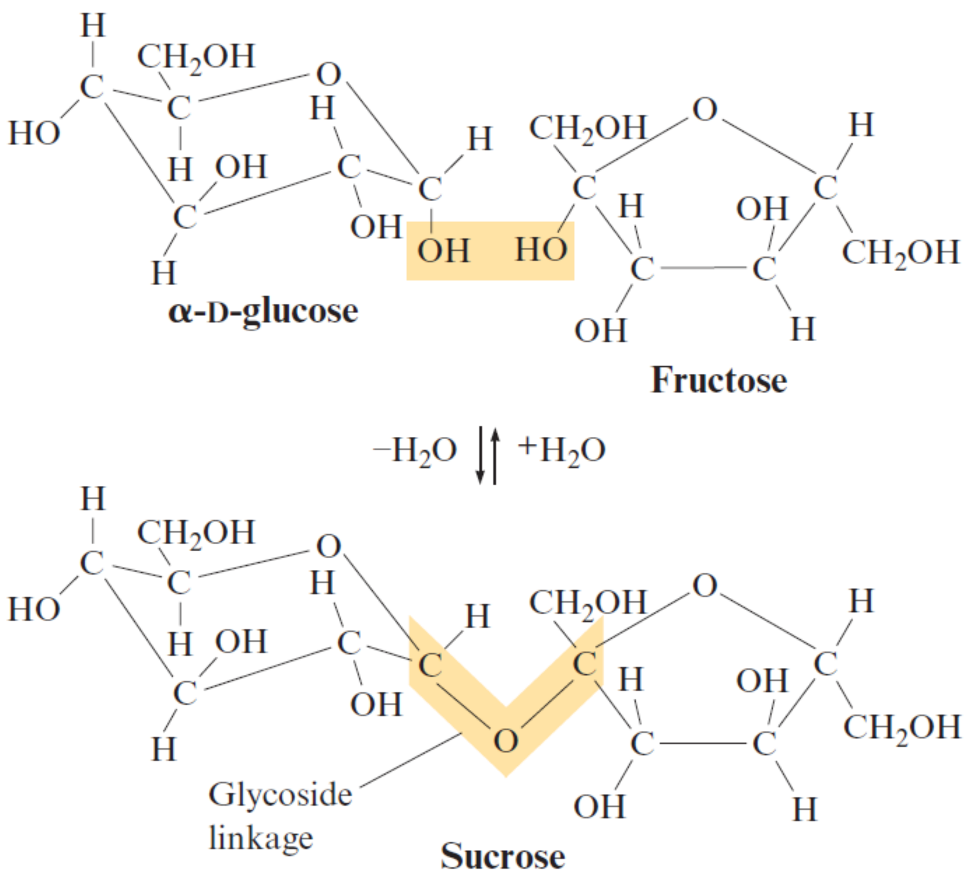
- Monosaccharides cyclize or form a ring structure in aqueous solutions
  - Example - Cyclization of D-fructose



Disaccharides

- Formed from two monosaccharides joined by a glycoside linkage
  - **Glycoside linkage**: C—O—C bond formed between the rings of two cyclic monosaccharides by the elimination of water
- Example - **Sucrose** (common table sugar)
  - When consumed in food, the reaction is reversed due to an enzyme in the saliva

Figure 22.31 - Formation of Sucrose, a Disaccharide



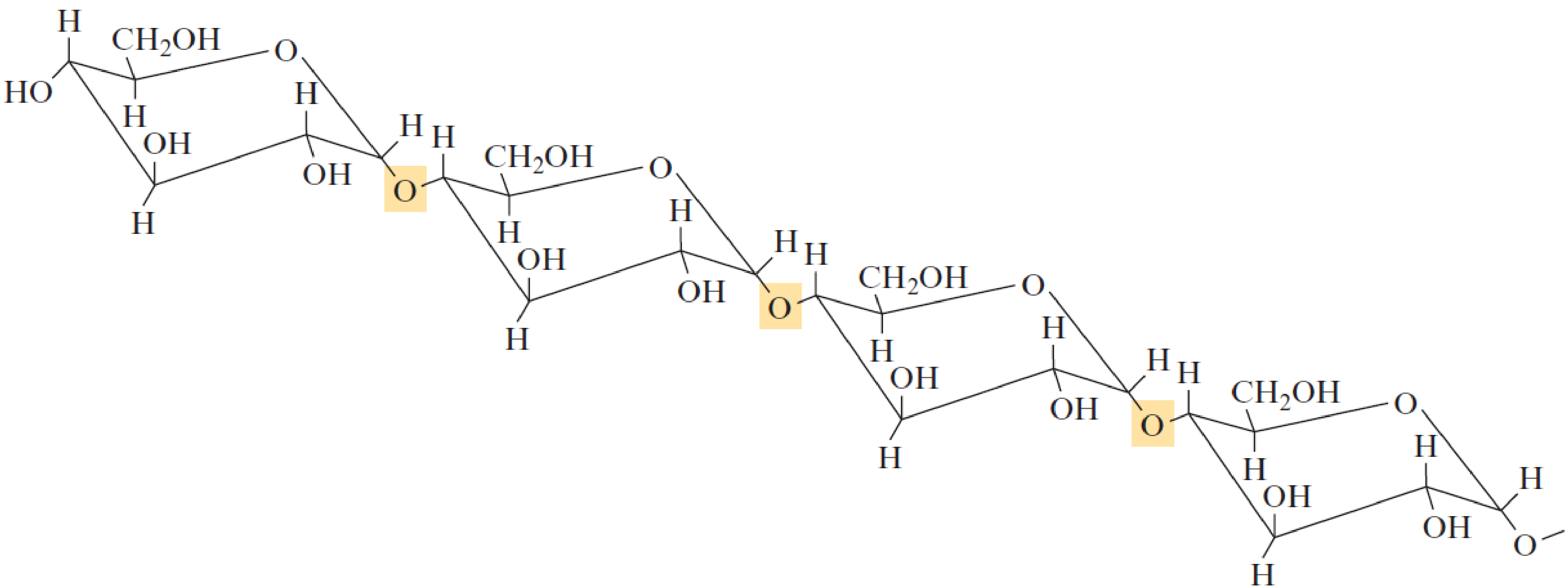
Polysaccharides

- Large polymers that are composed of many monosaccharide units
- Formed when each ring forms two glycoside linkages
- Important polysaccharides
  - Starch
  - Cellulose
  - Glycogen

Starch

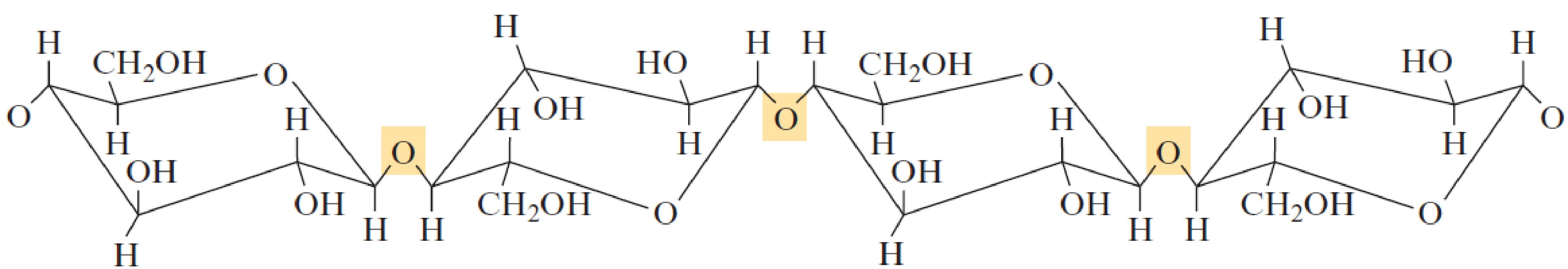
- Polymer of α-D-glucose
- Consists of two parts
  - Amylose - Straight-chain polymer of α-glucose
  - Amylopectin - Highly branched polymer of α-glucose
- Branching occurs when a third glycoside linkage attaches a branch to the main polymer chain

Figure 22.32 - The Polymer Amylose



Cellulose

- Major structural component of:
  - Woody plants
  - Natural fibers such as cotton
- Polymer of β-D-glucose monomers



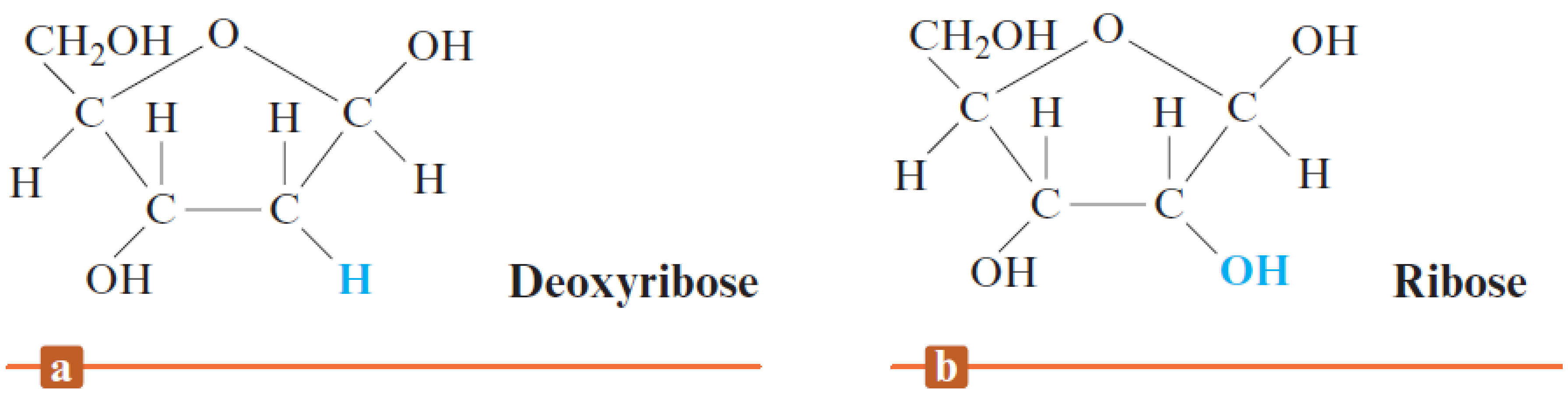
Glycogen

- Structure is similar to that of amylopectin but with more branching
  - Branching facilitates rapid breakdown of glycogen into glucose when energy is required
- Main carbohydrate reservoir in animals

Nucleic Acids

- **DNA** (**deoxyribonucleic acid**): Stores and transmits genetic information
  - Molecular weight is as high as several billion g/mol
  - Responsible for protein synthesis in combination with **RNA** (**ribonucleic acid**)
    - Molecular weight - 20,000–40,000 g/mol

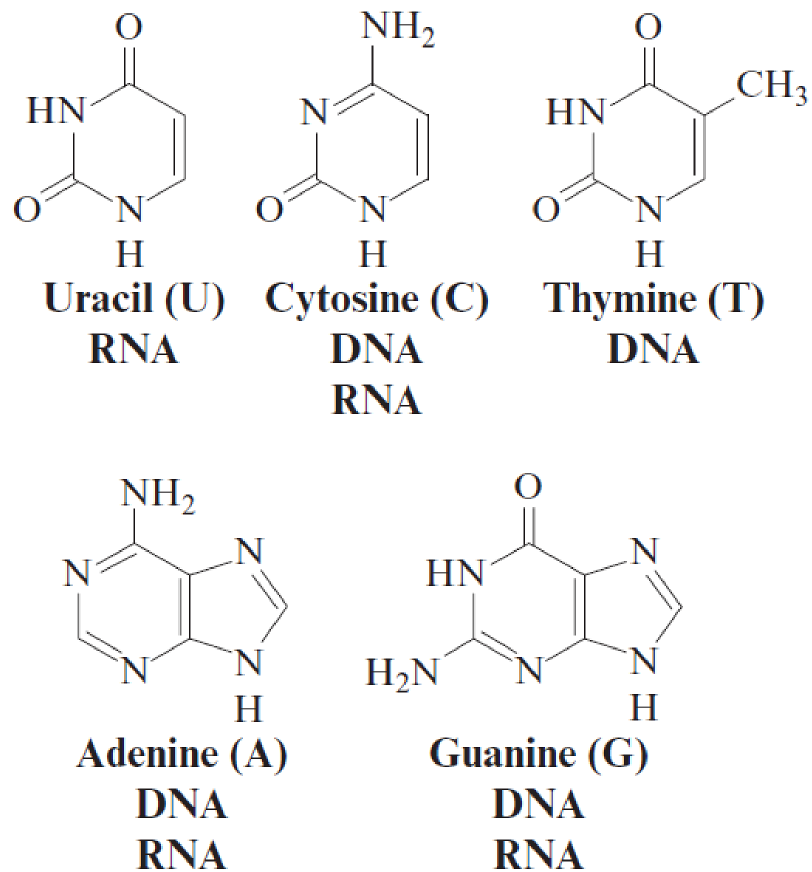
Figure 22.33 - Structure of the Pentoses, Deoxyribose and Ribose



Nucleotides

- Monomers of the nucleic acids
- Composed of:
  - A five-carbon sugar, deoxyribose in DNA and ribose in RNA
  - A nitrogen-containing organic base
  - A phosphoric acid molecule (H_3PO_4)

Figure 22.34 - Organic Bases Found in DNA and RNA



DNA

- Key to DNA's functioning is its double-helical structure with complementary bases on the two strands
  - Contains two sugar–phosphate backbones whose bases form hydrogen bonds to each other
    - Facilitated by thymine-adenine and cytosine-guanine pairs

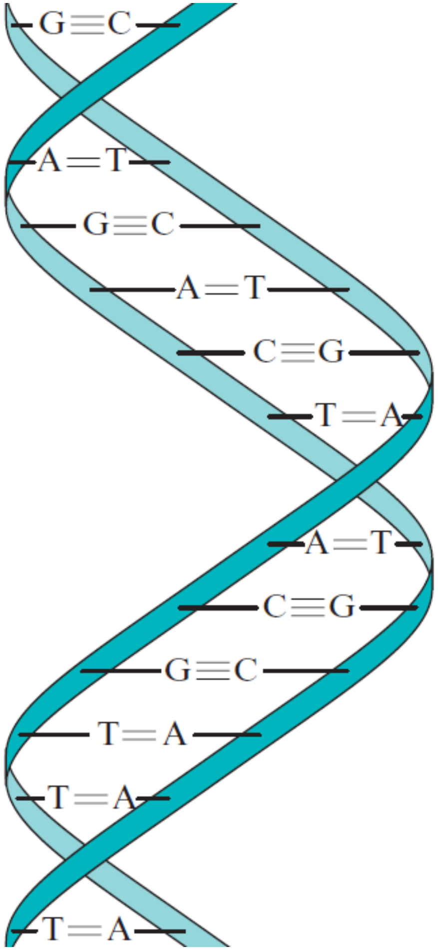
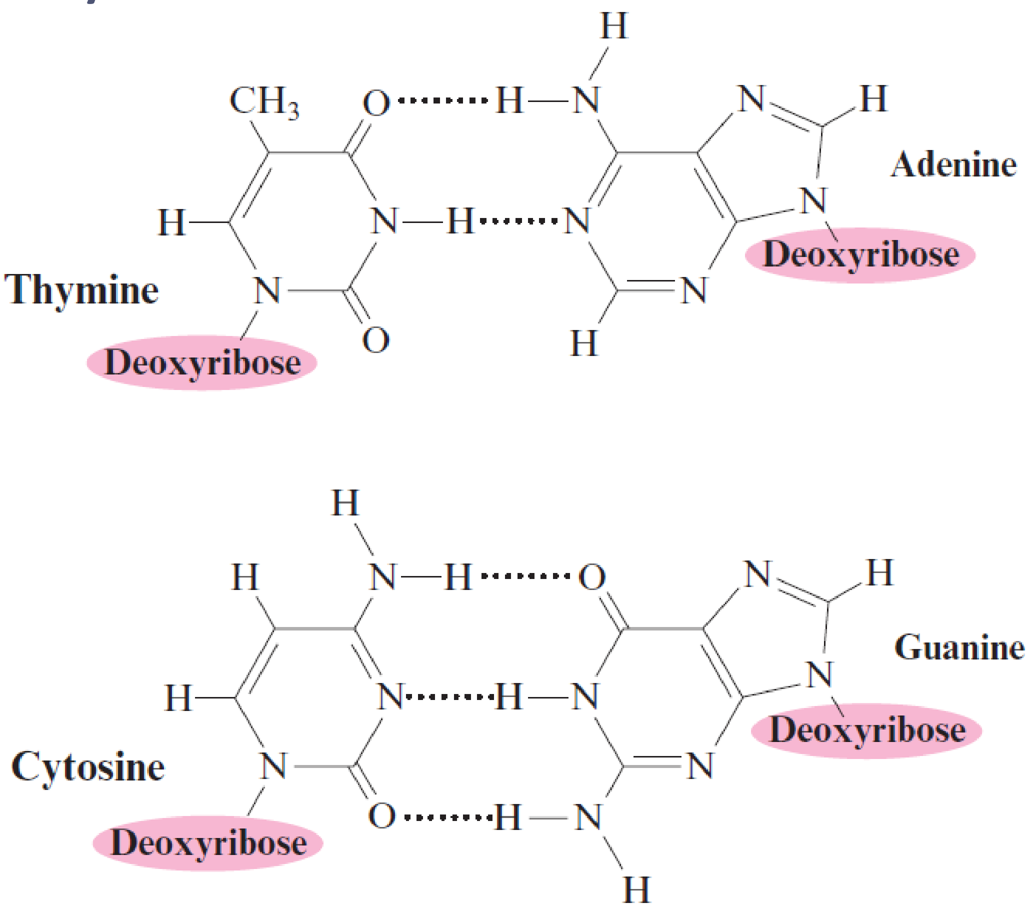
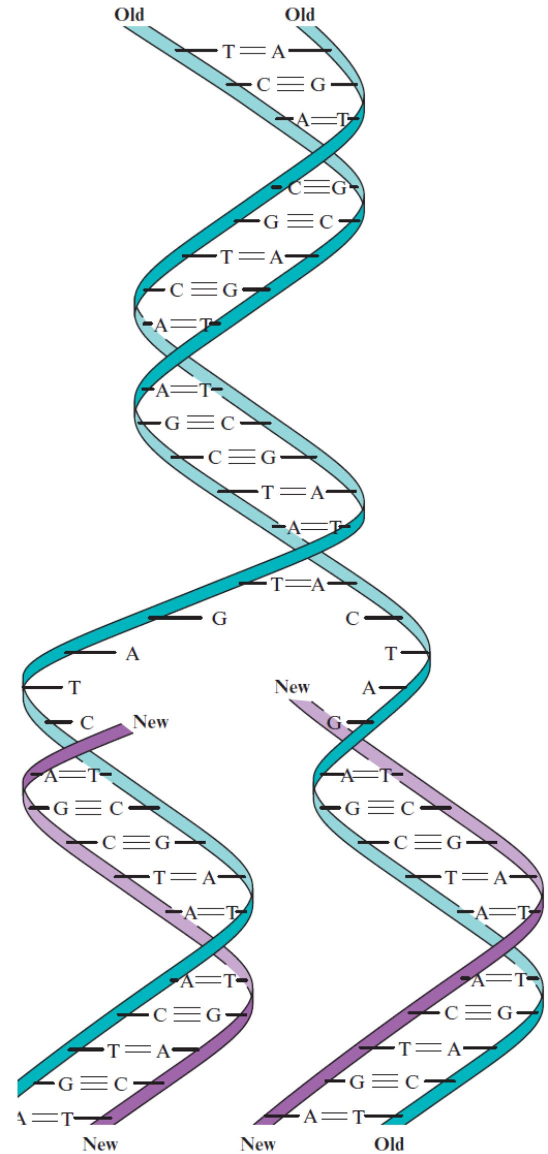


Figure 22.37 - Complementarity of the Thymine-Adenine and Cytosine-Guanine Pairs



Unwinding of DNA Strands

- Occurs during cell division
- New complementary strands are constructed on the unraveled ones
  - Each unraveled strand serves as a template for attaching the complementary bases
- Replication of DNA allows for the transmission of genetic information



Protein Synthesis

- **Gene**: Segment of the DNA that contains the genetic code for a certain protein
  - Codes transmit the primary structure of the protein to the construction machinery of the cell
    - Consist of a set of three bases called a **codon**

Protein Synthesis - Process

- DNA creates a special RNA molecule called **mRNA** (**messenger RNA**), which is built in the cell nucleus on the gene
  - Double helix is unzipped
    - Complementarity of the bases is used in a process similar to that used in DNA replication
  - mRNA migrates into the cytoplasm
    - Protein synthesis occurs with the assistance of ribosomes

Protein Synthesis - Process (Continued)

- **tRNA** (**transfer RNA**): Small RNA fragments
  - Search for specific amino acids to attach them to the growing protein chain as dictated by the codons
  - Has a lower molecular weight
  - Consists of a chain of 75 to 80 nucleotides
  - **Anticodon**: Complementary triplet of bases used to decode genetic messages from the mRNA
    - Nature of the anticodon governs which amino acid will be brought to the protein under construction

Figure 22.39 - Process of Building a Protein