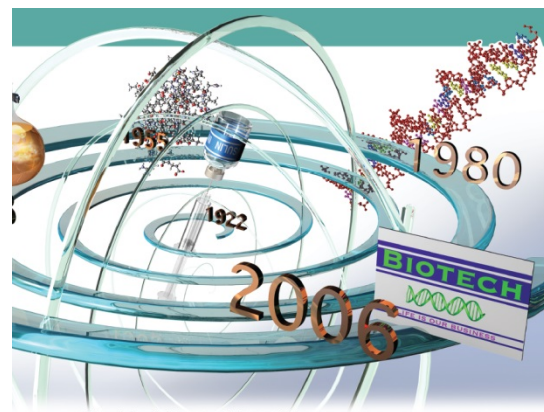


[http://hsmaterial.moe.edu.tw/sch
ema/che/course/index_4.html](http://hsmaterial.moe.edu.tw/schema/che/course/index_4.html)

- 21.1 Diabetes and the Synthesis of Human Insulin 1001
- 21.2 Lipids 1002
- 21.3 Carbohydrates 1006
- 21.4 Proteins and Amino Acids 1010
- 21.5 Protein Structure 1014
- 21.6 Nucleic Acids: Blueprints for Proteins 1018
- 21.7 DNA Replication, the Double Helix, and Protein Synthesis 1022
- Key Learning Outcomes 1027

Lecture Presentation



Chapter 21

Biochemistry

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Grand Valley State University

21.1 Diabetes and the Synthesis of Human Insulin

- Over 16 million people in the United States are afflicted with diabetes.
 - Generally controllable, but may be fatal
- **Type 1 diabetes is caused by the inability of the pancreas to produce enough insulin.**
- Insulin is a protein needed to promote the adsorption of glucose into the cells.
- Animal insulin was used as a treatment.
- Now human insulin can be synthesized and manufactured because Sanger was able to determine the exact structure of human insulin.

Biochemistry

- **Biochemistry** is the study of the chemistry of living organisms.
- Much of biochemistry deals with the large, complex molecules necessary for life as we know it.
- However, most of these complex molecules are actually made of smaller, simpler units; they are *biopolymers*.
- There are four main classes of biopolymers—lipids, proteins, carbohydrates, and nucleic acids.

21.2 Lipids

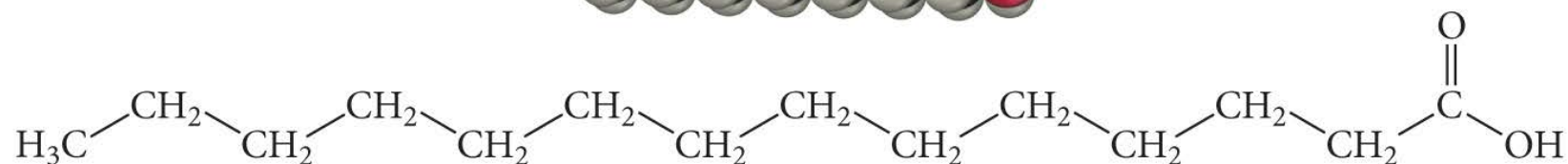
- Chemicals of the cell that are insoluble in water, but soluble in nonpolar solvents.
- Fatty acids, fats, oils, phospholipids, glycolipids, some vitamins, steroids, and waxes
- Structural components of cell membrane
 - Because they don't dissolve in water
- Long-term energy storage
- Insulation

Fatty Acids

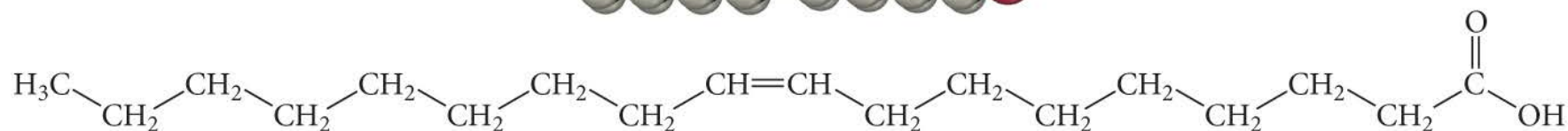
- Carboxylic acid (head) with a very long hydrocarbon side chain (tail).
- Saturated fatty acids contain no $C=C$ double bonds in the hydrocarbon side chain.
- Unsaturated fatty acids have $C=C$ double bonds.
 - Monounsaturated have 1 $C=C$.
 - Polyunsaturated have more than 1 $C=C$.

Fatty Acids

Myristic acid a saturated fatty acid



Oleic acid – $\text{C}_{18}\text{H}_{34}\text{O}_2$ a monounsaturated fatty acid



Fatty Acids

TABLE 21.1 Fatty Acids

Saturated Fatty Acids					
Name	Number of Carbons		mp (°C)	Structure	Sources
Butyric acid	4		−7.9	CH ₃ CH ₂ CH ₂ COOH	Milk fat
Caproic acid	10		31	CH ₃ (CH ₂) ₈ COOH	Milk fat, whale oil
Myristic acid	14		59	CH ₃ (CH ₂) ₁₂ COOH	Butterfat, coconut oil
Palmitic acid	16		64	CH ₃ (CH ₂) ₁₄ COOH	Beef fat, butterfat
Stearic acid	18		70	CH ₃ (CH ₂) ₁₆ COOH	Beef fat, butterfat
Unsaturated Fatty Acids					
Name	Number of Carbons	Number of Double Bonds	mp (°C)	Structure	Sources
Oleic acid	18	1	4	CH ₃ (CH ₂) ₇ CH=CH(CH ₂) ₇ COOH	Olive oil, peanut oil
Linoleic acid	18	2	−5	CH ₃ (CH ₂) ₄ (CH=CHCH ₂) ₂ (CH ₂) ₆ COOH	Linseed oil, corn oil
Linolenic acid	18	3	−11	CH ₃ CH ₂ (CH=CHCH ₂) ₃ (CH ₂) ₆ COOH	Linseed oil, corn oil

Structure and Melting Point

- Larger fatty acid = higher melting point
- Double bonds decrease melting point
 - More DB = lower MP
- Saturated = no DB
- Monounsaturated = 1 DB
- Polyunsaturated = many DB

Effect on Melting Point

- Because fatty acids are largely nonpolar, the main attractive forces are dispersion forces.
- Larger size = more electrons = larger dipole = stronger attractions = higher melting point
- More straight = more surface contact = stronger attractions = higher melting point

cis Fats and *trans* Fats

- Naturally unsaturated fatty acids contain *cis* double bonds.
- Processed fats come from polyunsaturated fats that have been partially hydrogenated, resulting in *trans* double bonds.
- *Trans* fats seem to increase the risk of coronary disease.

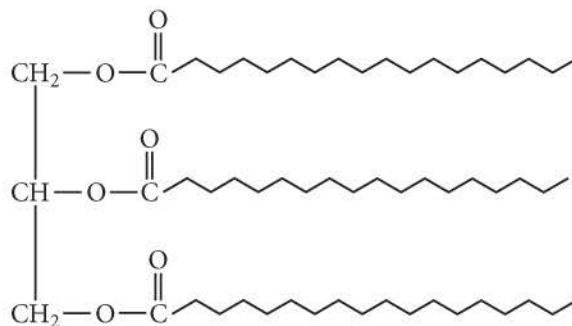
Triglycerides

- Triglycerides differ in the length of the fatty acid side chains and degree of unsaturation.
 - Side chains range from 12 to 20 C.
 - Most natural triglycerides have different fatty acid chains in the triglyceride, simple triglycerides have three identical chains.
- Saturated fat = all saturated fatty acid chains
 - Warm-blooded animal fat
 - Solids
- Unsaturated fats = some unsaturated fatty acid chains
 - Cold-blooded animal fat or vegetable oils
 - Liquids

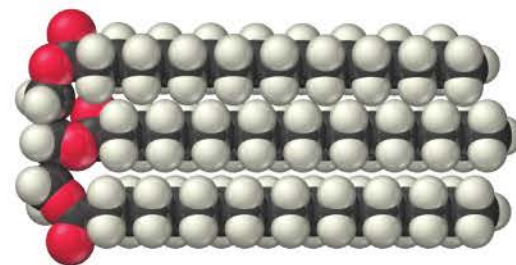
Tristearin – A Simple Triglyceride Found in Lard

Saturated Triglyceride or fatty acid

Tristearin: A Saturated Fat



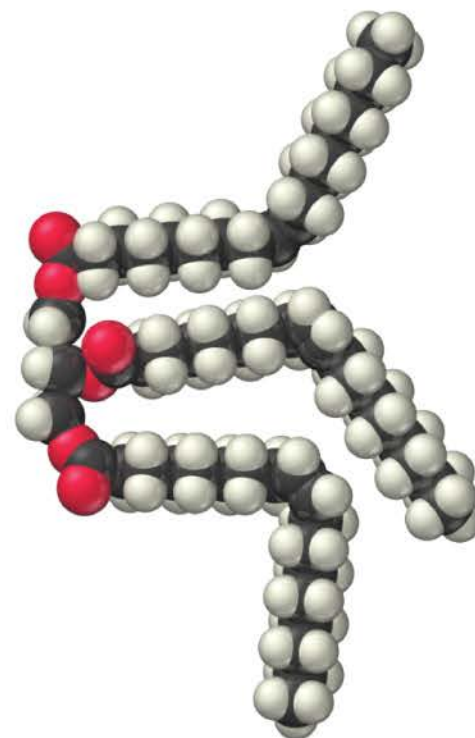
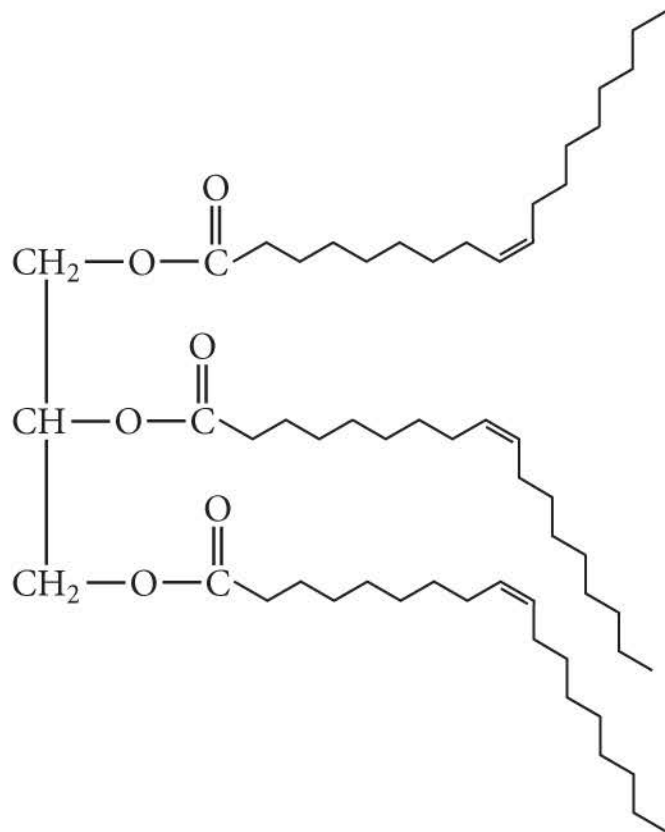
Tristearin, mp 72 °C



Triolein – A Simple Triglyceride(三酸甘油酯) Found in Olive Oil

unsaturated Triglyceride or fatty acid

Triolein: A Monounsaturated Fat



Triolein, mp -4°C

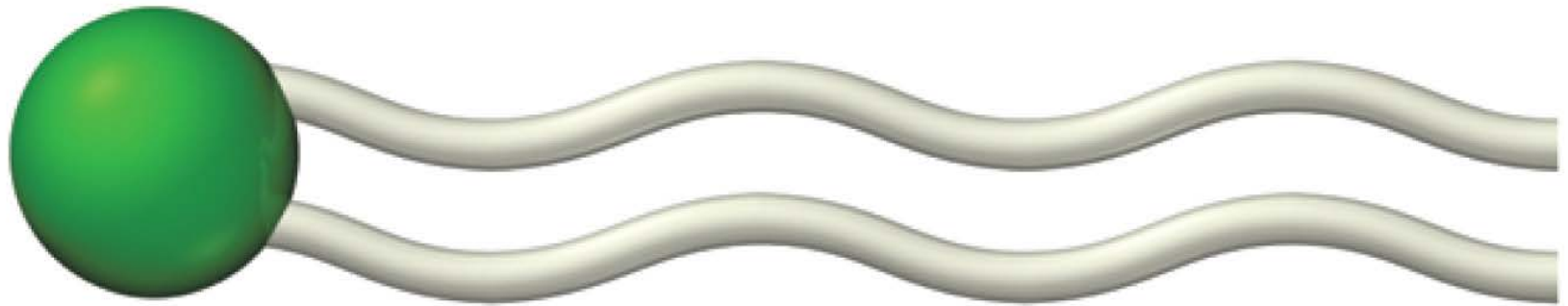


3 Stearic acid molecules



Phospholipids

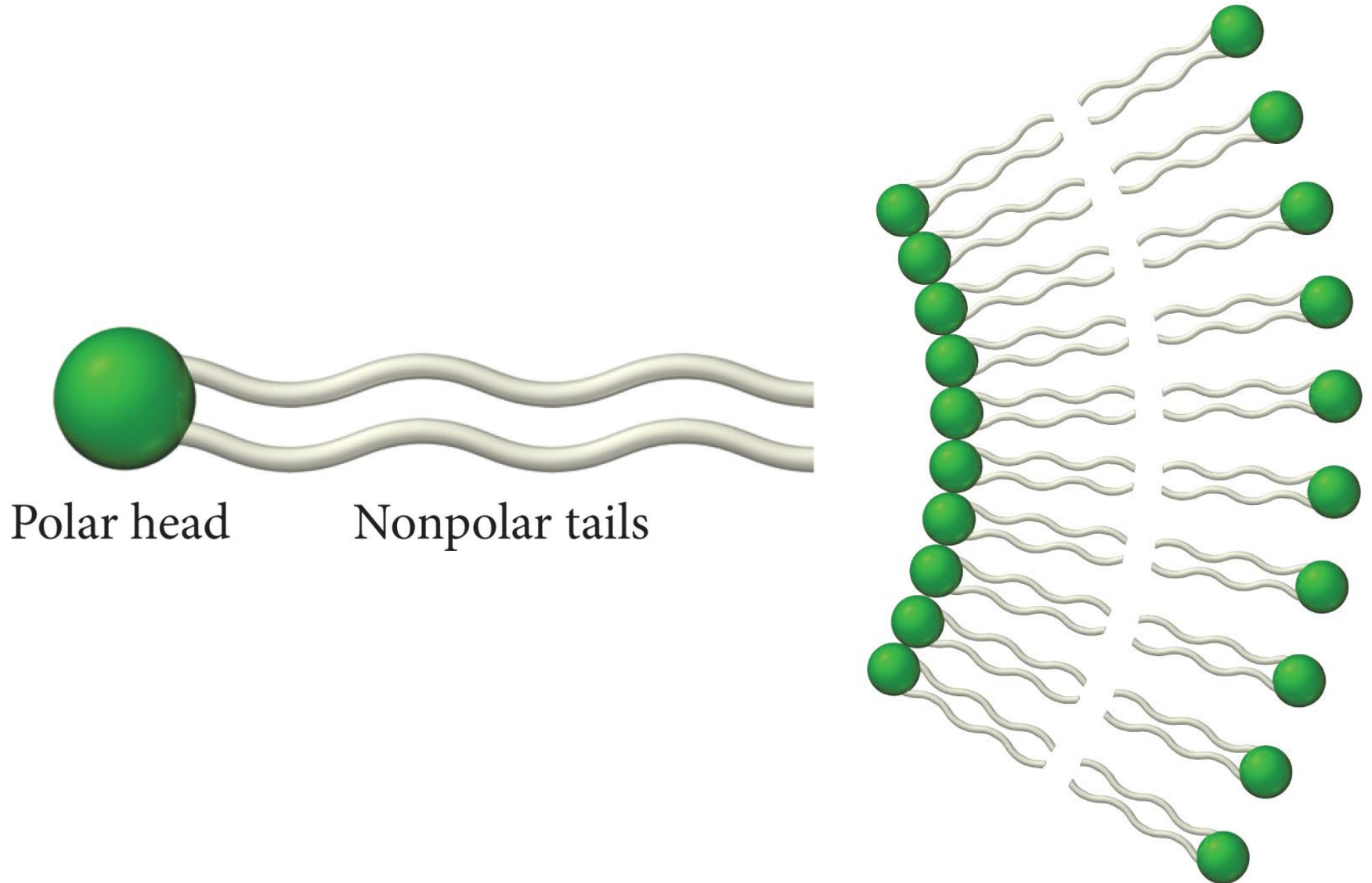
- **Phospholipids** are esters of glycerol in which one of the OH groups of glycerol esterifies with phosphate.
 - Other two OH are esterified with fatty acids
- Phospholipids have a **hydrophilic head** due to phosphate group, and a **hydrophobic tail** from the fatty acid hydrocarbon chain.
- Part of **lipid bilayer** found in animal cell membranes



Polar head

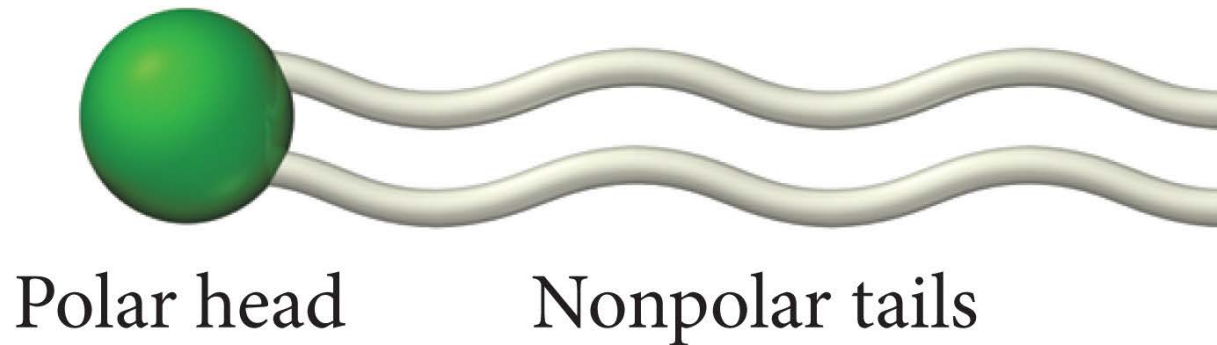
Nonpolar tails

Lipid Bilayer



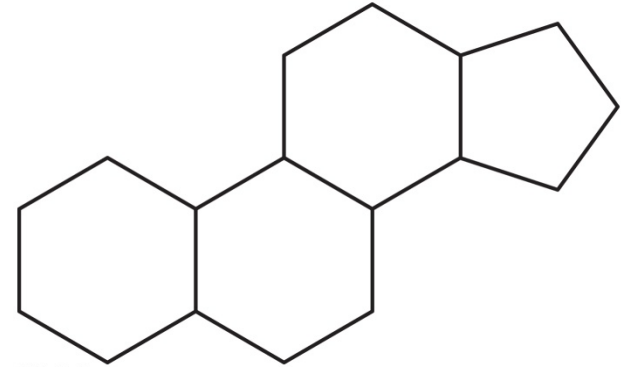
Glycolipids 糖脂

- Similar structure and properties to the phospholipids
- The nonpolar part composed of a fatty acid chain and a hydrocarbon chain
- The polar part is a sugar molecule
 - For example, glucose

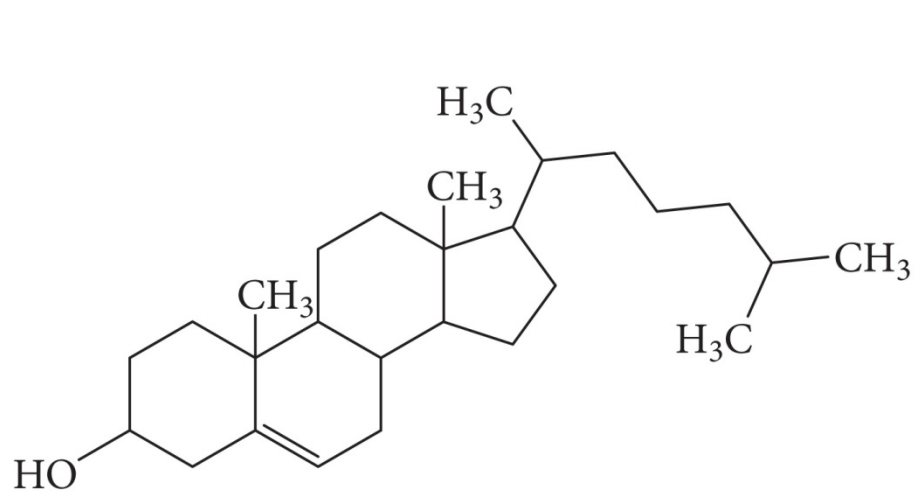


Steroids類固醇

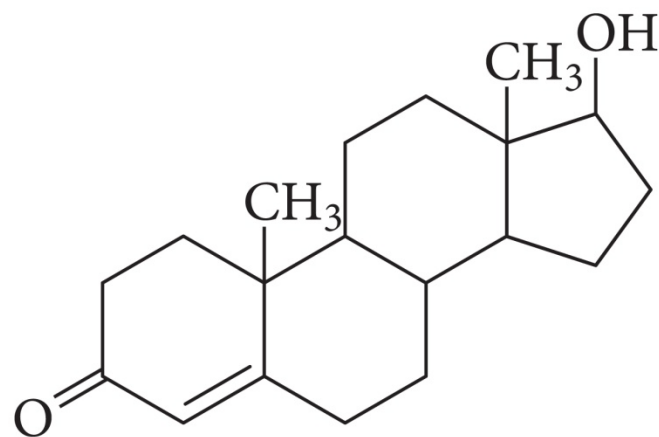
- Characterized by four linked carbon rings
- Mostly hydrocarbon-like
 - Dissolve in animal fat
- Mostly have hormonal effects
- Serum cholesterol levels linked to heart disease and stroke
 - Levels depend on diet, exercise, emotional stress, genetics, etc.
- Cholesterol synthesized in the liver from saturated fats.



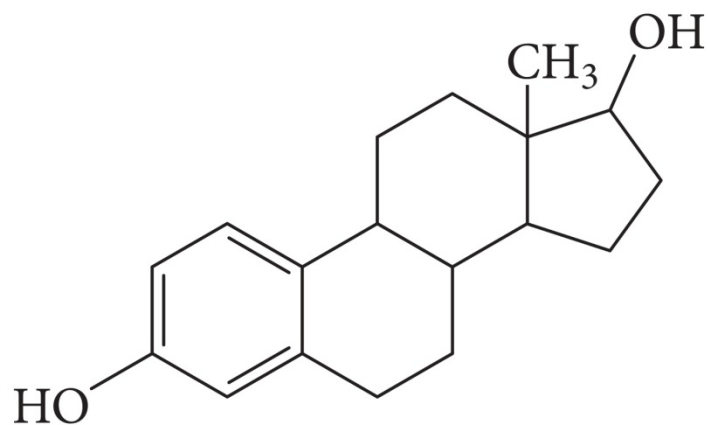
Steroid Rings



Cholesterol



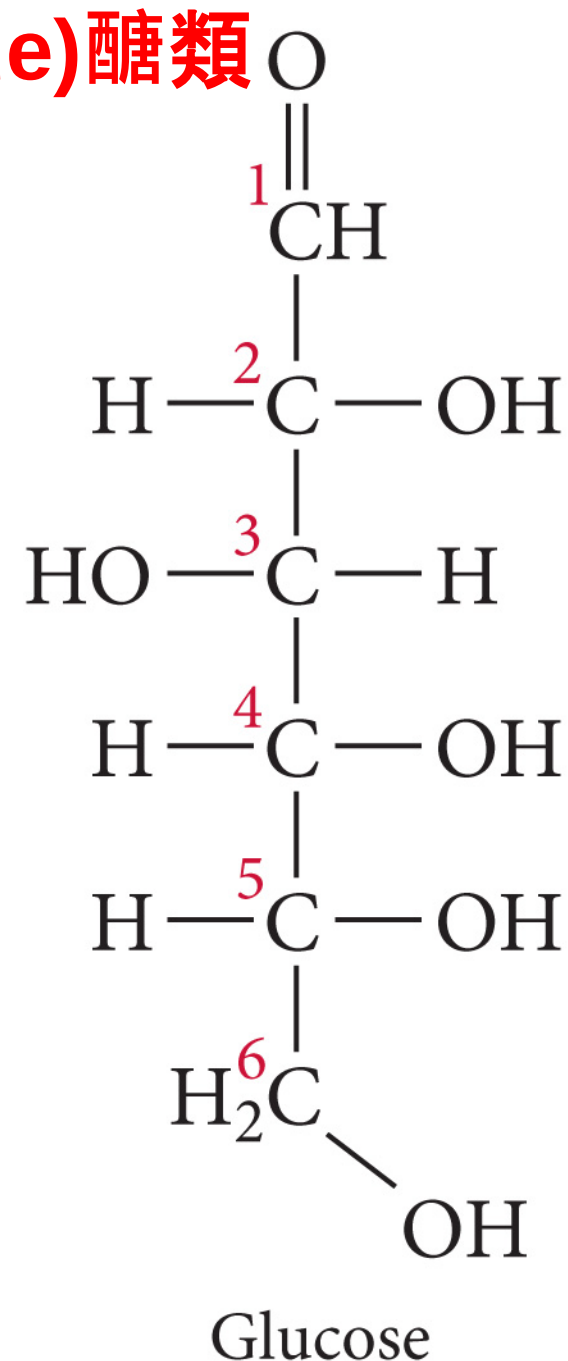
Testosterone



β -Estradiol

21.3 Carbohydrates (saccharide) 醣類

- Carbon, hydrogen, and oxygen
- Ratio of H:O = 2:1
 - Same as in water
- Polyhydroxycarbonyls have many OH and one C=O.
 - Aldose when C=O is aldehyde
 - Ketose when C=O is ketone
- The many polar groups make simple carbohydrates soluble in water.
 - Blood transport
- Also known as sugars, starches, cellulose, dextrans, and gums

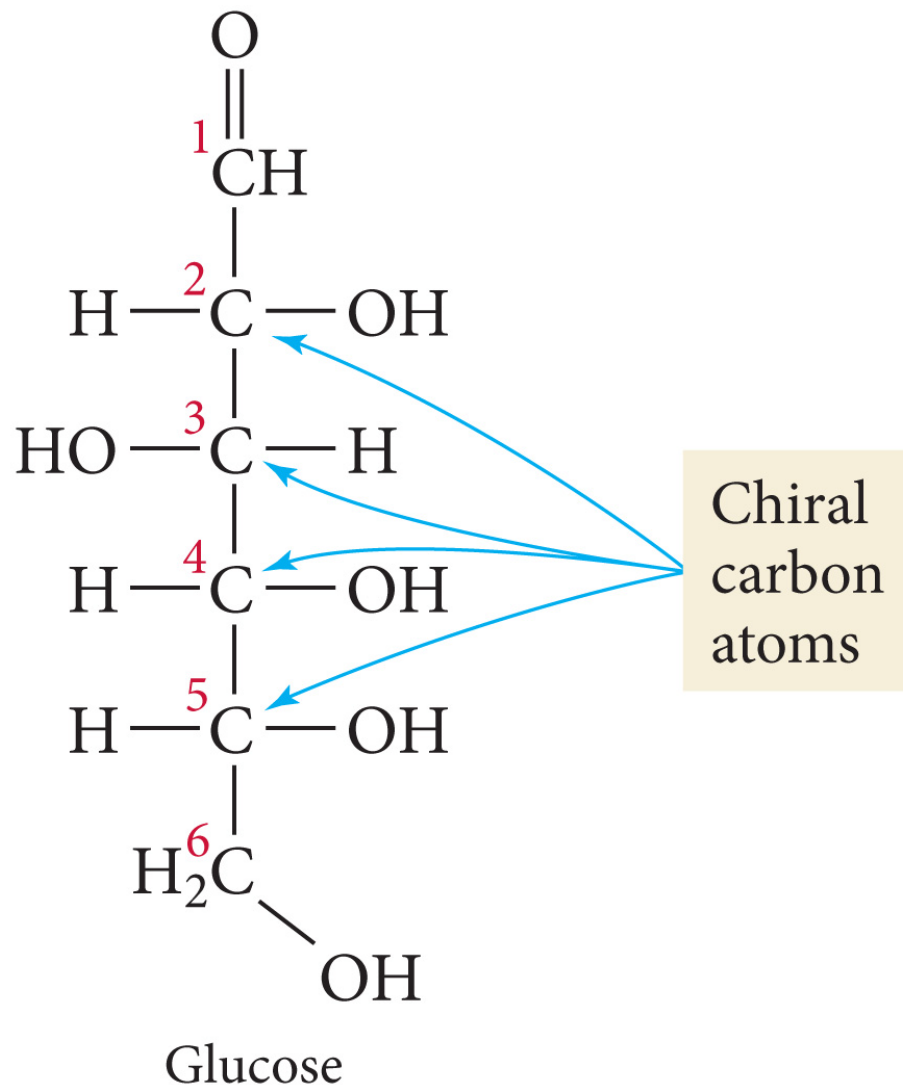


Classification of Carbohydrates

- **Monosaccharides** cannot be broken down into simpler carbohydrates.
 - Triose, tetrose, pentose, hexose
- **Disaccharides** are two monosaccharides attached by a glycosidic link.
 - Lose H from one and OH from other
- **Polysaccharides** are three or more monosaccharides linked into complex chains.
 - Starch and cellulose are polysaccharides of glucose.

Optical Activity

- There are always several chiral carbons in a carbohydrate, resulting in many possible optical isomers.



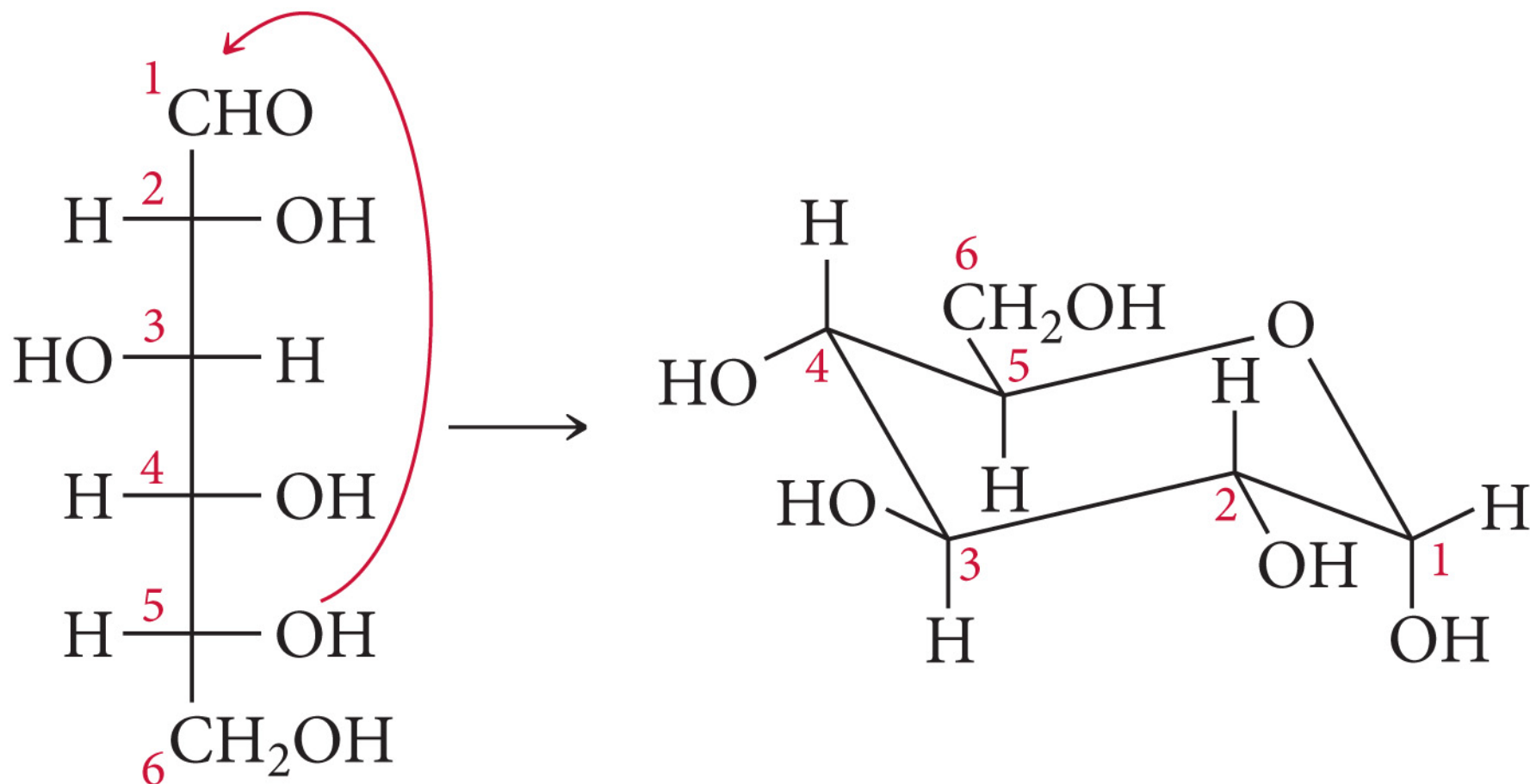
Ring Structure

- In aqueous solution, monosaccharides exist mainly in the ring form.
 - However, there is a small amount of chain form in equilibrium.

Cyclic Monosaccharides

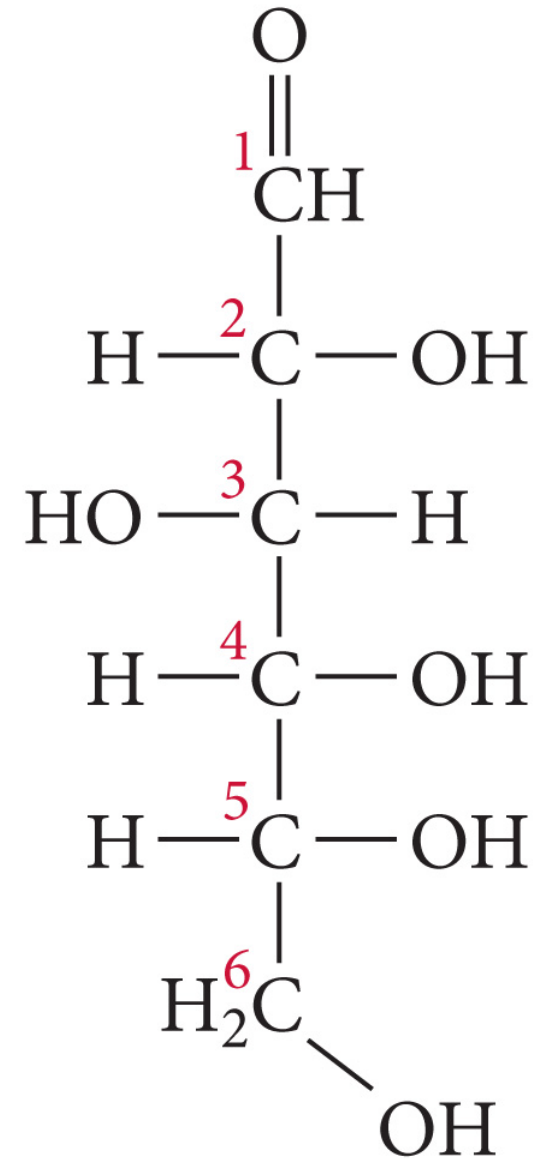
- Oxygen attached to second last carbon bonds to carbonyl carbon
 - Acetal formation
- Convert carbonyl to OH
 - Transfer H from original O to carbonyl O
- New OH group may be same side as CH₂OH (β) or opposite side (α)
- Haworth projection

Formation of Ring Structure



Glucose

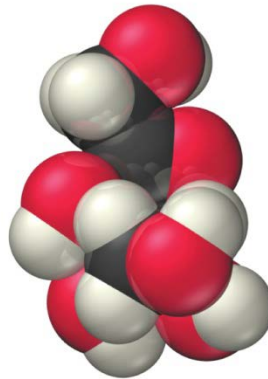
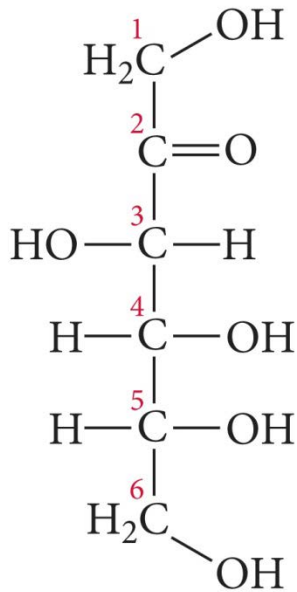
- Also known as blood sugar, grape sugar, and **dextrose**
- Aldohexose = sugar containing aldehyde group and six carbons
- Source of energy for cells
 - 5 to 6 grams in bloodstream
 - Supply energy for about 15 minutes



Glucose

Fructose

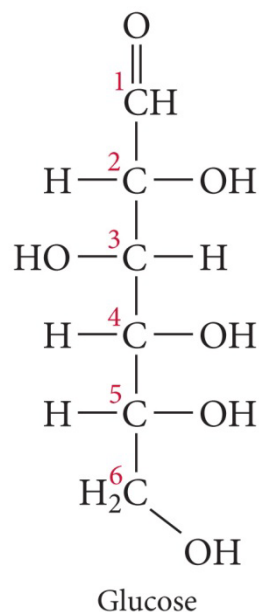
- Also known as **levulose**, fruit sugar
- Ketohexose = sugar containing ketone group and six carbons
- Sweetest known natural sugar



Fructose

Example 21.1 Carbohydrates and Optical Isomerism

Closely examine the structure of glucose shown here. Does glucose exhibit optical isomerism (discussed in Section 20.3)? If so, which carbon atoms are chiral?

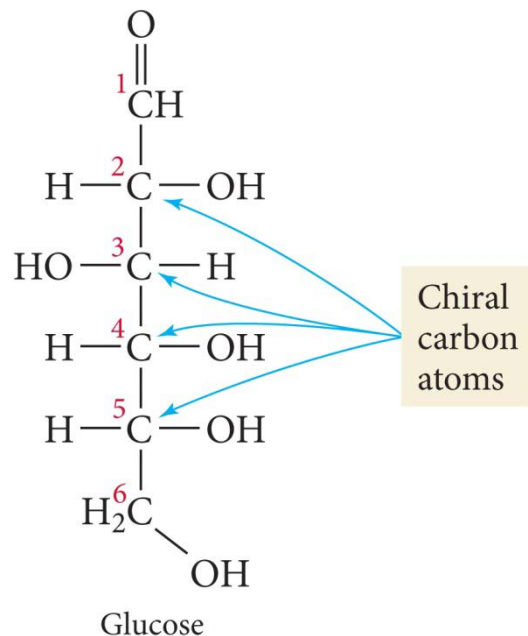


Solution

Any carbon atom with four different substituents attached to it is chiral. Glucose has four chiral carbon atoms (labeled 2, 3, 4, and 5) and therefore exhibits optical isomerism.

Example 21.1 Carbohydrates and Optical Isomerism

Continued



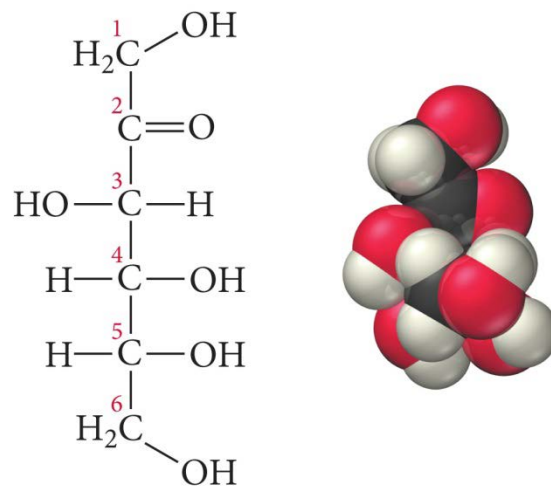
Variations in the positions of the —OH and —H groups on these carbon atoms result in a number of different possible isomers for glucose. For example, switching the relative positions of the —OH and —H group on the carbon atom closest to the carbonyl group results in mannose, an optical isomer of glucose.

Example 21.1 Carbohydrates and Optical Isomerism

Continued

For Practice 21.1

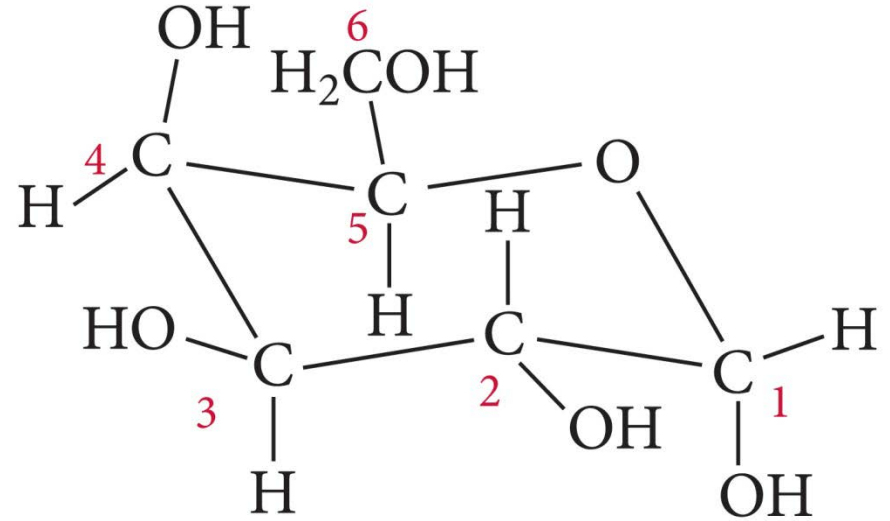
Examine the structure of fructose (p. 1007). Does fructose exhibit optical isomerism? How many of the carbon atoms in fructose are chiral?



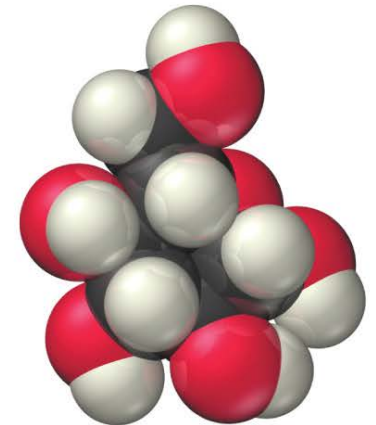
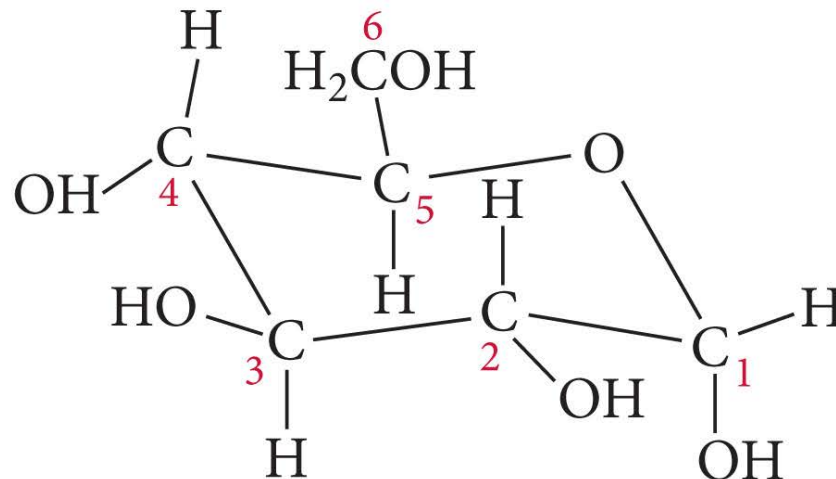
Fructose

Galactose

- Found in the brain and nervous system
- Only difference between glucose and galactose – spatial orientation of groups on C4



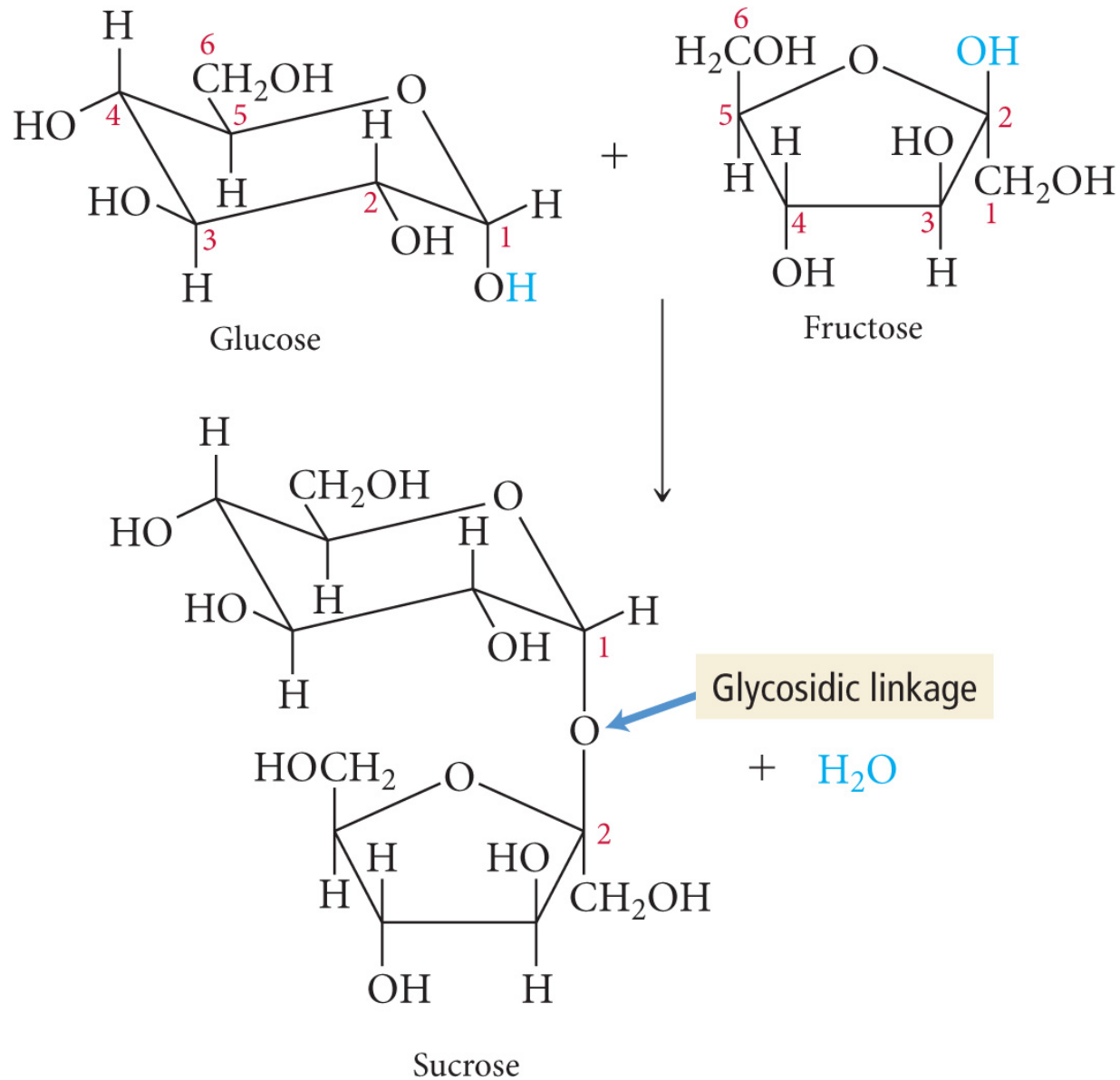
Galactose



Sucrose

- Also known as table sugar, cane sugar, beet sugar
- Glucose + fructose = sucrose
- α -1,2-glycosidic linkage involves aldehyde group from glucose and ketone group from fructose
- Nonreducing

Sucrose



Digestion and Hydrolysis

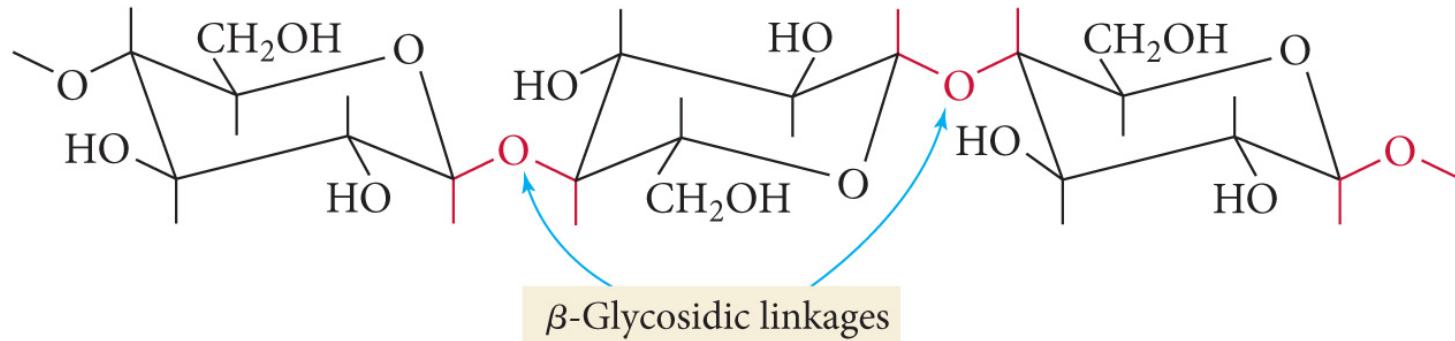
- Digestion breaks polysaccharides and disaccharides into monosaccharides.
- **Hydrolysis** is the addition of water to break glycosidic link.
 - Under acidic or basic conditions
- Monosaccharides can pass through intestinal wall into the bloodstream; larger sugars cannot.

Polysaccharides

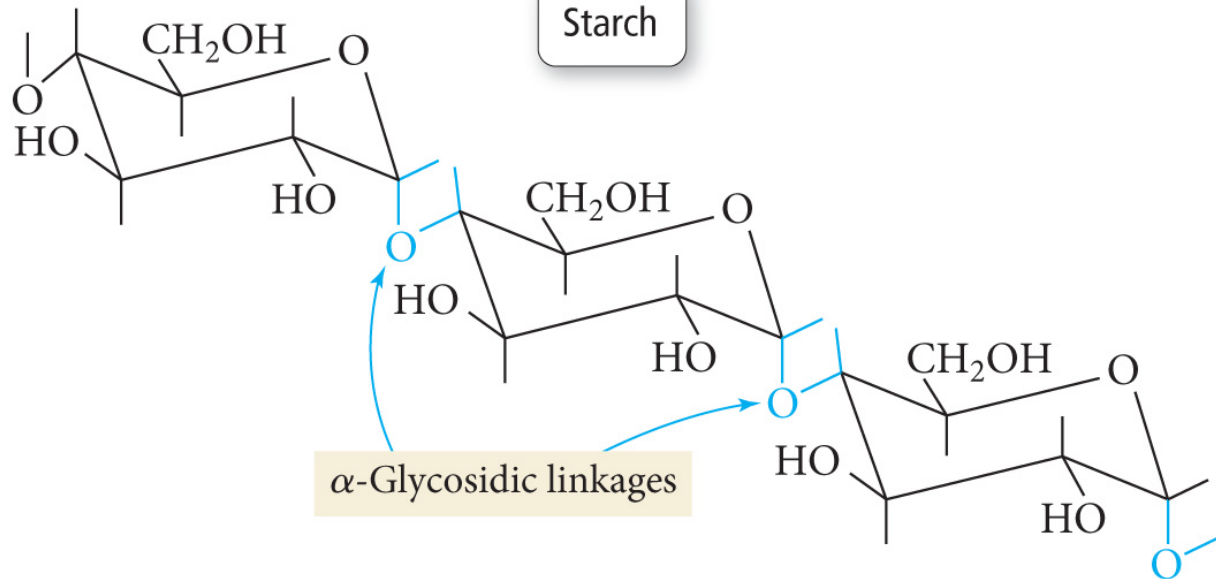
- Also known as **complex carbohydrates**
- Polymer of monosaccharide units bonded together in a chain
- The glycosidic link between units may be either α or β .
 - In α , the rings are all oriented the same direction.
 - In β , the rings alternate orientation.

α and β Glycosidic Links

Cellulose



Starch



Starch

- Made of glucose rings linked together
 - Give only glucose on hydrolysis
- Main energy storage medium
- Digestible, soft, and chewy
- α -1,4-glycosidic link
- Composed of straight amylose polymer chains and branched amylopectin polymer chains

Cellulose

- Made of glucose rings linked together
 - Give only glucose on hydrolysis
- Not digestible
- Fibrous, plant structural material
- β -1,4-glycosidic link
- Allows neighboring chains to H bond, resulting in a rigid structure

Glycogen

- Made of glucose rings linked together
 - Give only glucose on hydrolysis
- Animal energy storage in muscles
- α -1,4-glycosidic link
- Branched structure similar to amylopectin polymer chains, except more highly branched
- Many branches mean faster hydrolysis—a quickly accessible energy reserve.
- Glycogen depletion from muscles results in the muscle cells having to try and acquire energy needs through glucose in the bloodstream, which may not be available as quickly.

21.4 Proteins and Amino Acids

Proteins

- Involved in practically all facets of cell function
- Polymers of amino acids

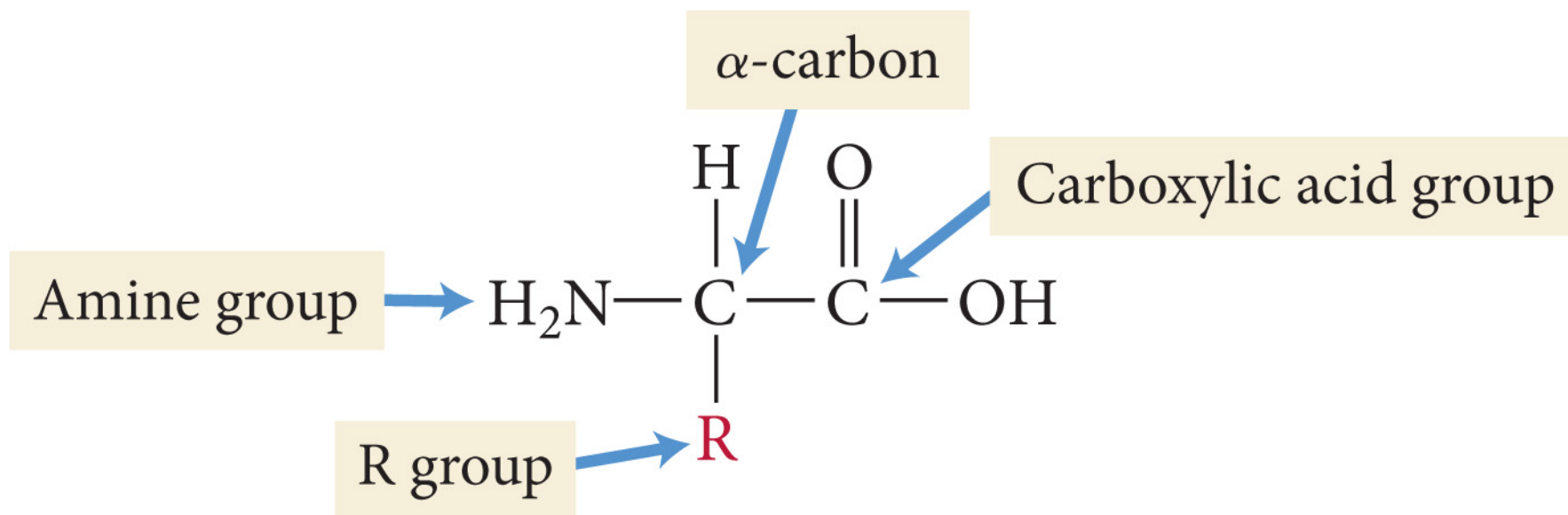
TABLE 21.2 Protein Functions

Class of Protein	Primary Function	Example
Structural proteins	Compose structures within living organisms	Collagen (skin, tendon, cartilage), keratin (hair, fingernails)
Enzymes	Catalyze and control biochemical reactions	DNA polymerase (involved in replication of DNA)
Hormones	Regulate metabolic processes	Insulin (regulates glucose metabolism)
Transport proteins	Transport substances from one place to another	Hemoglobin (transports oxygen)
Storage proteins	Provide source of essential nutrients	Casein (protein in mammalian milk)
Contractile and motile proteins	Mediate motion and muscle contraction	Actin and myosin (provide muscle contraction)
Protective proteins	Protect and defend cells	Antibodies (neutralize infectious agents)

Amino Acids

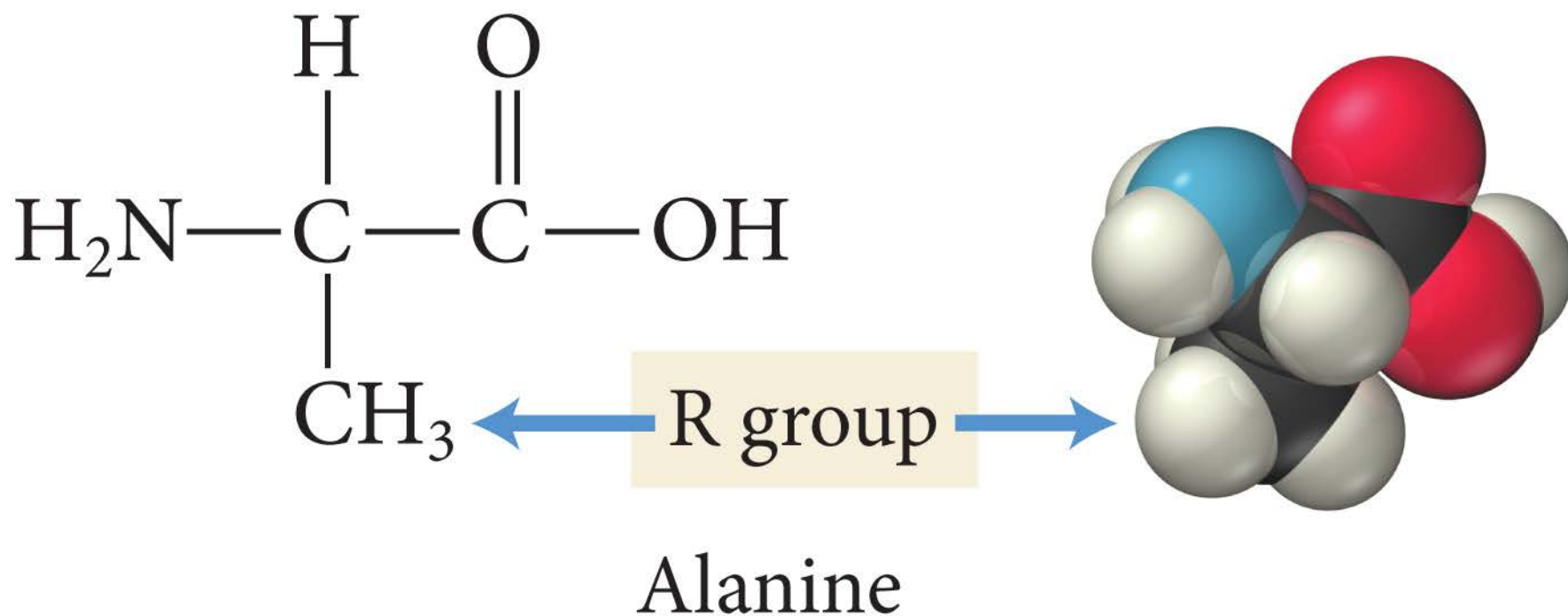
- NH_2 group on carbon adjacent to COOH
 - α -amino acids
- About 20 amino acids found in proteins
 - 10 synthesized by humans, 10 “essential”
- Each amino acid has a three-letter abbreviation.
 - Glycine = Gly
- High melting points
 - Generally decompose at temp $> 200^\circ \text{C}$
- Good solubility in water
- Less acidic than most carboxylic acids and less basic than most amines

Basic Structure of Amino Acids



Amino acid general structure

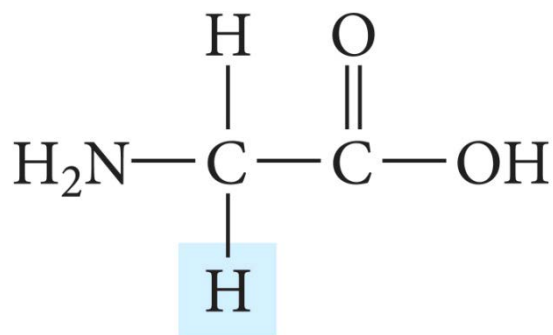
Basic Structure of Amino Acids



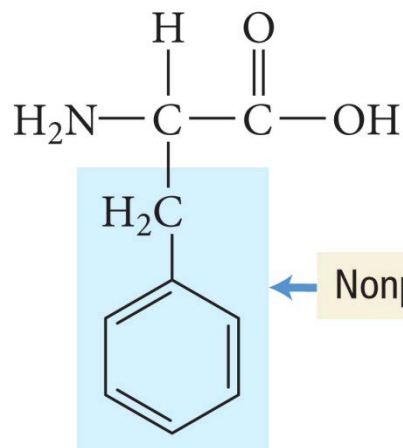
Amino Acids

- Building blocks of proteins
- Main difference between amino acids is the side chain
 - R group
- Some R groups are polar, while others are nonpolar.
- Some polar R groups are acidic, while others are basic.
- Some R groups contain O, others contain N, and others contain S.
- Some R groups are rings, while others are chains.

Some Amino Acids

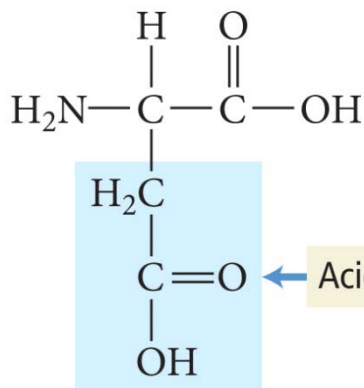


Glycine



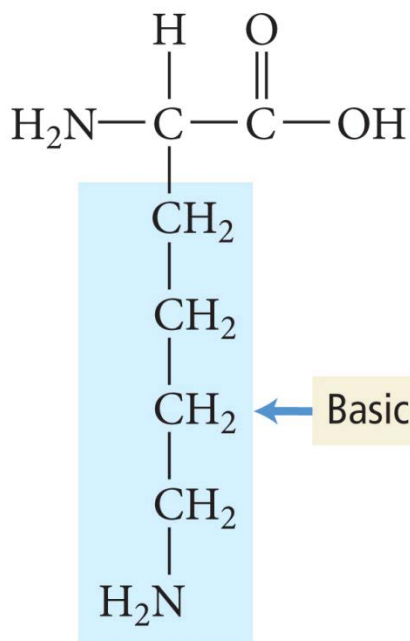
Nonpolar R group

Phenylalanine



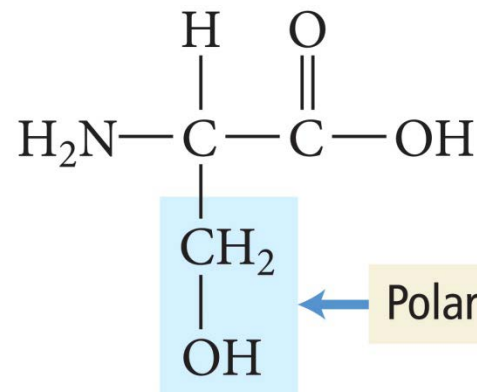
Acidic R group

Aspartic acid



Basic R group

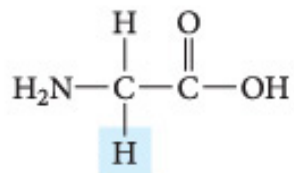
Lysine



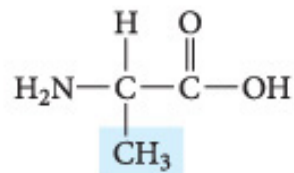
Polar R group

Serine

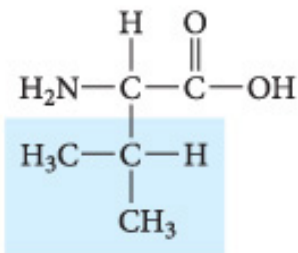
TABLE 21.3 Common Amino Acids



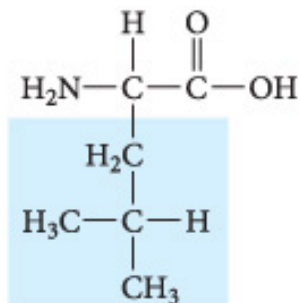
Glycine (Gly)



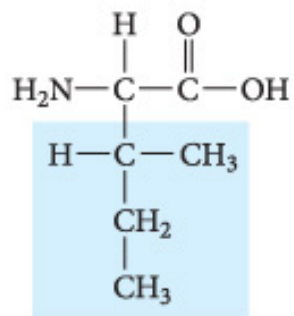
Alanine (Ala)



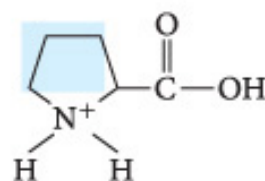
Valine (Val)



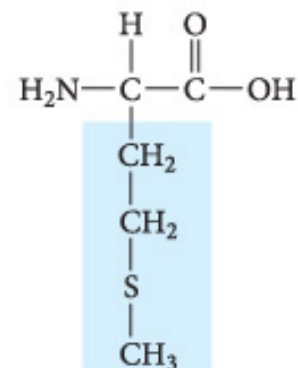
Leucine (Leu)



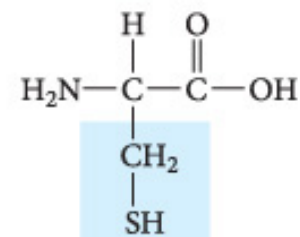
Isoleucine (Ile)



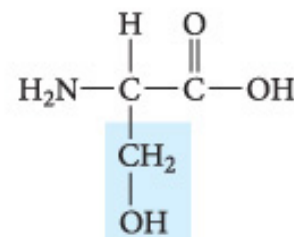
Proline (Pro)



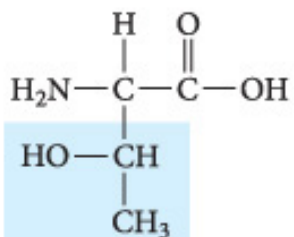
Methionine (Met)



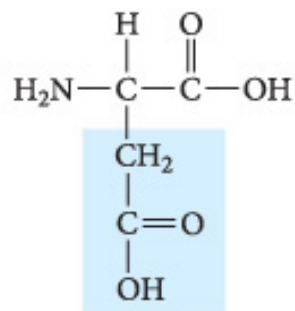
Cysteine (Cys)



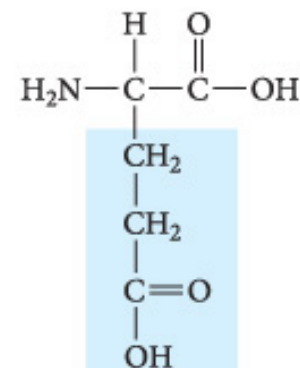
Serine (Ser)



Threonine (Thr)

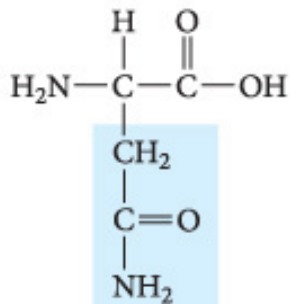


Aspartic acid (Asp)

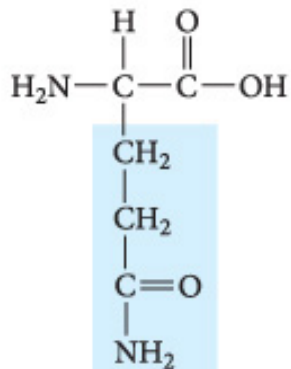


Glutamic acid (Glu)

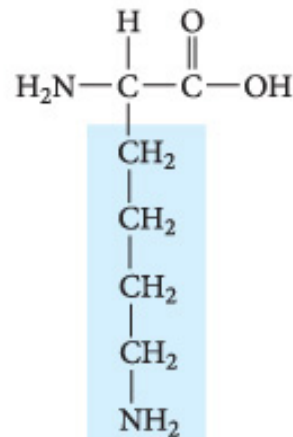
TABLE 21.3 Common Amino Acids (Cont.)



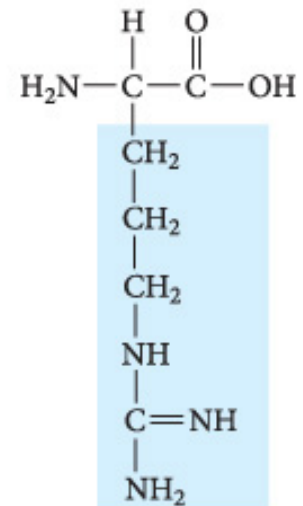
Asparagine (Asn)



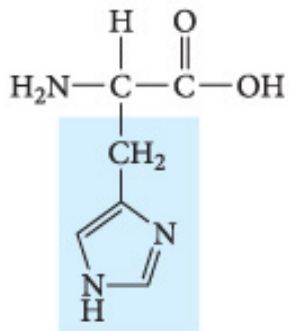
Glutamine (Gln)



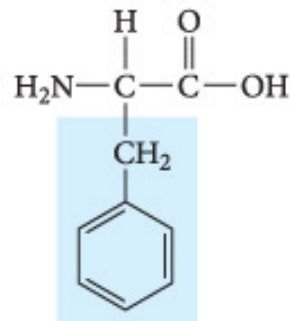
Lysine (Lys)



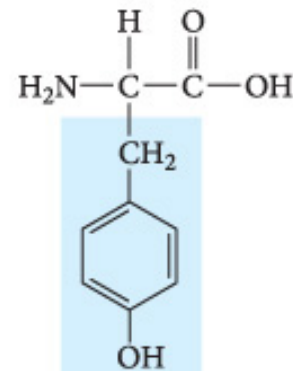
Arginine (Arg)



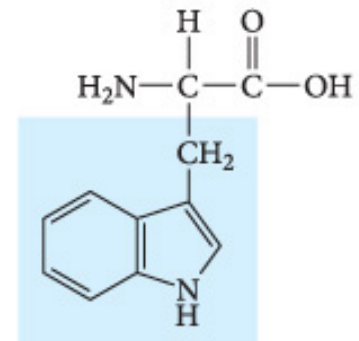
Histidine (His)



Phenylalanine (Phe)



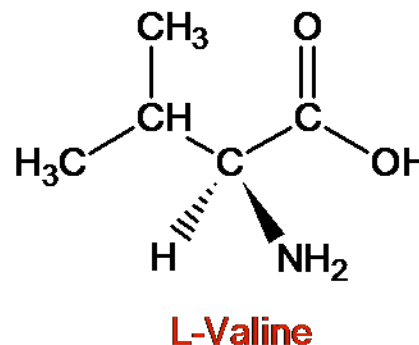
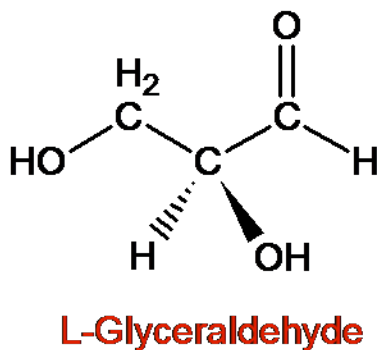
Tyrosine (Tyr)



Tryptophan (Trp)

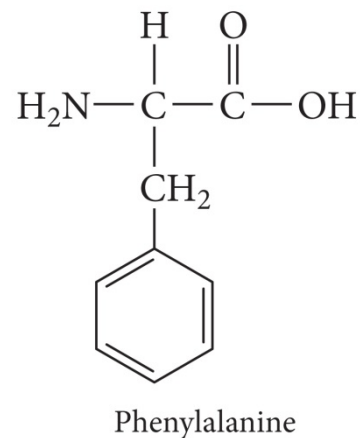
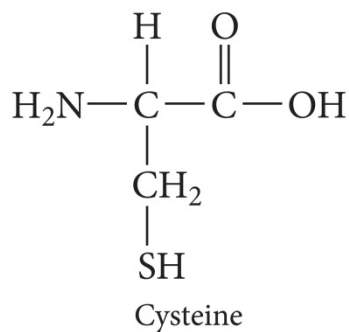
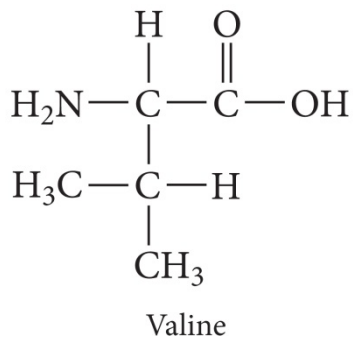
Optical Activity

- The α carbon is chiral on the amino acids.
 - Except for glycine
- Most naturally occurring amino acids have the same orientation of the groups as occurs in L-(*l*)-glyceraldehyde.
- Therefore, they are called the L-amino acids.
 - Not / for levorotatory



Example 21.2 Peptide Bonds

Show the reaction by which valine, cysteine, and phenylalanine (in that order) link via peptide bonds. Designate valine as N-terminal and label the N-terminal and C-terminal ends in the resulting tripeptide.

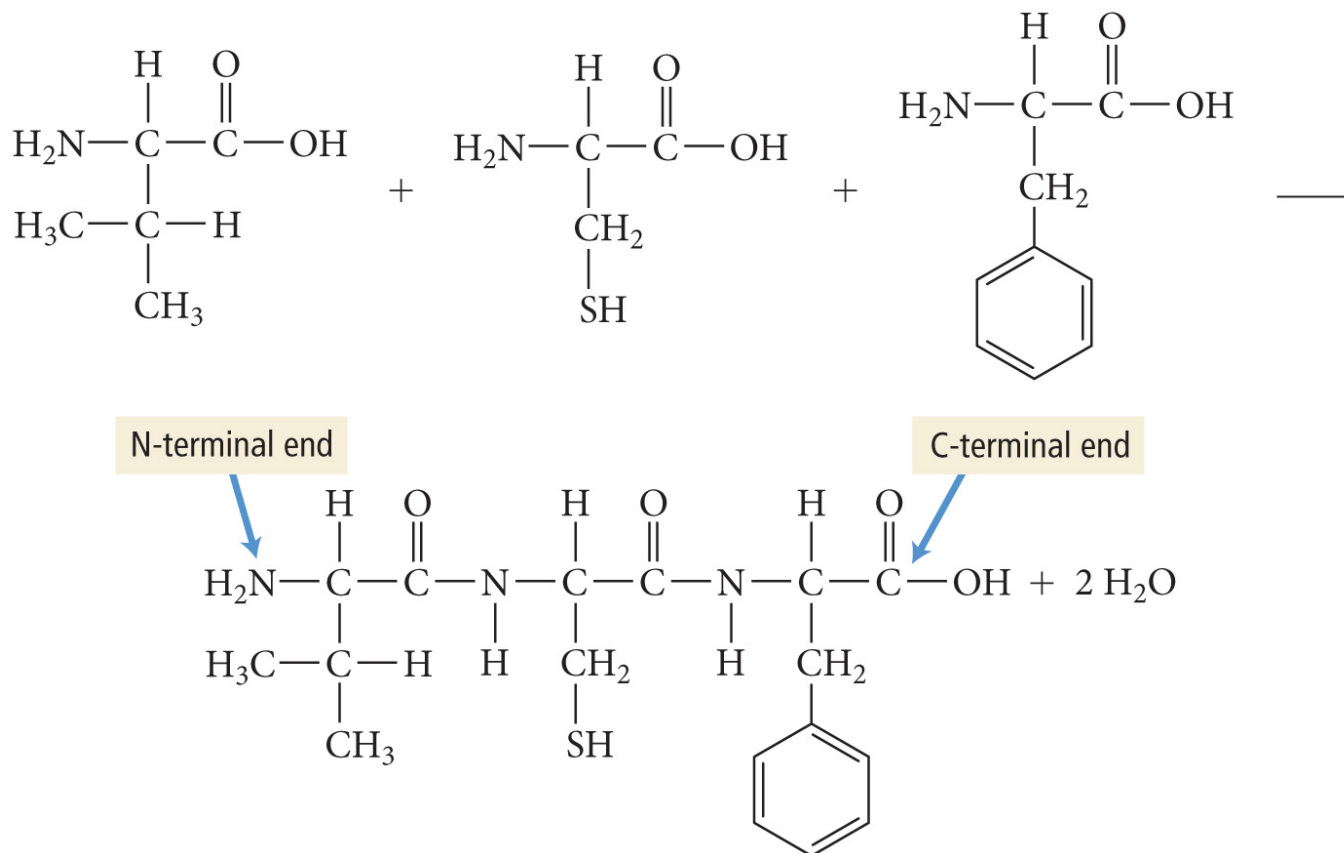


Example 21.2 Peptide Bonds

Continued

Solution

Peptide bonds form when the carboxylic end of one amino acid reacts with the amine end of another amino acid.

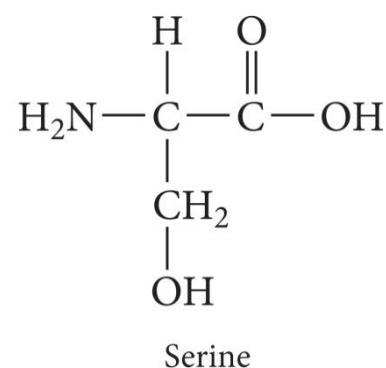
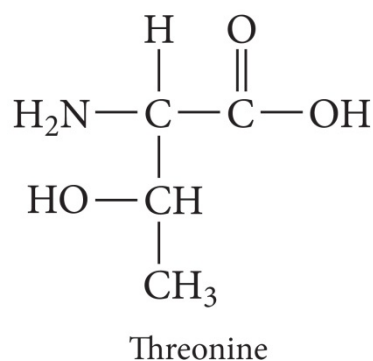
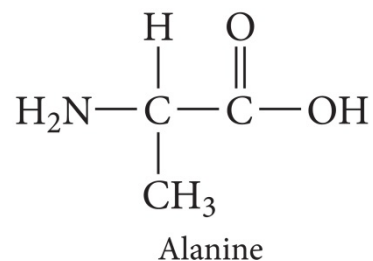


Example 21.2 Peptide Bonds

Continued

For Practice 21.2

Show the reaction by which alanine, threonine, and serine (in that order) link via peptide bonds. Designate alanine as the N-terminal and label the N-terminal and C-terminal ends in the resulting tripeptide.

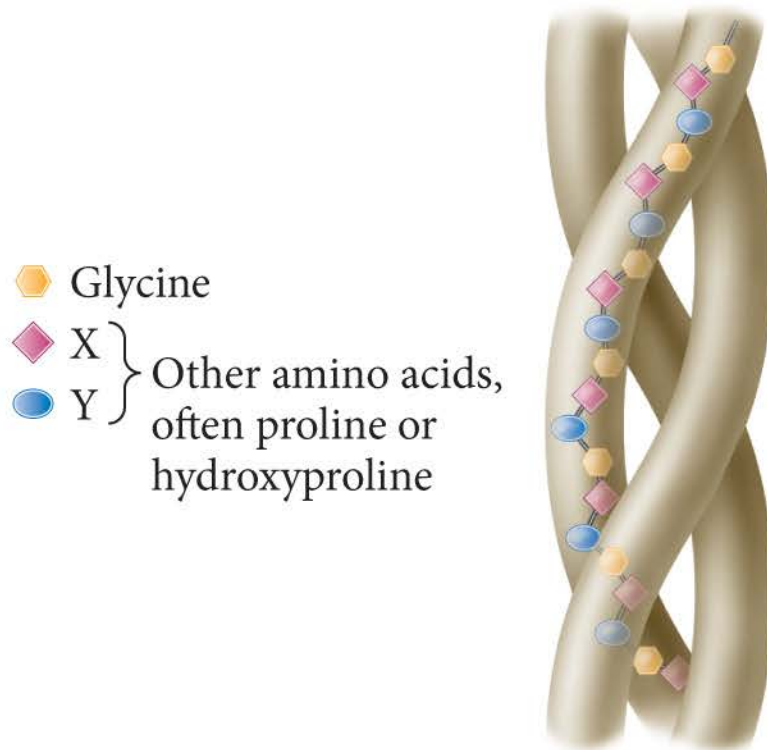


21.5 Protein Structure

- The structure of a protein is key to its function.
- Most proteins are classified as either fibrous or globular.
- Fibrous proteins have a linear, simple structure.
 - Insoluble in water
 - Used in structural features of the cell
- Globular proteins have a complex, three-dimensional structure.
 - Generally have polar R groups of the amino acids pointing out – so they are somewhat soluble, but also maintain an area that is nonpolar in the interior

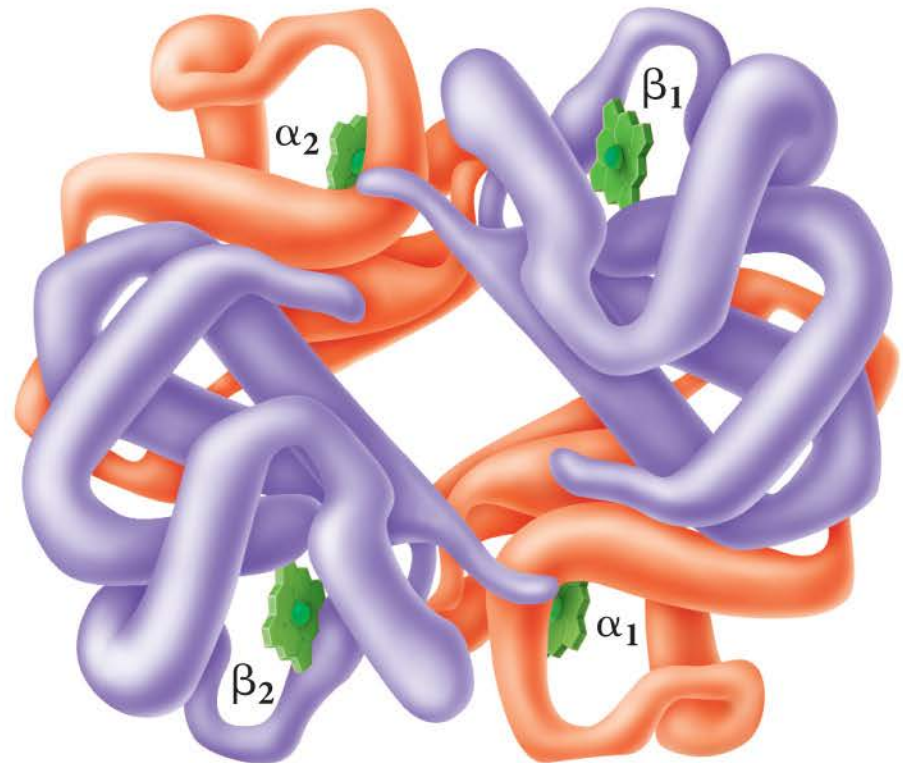
Fibrous and Globular Proteins

Fibrous protein



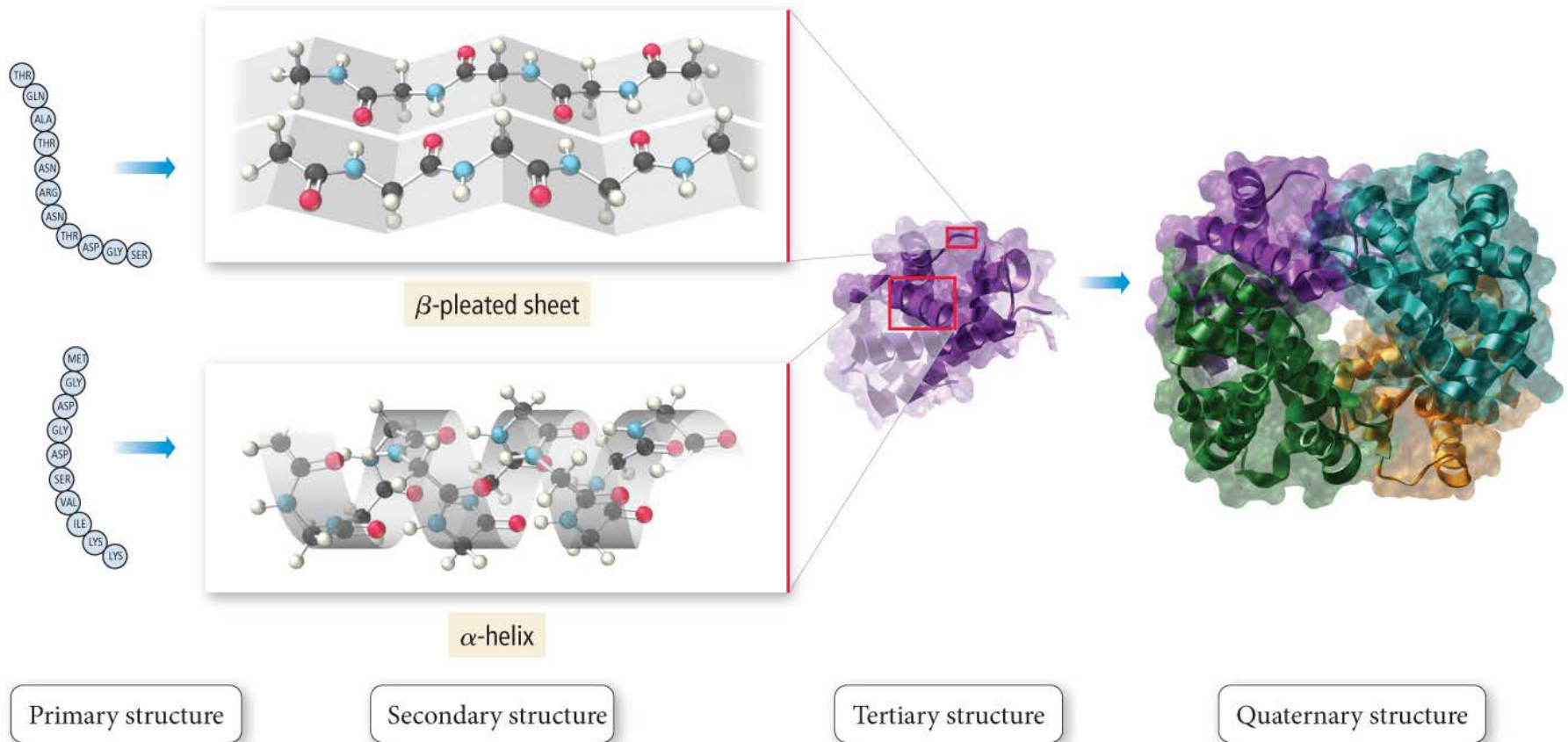
Collagen

Globular protein



Hemoglobin

Levels of Protein Structure

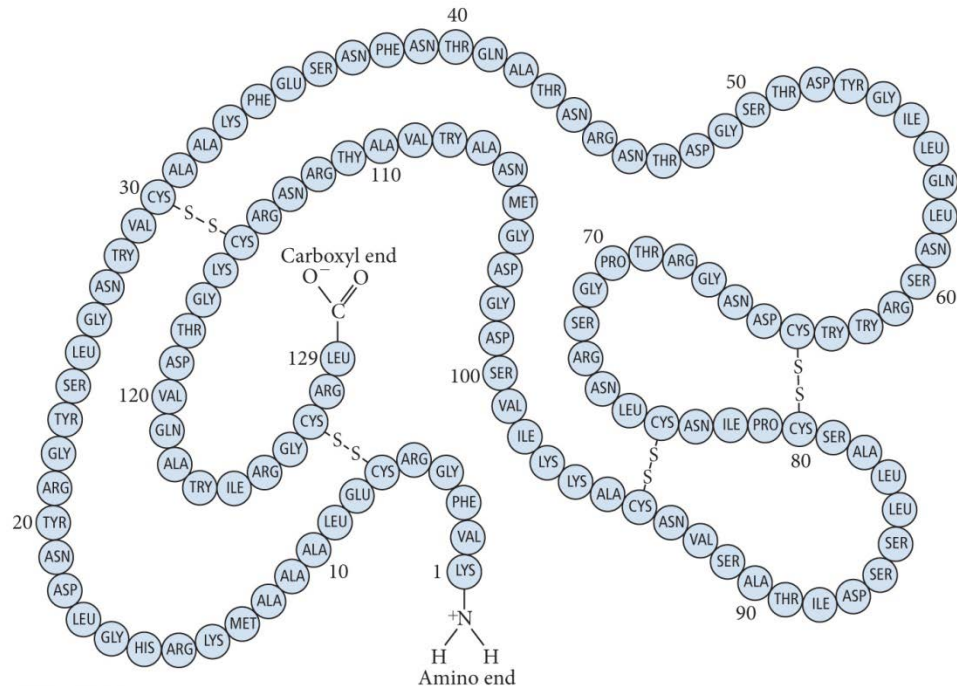


Primary Protein Structure

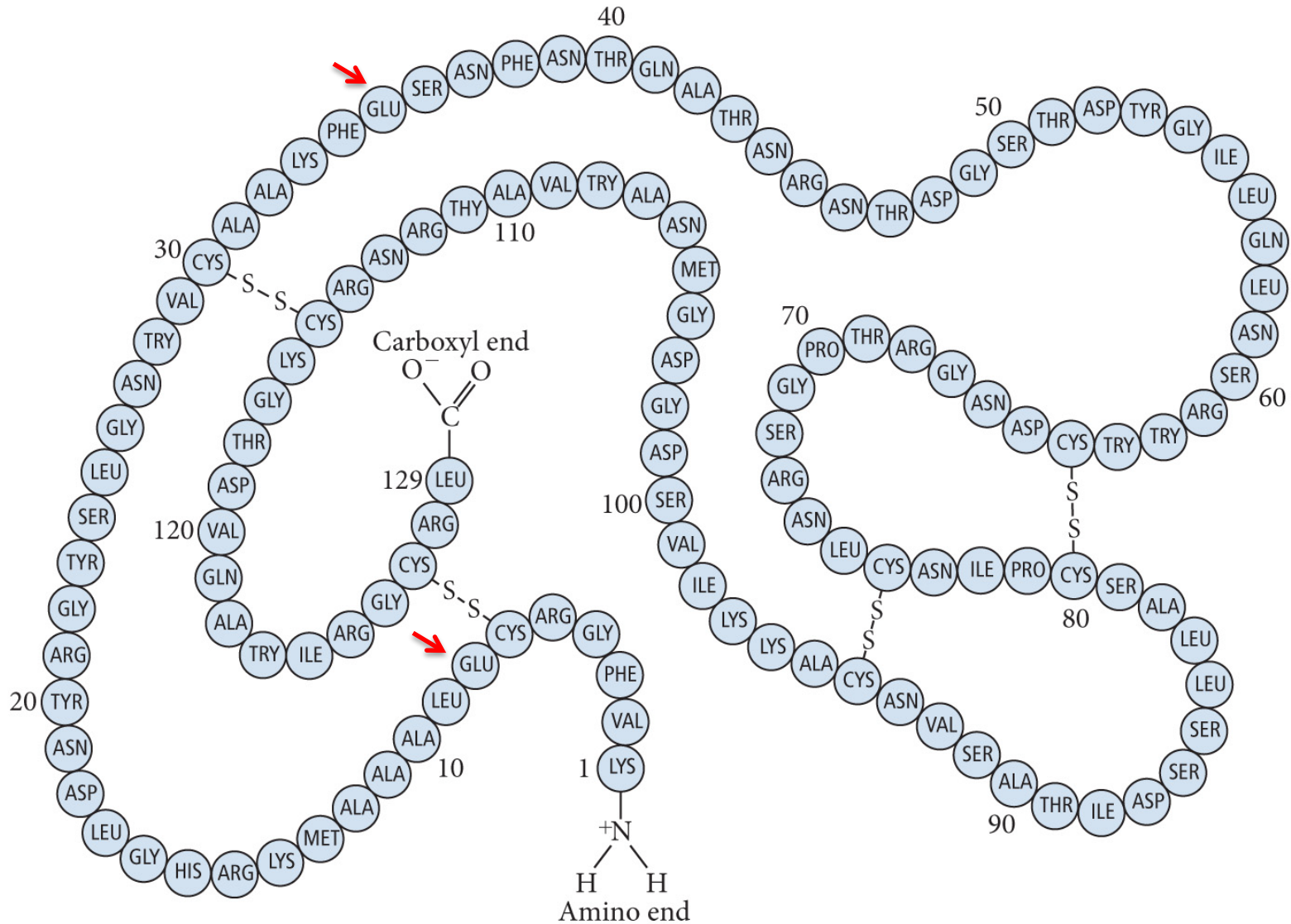
- **The primary structure is determined by the order of amino acids in the polypeptide.**
- Link COOH group of first to NH₂ of second.
 - Loss of water, condensation
 - Forms an **amide** structure
 - The amide bond between amino acids is called a **peptide bond**.
- Linked amino acids are called **peptides**.
 - Dipeptide = 2 amino acids; tripeptide = 3, etc.
 - Oligopeptides = short peptide chains
 - Polypeptides = many linked amino acids in a long chain

Primary Structure Sickle-Cell Anemia

- Changing one amino acid in the protein can vastly alter the biochemical behavior.
- Sickle-cell anemia
 - Replace one Val amino acid with Glu on two of the four chains
 - Red blood cells take on sickle shape that can damage organs



Egg-White Lysozyme Primary Structure



Secondary Structure

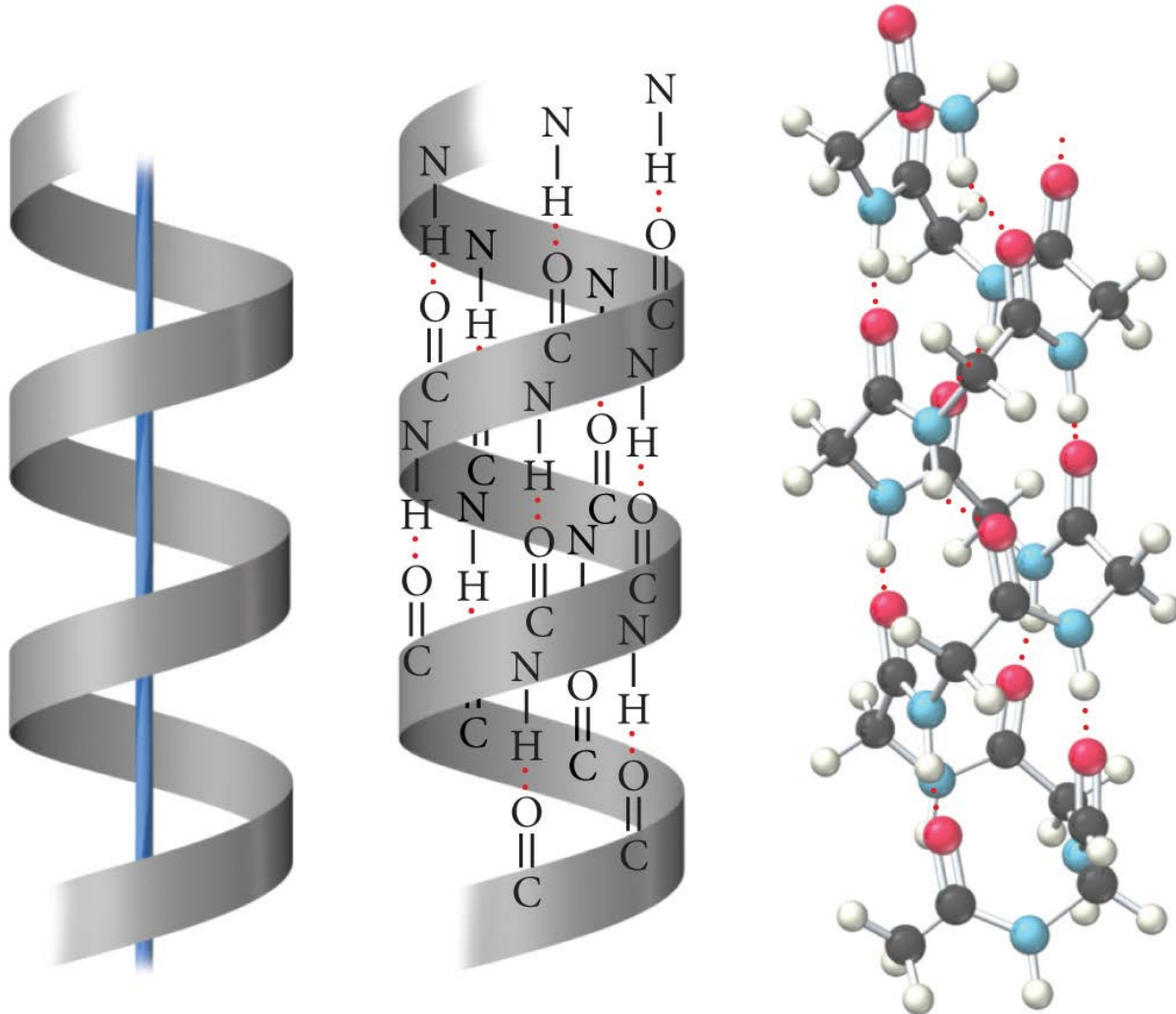
- Short-range repeating patterns found in protein chains
- Maintained by interactions between amino acids that are near each other in the chain
- Formed and held by H-bonds between NH and C=O
- α -helix
 - Most common
- β -pleated sheet
- Many proteins have sections that are α -helix, other sections are β -sheets, and others are **random coils**.

α -Helix

- The α -helix is a secondary structure in which the amino acid chain is wrapped into a tight coil with the R groups pointing outward from the coil
- The **pitch** is the distance between the coils.
- The pitch and helix diameter ensure bond angles are not strained and H-bonds are as strong as possible.

α -Helix

α -Helix protein structure

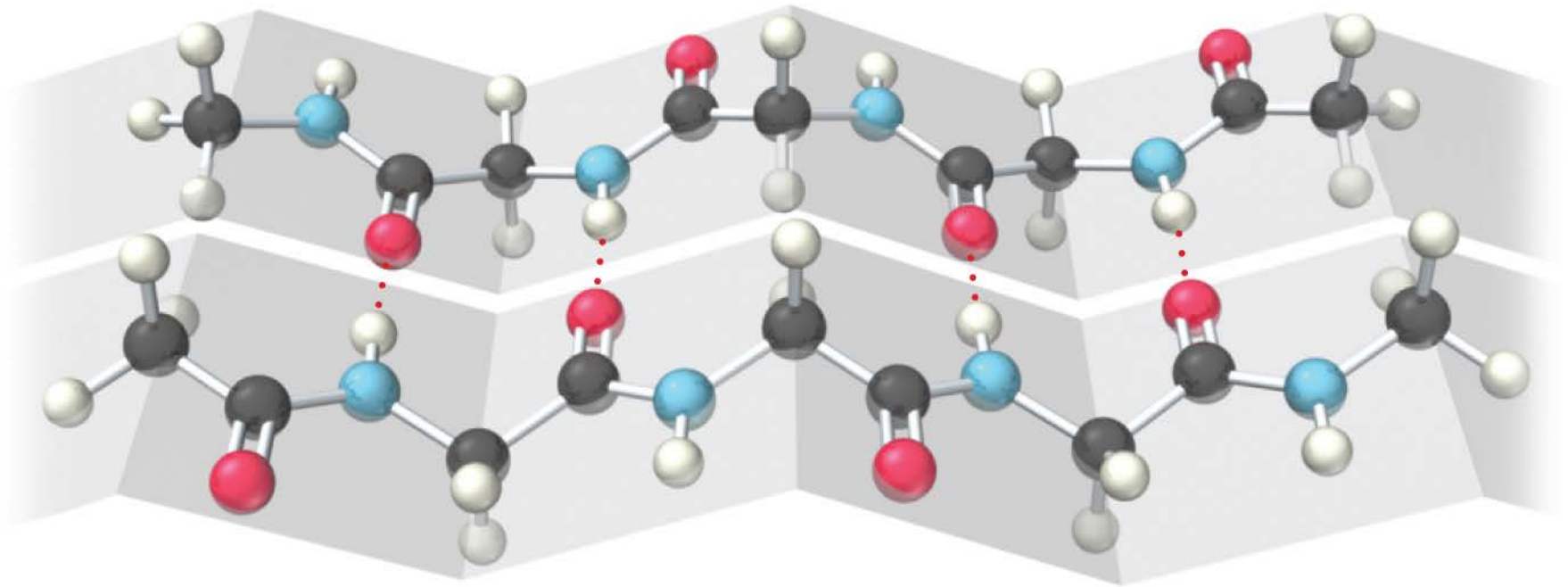


β -Pleated Sheet

- The β -pleated sheet is a secondary structure in which the amino acid chains are extended in a zig-zag pattern, and then the chains are linked together to form a structure that looks like a folded piece of paper.
- Chains linked together by H-bonds
- Silk

β -Pleated Sheet Structure

β -Pleated sheet protein structure

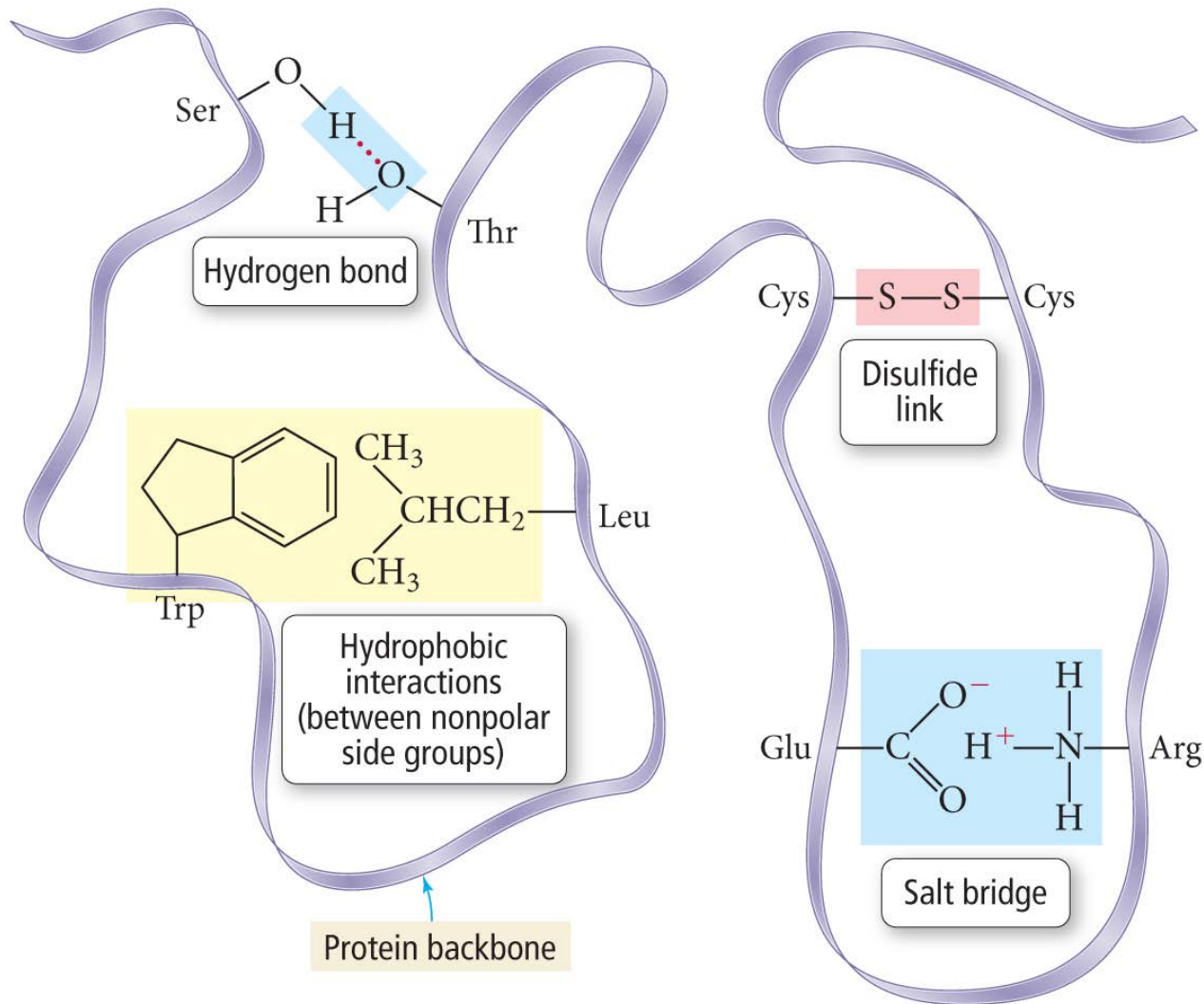


Tertiary Structure

- The **tertiary structure** comprises the large-scale bends and folds due to interactions between R groups separated by large distances on the chains.
- Types of interactions include
 - H-bonds
 - Disulfide linkages
 - Between cysteine amino acids
 - Hydrophobic interactions
 - Between large, nonpolar R groups
 - Salt bridges
 - Between acidic and basic R groups

Interactions That Create Tertiary Structure

Interactions That Maintain Tertiary Structure



Tertiary Structure and Protein Type

- Fibrous proteins generally lack tertiary structure
 - Extend as long, straight chains with some secondary structure
- Globular proteins fold in on themselves, forming complex shapes due to the tertiary interactions

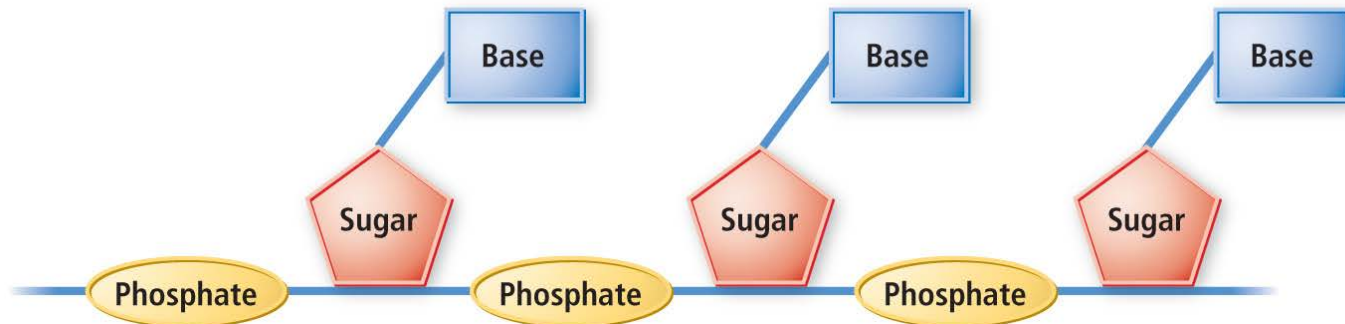
Quaternary Structure

- Many proteins are composed of multiple amino acid chains.
- The way the chains are linked together is called **quaternary structure**.
- Interactions holding the chains together are the same kinds as in tertiary structure.

21.6 Nucleic Acids

- Carry genetic information
- DNA molar mass = 6 to 16 million amu
- RNA molar mass = 20 K to 40 K amu
- Made of nucleotides
 - Phosphoric acid unit
 - 5-carbon sugar
 - Cyclic amine (base) → (A'G'C'T)
- Nucleotides are joined by **phosphate linkages**.

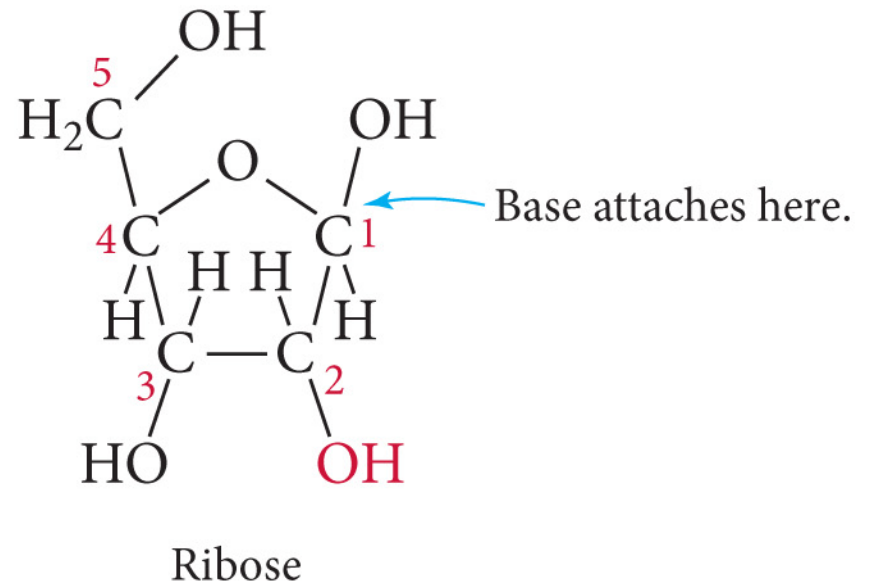
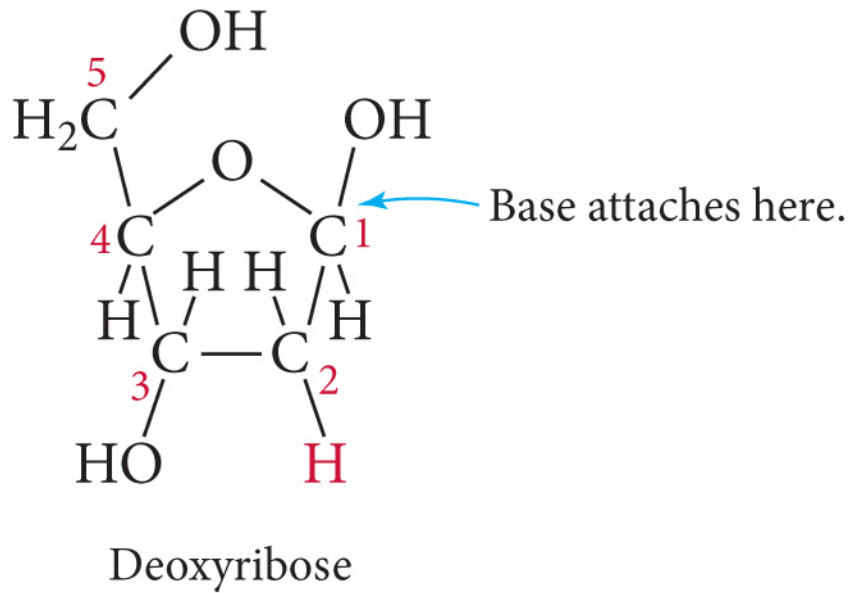
DNA: Basic Structure



Nucleotide Structure

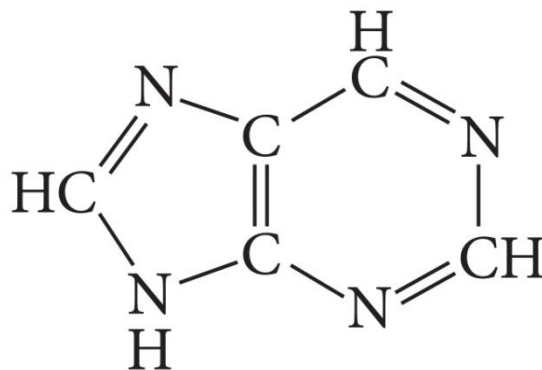
- Each nucleotide has three parts—a cyclic pentose, a phosphate group, and an organic aromatic base.
- The pentoses are ribose or deoxyribose.
- The pentoses are the central backbone of the nucleotide.
- The pentose is attached to the organic base at C1 and to the phosphate group at C5.

Sugars

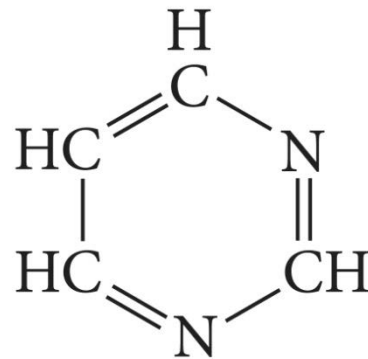


Bases

- The bases are organic amines that are aromatic .
 - Like benzene, except containing N in the ring
 - Means the rings are flat rather than puckered like the sugar rings
- Two general structures: two of the bases are similar in structure to the organic base **purine**; the other two bases are similar in structure to the organic base **pyrimidine**.



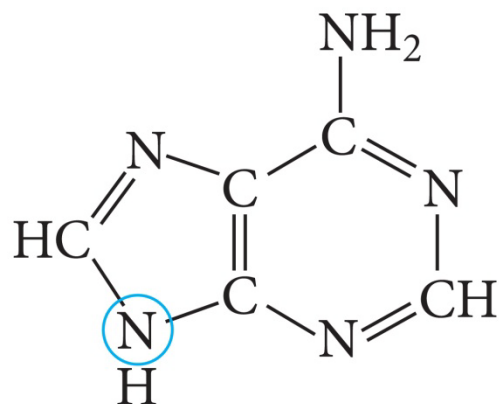
Purine



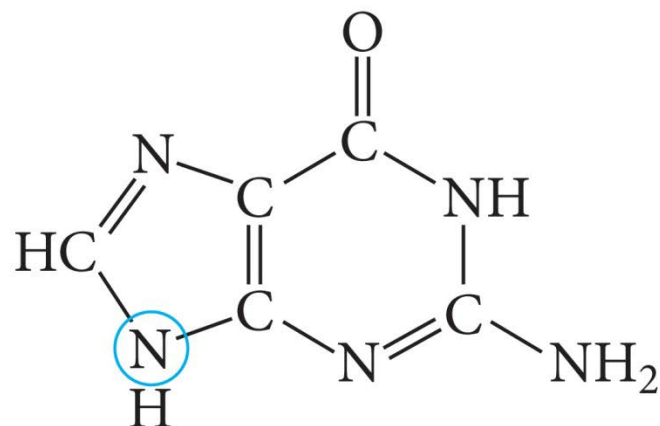
Pyrimidine

Organic Bases

Purine Bases

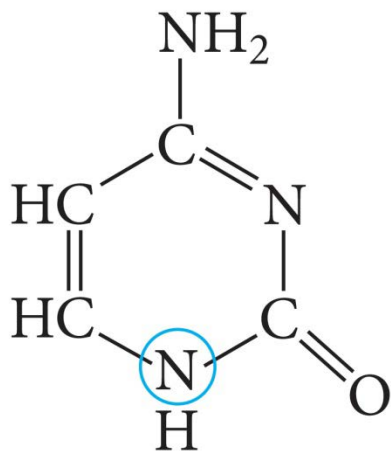


Adenine

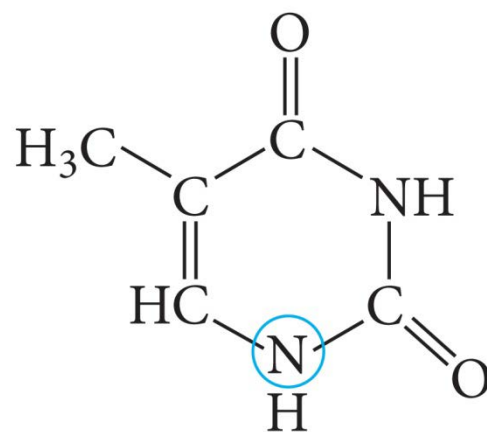


Guanine

Pyrimidine Bases



Cytosine

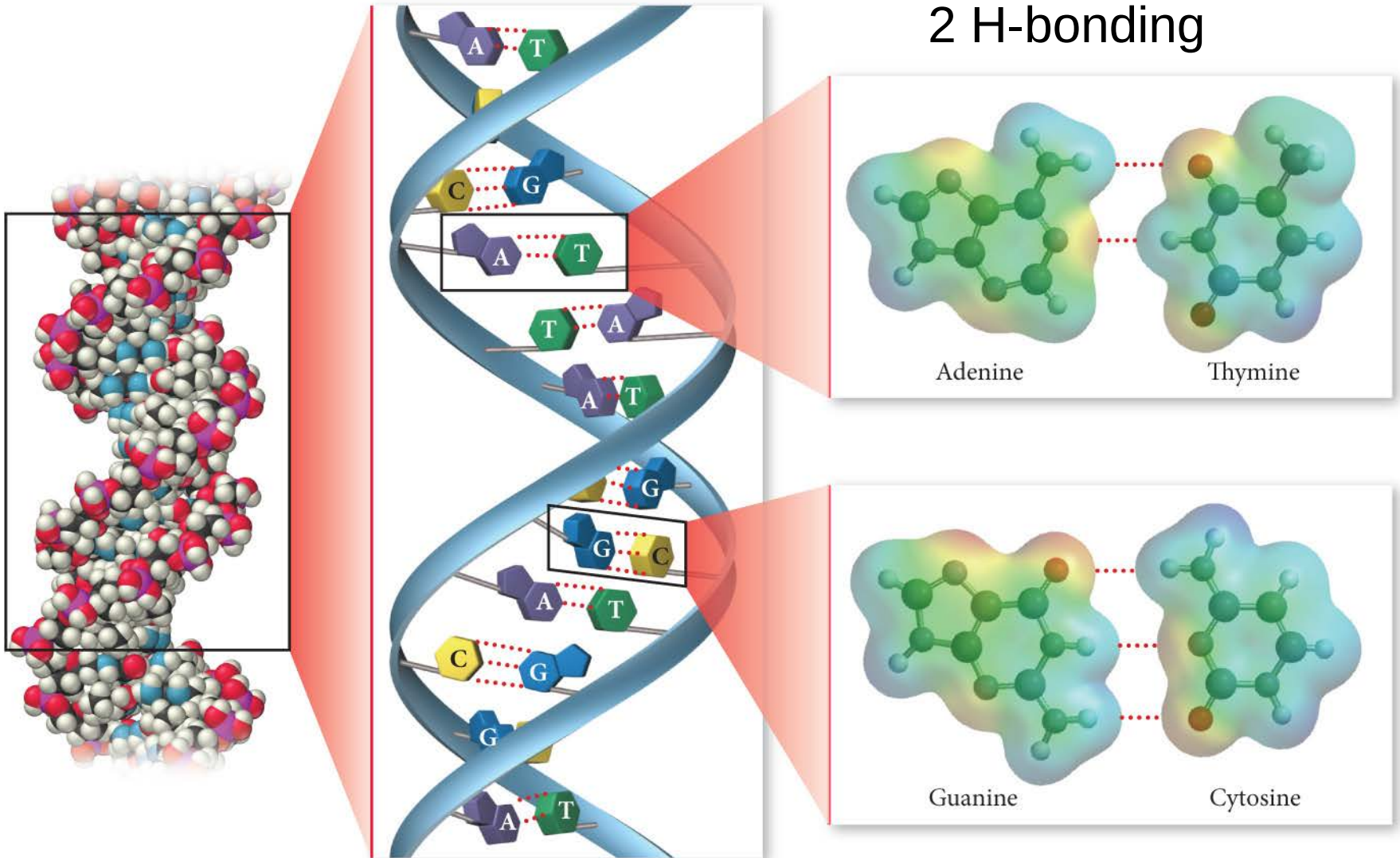


Thymine

Bases

- The structures of the base are **complementary**(互補), meaning that a purine and pyrimidine will precisely align to **H-bond** with each other.
 - Adenine matches thymine or uracil.
 - Guanine matches cytosine.
- Attach to sugar at C1 of the sugar through circled N

Base Pairing in DNA



2 H-bonding

Adenine

Thymine

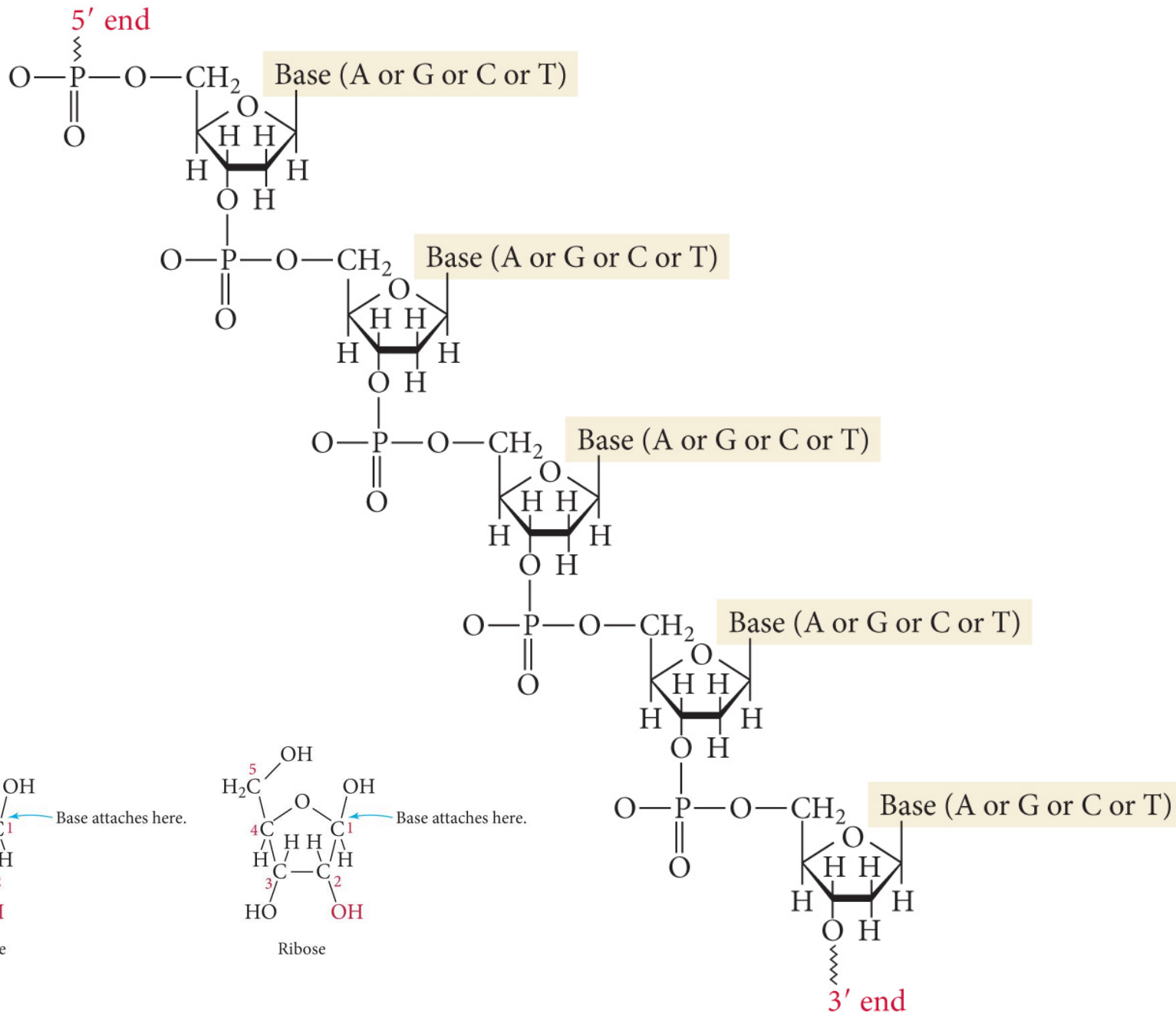
Guanine

Cytosine

3 H-bonding

Primary Structure of Nucleic Acids

- Nucleotides are linked together by attaching the phosphate group of one to the sugar of another at the O of C3.
- The attachment is called **phosphate ester bond**.
- The phosphate group attaches to C3 of the sugar on the next nucleotide.



The Genetic Code

- The order of nucleotides on a nucleic acid chain specifies the order of amino acids in the primary protein structure.
- A sequence of three nucleotide bases determines which amino acid is next in the chain; this sequence is called a **codon**.
- The sequence of nucleotide bases that code for a particular amino acid is practically universal.

Genetic Structure

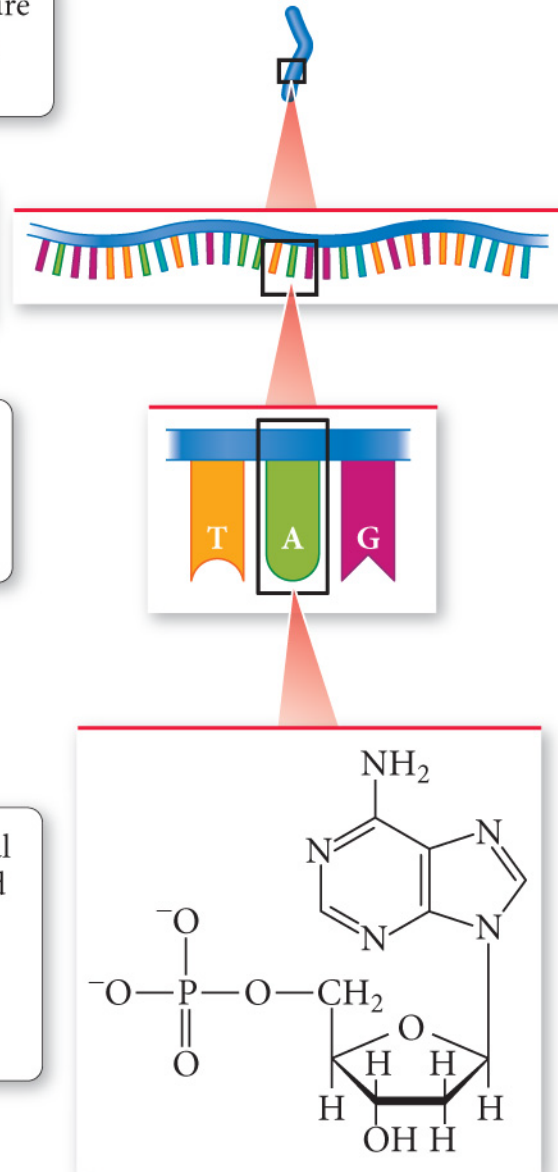
Important
all

Chromosome—structure within cell nucleus that houses DNA.

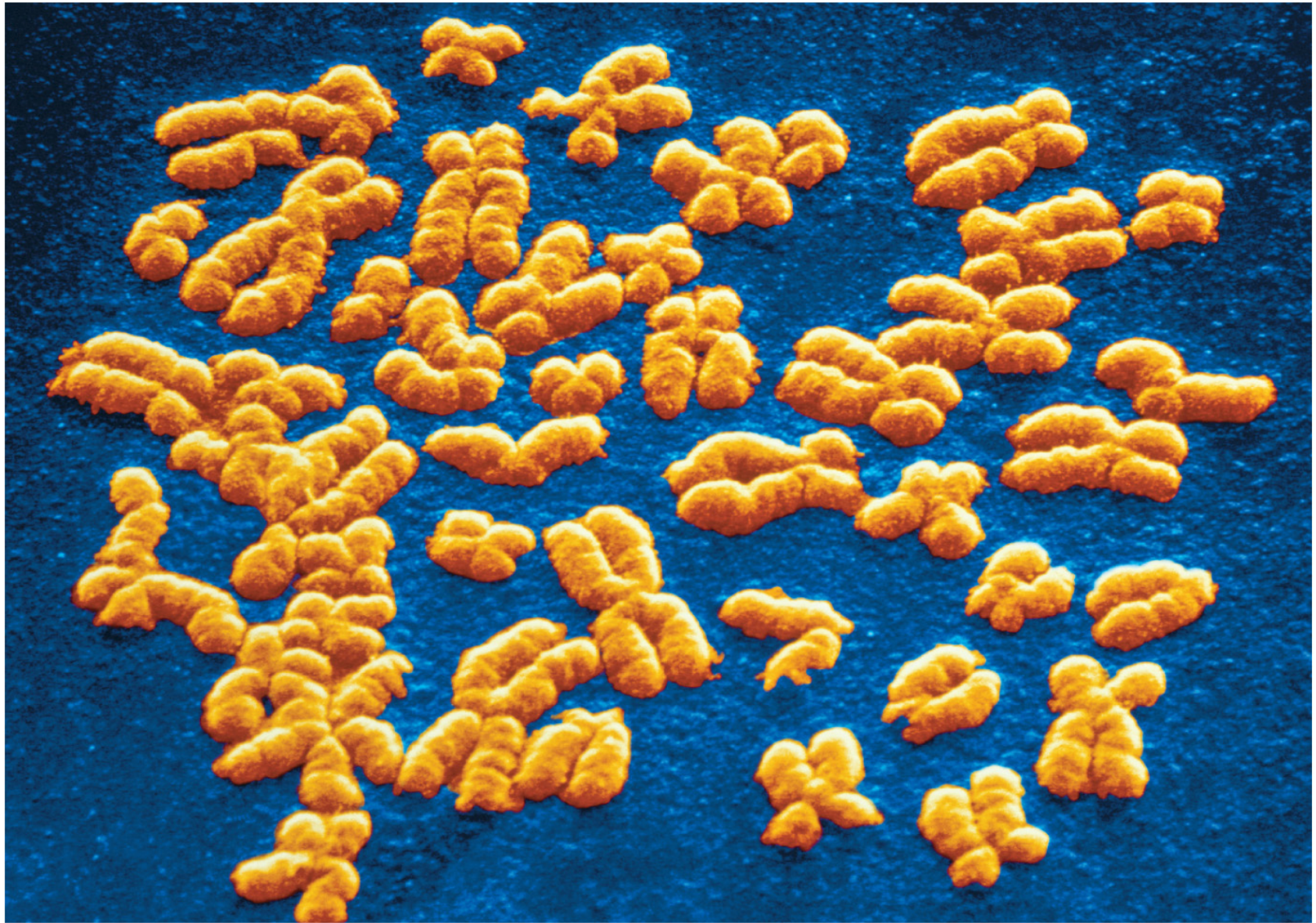
Gene—portion of DNA that codes for a single protein.

Codon—sequence of three nucleotides. A codon codes for one amino acid.

Nucleotide—individual links in the nucleic acid chain. Nucleotides are composed of a sugar group, a phosphate group, and a base.



Chromosomes



21.7 DNA Replication, the Double Helix, and Protein Synthesis

DNA

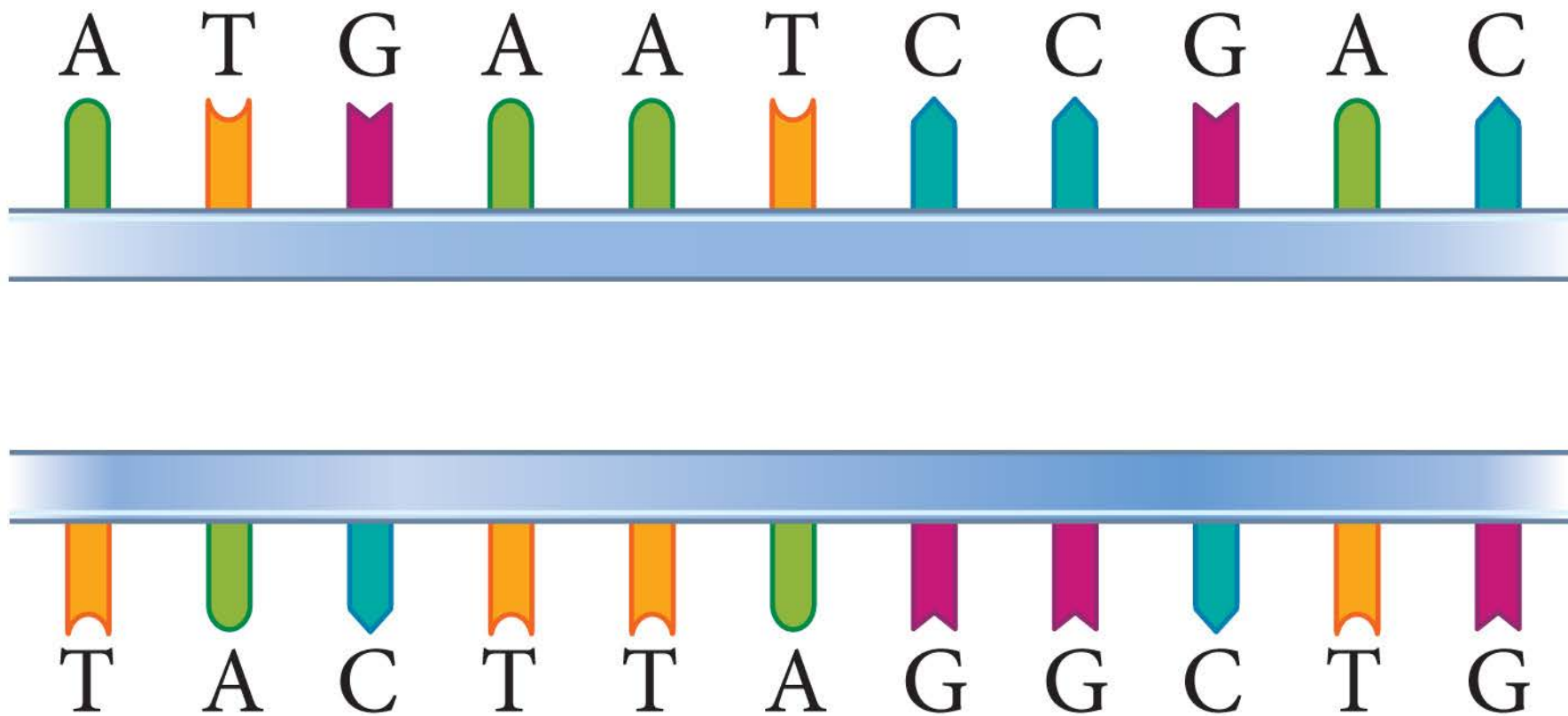
- Deoxyribonucleic acid
- Sugar is deoxyribose.
- DNA is made up of the following amine bases:
 - Adenine (A)
 - Guanine (G)
 - Cytosine (C)
 - Thymine (T)
- Two DNA strands wound together in double helix
- Each of the 10 trillion cells in the body has the entire DNA structure.

RNA

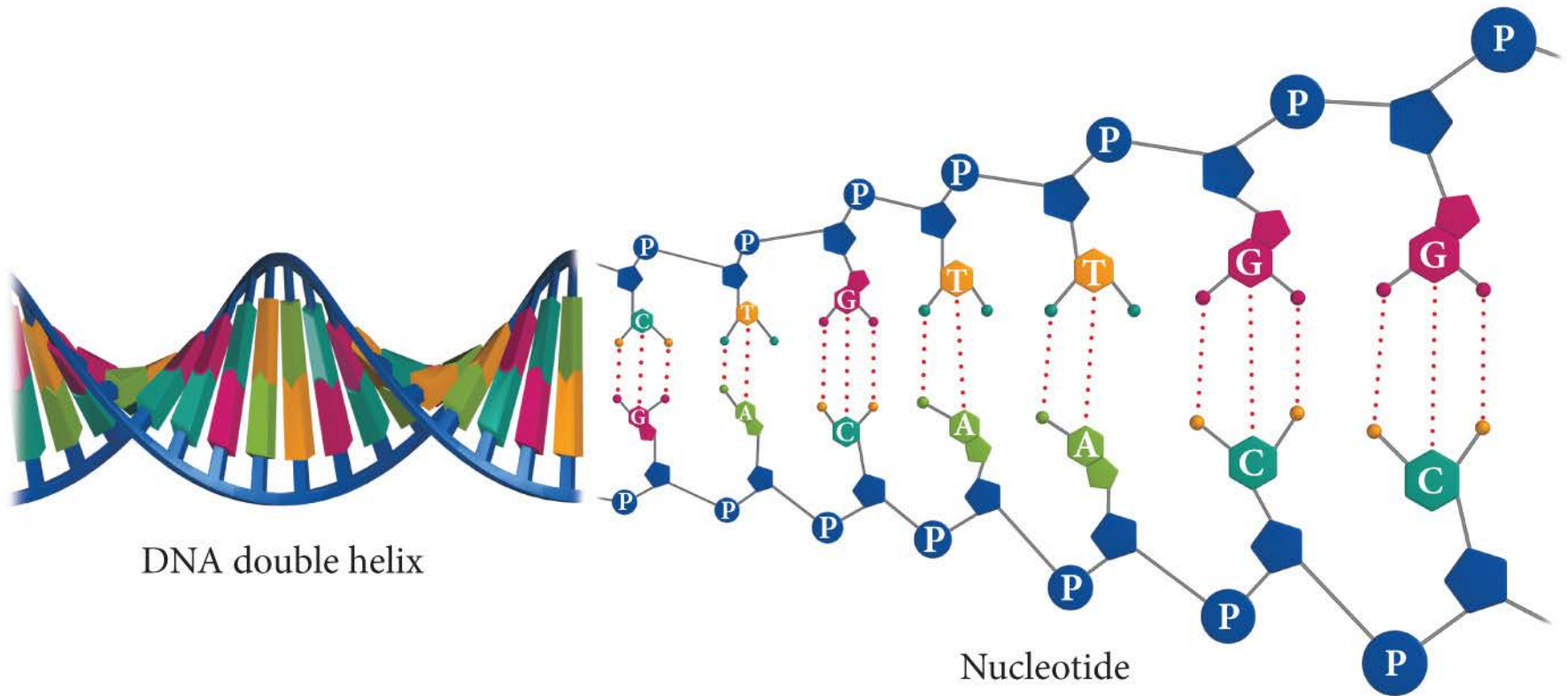
- Ribonucleic acid
- Sugar is ribose.
- RNA is made of up of the following amine bases:
 - Adenine (A)
 - Guanine (G)
 - Cytosine (C)
 - Uracil (U)
- Single strands wound in helix

DNA Structure

- DNA made of two strands linked together by H-bonds between bases
- Strands are antiparallel
 - One runs 3'→ 5', while other runs 5'→ 3'.
- Bases are complementary and directed to the interior of the helix.
 - A pairs with T, and C with G.



DNA Double Helix



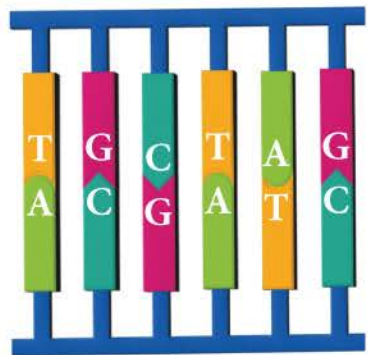
Base Pairing

- Base pairing generates the helical structure.
- In DNA, the complementary bases hold strands together by H-bonding.
 - Allow replication of strand

DNA Replication

- When the DNA is to be replicated, the region to be replicated uncoils.
- This H-bond between the base pairs is broken, separating the two strands.
- With the aid of enzymes, new strands of DNA are constructed by linking the complementary nucleotides and the original strand together.

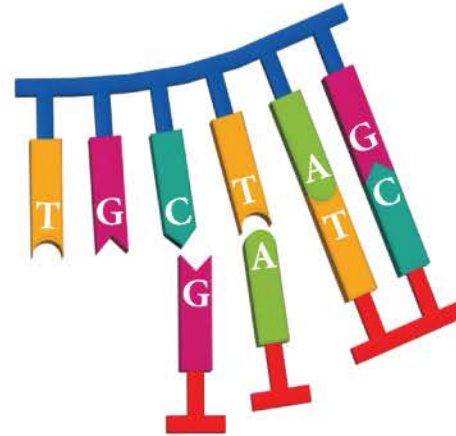
DNA Replication



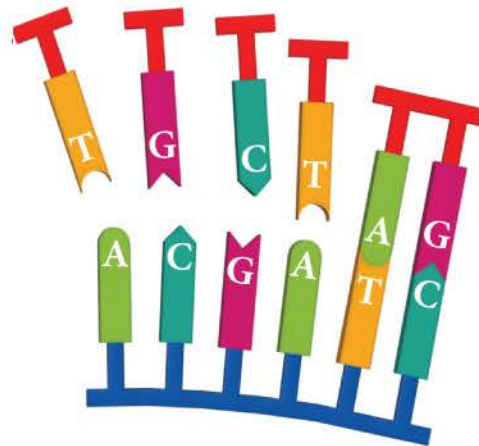
DNA to be replicated



Strands separate



A complement to each daughter strand is formed.



Two complete copies of original DNA.



Protein Synthesis

- Transcription → translation
- In the nucleus, the DNA strand at the gene separates and a complementary copy of the gene is made in RNA.
 - Messenger RNA = mRNA
- The mRNA travels into the cytoplasm where it links with a **ribosome**.
- At the ribosome, each codon on the RNA codes for a single amino acid, and these are joined together to form the polypeptide chain.

Protein Synthesis

