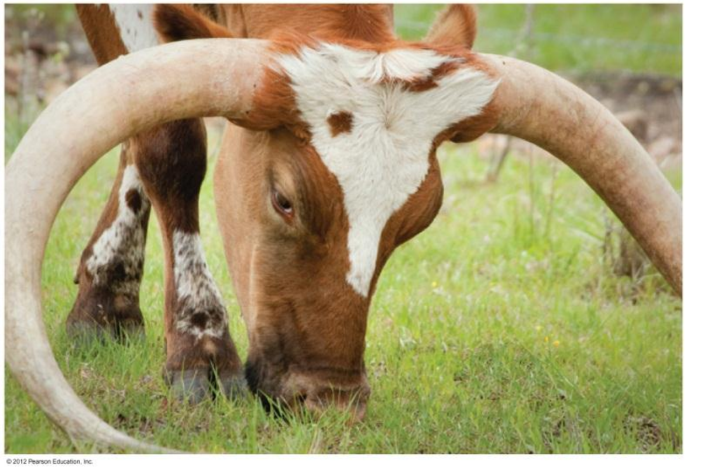
Chapter 16 Amino Acids, Proteins, and Enzymes

Functions of Proteins

Proteins

- in the body are polymers made from 20 different amino acids
- differ in characteristics and functions that depend on the order of amino acids that make up the protein
- perform many different functions in the body, such as provide structure, transport oxygen, direct biological reactions, control against infection, and even be a source of energy



The horns of animals are made of proteins.

Functions of Proteins

TABLE 16.1 Classification of Some Proteins and Their Functions

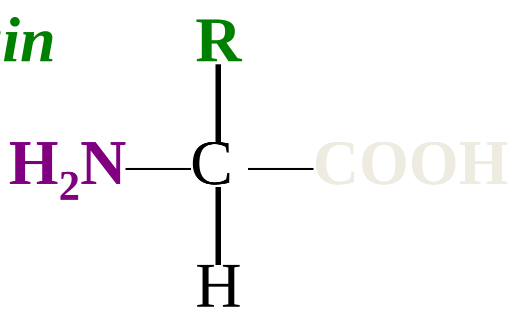
Class of Protein	Function	Examples
Structural	Provide structural components	*Collagen* is in tendons and cartilage. *Keratin* is in hair, skin, wool, and nails.
Contractile	Make muscles move	*Myosin* and *actin* contract muscle fibers.
Transport	Carry essential substances throughout the body	*Hemoglobin* transports oxygen. *Lipoproteins* transport lipids.
Storage	Store nutrients	*Casein* stores protein in milk. *Ferritin* stores iron in the spleen and liver.
Hormone	Regulate body metabolism and nervous system	*Insulin* regulates blood glucose level. *Growth hormone* regulates body growth.
Enzyme	Catalyze biochemical reactions in the cells	*Sucrase* catalyzes the hydrolysis of sucrose. *Trypsin* catalyzes the hydrolysis of proteins.
Protection	Recognize and destroy foreign substances	*Immunoglobulins* stimulate immune responses.

Amino Acids

Amino acids

- are the molecular building blocks of proteins
- contain a **carboxylic acid group** and an **amino group** on the alpha (α) carbon
- are ionized in solution
- each contain a different **side group (R)**

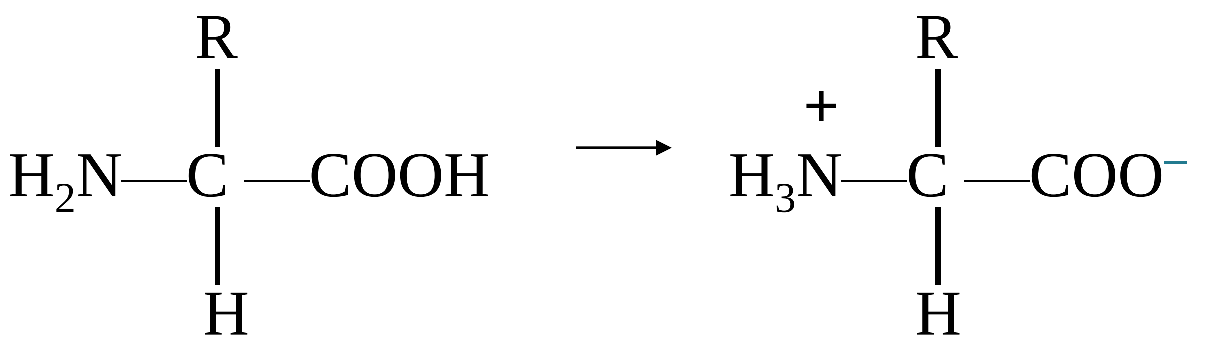
side chain



Ionization of Amino Acids

In most body fluids the carboxylic group (−COOH) and the amino group ($-NH_2$) are ionized.

An ionized amino acid that has a positive and negative charge is a dipolar ion called a **zwitterion.**



Zwitterion (ionized form)

Fischer Projections of Amino Acids

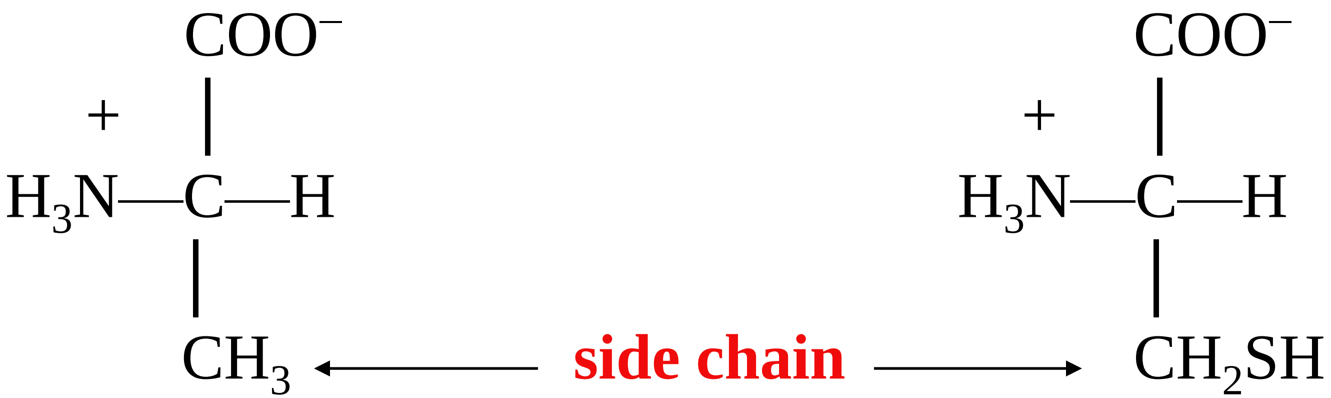
Amino acids

- are chiral except for glycine
- have Fischer projections that are stereoisomers
- with the

    - carboxylate group at the top,
    - R group at the bottom, and
    - amino group on the left

  are the L isomers
- **in proteins are all L isomers; no D isomers are found in proteins**

Stereoisomers of Amino Acids

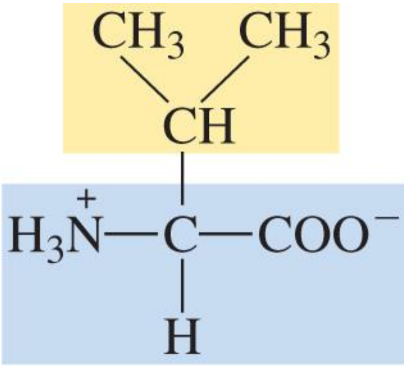


L–Alanine **L–Cysteine**

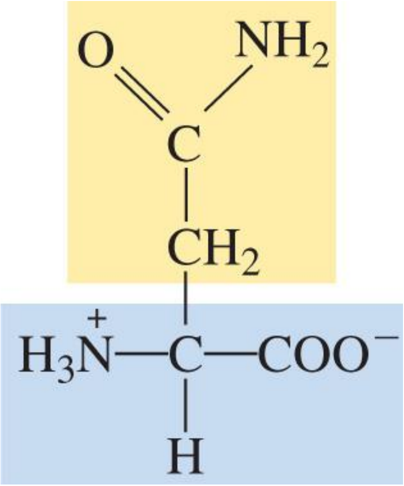
Types of Amino Acids

Amino acids are classified as

- **nonpolar** (hydrophobic) with hydrocarbon side chains
- **polar** (hydrophilic) with polar or ionic side chains



Nonpolar
Valine

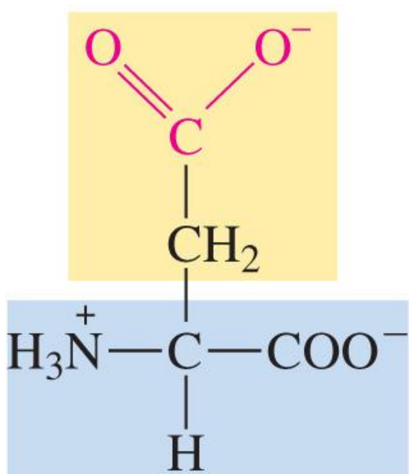


Polar
Asparagine

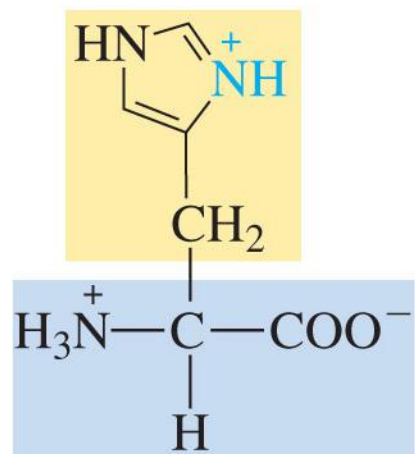
Types of Amino Acids

Amino acids are classified as

- **acidic** (hydrophilic) with acidic side chains
- **basic** (hydrophilic) with $-NH_2$ side chains



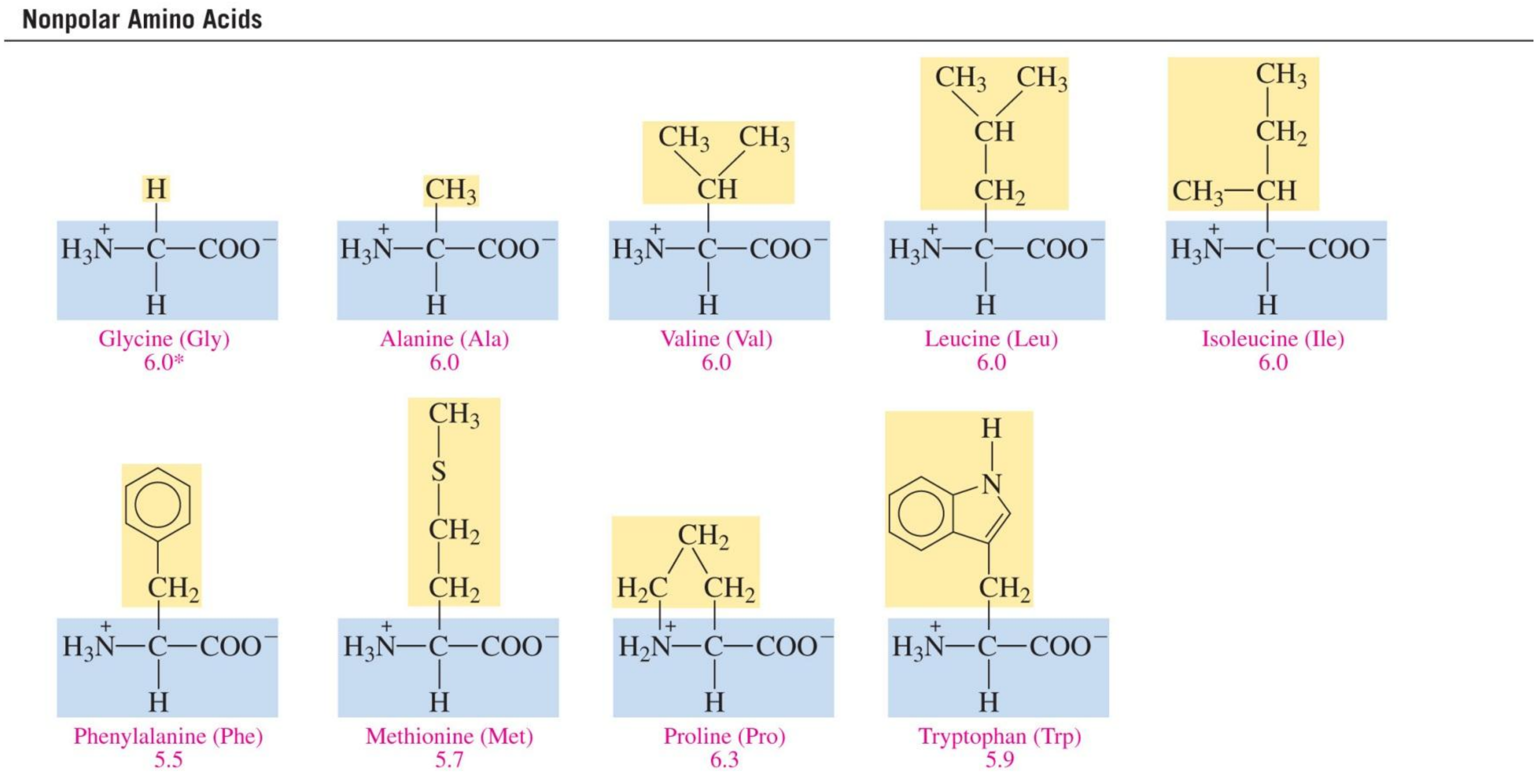
Acidic
Aspartic Acid



Basic
Histidine

Nonpolar Amino Acids

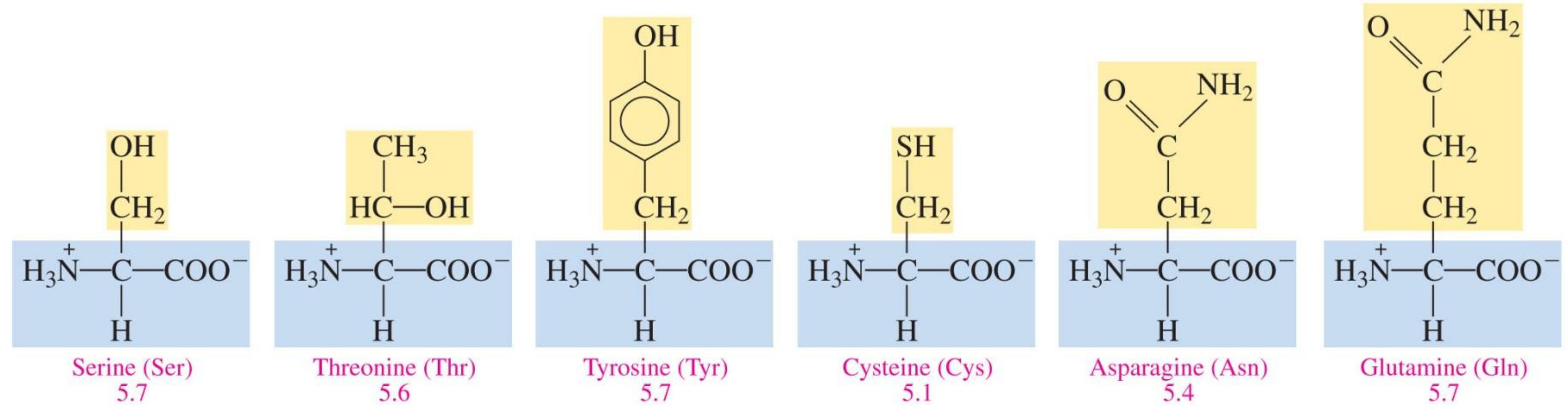
An amino acid is nonpolar when the R group is H, alkyl, or aromatic.



Polar Amino Acids

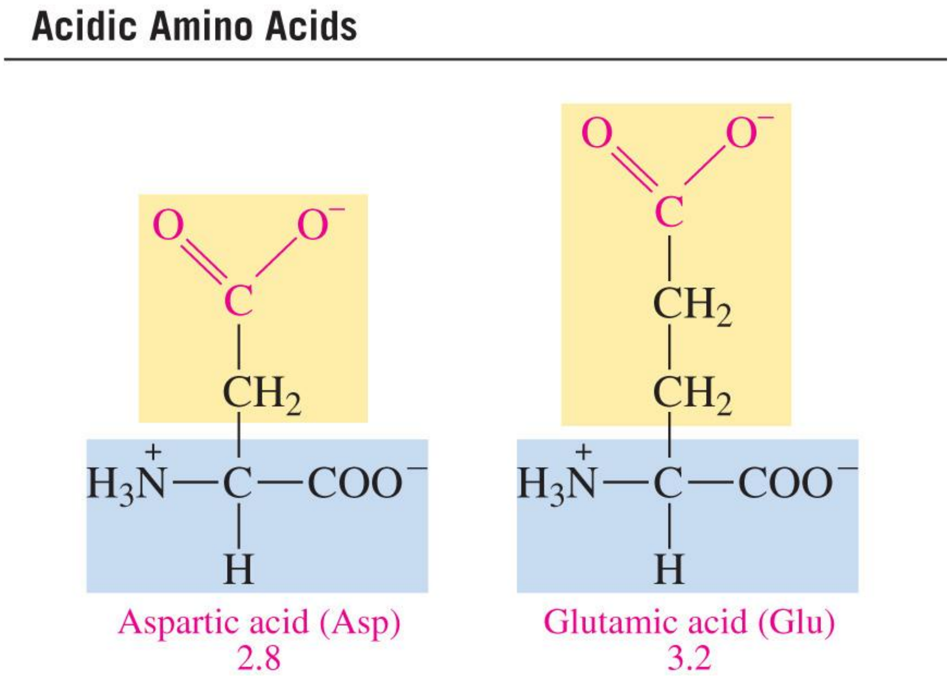
An amino acid is polar when the R group is an alcohol, thiol, or amide.

Polar Amino Acids (Neutral)



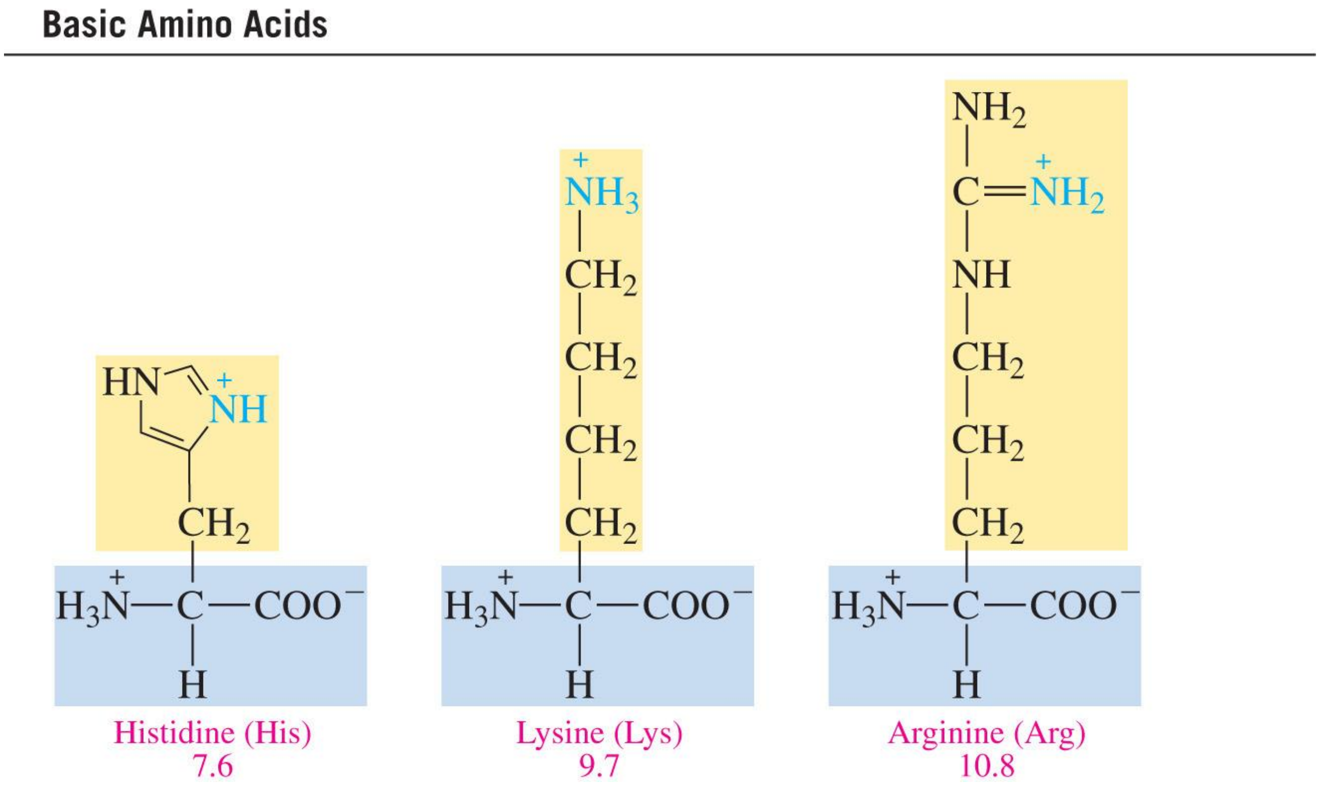
Acidic Amino Acids

An amino acid is acidic when the R group is a carboxylic acid.



Basic Amino Acids

An amino acid is basic when the R group is an amine.



Learning Check

Identify each of the following amino acids as polar or nonpolar.

A. $\overset{+}{H_3N}\text{–}CH_2\text{–}COO^-$ Glycine

$$
\begin{array}{l}
\qquad\qquad CH_3 \\
\qquad\qquad | \\
\qquad\qquad CH\text{–}OH \\
\qquad\qquad | \\
\text{B.}\ \overset{+}{H_3N}\text{–}CH\text{–}COO^- \quad \text{Threonine}
\end{array}
$$

Essential Amino Acids

Essential amino acids

- are 10 amino acids not synthesized by the body
- must be consumed from proteins in the diet

TABLE 16.3 Essential Amino Acids

Arginine (Arg)*	Methionine (Met)
Histidine (His)*	Phenylalanine (Phe)
Isoleucine (Ile)	Threonine (Thr)
Leucine (Leu)	Tryptophan (Trp)
Lysine (Lys)	Valine (Val)

*Required in diets of children, not adults.

Amino Acid Deficiency in Selected Vegetables and Grains

Diets that rely on plant foods for protein must contain a variety of protein sources to obtain all the essential amino acids.

TABLE 16.4 Amino Acid Deficiency in Selected Vegetables and Grains

Food Source	Amino Acids Missing
Eggs, milk, meat, fish, poultry	None
Wheat, rice, oats	Lysine
Corn	Lysine, tryptophan
Beans	Methionine, tryptophan
Peas	Methionine
Almonds, walnuts	Lysine, tryptophan
Soy	Low in methionine

Ionized Forms of Amino Acids

An amino acid

- may have an overall neutral charge that forms only at a specific pH or **isoelectric point (pI)**
- can exist as a positive ion if the solution is more acidic than its pI
- can exist as a negative ion if the solution is more basic than its pI

Amino Acids as Bases

In solution more acidic than physiological pH, the COO^- in the amino acid accepts a proton.

$$\overset{+}{H_3N}—CH_2—COO^- \overset{H^+}{\rightleftharpoons} \overset{+}{H_3N}—CH_2—COOH$$

Zwitterion
at its pI
Total charge = 0

Positive ion at a
pH lower than pI
Total charge = 1+

Amino Acids as Acids

In solutions more basic than physiological pH, the $–NH_3^+$ in the amino acid donates a proton.

$$\overset{+}{H_3N}—CH_2—COO^- \xrightarrow{OH^-} H_2N—CH_2—COO^-$$

Zwitterion
at its pI
Total charge = 0

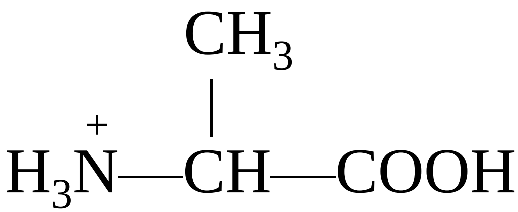
Negative ion at
pH higher than its pI
Total charge = −1

pH and Ionization

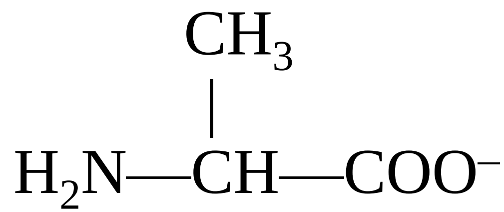
$\xleftarrow{H^+}$ $\xrightarrow{OH^-}$

$H_3\overset{+}{N}{-}CH_2{-}COOH$	$H_3\overset{+}{N}{-}CH_2{-}COO^-$	$H_2N{-}CH_2{-}COO^-$
Positive ion	**Zwitterion**	**Negative ion**
low pH	**pI**	**high pH**

Learning Check



(1)



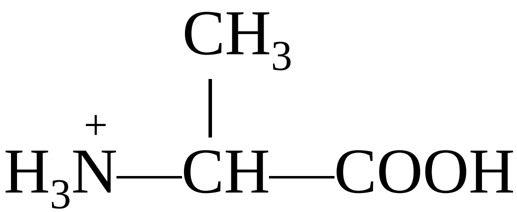
(2)

Which structure represents

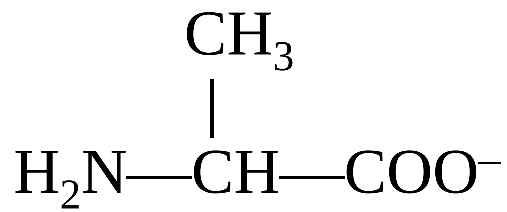
A. alanine at a pH above its pI?

B. alanine at a pH below its pI?

Solution



(1)



(2)

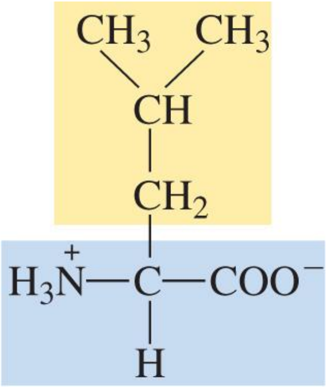
Which structure represents

A. alanine at a pH above its pI? **(2)**

B. alanine at a pH below its pI? **(1)**

Learning Check

Consider the amino acid leucine that has a pI of 6.0.



A. At a pH of 3.0 how does the zwitterion of leucine change?

B. At a pH of 9.0 how does the zwitterion of leucine change?

Solution

Consider the amino acid leucine with a pI of 6.0.

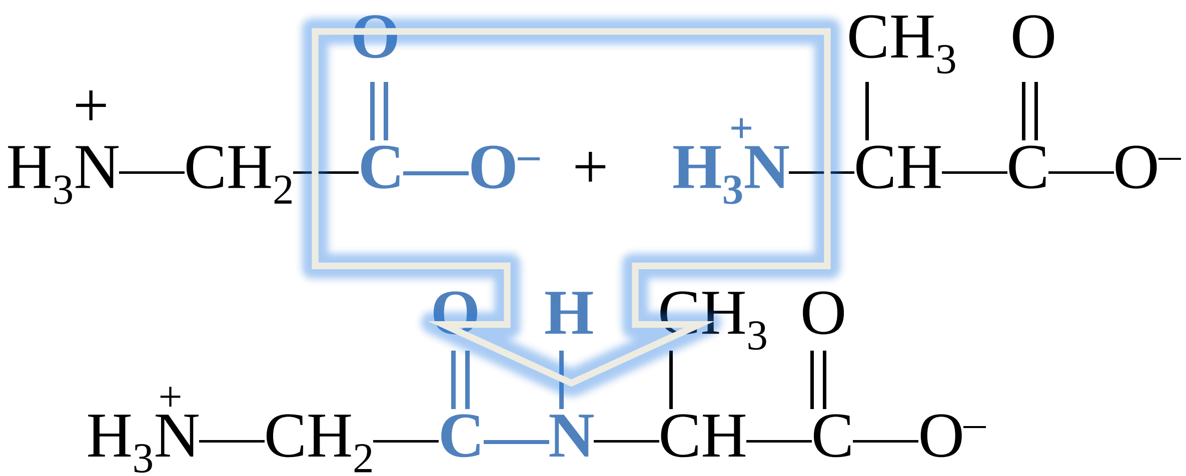
A. At a pH of 3.0 how does the zwitterion of leucine change?
   Because the pH of 3.0 is more acidic than the pI at 6.0, the $-COO^-$ group gains an H^+ to give $-COOH$. The remaining $-NH_3^+$ gives leucine an overall positive charge (1+).

B. At a pH of 9.0 how does the zwitterion of leucine change?
   Because a pH of 9.0 is more basic and above the pI of leucine, the $-NH_3^+$ loses H^+ to give $-NH_2$. The remaining gives leucine an overall negative charge (1-).

Formation of Peptides

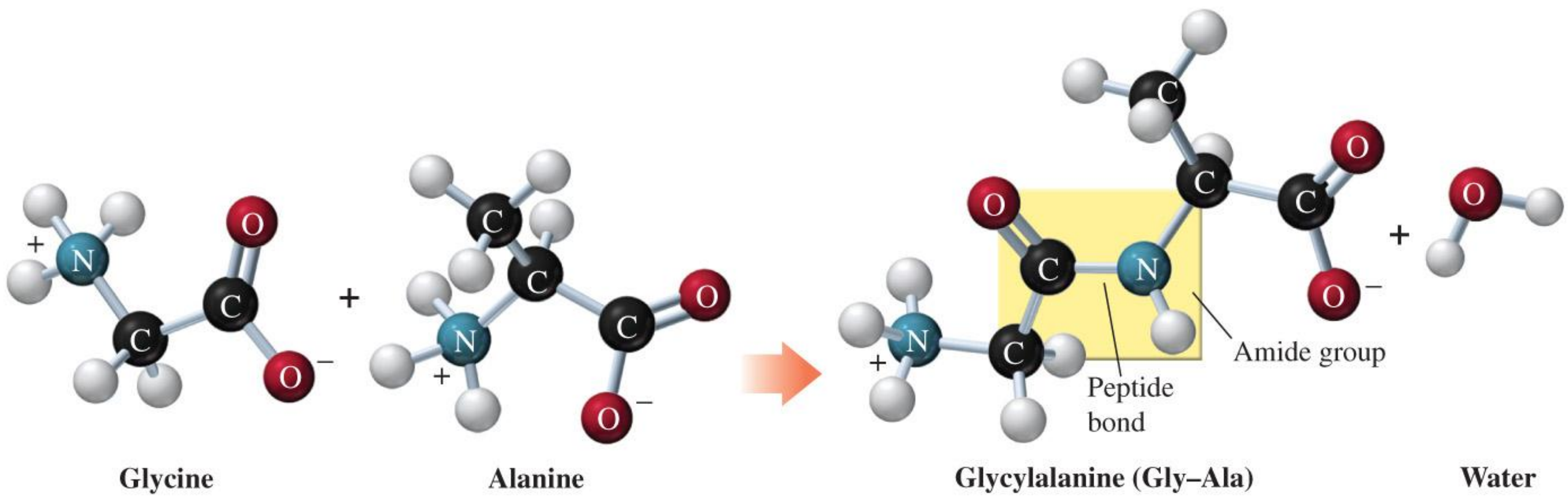
A **peptide bond**

- is an amide bond
- forms between the carboxyl group of one amino acid and the amino group of the next amino acid



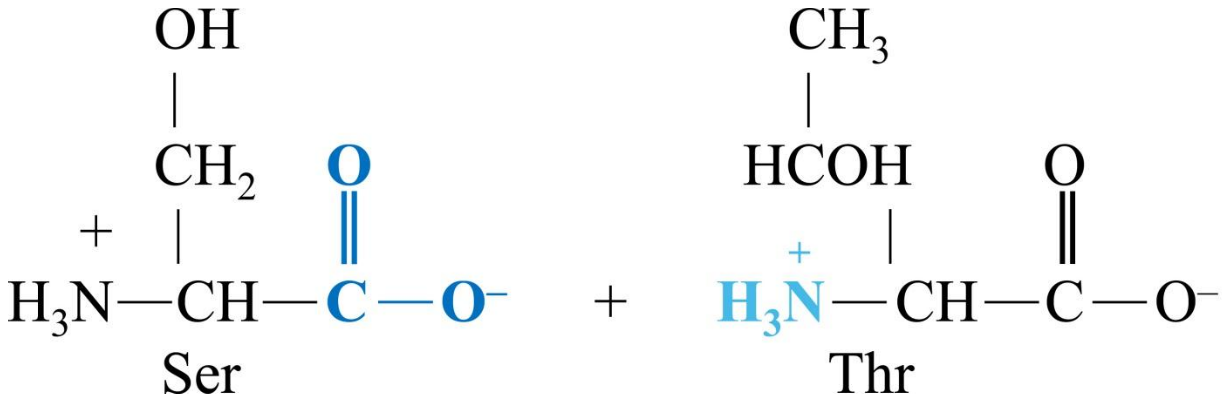
peptide bond

Formation of a Dipeptide



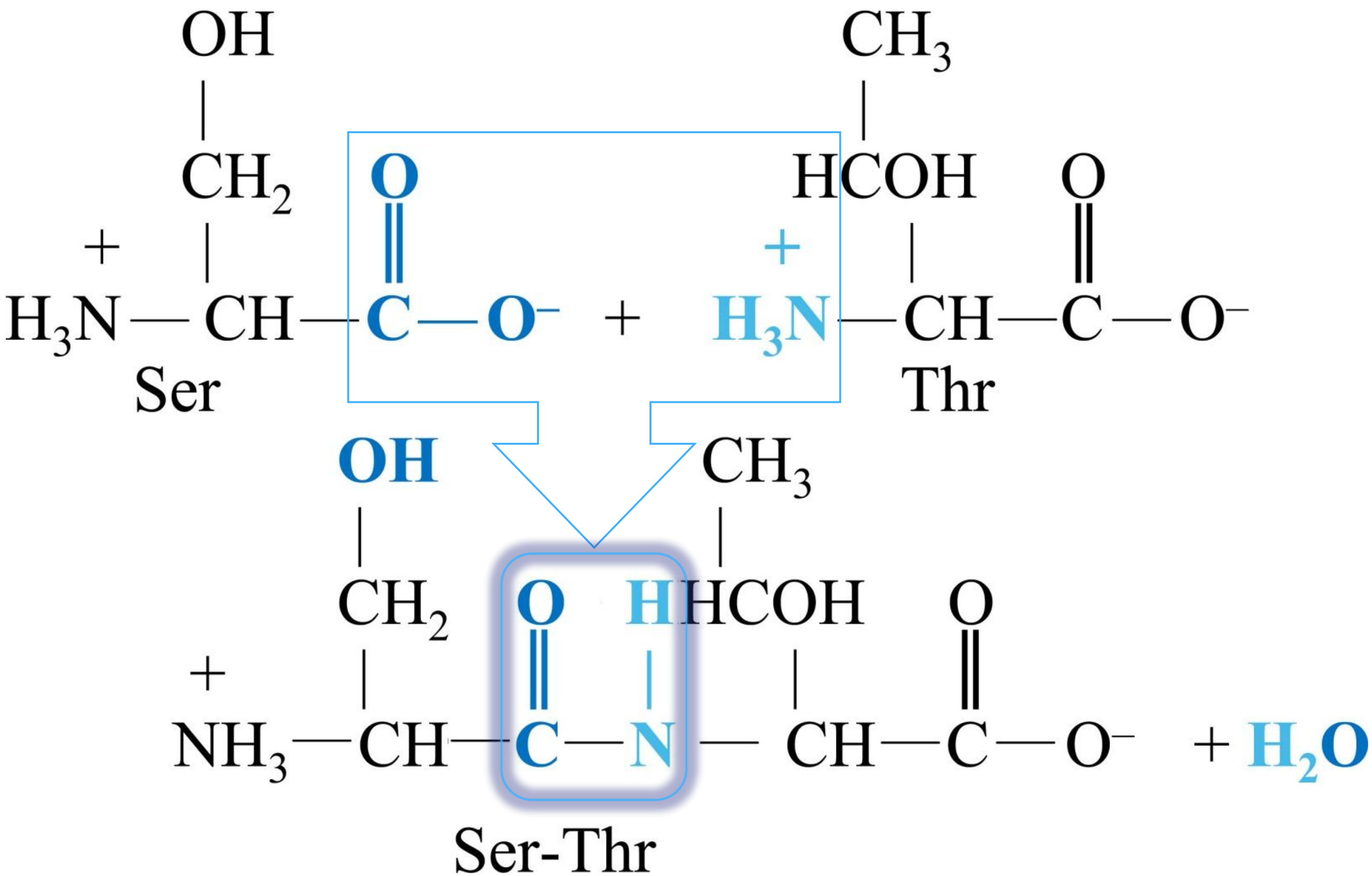
Learning Check

Write the dipeptide Ser-Thr.



Solution

Write the dipeptide Ser-Thr.

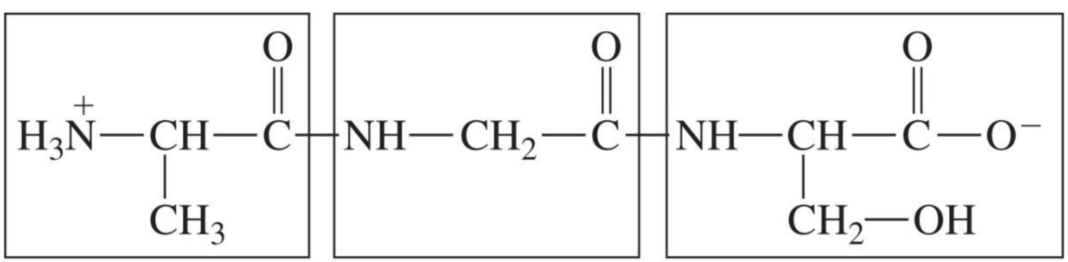


Naming Peptides

A peptide

- is named with names of all amino acids in the peptide using a ***-yl*** ending for the name
- is named using the full amino acid name for the amino acid at the the C terminal

N Terminal **C Terminal**



From alanine
Alanyl

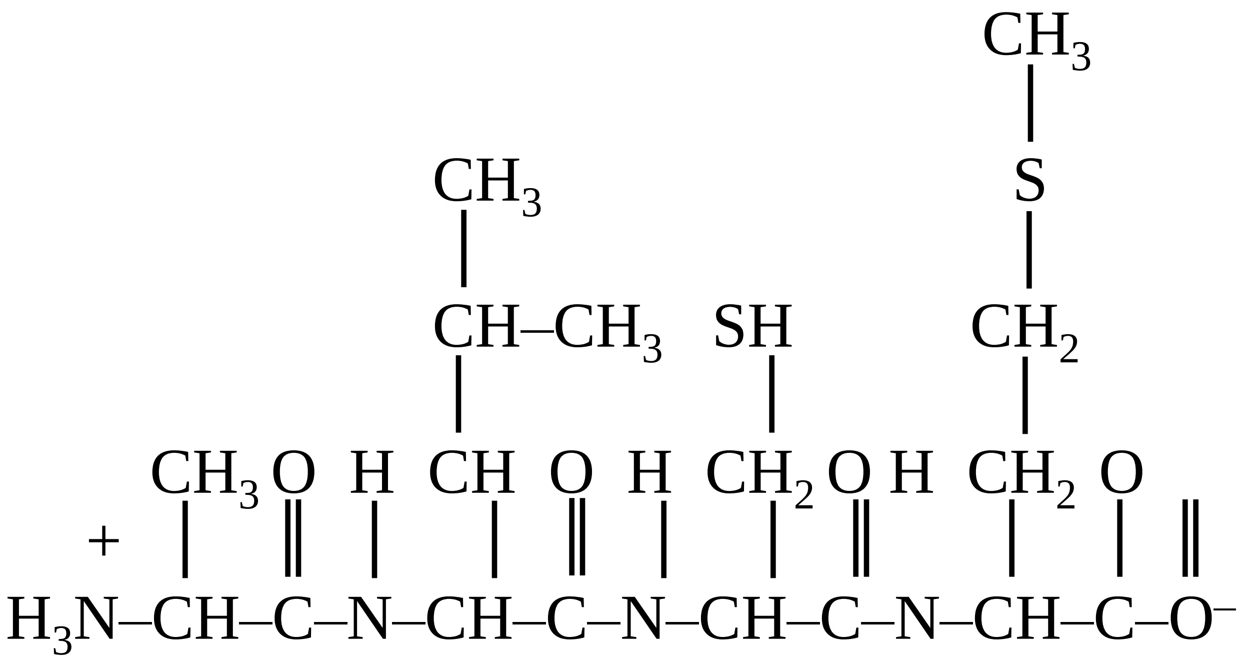
From glycine
Glycyl

From serine
Serine

Alanylglycylserine
(Ala–Gly–Ser)

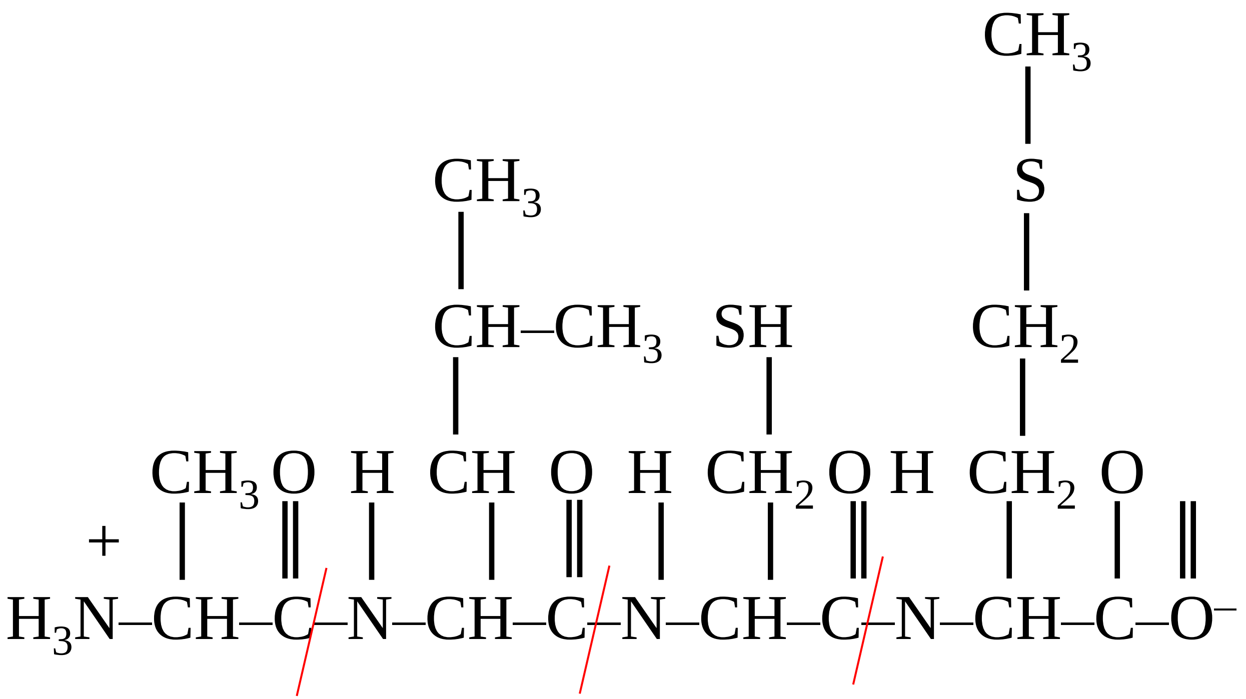
Learning Check

Write the three-letter abbreviation and name for the following tetrapeptide.



Solution

Ala-Leu-Cys-Met **Alanylleucylcysteinylmethionine**

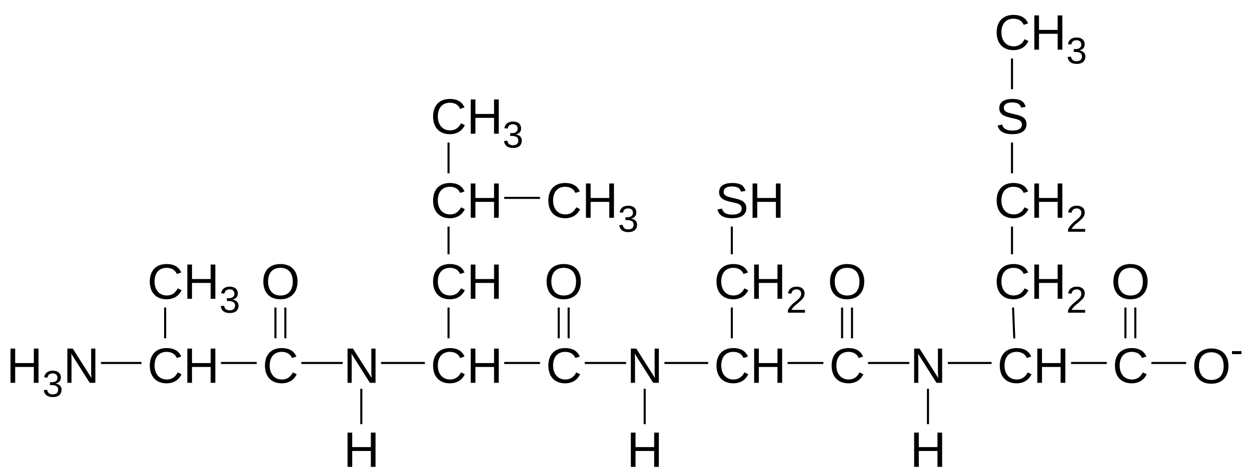


Alanine **Leucine** **Cysteine** **Methionine**

Primary Structure of Proteins

The **primary structure** of a protein is

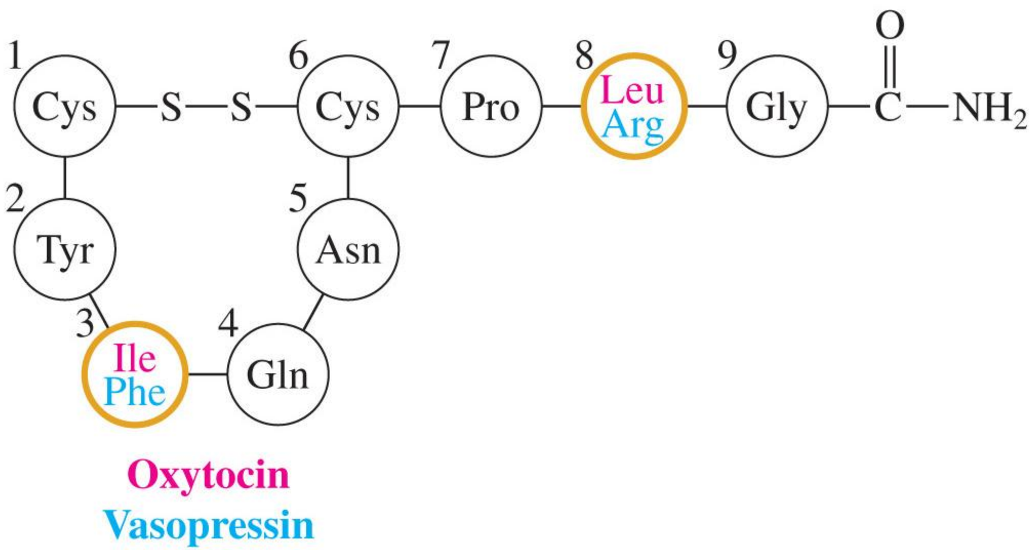
- the particular sequence of amino acids
- the backbone of a peptide chain or protein



Ala–Leu–Cys–Met

Primary Structures

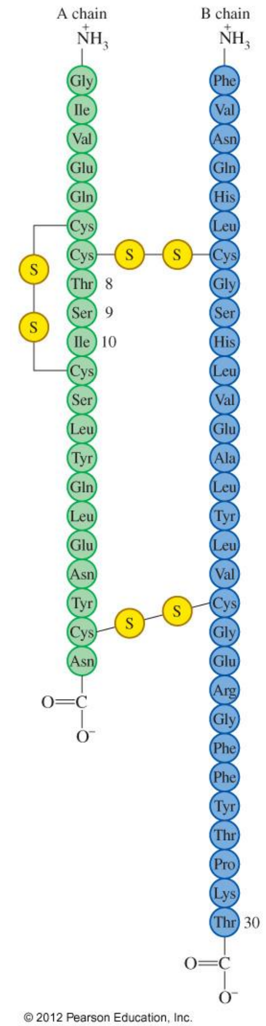
- The nonapeptides oxytocin and vasopressin have similar primary structures.
- Only the amino acids at positions 3 and 8 differ.



Primary Structure of Insulin

Insulin

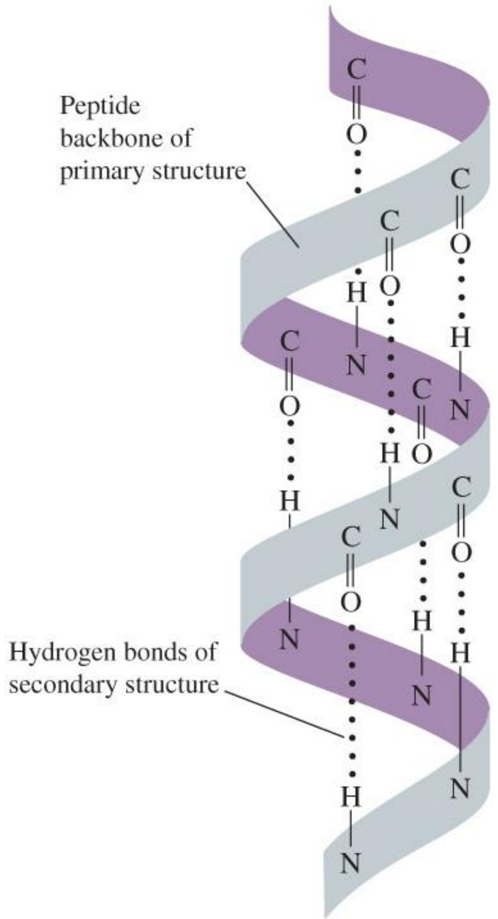
- was the first protein to have its primary structure determined
- has a primary structure of two polypeptide chains linked by disulfide bonds
- has a chain A with 21 amino acids and a chain B with 30 amino acids



Secondary Structure–Alpha Helix

The **secondary structure of an alpha helix** is

- a three-dimensional spatial arrangement of amino acids in a polypeptide chain
- held by H bonds between the H of –N-H group and the O of C=O of the fourth amino acid down the chain
- a corkscrew shape that looks like a coiled "telephone cord"

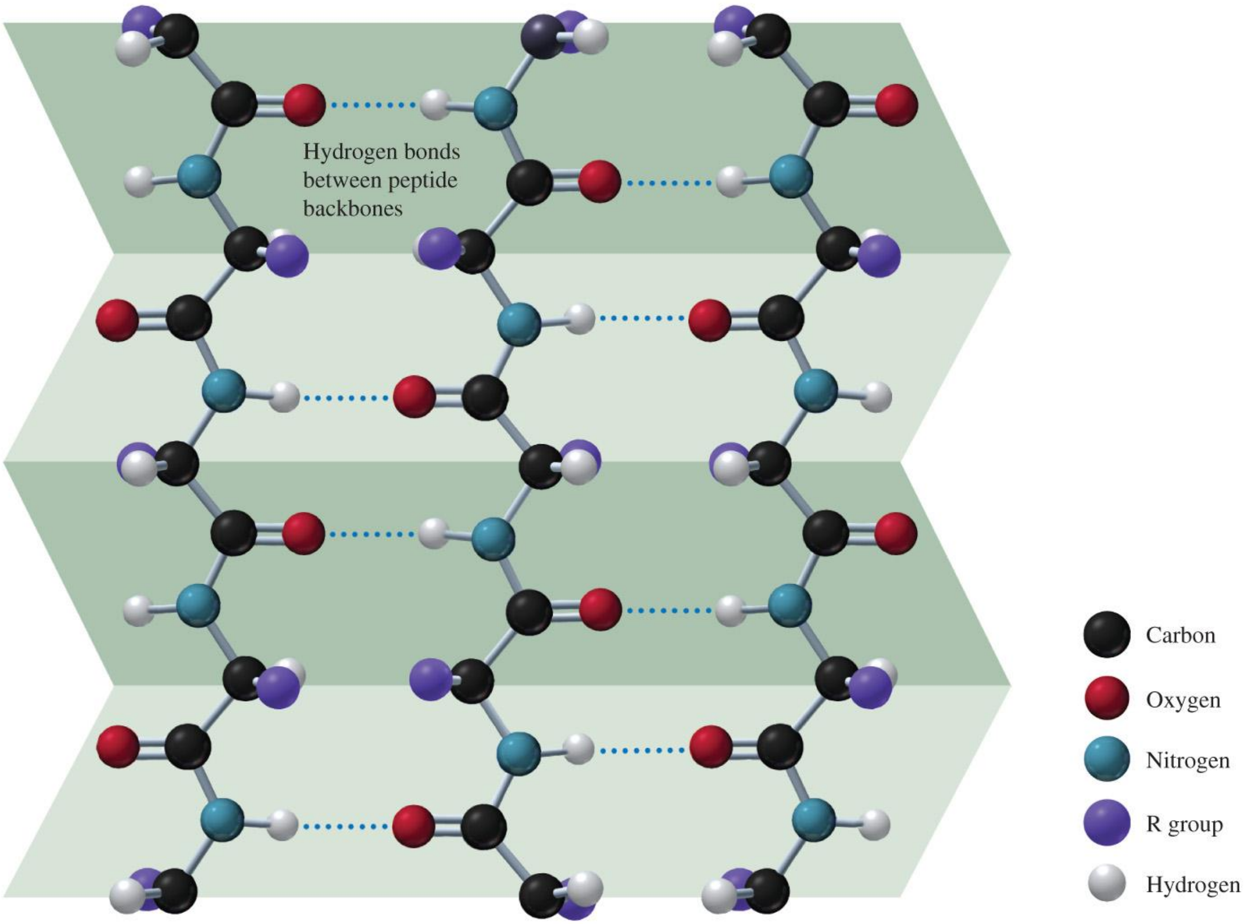


Secondary Structure–
Beta-Pleated Sheet

The **secondary structure of a beta-pleated sheet**

- consists of polypeptide chains arranged side by side
- has hydrogen bonds between chains
- has R groups above and below the sheet
- is typical of fibrous proteins, such as silk

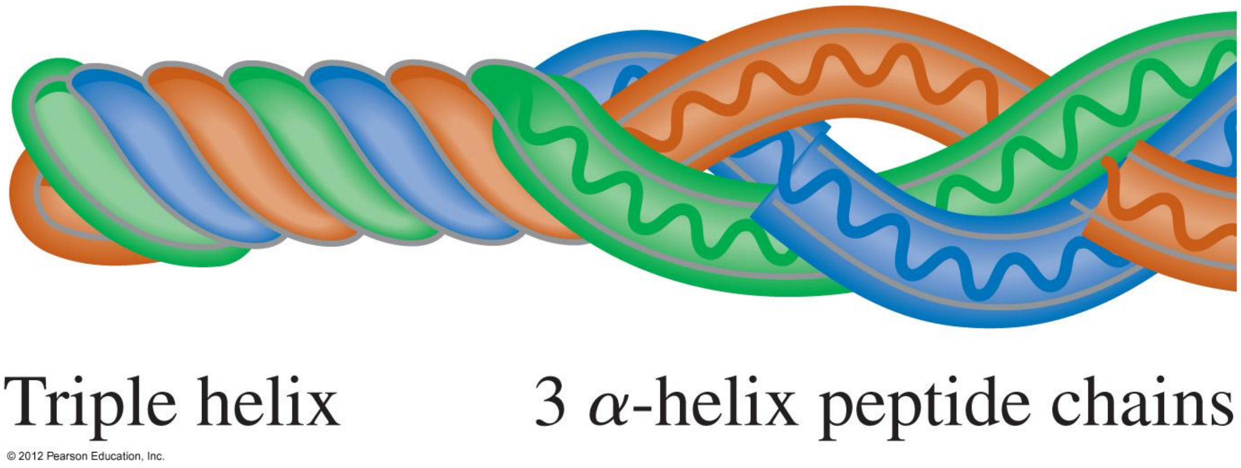
Secondary Structure–Beta-Pleated Sheet



Secondary Structure–Triple Helix

The **secondary structure of a triple helix** is

- three polypeptide chains woven together
- typical of collagen, connective tissue, skin, tendons, and cartilage



Collagen fibers are triple helices of polypeptide chains held together by hydrogen bonds.

Learning Check

Indicate the type of protein structure.

primary	alpha helix
beta-pleated sheet	triple helix

A. polypeptide chains held side by side by H bonds

B. sequence of amino acids in a polypeptide chain

C. corkscrew shape with H bonds between amino acids

D. three peptide chains woven like a rope

Solution

A. polypeptide chains held side by side by H bonds

beta-pleated sheet

B. sequence of amino acids in a polypeptide chain

primary

C. corkscrew shape with H bonds between amino acids

alpha helix

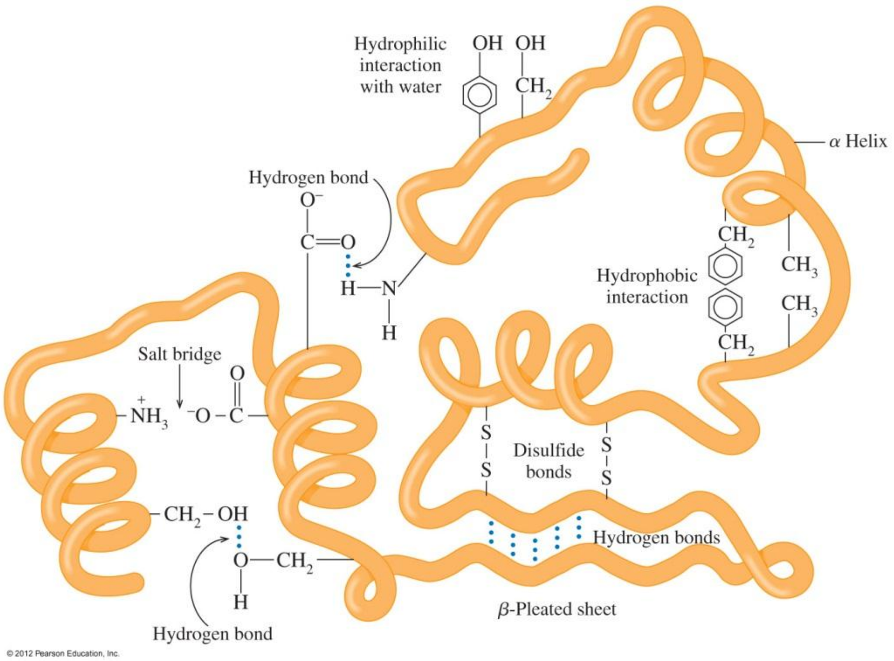
D. three peptide chains woven like a rope

triple helix

Tertiary Structure

The **tertiary structure** of a protein

- is an overall three-dimensional shape.
- is determined by **cross-links,** the attractions and repulsions between the side chains (R groups) of the amino acids in a peptide chain



Cross-links in Tertiary Structures

There are five types of **cross-links in tertiary structures.**

1. Hydrophobic interactions are interactions between two nonpolar R groups. Within a protein, the amino acids with nonpolar R groups move away from the aqueous environment to form a hydrophobic center at the interior of the protein molecule.

2. Hydrophilic interactions are attractions between the external aqueous environment and the R groups of polar amino acids moving the polar amino acids toward the outer surface of globular proteins where they form hydrogen bonds with water.

Cross-links in Tertiary Structures

3. **Salt bridges are ionic bonds between ionized R groups of basic and acidic amino acids.** For example, the ionized R group of arginine, which has a positive charge, can form a salt bridge (ionic bond) with the R group in aspartic acid, which has a negative charge.
4. **Hydrogen bonds form between H of a polar R group and the O or N of another** amino acid. For example, a hydrogen bond can form between the groups of two serines or between the of serine and the in the R group of glutamine.
5. **Disulfide bonds are covalent bonds that form between the** groups of cysteines in a polypeptide chain.

Learning Check

Select the type of tertiary interaction.

disulfide	ionic
H bonds	hydrophobic

A. leucine and valine

B. two cysteines

C. aspartic acid and lysine

D. serine and threonine

Solution

Select the type of tertiary interaction.

disulfide	ionic
H bonds	hydrophobic

A. leucine and valine **hydrophobic**

B. two cysteines **disulfide**

C. aspartic acid and lysine **ionic**

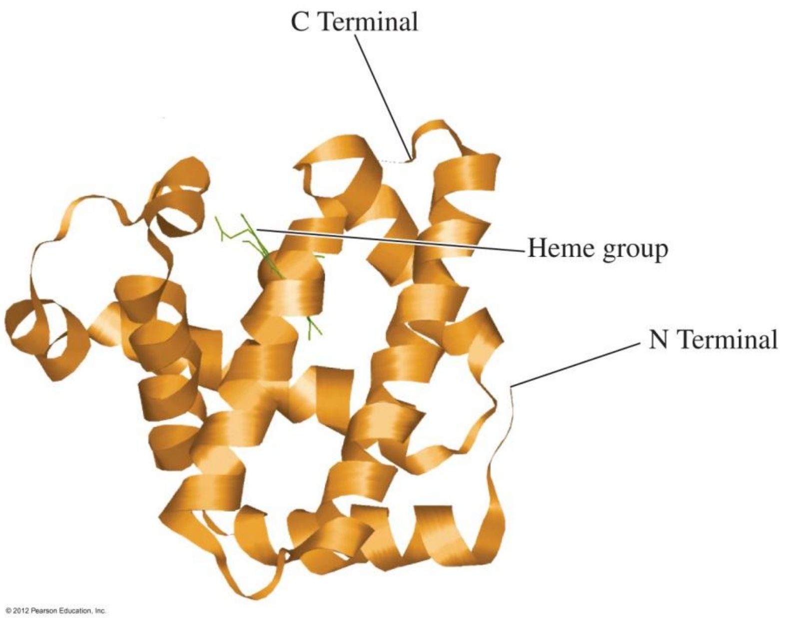
D. serine and threonine **H bonds**

Globular Proteins

Globular proteins

- have compact, spherical shapes
- carry out synthesis, transport, and metabolism in the cells
- such as myoglobin store and transport oxygen in muscle

The ribbon structure represents the tertiary structure of myoglobin.



Myoglobin

Fibrous Proteins

Fibrous proteins

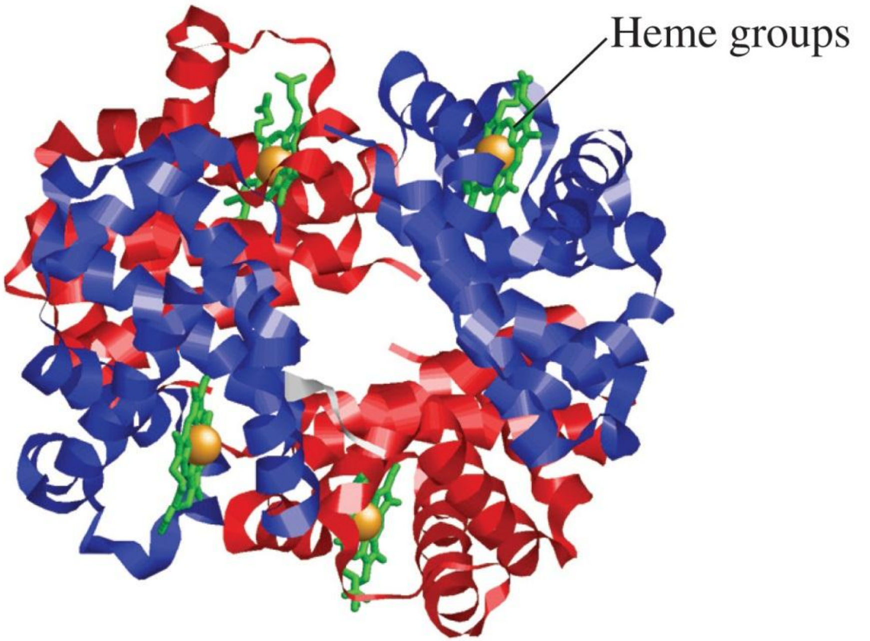
- consist of long, fiber-like shapes
- such as alpha keratins make up hair, wool, skin, and nails
- such as feathers contain beta keratins with large amounts of beta-pleated sheet structures

The fibrous proteins of α-keratin wrap together to for fibrils of hair and wool.

Quaternary Structure

The **quaternary structure**

- is the combination of two or more protein units
- of hemoglobin consists of four polypeptide chains as subunits
- is stabilized by the same interactions found in tertiary structures



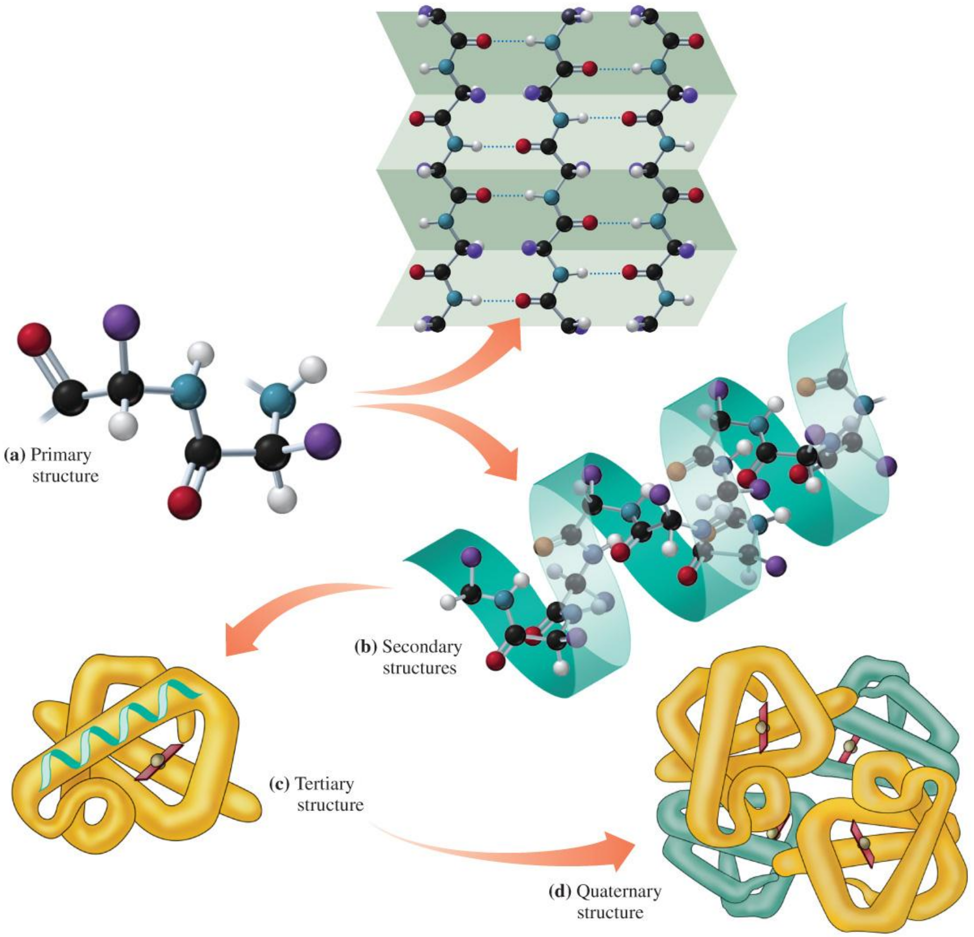
In the ribbon structure of hemoglobin, the quaternary structure is made up of four polypeptide subunits, two (red) are α chains and two (blue) are β chains. The heme groups (green) in the four subunits bind oxygen.

Summary of Protein Structural Levels

TABLE 16.6 Summary of Structural Levels in Proteins

Structural Level	Characteristics
Primary	The sequence of amino acids
Secondary	The coiled a helix, b-pleated sheet, or a triple helix form by hydrogen bonding between peptide bonds along the chain
Tertiary	A protein folds into a compact, three-dimensional shape stabilized by interactions between R groups of amino acids
Quaternary	Two or more protein subunits combine to form a biologically active protein

Summary of Protein Structure



Learning Check

Identify the level of protein structure.

primary secondary

tertiary quaternary

A. beta-pleated sheet

B. order of amino acids in a protein

C. a protein with two or more peptide chains

D. the shape of a globular protein

E. disulfide bonds between R groups

Solution

Identify the level of protein structure.

primary secondary

tertiary quaternary

A. beta-pleated sheet **secondary**

B. order of amino acids in a protein **primary**

C. a protein with two or more peptide chains **quaternary**

D. the shape of a globular protein **tertiary**

E. disulfide bonds between R groups **tertiary**

Denaturation

Denaturation involves

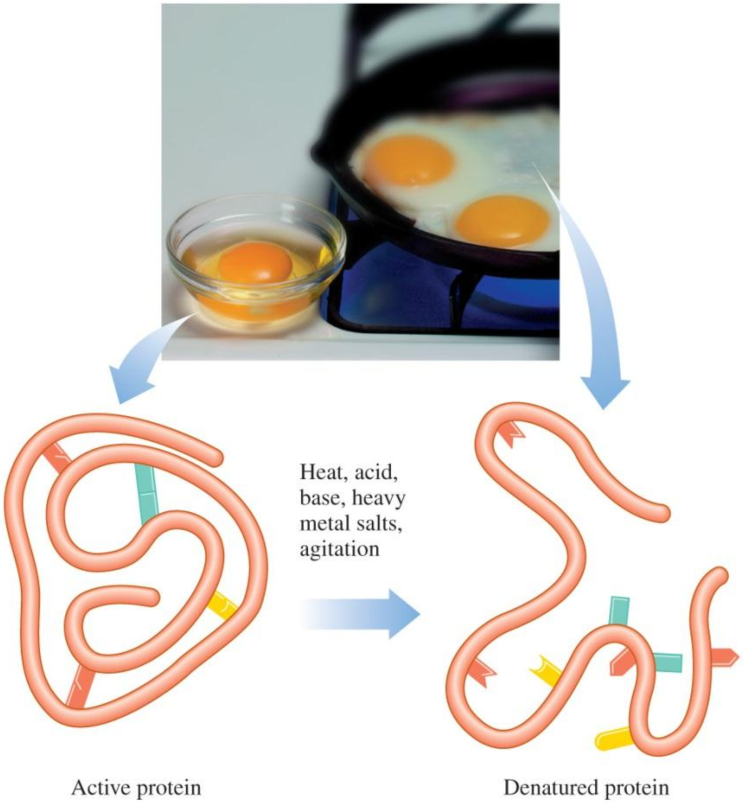
- the disruption of bonds in the secondary, tertiary, and quaternary protein structures
- **heat and organic compounds** that break apart H bonds and disrupt hydrophobic interactions
- **acids and bases** that break H bonds between polar R groups and disrupt ionic bonds
- **heavy metal ions** that react with S-S bonds to form solids
- **agitation** such as whipping that stretches peptide chains until bonds break

Applications of Denaturation

Denaturation of protein occurs when

- an egg is cooked
- the skin is wiped with alcohol
- heat is used to cauterize blood vessels
- instruments are sterilized in autoclaves

Denaturation of egg protein occurs when the bonds of the tertiary structure are disrupted.



Applications of Denaturation

TABLE 16.7 Examples of Protein Denaturation

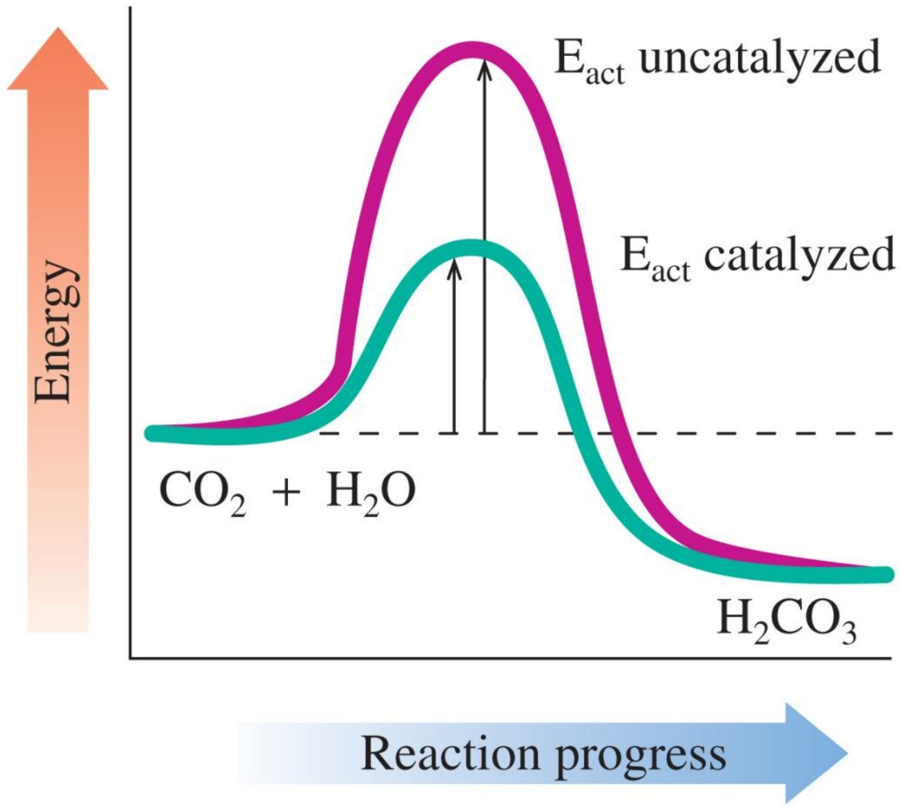
Denaturing Agent	Bonds Disrupted	Examples
Heat above 50 °C	Hydrogen bonds; hydrophobic interactions between nonpolar R groups	Cooking food and autoclaving surgical items
Acids and bases	Hydrogen bonds between polar R groups; salt bridges	Lactic acid from bacteria, which denatures milk protein in the preparation of yogurt and cheese
Organic compounds	Hydrophobic interactions	Ethanol and isopropyl alcohol, which disinfect wounds and prepare the skin for injections
Heavy metal ions Ag^{+}, Pb^{2+}, and Hg^{2+}	Disulfide bonds in proteins by forming ionic bonds	Mercury and lead poisoning
Agitation	Hydrogen bonds and hydrophobic interactions by stretching polypeptide chains and disrupting stabilizing interactions	Whipped cream, meringue made from egg whites

Enzymes Are Biological Catalysts

Enzymes are proteins that

- catalyze nearly all the chemical reactions taking place in the cells of the body
- increase the rate of reaction by lowering the energy of activation

The enzyme carbonic anhydrase lowers the activation energy needed for the reaction of CO2 and H2O.



Names of Enzymes

The name of an enzyme

- usually ends in –***ase***
- identifies the reacting substance; for example, *sucrase* catalyzes the reaction of sucrose
- describes the function of the enzyme; for example, *oxidases* catalyze oxidation
- could be a common name, particularly for the digestion enzymes, such as *pepsin* and *trypsin*

Classification of Enzymes

Enzymes are classified by the reaction they catalyze.

Class	Type of Reactions Catalyzed
Oxidoreductases	Oxidation-reduction
Transferases	Transfer groups of atoms
Hydrolases	Hydrolysis
Lyases	Add atoms/remove atoms to or from a double bond
Isomerases	Rearrange atoms
Ligases	Use ATP to combine small molecules

Learning Check

Match the type of reaction with an enzyme.

aminase	dehydrogenase
isomerase	synthetase

A. converts a *cis*-fatty acid to a *trans*-fatty acid

B. removes 2 H atoms to form double bond

C. combines two molecules to make a new compound

D. adds NH_3

Solution

Match the type of reaction with an enzyme.

aminase dehydrogenase

isomerase synthetase

A. converts a *cis*-fatty acid to a *trans*-fatty acid

isomerase

B. removes 2 H atoms to form double bond

dehydrogenase

C. combines two molecules to make a new compound

synthetase

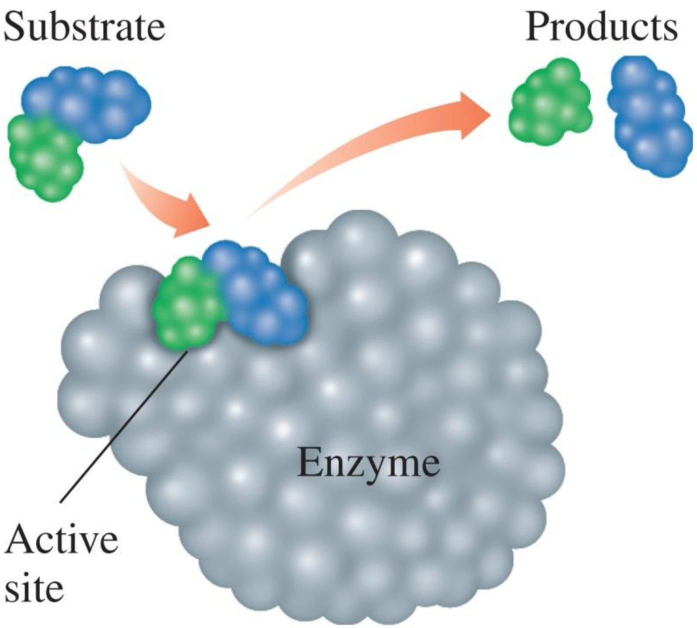
D. adds NH_3 **aminase**

Active Site

The **active site**

- is a region within an enzyme that fits the shape of the reacting molecule called a **substrate**
- contains amino acid R groups that bind the substrate
- releases products when the reaction is complete

On the surface of an enzyme, a small region called an active site binds a substrate and catalyzes a reaction of that substrate.

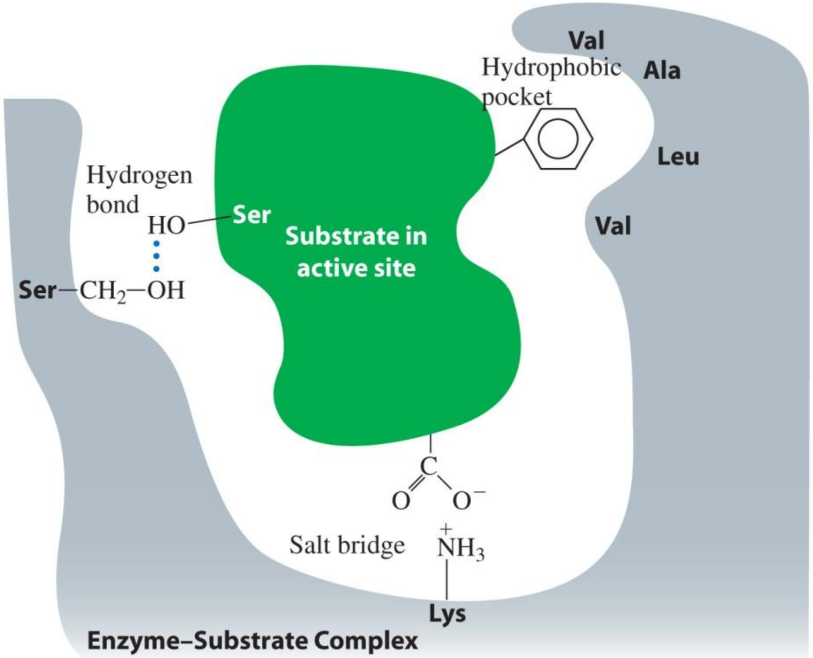


Enzyme-Catalyzed Reaction

In an **enzyme-catalyzed reaction,**

- a substrate attaches to the active site
- an enzyme–substrate (ES) complex forms
- reaction occurs and products are released
- an enzyme is used over and over

$$E + S \rightleftharpoons ES \longrightarrow E + P$$



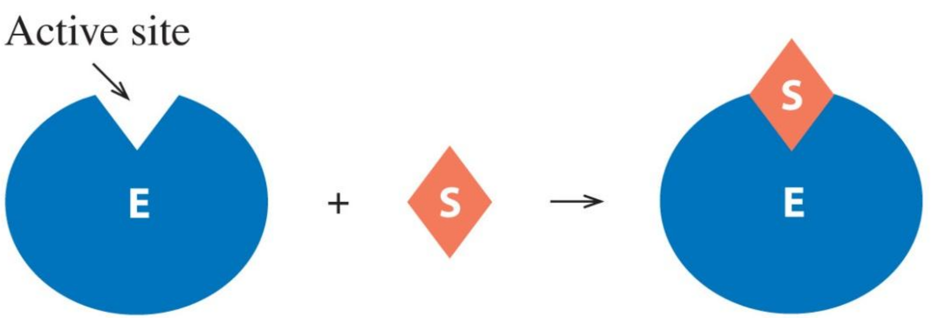
Binding of a substrate occurs when it interacts with the amino acids within the active site.

Lock-and-Key Model

In the **lock-and-key model**, the

- active site has a rigid shape
- enzyme only binds substrates that exactly fit the active site
- enzyme is analogous to a lock
- substrate is the key that fits that lock

In the lock-and-key model, a substrate fits the shape of the active site and forms an enzyme–substrate complex.



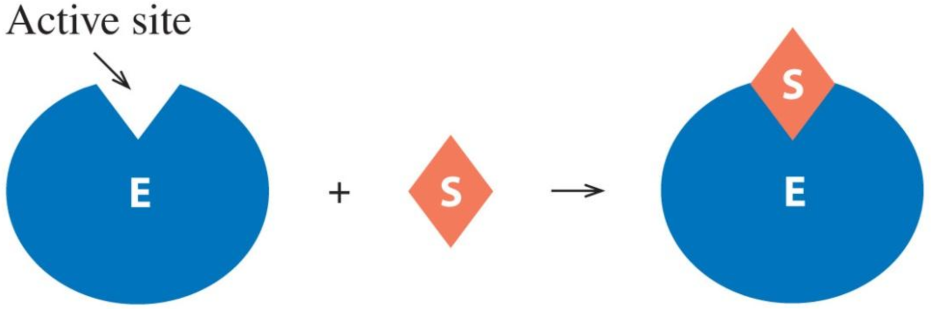
(a) Lock-and-key model **Enzyme–substrate complex**

Induced-Fit Model

In the **induced-fit model,**

- enzyme structure is flexible, not rigid
- enzyme and substrate adjust the shape of the active site to bind substrate
- the range of substrate specificity increases
- shape changes improve catalysis during reaction

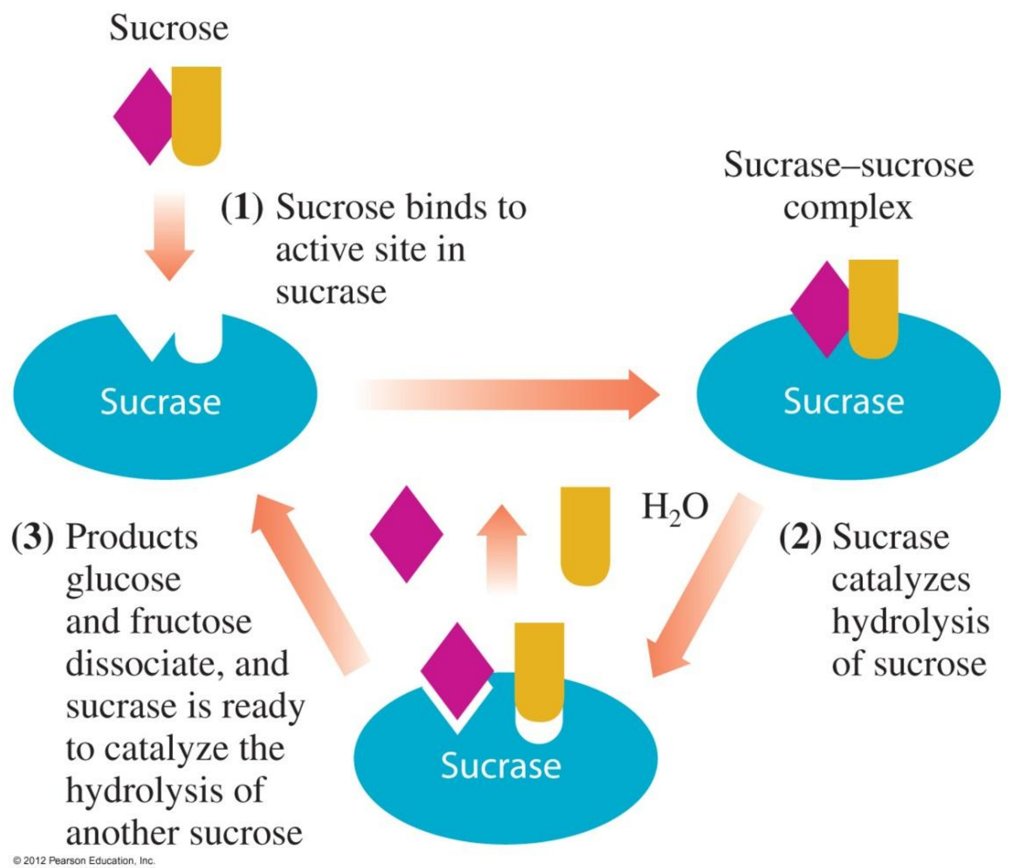
In the induced-fit model, a flexible active site and substrate adjust shape to provide the best fit for the reaction.



(a) Lock-and-key model **Enzyme–substrate complex**

Example of an Enzyme-Catalyzed Reaction

At the active site, sucrose is aligned for the hydrolysis reaction. The monosaccharides produced dissociate from the active site, and the enzyme is ready to bind to another sucrose molecule.



Learning Check

1. The active site is
   A. the enzyme
   B. a section of the enzyme
   C. the substrate

2. In the induced-fit model, the shape of the enzyme when substrate binds
   A. stays the same
   B. adapts to the shape of the substrate

Solution

1. The active site is

   B. a section of the enzyme

2. In the induced-fit model, the shape of the enzyme when substrate binds

   B. adapts to the shape of the substrate

Diagnostic Enzymes

Diagnostic enzymes

- determine the amount of damage in tissues
- that are elevated may indicate damage or disease in a particular organ

TABLE 16.10 Serum Enzymes Used in Diagnosis of Tissue Damage

Condition	Diagnostic Enzymes Elevated
Heart attack or liver disease (cirrhosis, hepatitis)	Lactate dehydrogenase (LDH)
	Aspartate transaminase (AST)
Heart attack	Creatine kinase (CK)
Hepatitis	Alanine transaminase (ALT)
Liver (carcinoma) or bone disease (rickets)	Alkaline phosphatase (ALP)
Pancreatic disease	Pancreatic amylase (PA), cholinesterase (CE), lipase (LPS)
Prostate carcinoma	Acid phosphatase (ACP) Prostate specific antigen (PSA)

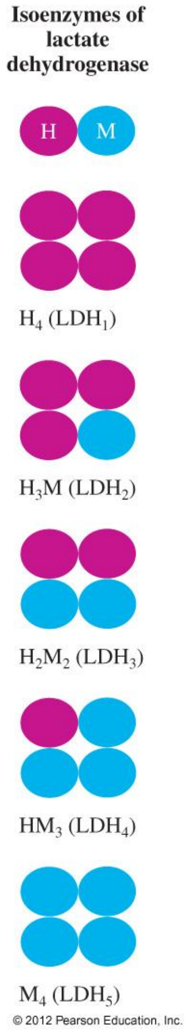
Isoenzymes

Isoenzymes

- catalyze the same reaction in different tissues in the body
- can be used to identify the organ or tissue involved in damage or disease
- such as lactate dehydrogenase (LDH), which converts lactate to pyruvate, consist of five isoenzymes
- such as LDH have one form more prevalent in heart muscle and another form in skeletal muscle and liver

Isoenzymes

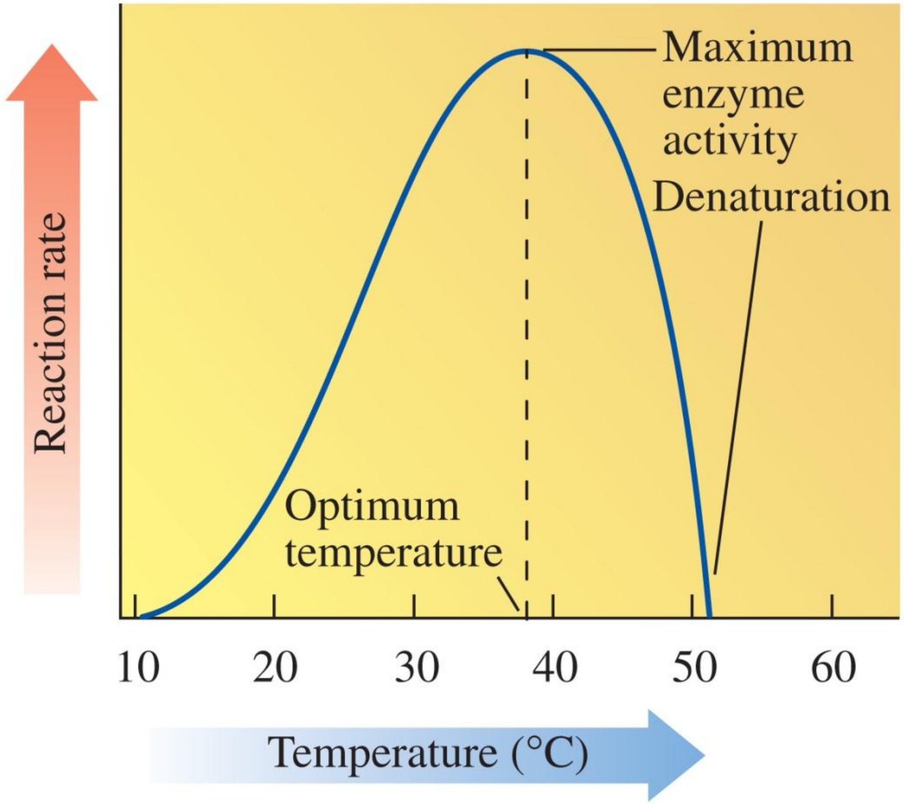
The different isoenzymes of lactate dehydrogenase (LDH) indicate damage to different organs in the body.



Temperature and Enzyme Action

Enzymes

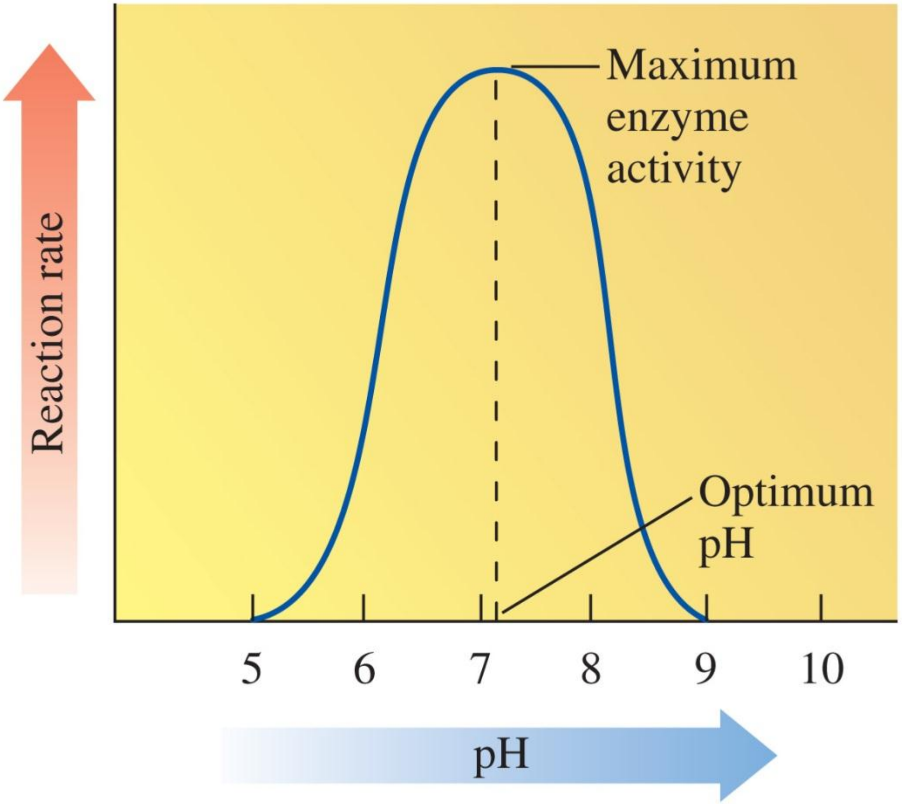
- are most active at an optimum temperature (usually 37 °C in humans)
- show little activity at low temperatures.
- lose activity at high temperatures as denaturation occurs with loss of catalytic activity



pH and Enzyme Action

Enzymes

- are most active at optimum pH
- contain R groups of amino acids with proper charges at optimum pH
- lose activity in low or high pH as tertiary structure is disrupted



Optimum pH Values

Enzymes in

- the body have an **optimum pH** of about 7.4
- certain organs operate at lower and higher optimum pH values

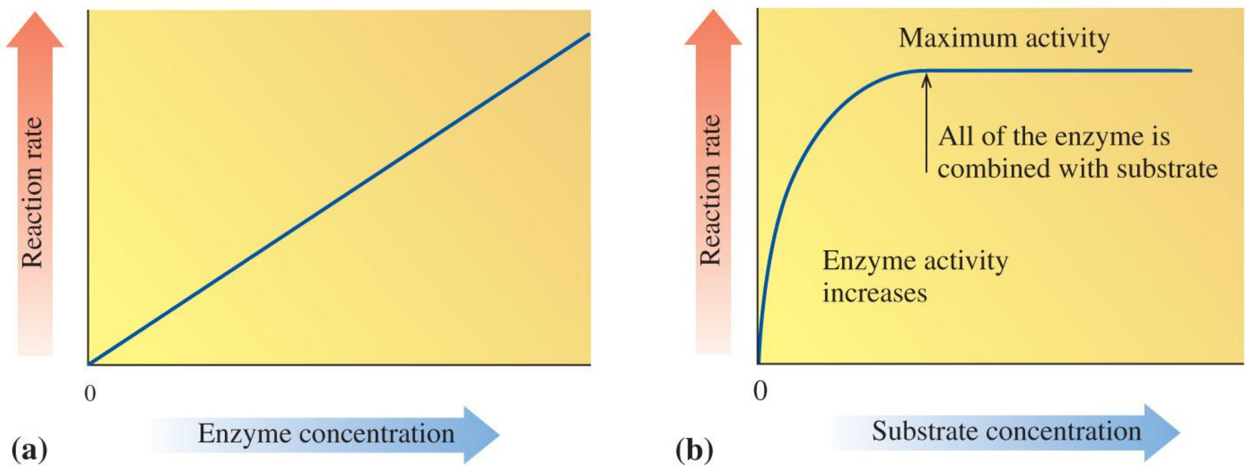
TABLE 16.11 Optimum pH for Selected Enzymes

Enzyme	Location	Substrate	Optimum pH
Pepsin	Stomach	Peptide bonds	1.5–2.0
Sucrase	Small intestine	Sucrose	6.2
Pancreatic amylase	Pancreas	Amylose	6.7–7.0
Urease	Liver	Urea	7.0
Trypsin	Small intestine	Peptide bonds	7.7–8.0
Lipase	Pancreas	Lipid (ester bonds)	8.0
Arginase	Liver	Arginine	9.7

Substrate Concentration

As **substrate concentration** increases,

- the **rate of reaction** increases (at constant enzyme concentration)
- the enzyme eventually becomes saturated, giving maximum activity



Learning Check

Sucrase has an optimum temperature of 37 °C and an optimum pH of 6.2. Determine the effect of the following on its rate of reaction.

no change   increase   decrease

A. Increasing the concentration of sucrase

B. Changing the pH to 4

C. Running the reaction at 70 °C

Solution

Sucrase has an optimum temperature of 37 °C and an optimum pH of 6.2. Determine the effect of the following on its rate of reaction.

no change　　　increase　　　decrease

A. Increasing the concentration of sucrase　　**increase**

B. Changing the pH to 4　　**decrease**

C. Running the reaction at 70 °C　　**decrease**

Enzyme Inhibition

Inhibitors

- are molecules that cause a loss of catalytic activity
- prevent substrates from fitting into the active sites

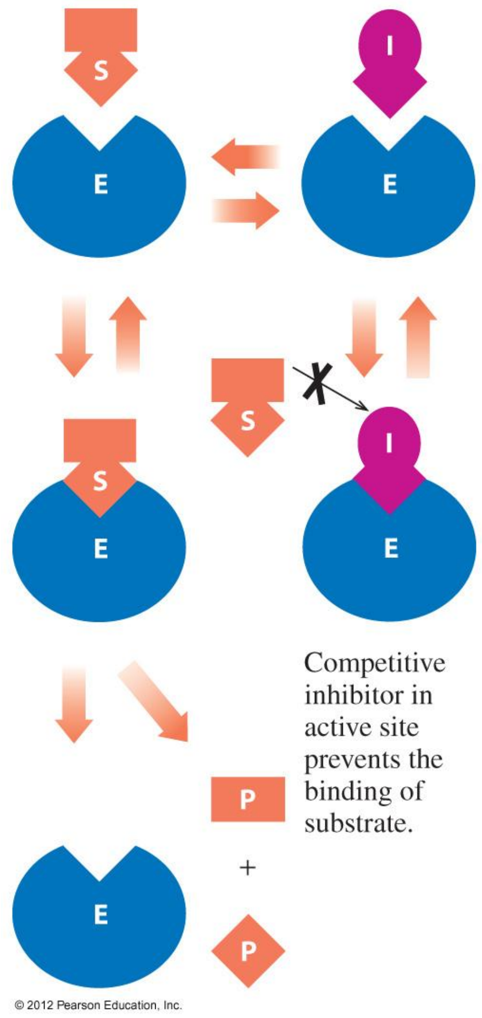
$$E + S \rightleftharpoons ES \longrightarrow E + P$$

$$E + I \rightleftharpoons EI \;\cancel{\longrightarrow}\; \text{no } P$$

Competitive Inhibition

A **competitive inhibitor**

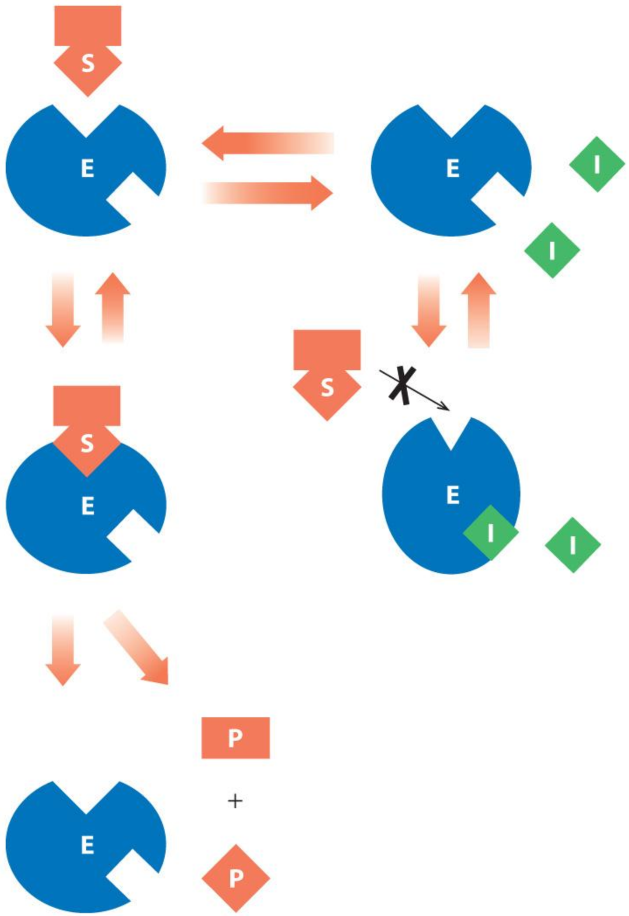
- has a structure that is similar to that of the substrate
- competes with the substrate for the active site
- has its effect reversed by increasing substrate concentration



Noncompetitive Inhibition

A **noncompetitive inhibitor**

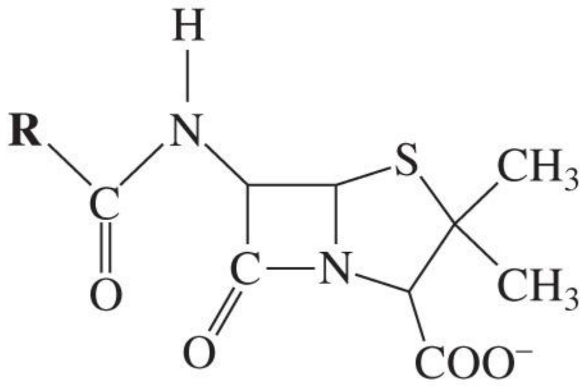
- has a structure that is much different than the substrate
- distorts the shape of the enzyme, which alters the shape of the active site
- prevents the binding of the substrate
- cannot have its effect reversed by adding more substrate



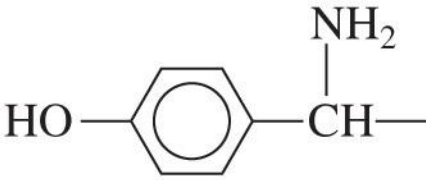
Irreversible Inhibition

An **irreversible inhibitor**

- has a molecule that causes the enzyme to lose all activity
- is often a toxic substance that destroys enzymes
- usually forms a covalent bond with an amino acid side chain preventing catalytic activity
- may be nerve gases or insecticides or antibiotics



Penicillin



Amoxicillin

Learning Check

Identify each description as an inhibitor that is competitive or noncompetitive.

A. Increasing substrate reverses inhibition.
B. Binds to enzyme surface, but not to the active site.
C. Structure is similar to substrate.
D. Inhibition is not reversed by adding more substrate.

Solution

A. Increasing substrate reverses inhibition. **competitive**

B. Binds to enzyme surface, but not to the active site. **noncompetitive**

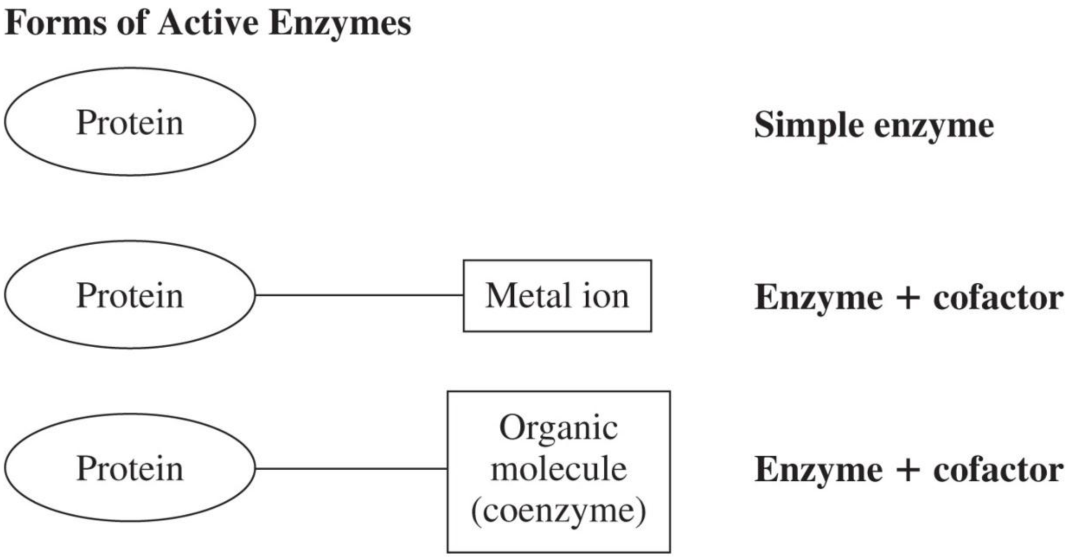
C. Structure is similar to substrate. **competitive**

D. Inhibition is not reversed by adding more substrate. **noncompetitive**

Function of Coenzymes

Cofactors

- assist enzymes in catalytic activity
- may be metal ions that are bonded to one of the amino acid side chains or small organic molecules known as **coenzymes**



Metal Ions as Coenzymes

TABLE 16.12 Enzymes and the Metal Ions Required as Cofactors

Metal Ion Cofactor	Function	Enzyme
Cu^{+}>Cu^{2+}	Oxidation–reduction	Cytochrome oxidase
Fe^{2+}>Fe^{3+}	Oxidation–reduction	Catalase Cytochrome oxidase
Zn^{2+}	Used with NAD^{+}	Alcohol dehydrogenase Carbonic anhydrase Carboxypeptidase A
Mg^{2+}	Hydrolyzes phosphate esters	Glucose-6-phosphatase
Mn^{2+}	Oxidation	Arginase
Ni^{2+}	Hydrolyzes amides	Urease

Water-Soluble Vitamins

Water-soluble vitamins

- are essential for normal health and growth
- are soluble in aqueous solutions due to the presence of −OH and −COOH groups
- act as cofactors for many enzymes
- are not stored in the body and are easily destroyed by heat, oxygen, and ultraviolet light

Water-Soluble Vitamins

TABLE 16.13 Vitamins and Function

Water-Soluble Vitamins	Coenzyme	Function
Thiamine (vitamin B_1)	Thiamine pyrophosphate	Decarboxylation
Riboflavin (vitamin B_2)	Flavin adenine dinucleotide (FAD); flavin mononucleotide (FMN)	Electron transfer
Niacin (vitamin B_3)	Nicotinamide adenine dinucleotide (NAD^+); nicotinamide adenine dinucleotide phosphate ($NADP^+$)	Oxidation–reduction
Pantothenic acid (vitamin B_5)	Coenzyme A	Acetyl group transfer
Pyridoxine (vitamin B_6)	Pyridoxal phosphate	Transamination
Cobalamin (vitamin B_{12})	Methylcobalamin	Methyl group transfer
Ascorbic acid (vitamin C)	Vitamin C	Collagen synthesis, healing of wounds
Biotin	Biocytin	Carboxylation
Folic acid	Tetrahydrofolate	Methyl group transfer

Ascorbic Acid (Vitamin C)

Vitamin C

- is required in collagen synthesis
- deficiency can lead to weakened connective tissue, slow-healing wounds, and anemia
- is found in blueberries, citrus fruits, tomatoes, broccoli, and red and green vegetables

Fat-Soluble Vitamins

Fat-soluble vitamins, including A, D, E, and K, are

- soluble in lipids, but not in aqueous solutions
- important in vision, bone formation, antioxidants, and blood clotting
- stored in the body

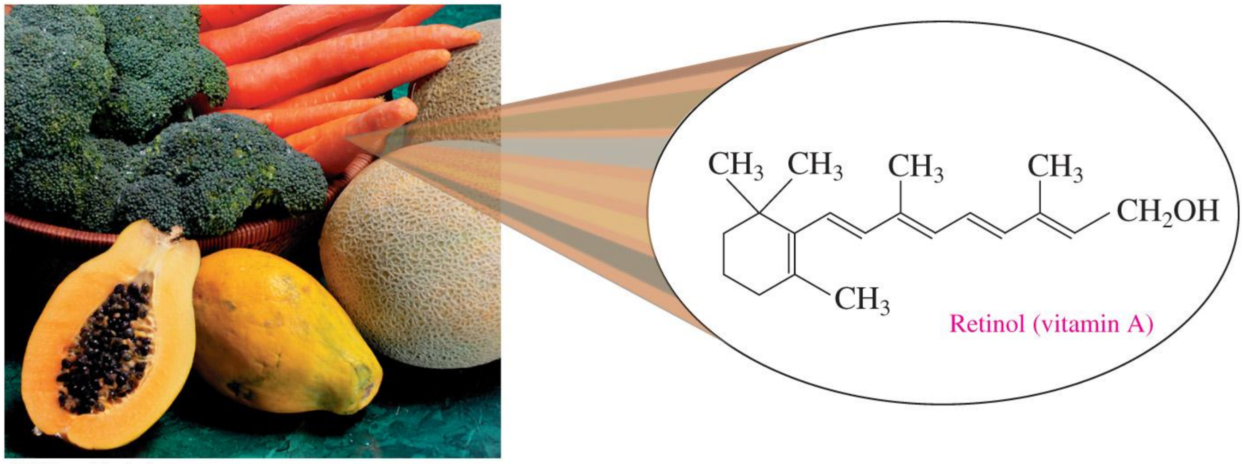
TABLE 16.13 Vitamins and Function

Fat-Soluble Vitamins	
Vitamin A	Formation of visual pigments; development of epithelial cells
Vitamin D	Absorption of calcium and phosphate; deposition of calcium and phosphate in bone
Vitamin E	Antioxidant; prevents oxidation of vitamin A and unsaturated fatty acids
Vitamin K	Synthesis of prothrombin for blood clotting

Vitamin A

The orange pigment in carrots is used to help synthesize vitamin A in the body.

Vitamin A is a fat-soluble vitamin, stored in the body and not eliminated.



Learning Check

Identify the vitamin associated with each:

Thiamin (B_1) Vitamin A

Vitamin K Vitamin D

Ascorbic acid

A. collagen formation

B. absorption of phosphorus and calcium in bone

C. vision

D. blood clotting

Solution

Identify the vitamin associated with each:

Thiamin (B_1) Vitamin A

Vitamin K Vitamin D

Ascorbic acid

A. collagen formation **Ascorbic acid**

B. absorption of phosphorus and calcium in bone

Vitamin D

C. vision **Vitamin A**

D. blood clotting **Vitamin K**

Amino Acids, Proteins, and Enzymes Concept Map