Lecture Series 2

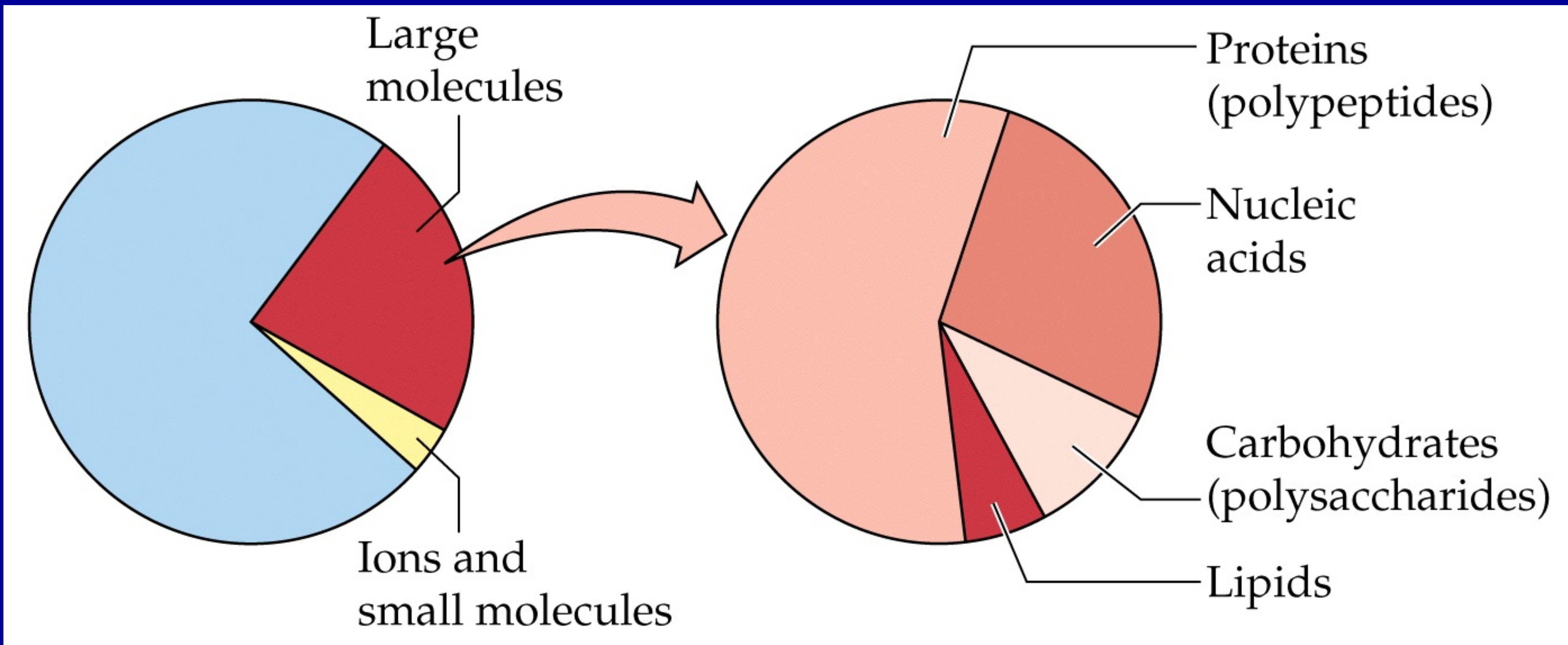
Macromolecules: Their Structure and Function

Reading Assignments

- Read Chapter 4

(Protein structure & Function)

Biological Substances found in Living Tissues

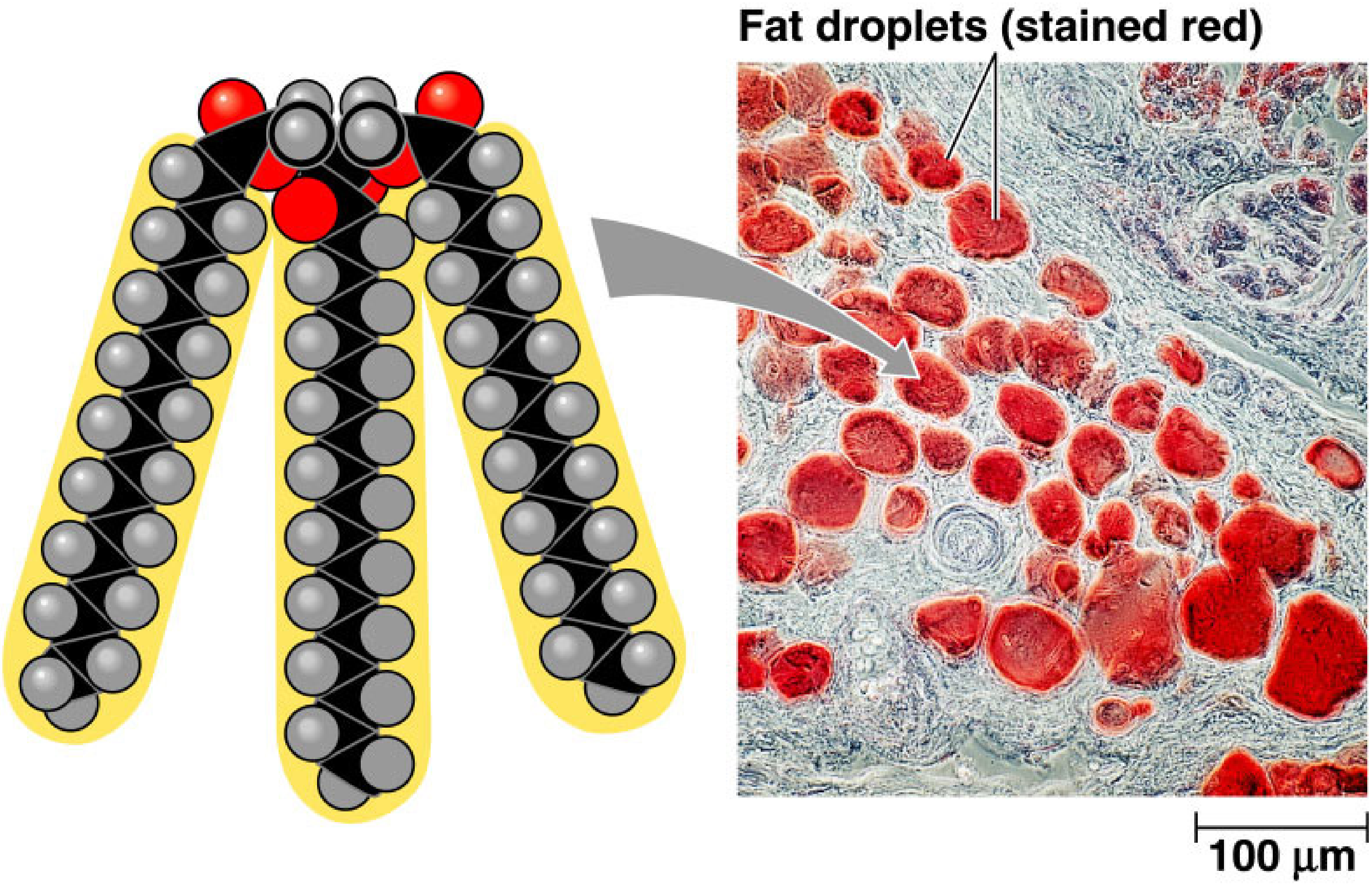


The big four in terms of macromolecules

A. Lipids: Water-Insoluble Molecules

- Lipids can form large biological molecules, but these aggregations are NOT chemically polymers because individual units are not linked by covalent bonds.
- Share the common trait of being hydrophobic.

The role of hydrocarbons in fats



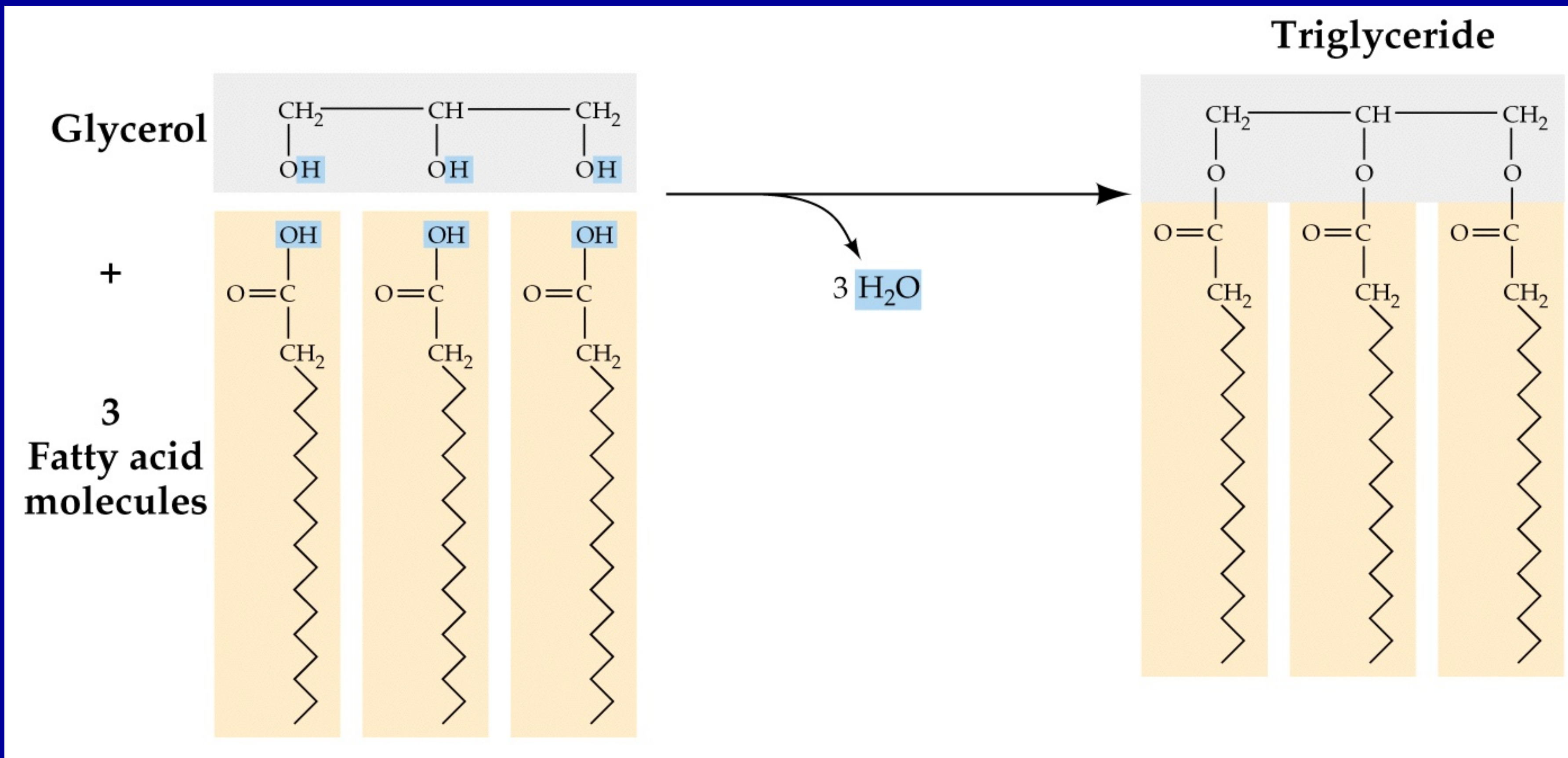
(a) A fat molecule

(b) Mammalian adipose cells

A. Lipids: Water-Insoluble Molecules

- Fats and oils are composed of three fatty acids covalently bonded to a glycerol molecule by ester linkages.
- Fats and oils function to efficiently store energy.

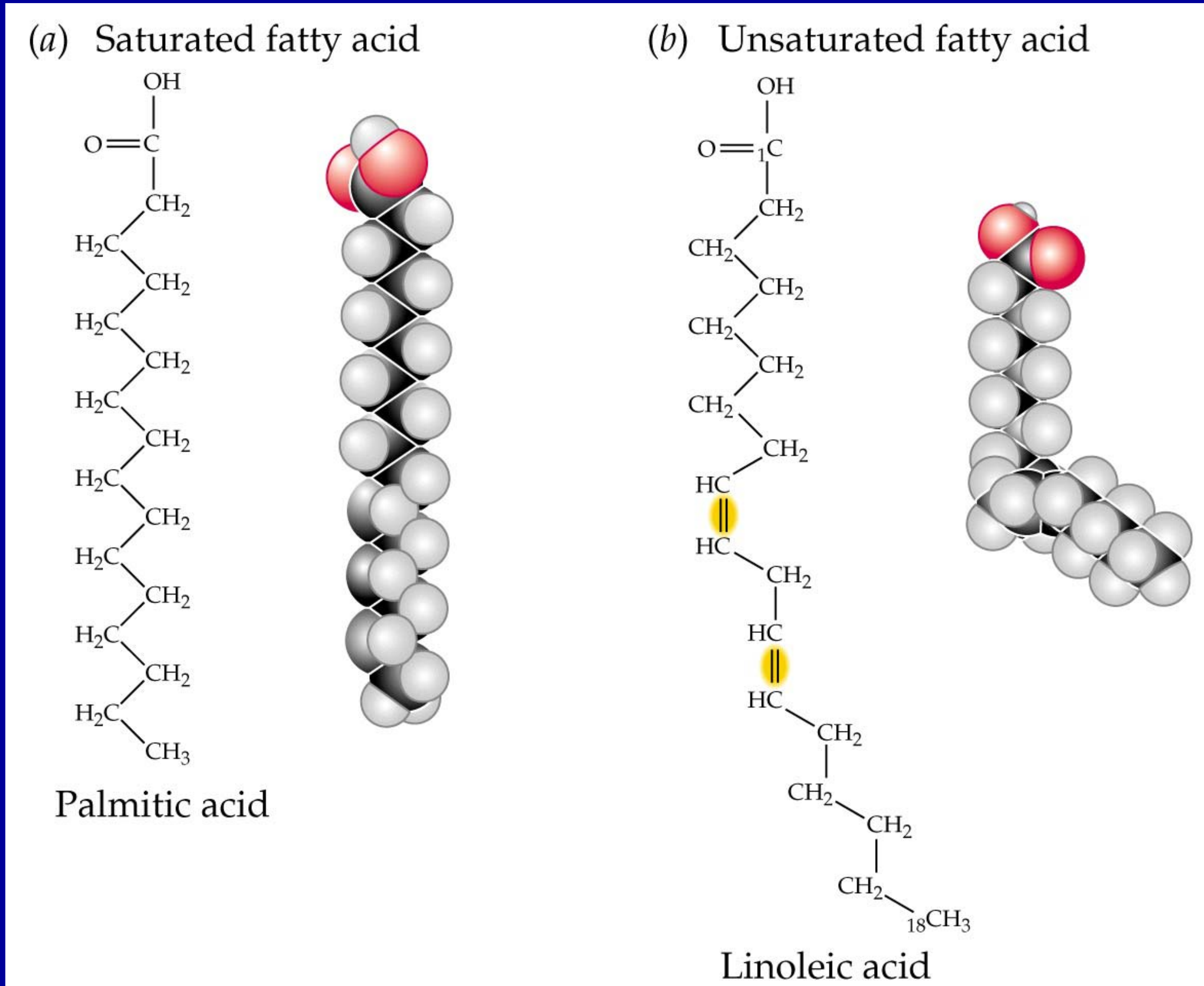
Synthesis of a Triglyceride



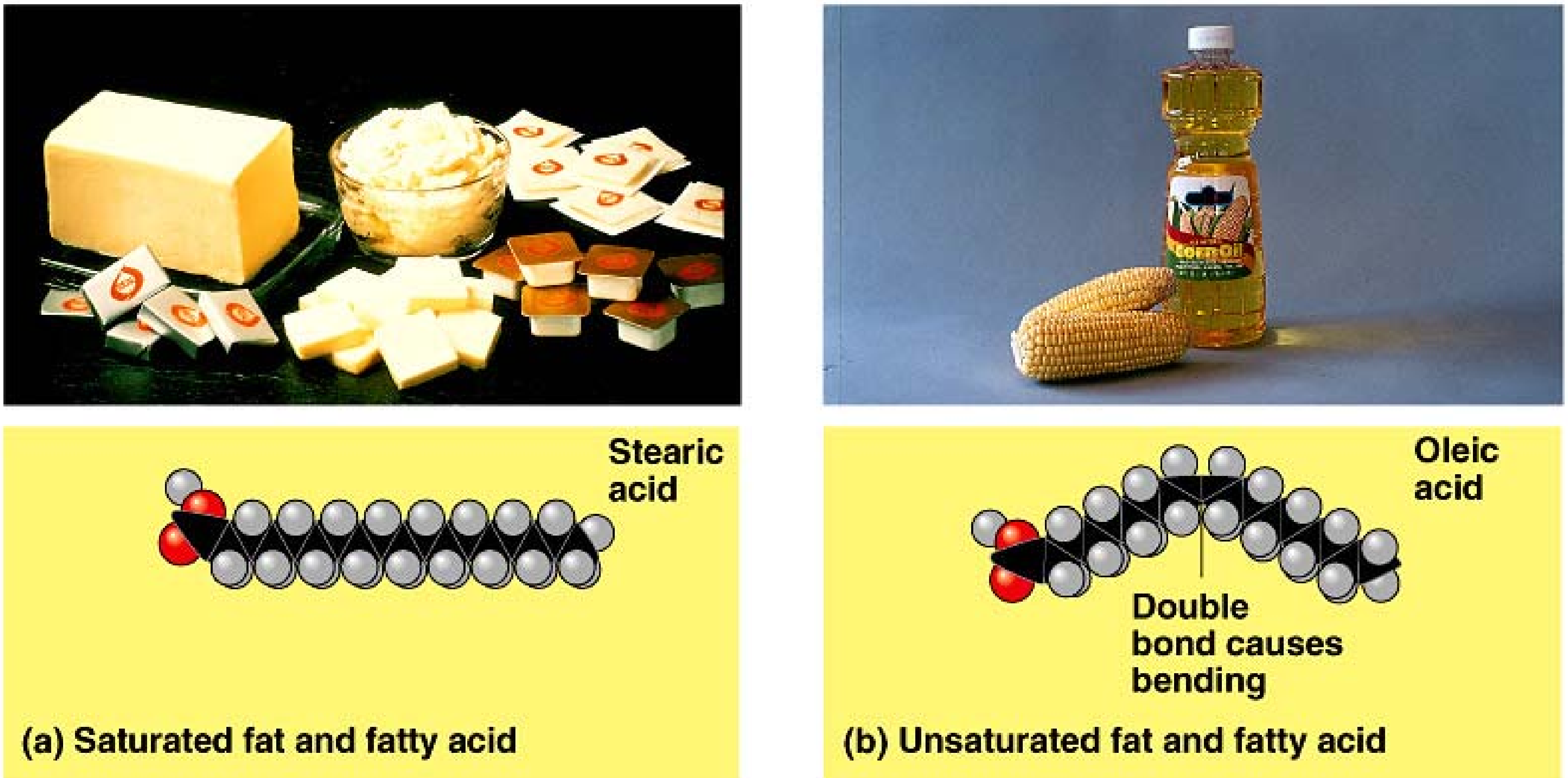
A. Lipids: Water-Insoluble Molecules

- Saturated fatty acids have a hydrocarbon chain with no double bonds. The hydrocarbon chains of unsaturated fatty acids have one or more double bonds that bend the chain, making close packing less possible.

Saturated and Unsaturated Fatty Acids



Examples of saturated and unsaturated fats and fatty acids



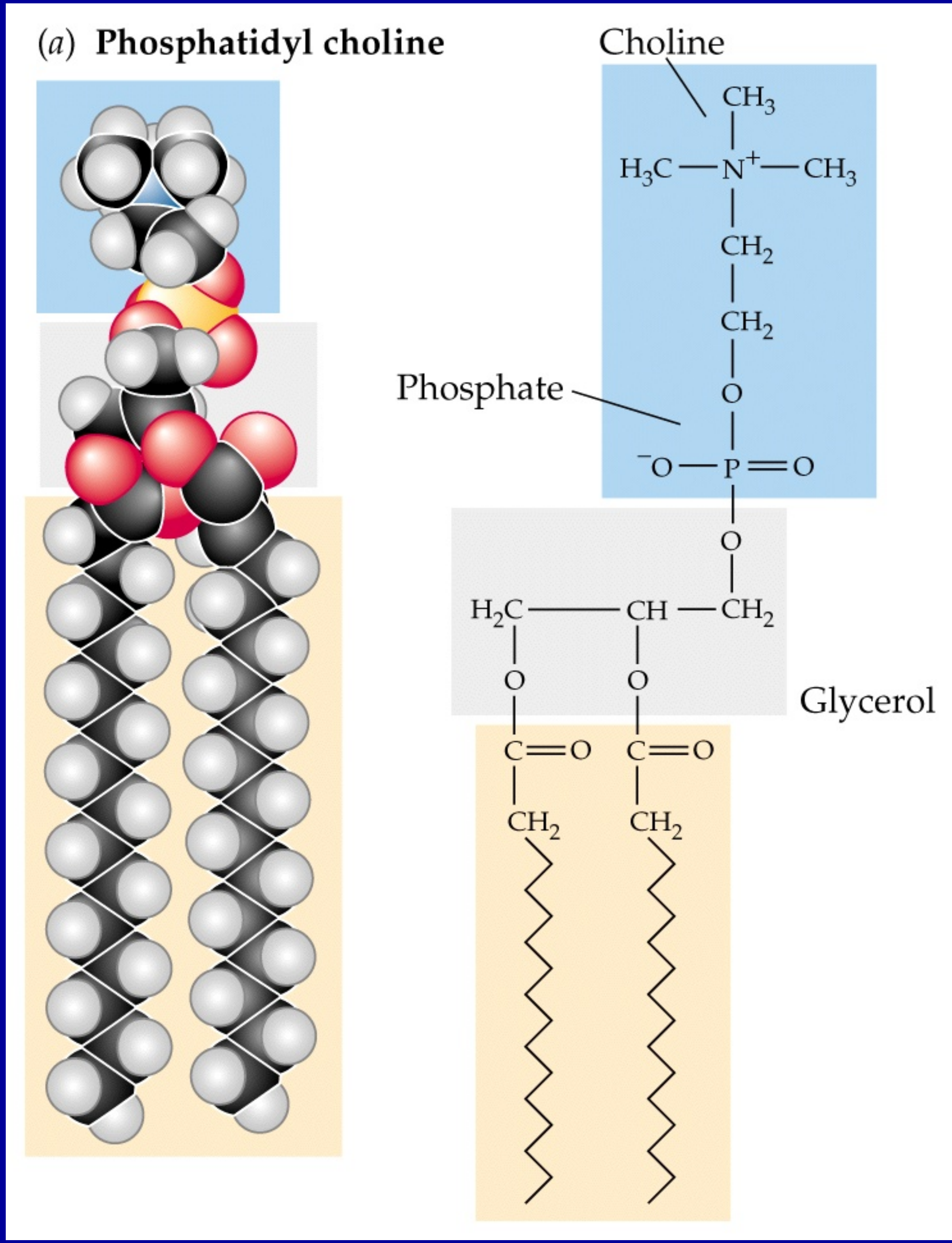
(a) Saturated fat and fatty acid

(b) Unsaturated fat and fatty acid

A. Lipids: Water-Insoluble Molecules

- Phospholipids have a hydrophobic hydrocarbon “tail” and a hydrophilic phosphate “head.”
- Phospholipids form the core of biological membranes.

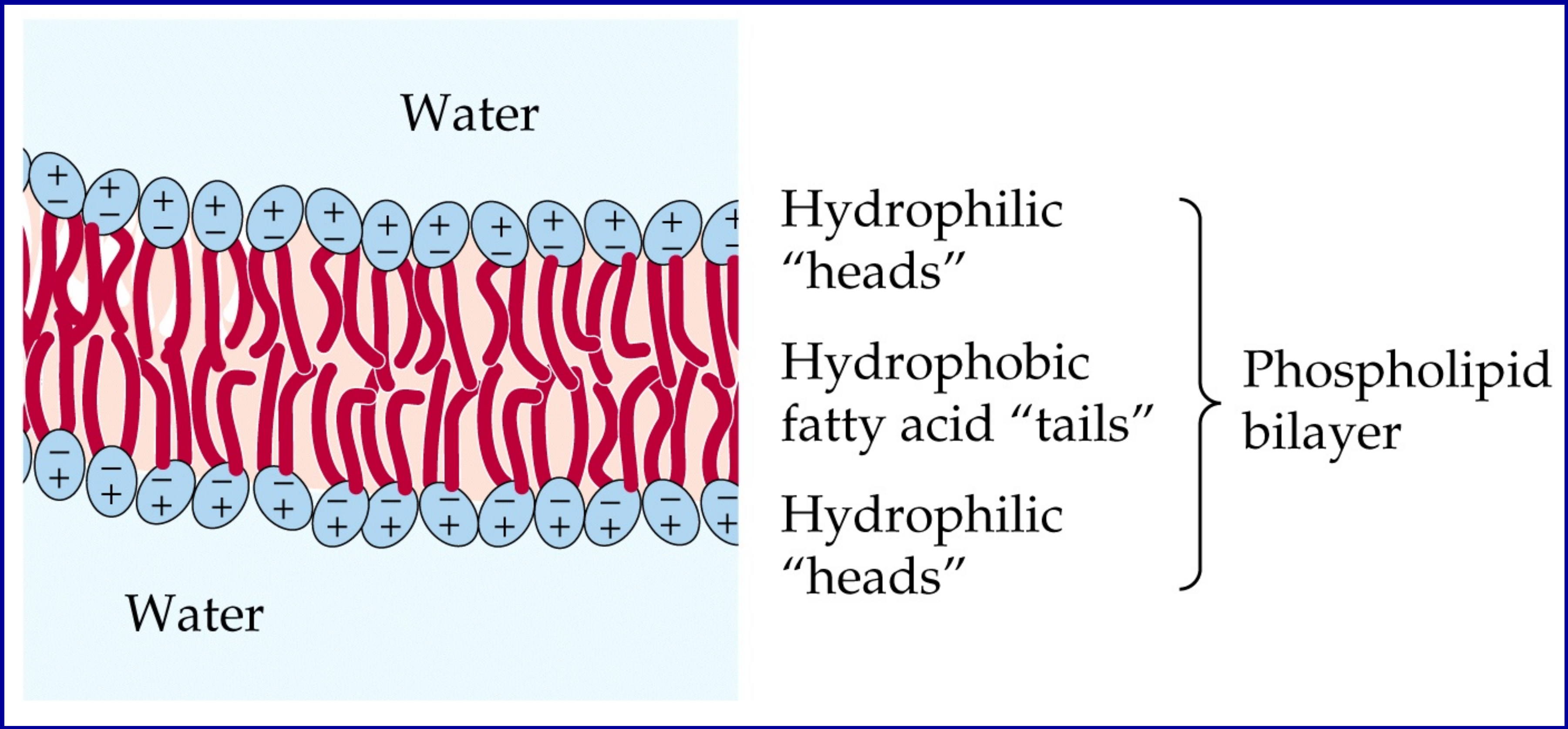
Phospholipid Structure



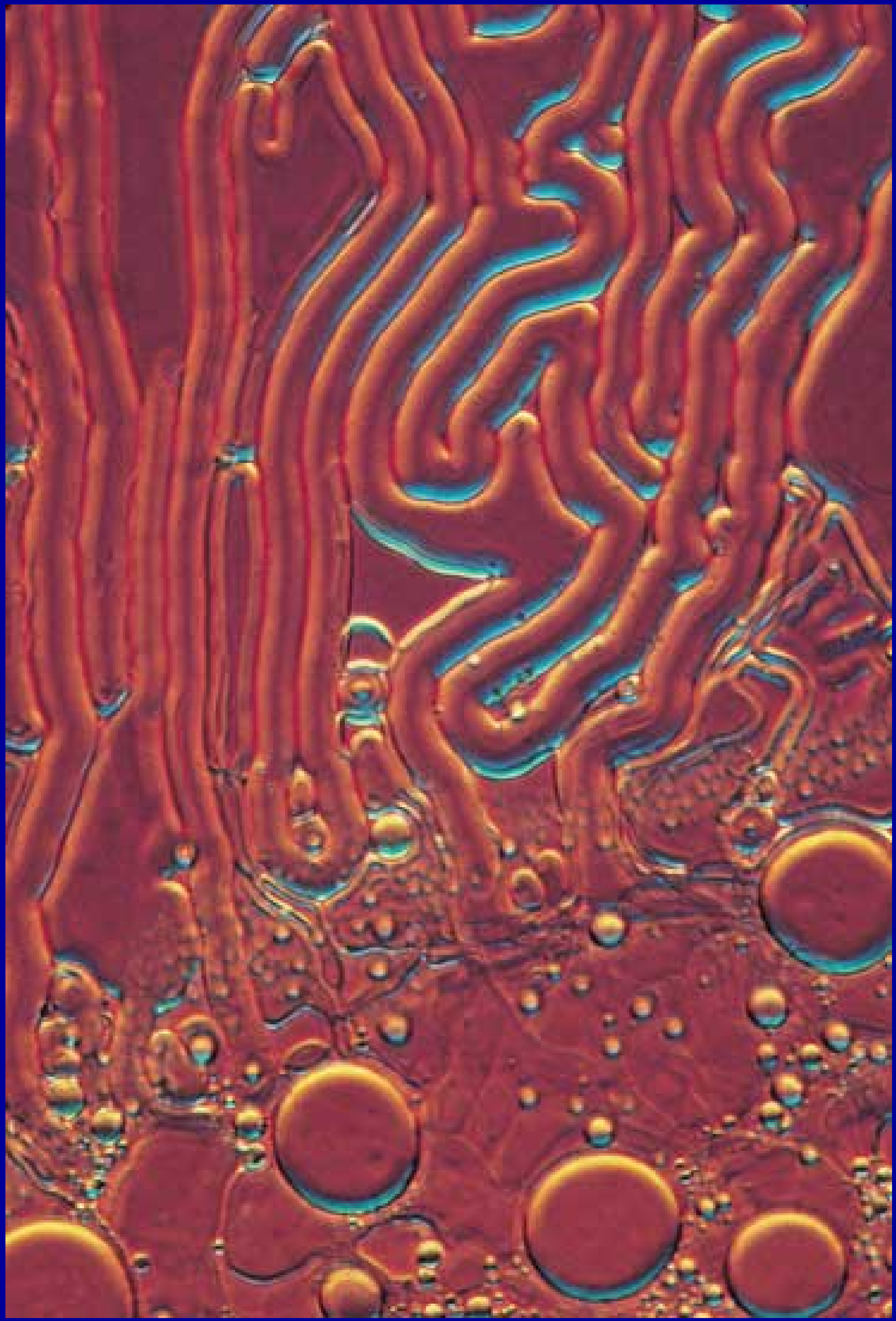
A. Lipids: Water-Insoluble Molecules

- In water, the interactions of the hydrophobic tails and hydrophilic heads generate a phospholipid bilayer two molecules thick. The head groups are directed outward, interacting with surrounding water. Tails are packed in the interior.

Phospholipids form a Bilayer



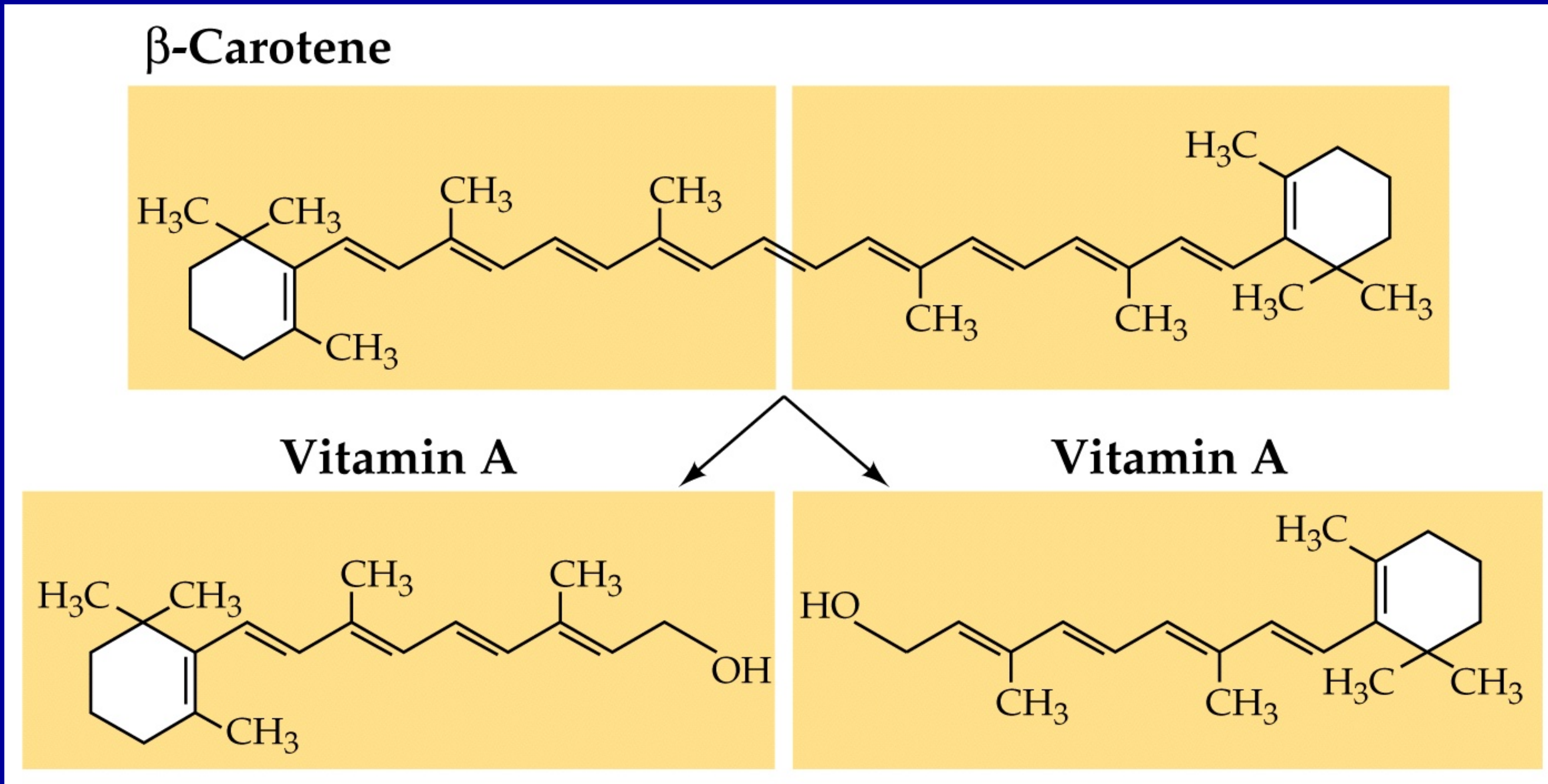
Phospholipid



A. Lipids: Water-Insoluble Molecules

- Carotenoids trap light energy in green plants. β-Carotene can be split to form vitamin A, a lipid vitamin.

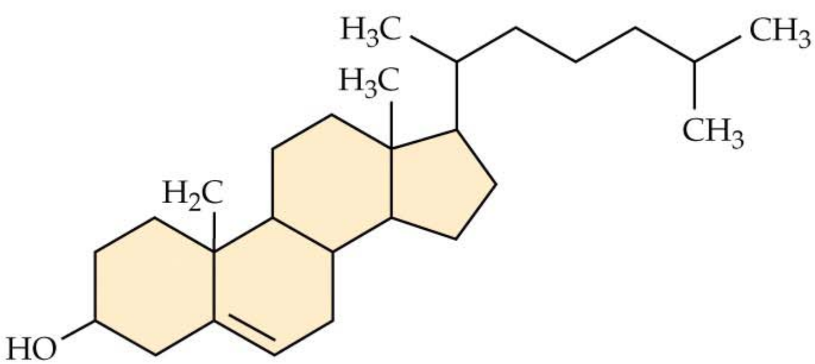
Example of an Important Lipid



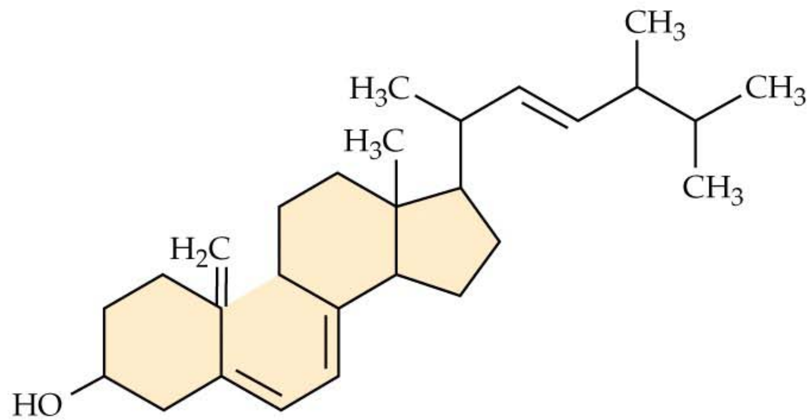
A. Lipids: Water-Insoluble Molecules

- Some lipids are steroids and function as hormones. Cholesterol is synthesized by the liver and has a role in some cell membranes, as well as in the digestion of other fats.
- Some lipids function as vitamins, required for normal functioning, must be acquired from the diet.

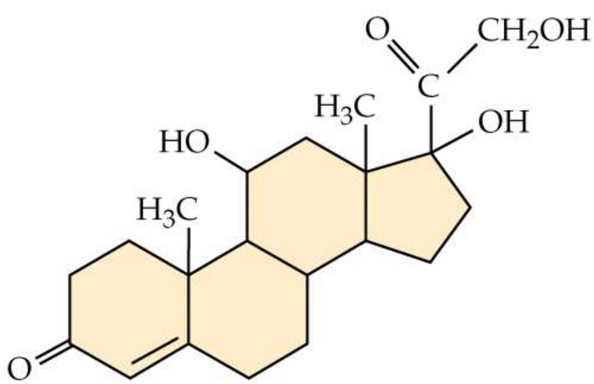
Examples of an Important Lipids that are also Steroids



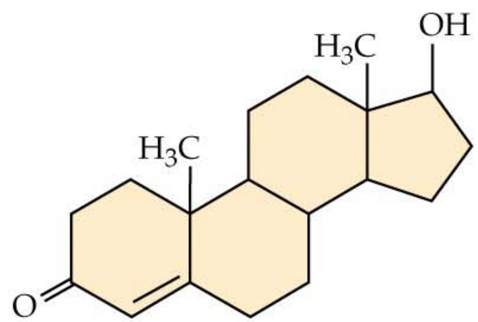
Cholesterol



Vitamin D_2



Cortisol



Testosterone

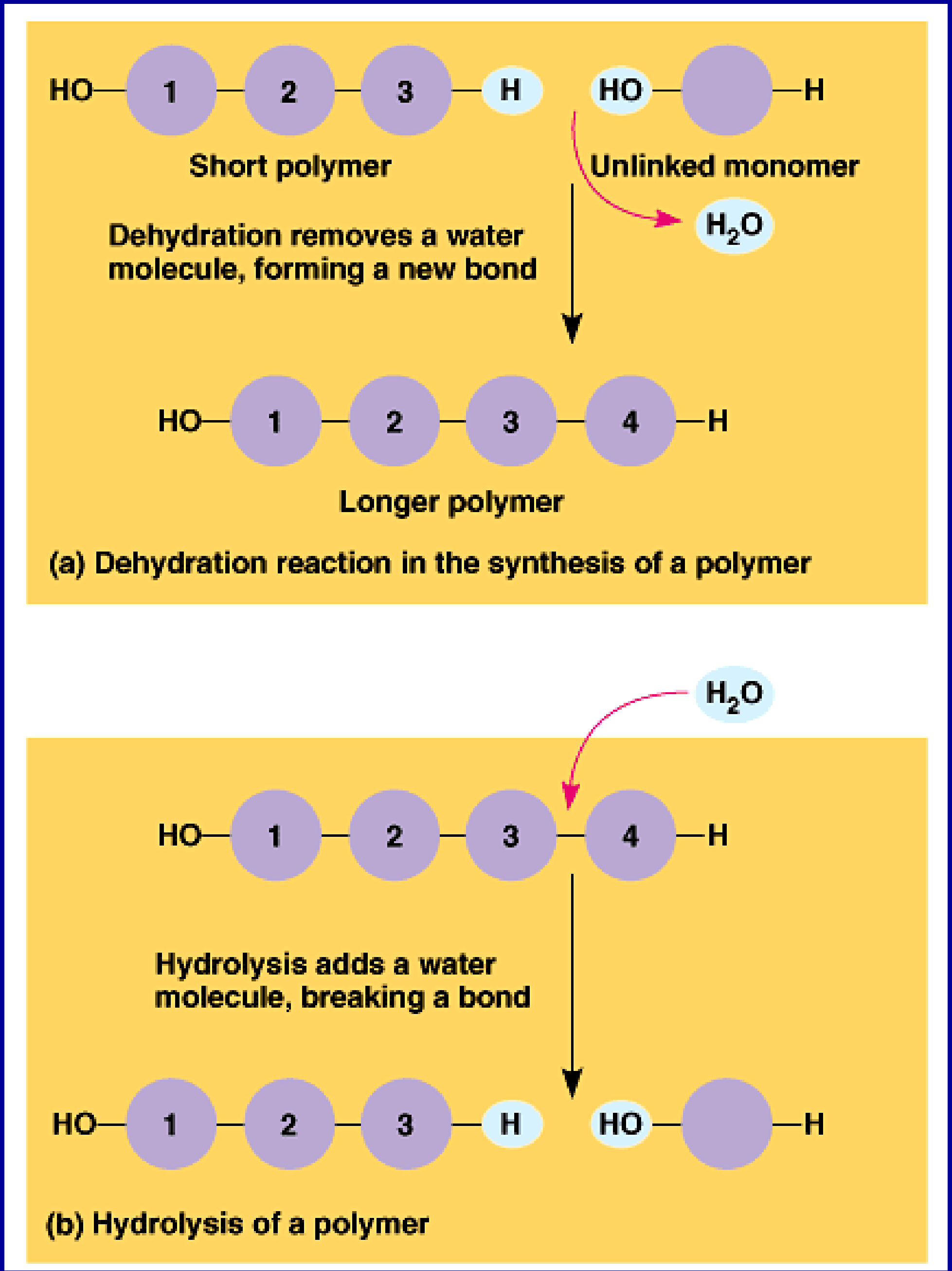
B. Macromolecules: Giant Polymers

- Macromolecules have specific three-dimensional shapes. Different functional groups give local sites on macromolecules specific properties.
- Monomers are joined by condensation reactions. Hydrolysis reactions break polymers into monomers.

3.1 The Building Blocks of Organisms

MONOMER	SIMPLE POLYMER	COMPLEX POLYMER
Amino acid	Peptide or oligopeptide	Polypeptide
Nucleotide	Oligonucleotide	Nucleic acid
Monosaccharide	Oligosaccharide	Polysaccharide

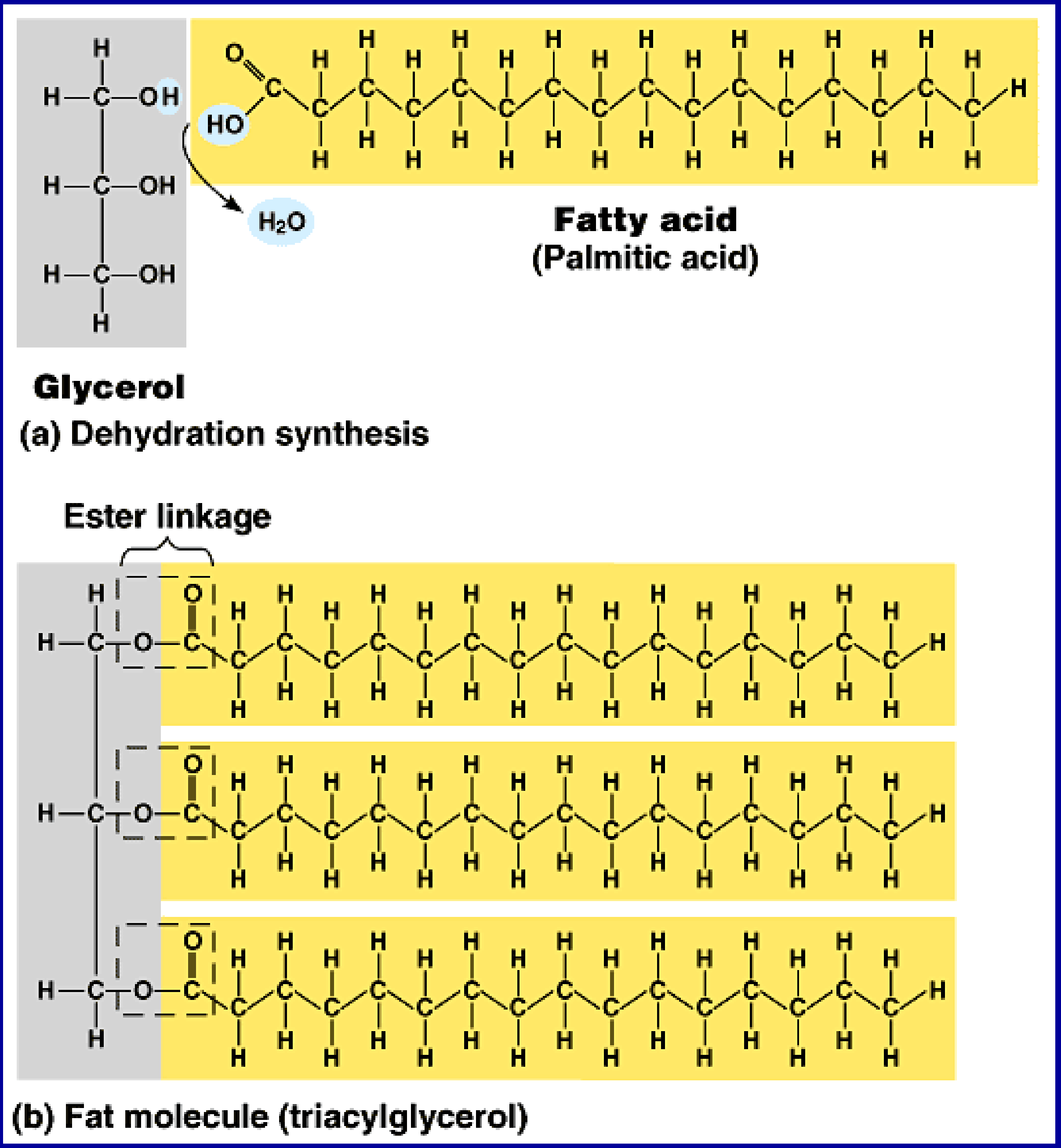
The synthesis and breakdown of polymers



Condensation or Dehydration reactions

Hydrolysis reactions

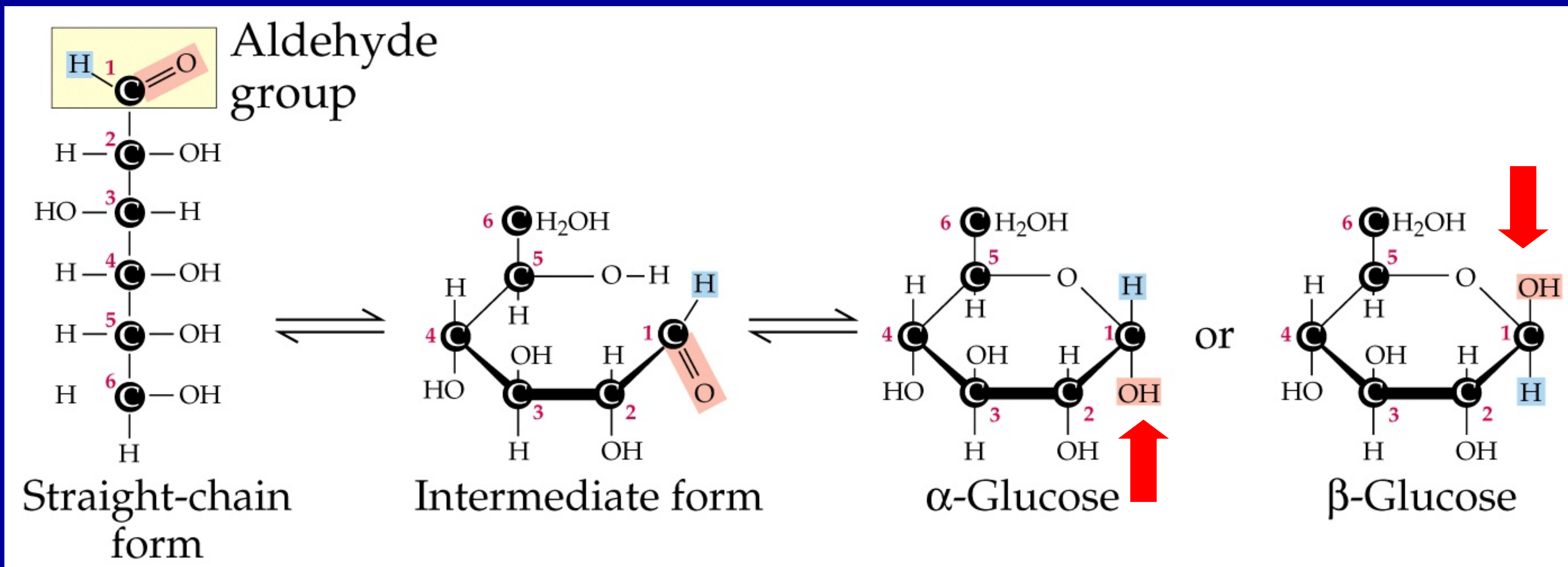
The synthesis and structure of a fat, or triacylglycerol



C. Carbohydrates: Sugars and Sugar Polymers

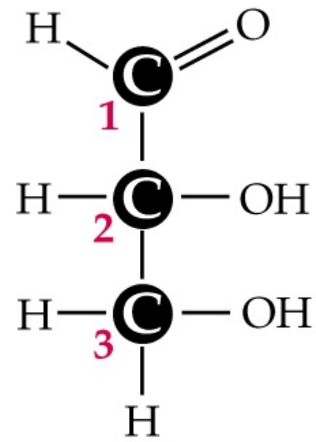
- All carbohydrates contain carbon bonded to H and OH groups. $[CH_2O]_N$
- Hexoses are monosaccharides that contain six carbon atoms.
- Monosaccharides are simple sugars.
  - Can be used for fuel.
  - Can be converted into other organic molecules.
  - Can be combined into polymers.

Various forms of Glucose

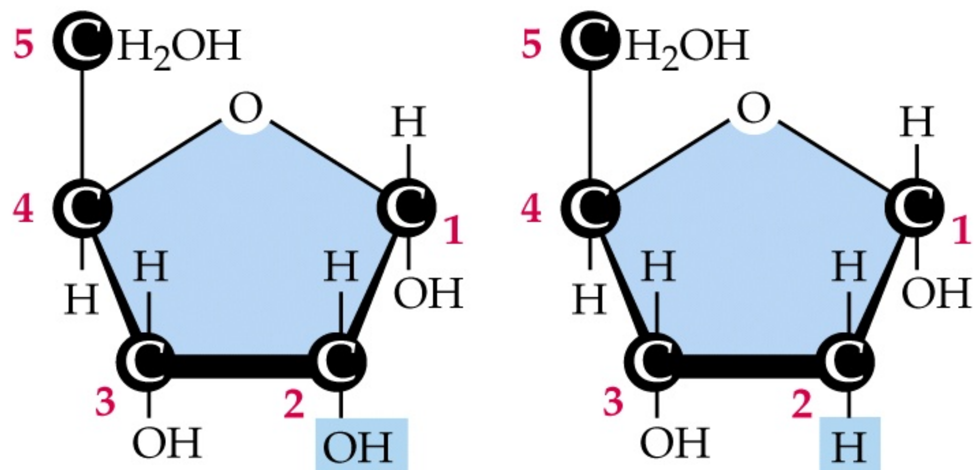


May be linear, but can form rings.

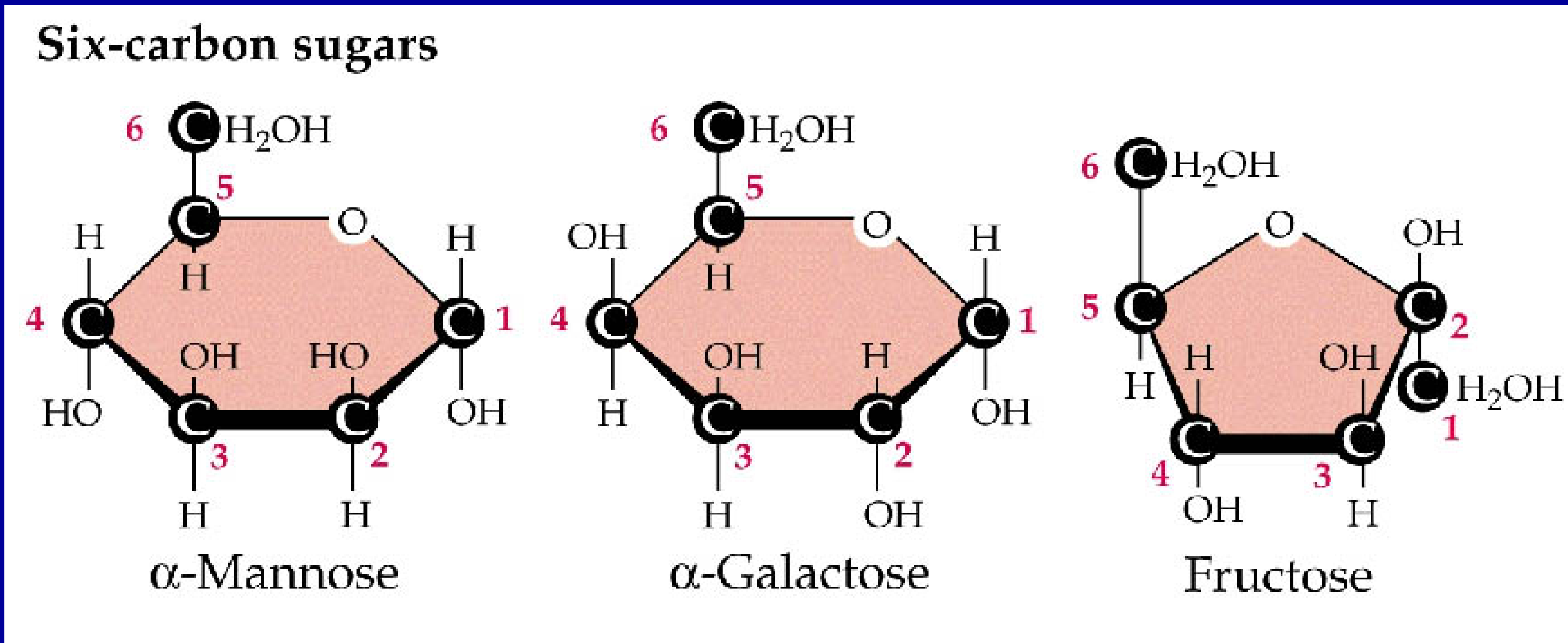
Three-carbon sugar



Five-carbon sugars

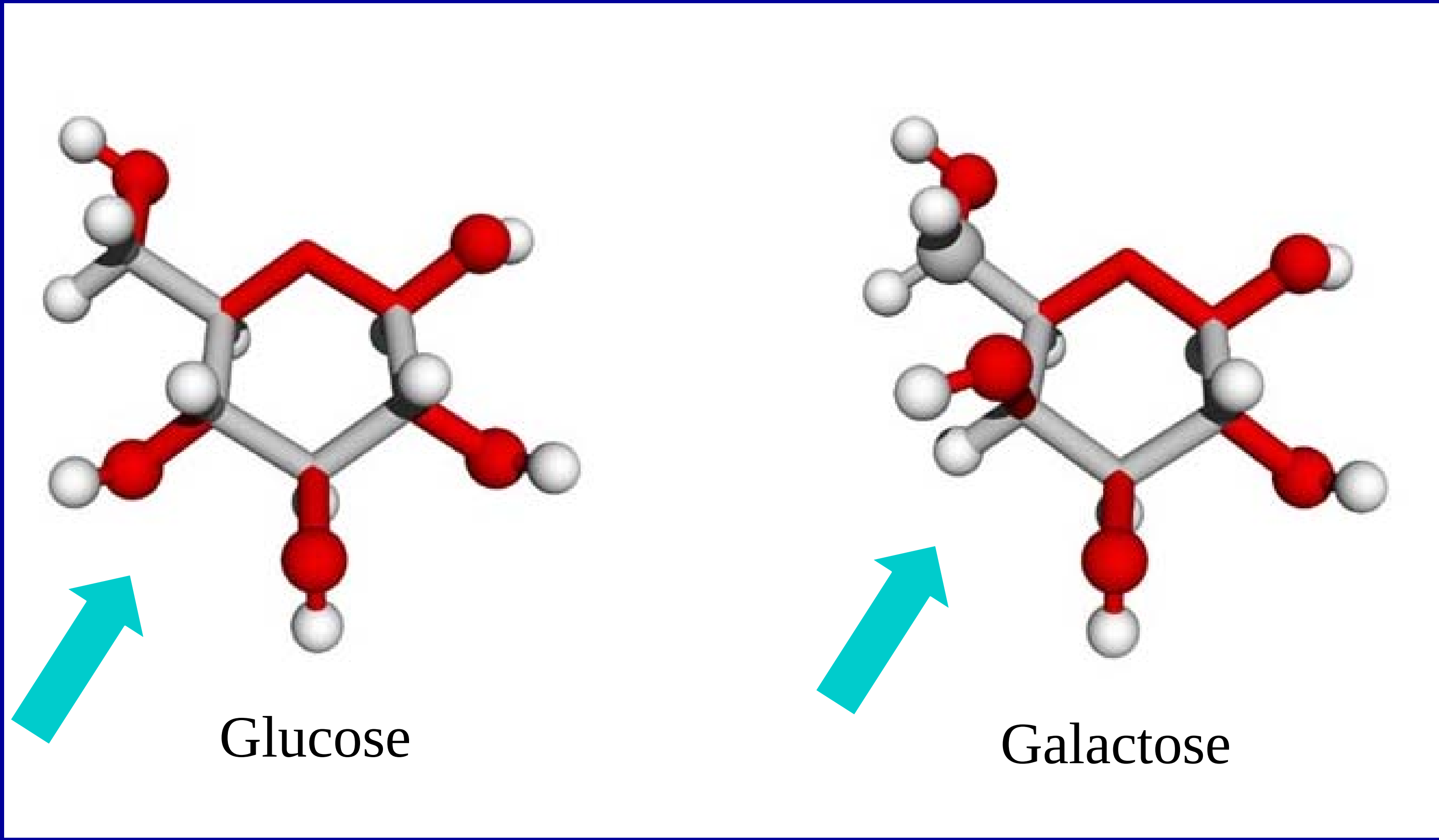


Ribose Deoxyribose



Six-carbon sugars
6
CH2OH
5
O
H
H
H
4
1
OH
HO
HO
OH
3
2
H
H
α-Mannose
6
CH2OH
5
O
OH
H
H
4
1
OH
H
H
OH
3
2
H
OH
α-Galactose
6
CH2OH
O
OH
5
2
H
H
OH
H
CH2OH
1
4
3
OH
H
Fructose

Hexose sugars

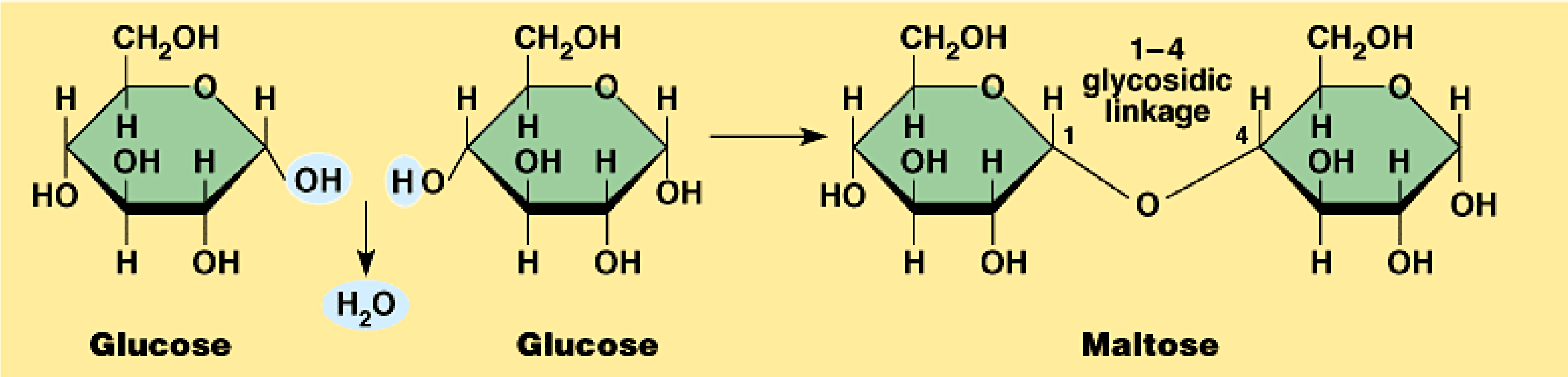


Alpha or Beta???

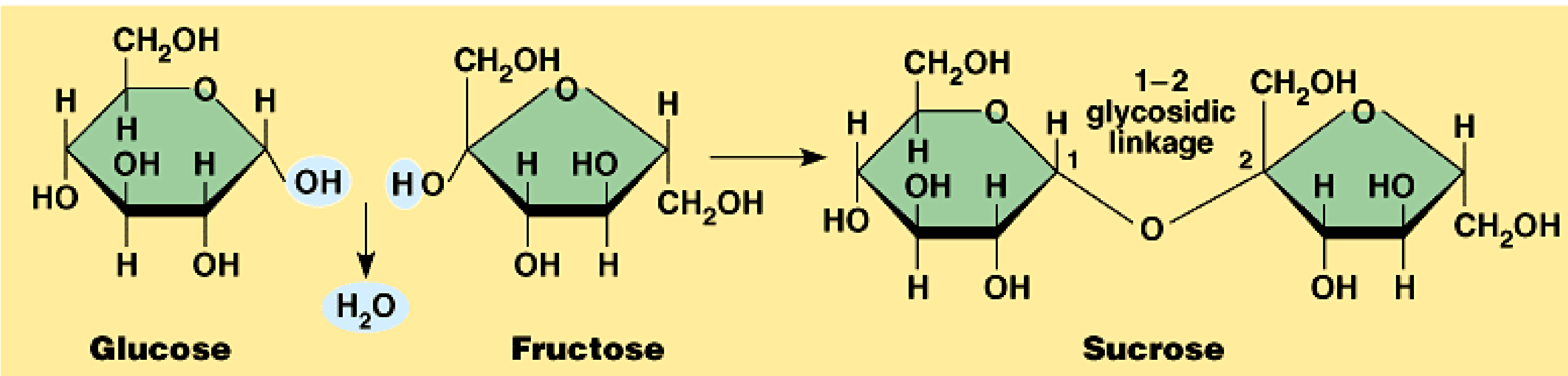
C. Carbohydrates: Sugars and Sugar Polymers

- Glycosidic linkages may have either α or β orientation in space. They covalently link monosaccharides into larger units.

Examples of disaccharide synthesis

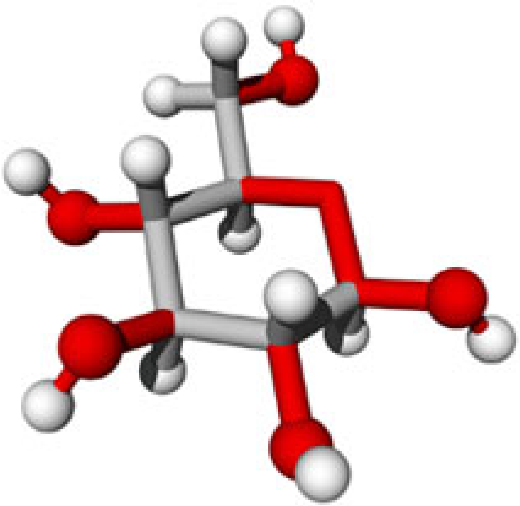


(a) Dehydration synthesis of maltose

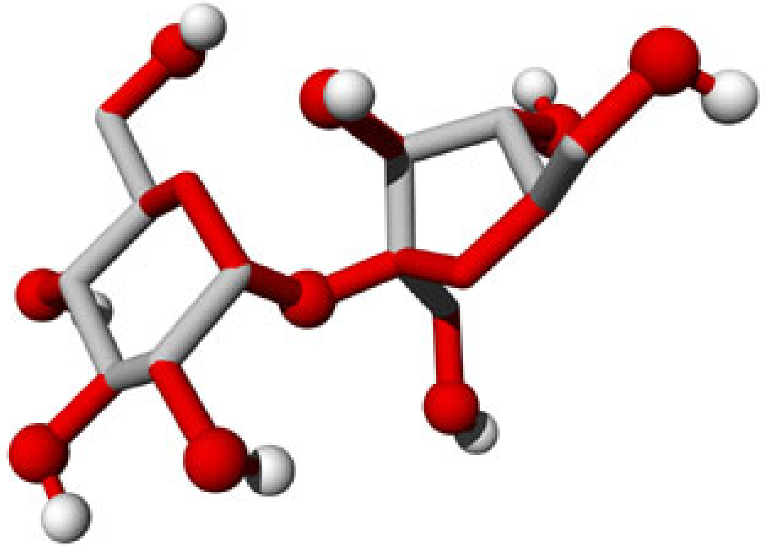


(b) Dehydration synthesis of sucrose

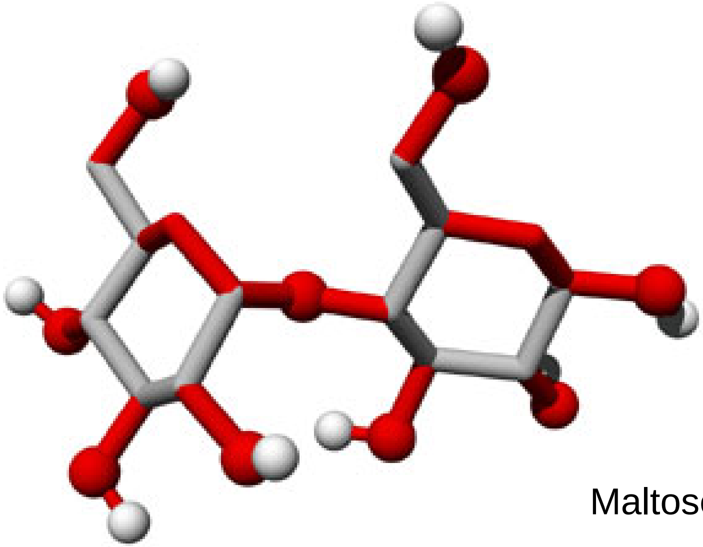
Glucose monomer and disaccharides



Glucose monomer



Sucrose



Maltose

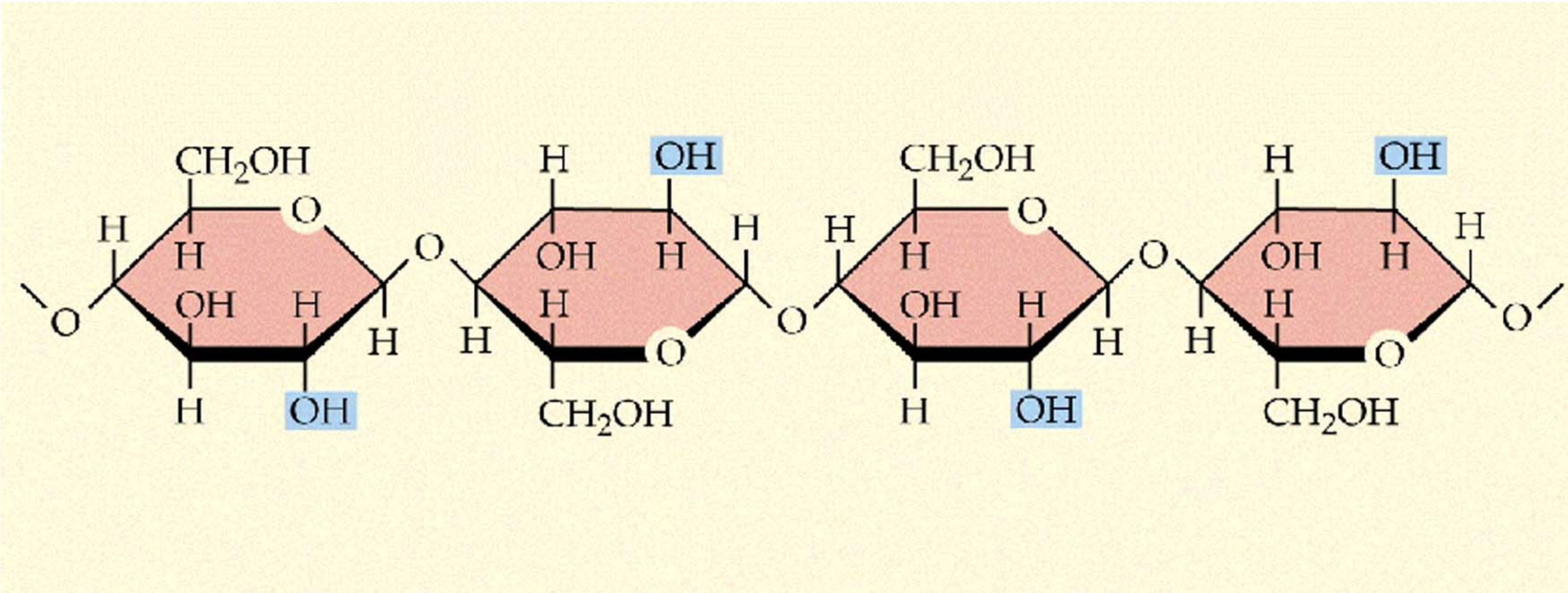
C. Carbohydrates: Sugars and Sugar Polymers

- Cellulose, a polymer, is formed by glucose units linked by β-glycosidic linkages between carbons 1 and 4.

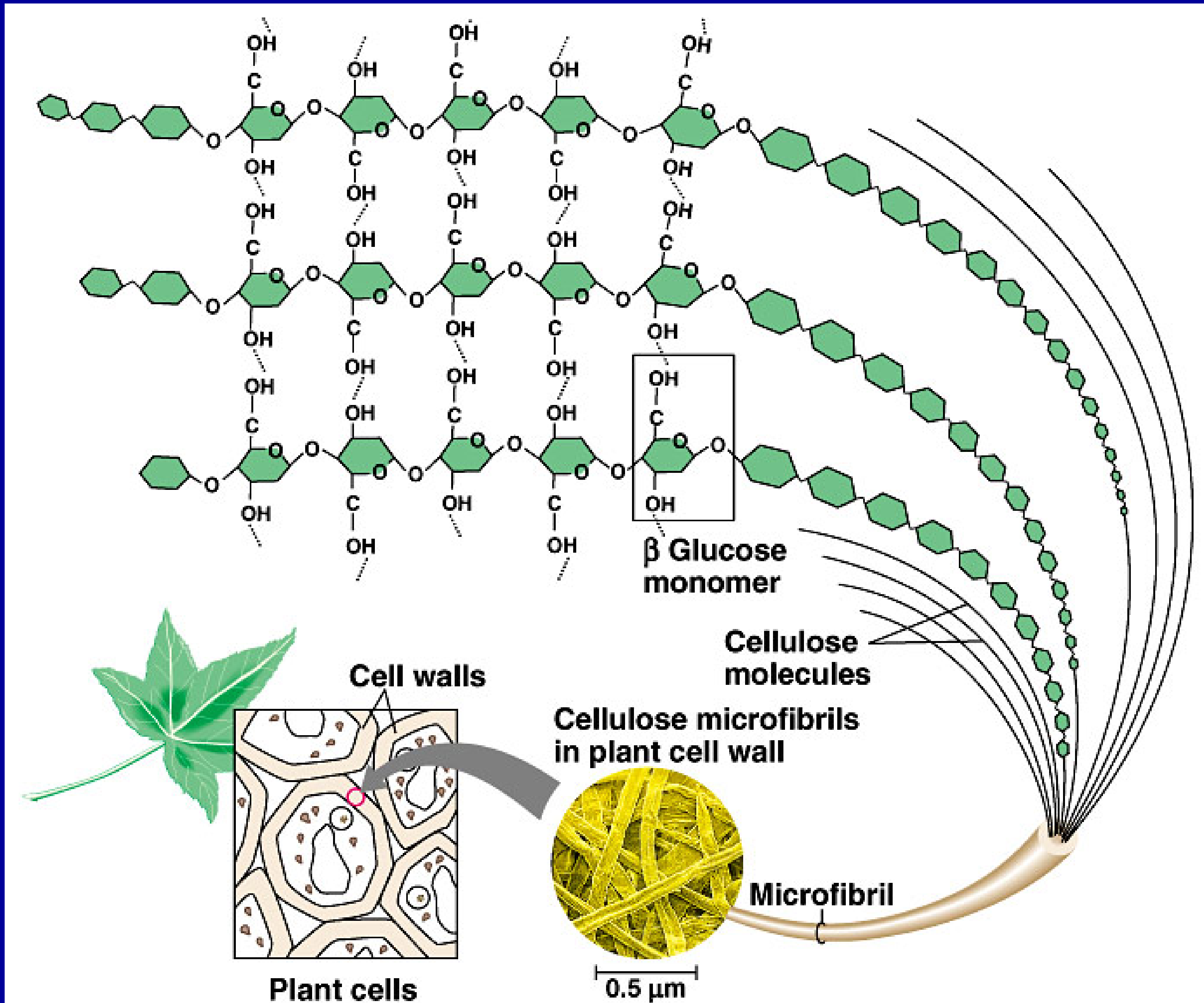
Glycosidic Linkages

(*a*) **Molecular structure**

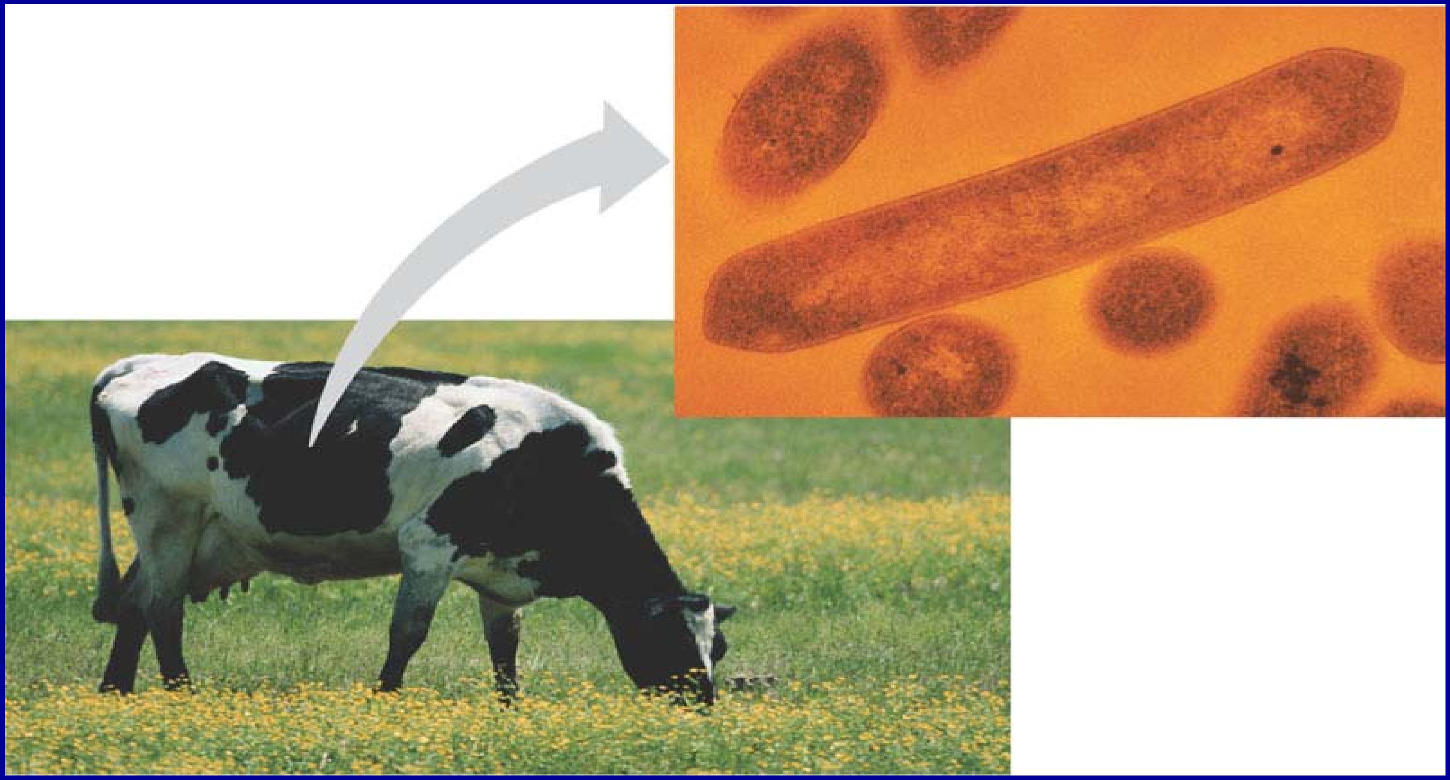
Cellulose



The arrangement of cellulose in plant cell walls



- Cellulose is difficult to digest
  - Cows have microbes in their stomachs to facilitate this process



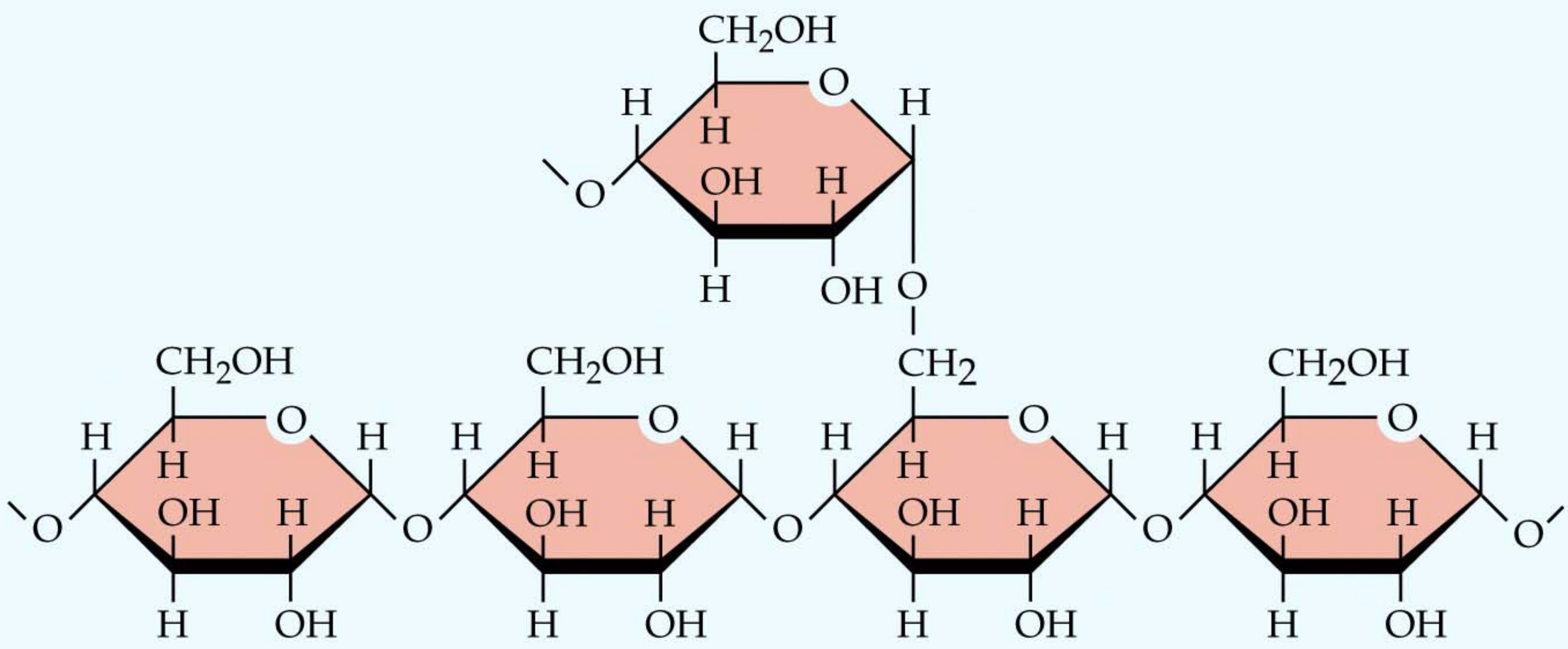
C. Carbohydrates: Sugars and Sugar Polymers

- Starches are formed by α-glycosidic linkages between carbons 1 and 4 and are distinguished by amount of branching through glycosidic bond formation at carbon 6.
- Glycogen contains α-1,4 glycosidic linkages and is highly branched.

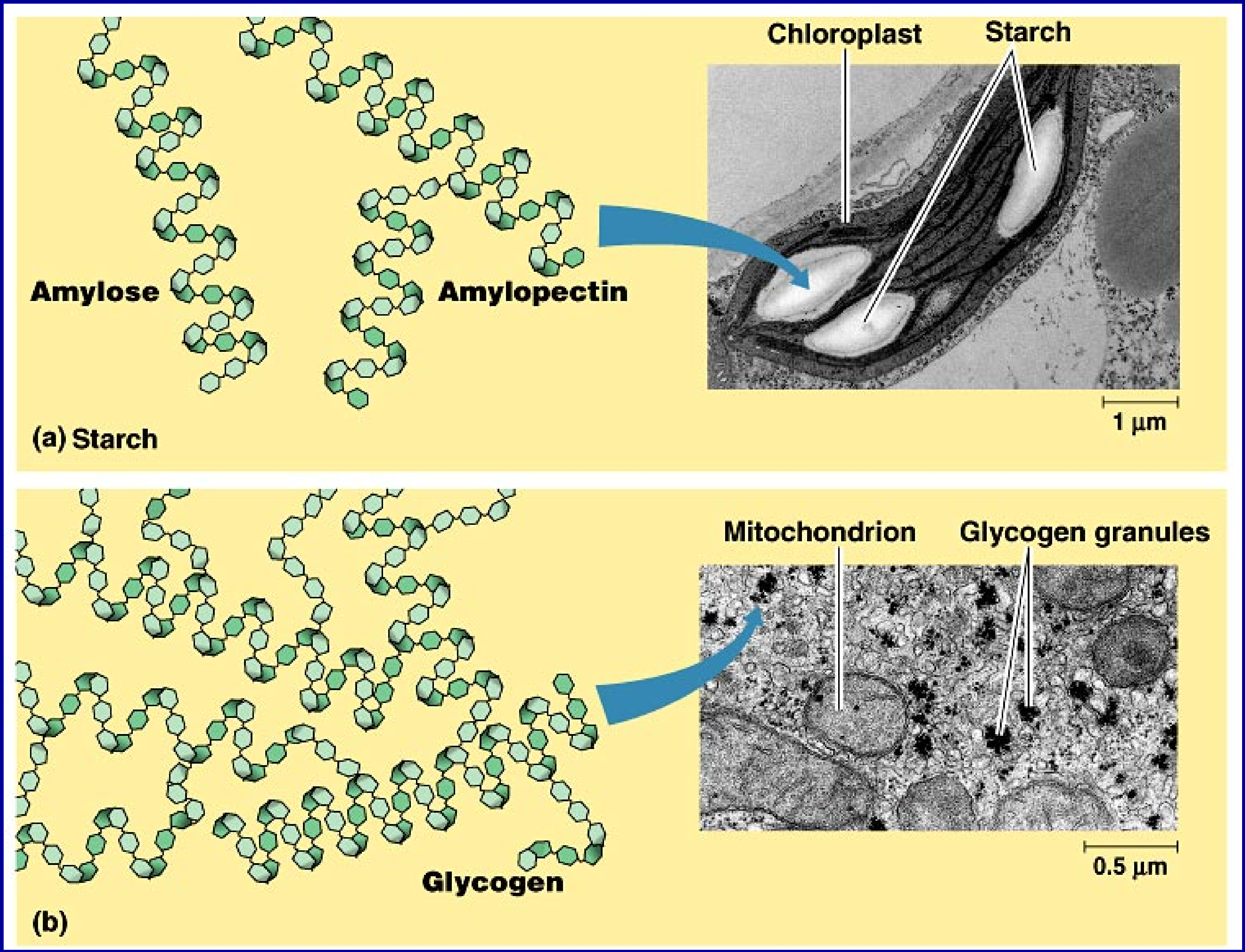
Glycosidic Linkages

(*a*) **Molecular structure**

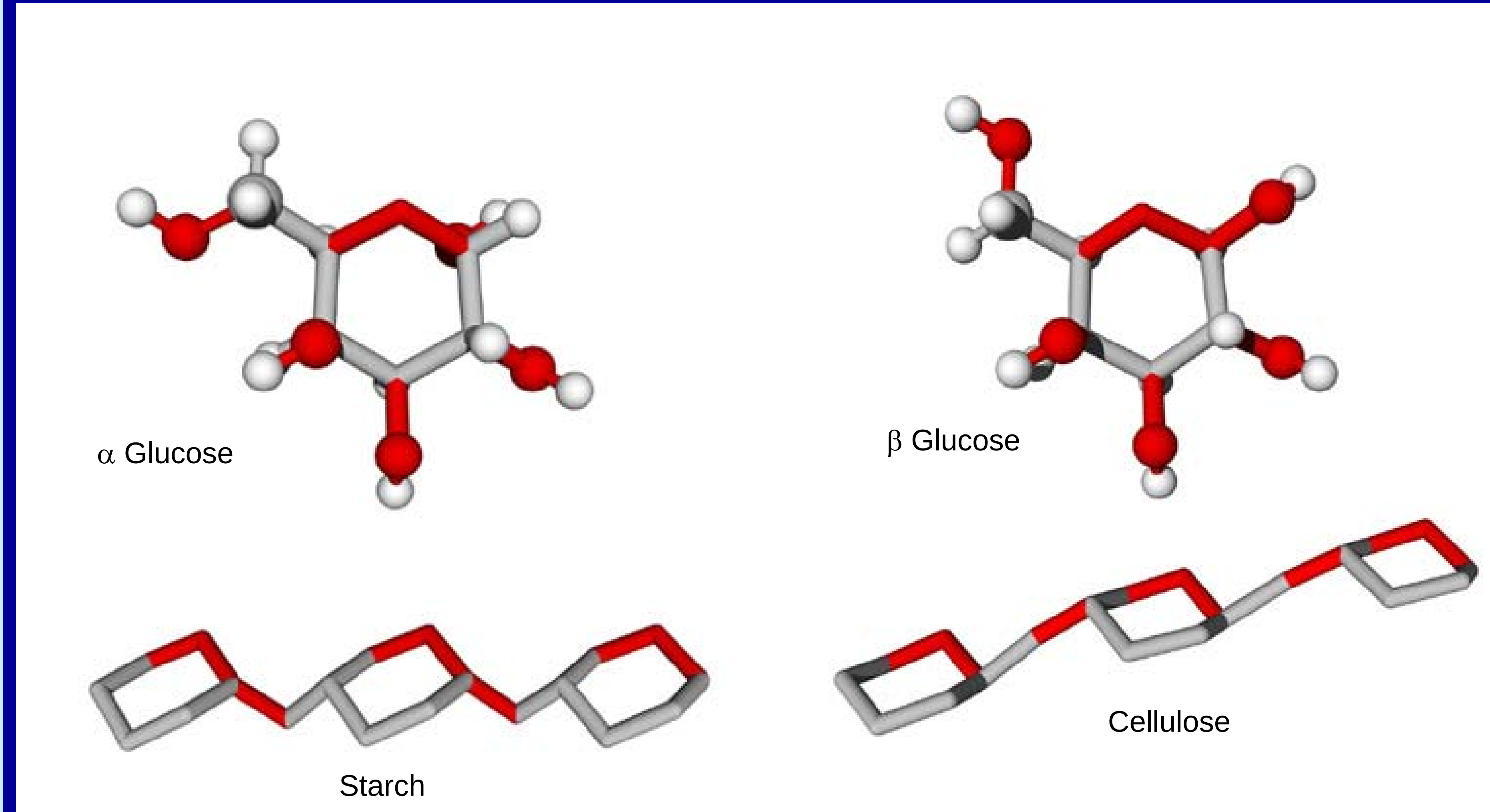
Starch and glycogen



Storage polysaccharides



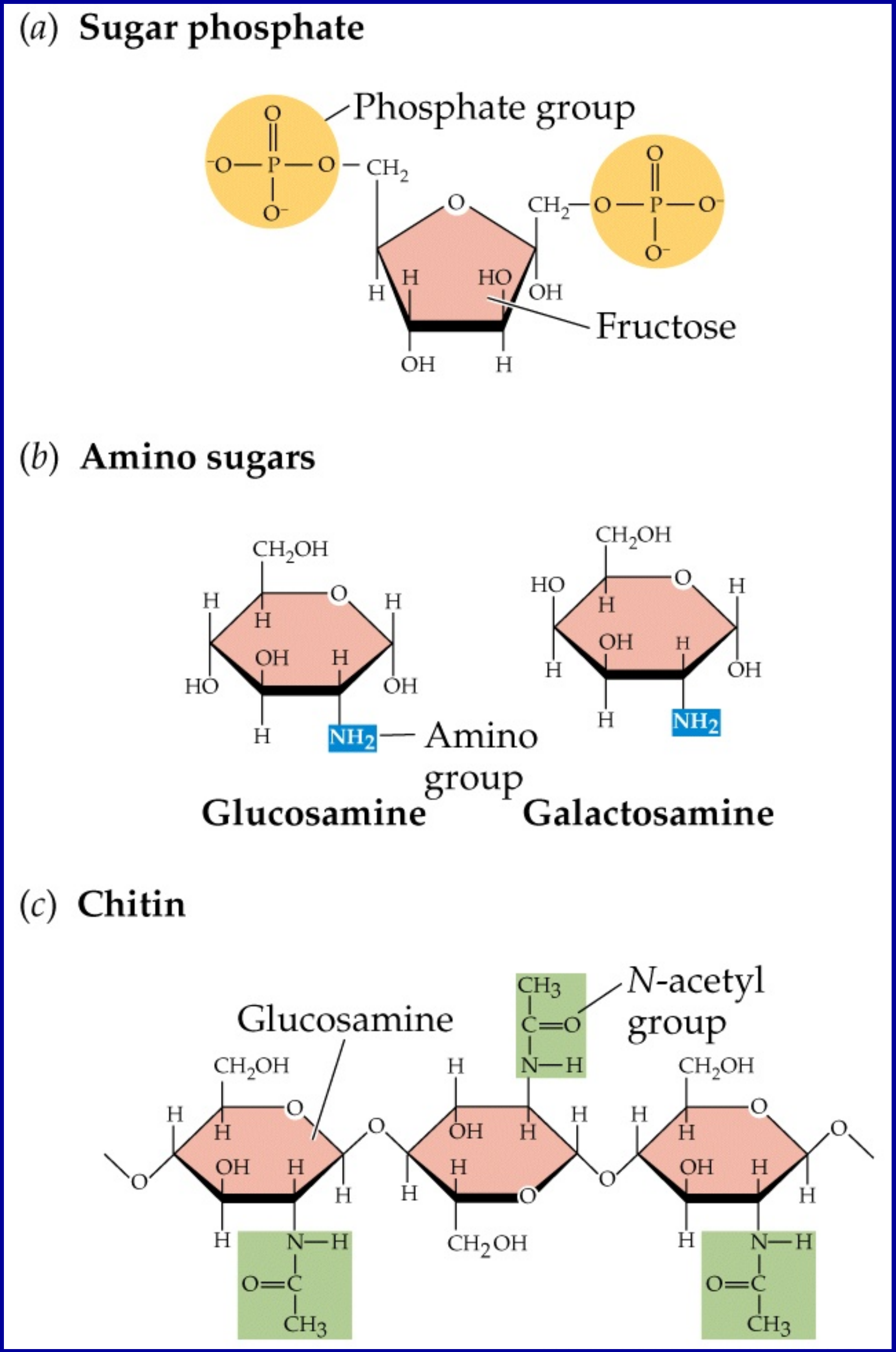
Starch and cellulose molecular models



C. Carbohydrates: Sugars and Sugar Polymers

- Chemically modified monosaccharides include the sugar phosphates and amino sugars. A derivative of the amino sugar glucosamine polymerizes to form the polysaccharide chitin.

Modified Sugars



- Chitin, another important structural polysaccharide
  - Is found in the exoskeleton of arthropods
  - Can be used as surgical thread

Chitin forms the exoskeleton of arthropods. This cicada is molting, shedding its old exoskeleton and emerging in adult form.

Chitin is used to make a strong and flexible surgical thread that decomposes after the wound or incision heals.

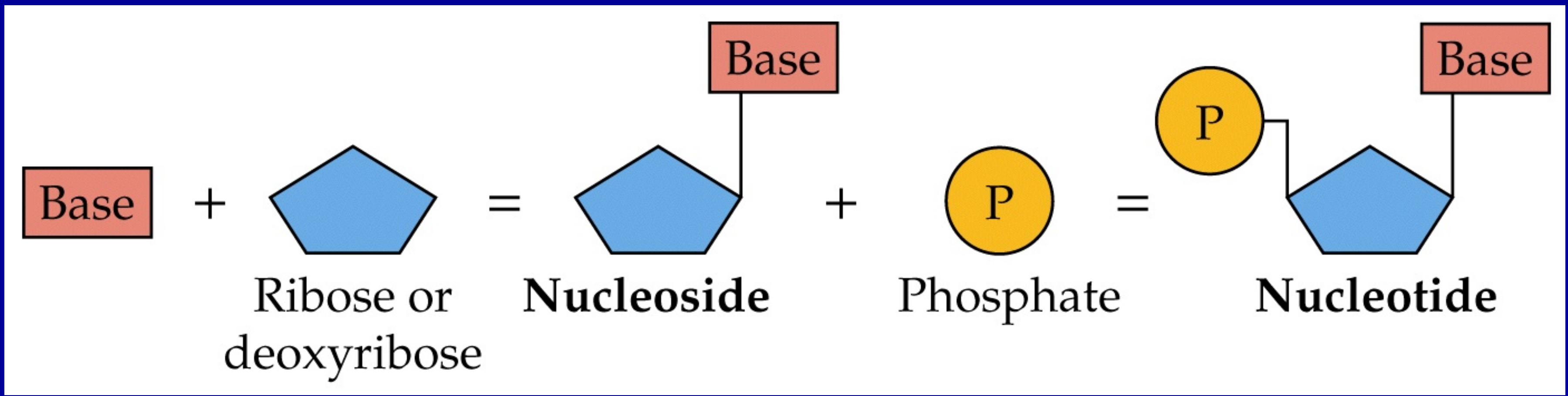
D. Nucleic Acids: Informational Macromolecules

- In cells, DNA is the hereditary material. DNA and RNA play roles in protein formation.

D. Nucleic Acids: Informational Macromolecules

- Nucleic acids are polymers of nucleotides consisting of a phosphate group, a sugar, and a nitrogen-containing base. The DNA bases are adenine, guanine, cytosine, and thymine. In RNA uracil substitutes for thymine and ribose substitutes for deoxyribose.

Nucleotides have three parts



3.3 Distinguishing RNA from DNA

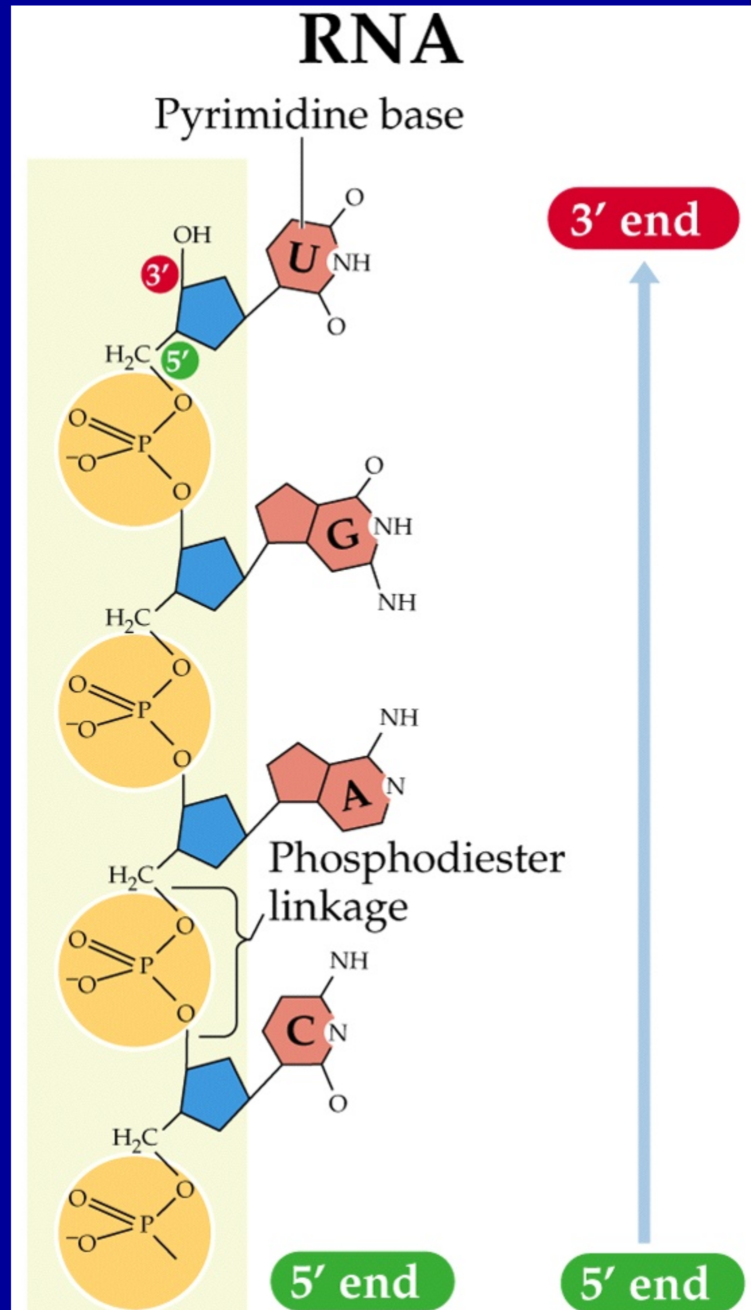
NUCLEIC ACID	SUGAR	BASES
RNA	Ribose	Adenine Cytosine Guanine **Uracil**
DNA	Deoxyribose	Adenine Cytosine Guanine **Thymine**

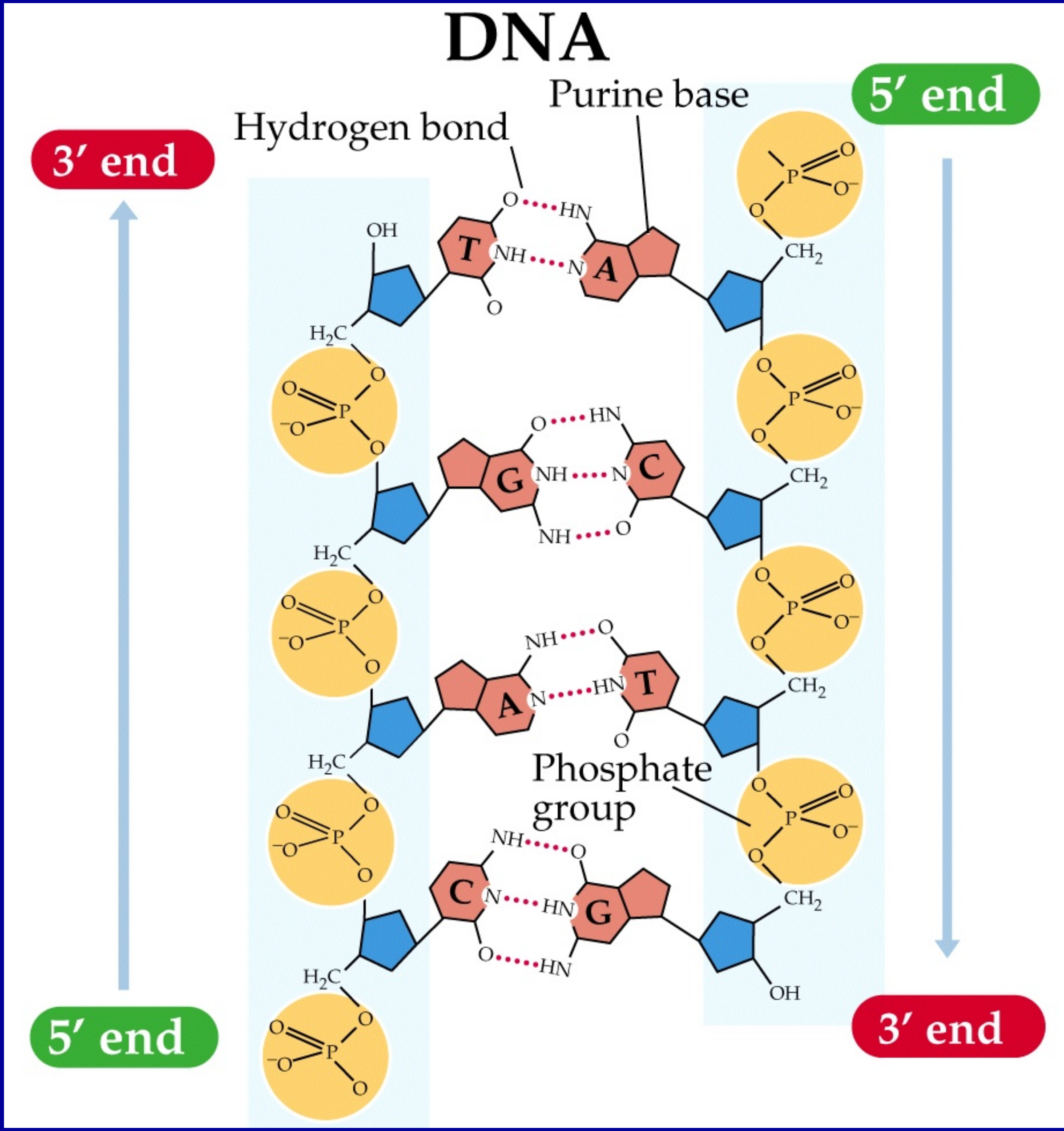
D. Nucleic Acids: Informational Macromolecules

- In the nucleic acids, bases extend from a sugar–phosphate backbone using the phosphodiester linkage.
- DNA and RNA information resides in their base sequences.

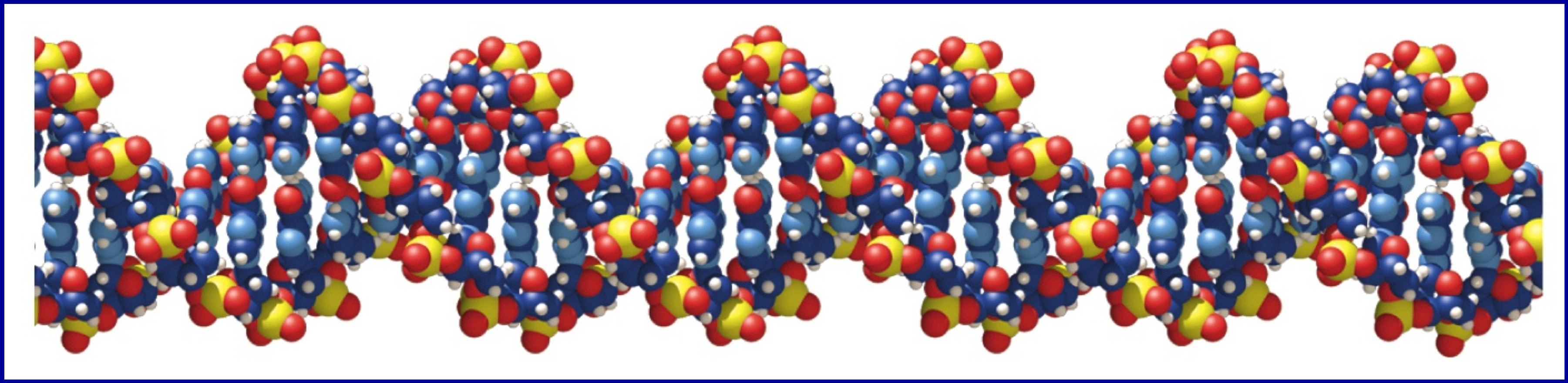
D. Nucleic Acids: Informational Macromolecules

- RNA is single-stranded.
- DNA is a double-stranded helix with complementary, hydrogen-bonded base pairing between adenine and thymine and guanine and cytosine. The two strands run in opposite 5′ to 3′ directions.


RNA
Pyrimidine base
3′ end
OH
3′
U
NH
O
O
H2C
5′
O
P
–O
G
NH
NH
A
N
Phosphodiester
linkage
C
N
5′ end
5′ end


DNA
Purine base
Hydrogen bond
3′ end
5′ end
5′ end
3′ end
Phosphate group
T
A
G
C
A
T
C
G
OH
OH

DNA structure: The double helix



D. Nucleic Acids: Informational Macromolecules

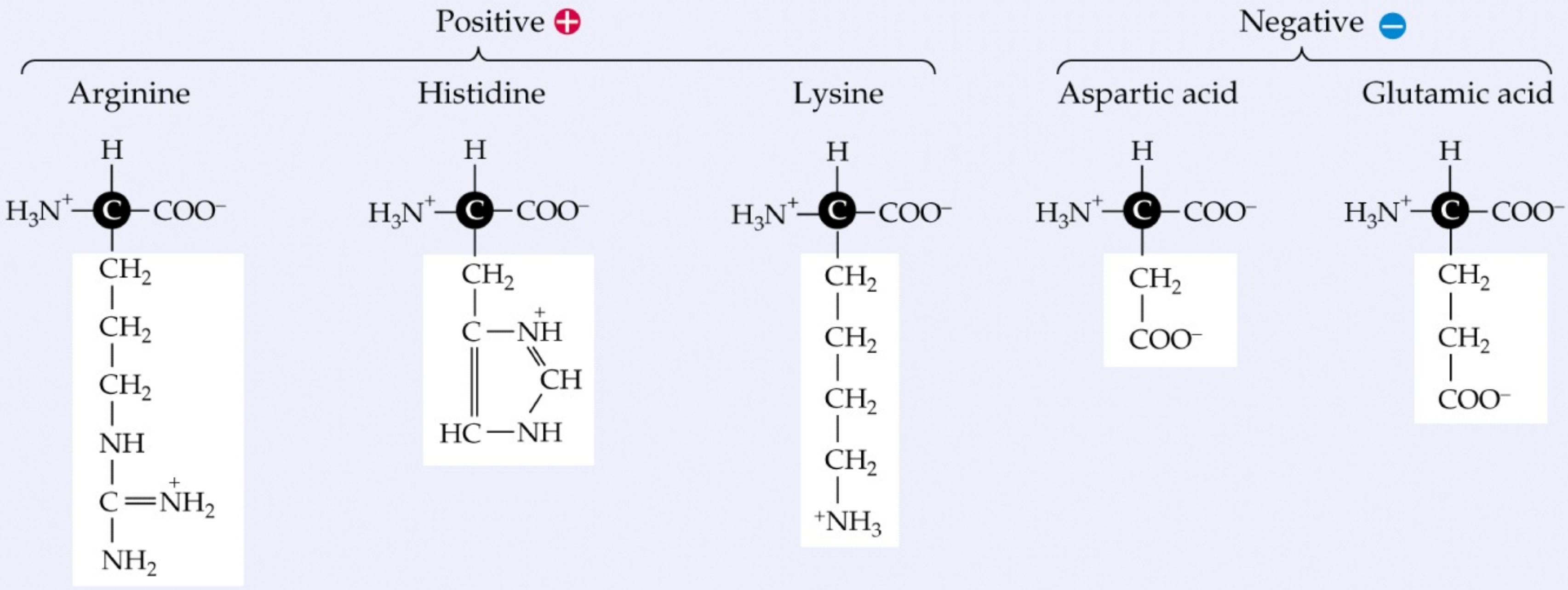
- Comparing the DNA base sequences of different living species provides information on evolutionary relatedness.
- This is called molecular phylogeny.

E. Proteins: Amazing Polymers of Amino Acids

- Functions of proteins include support, protection, catalysis, transport, defense, regulation, and movement. They sometimes require an attached prosthetic group.
- Twenty amino acids are found in proteins. Each consists of an amino group, a carboxyl group, a hydrogen, and a side chain bonded to the α carbon atom.

3.2 Twenty Amino Acids Found in Proteins

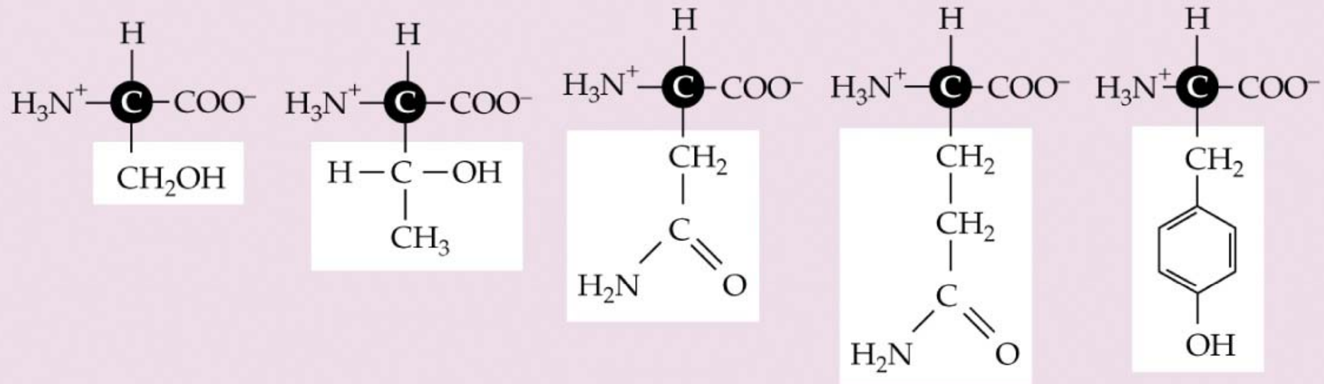
A. *Amino acids with electrically charged side chains*



3.2 **Twenty Amino Acids Found in Proteins**

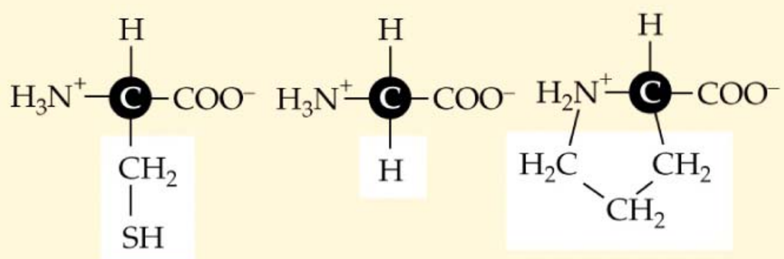
B. *Amino acids with polar but uncharged side chains*

Serine Threonine Asparagine Glutamine Tyrosine



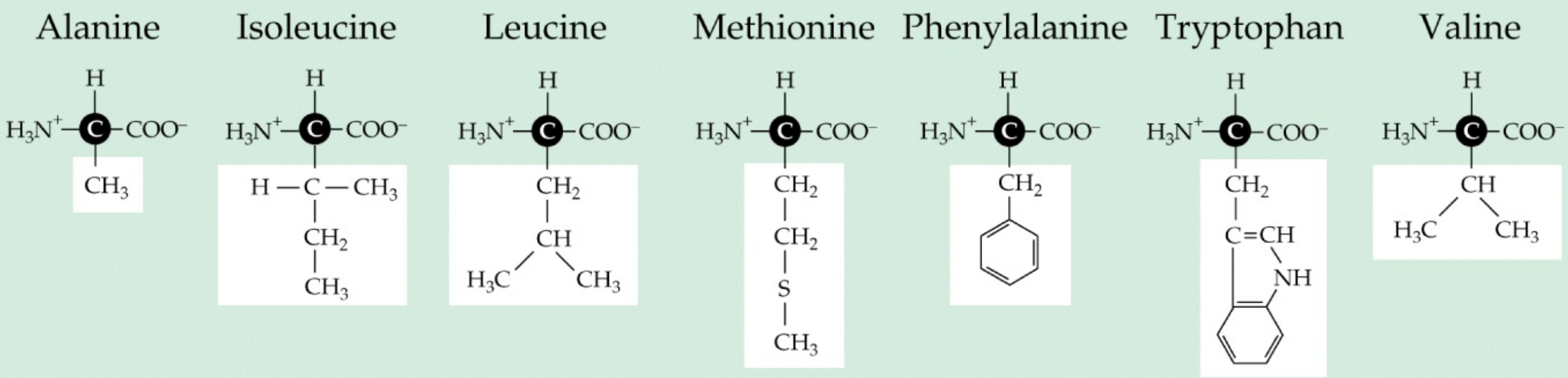
C. *Special cases*

Cysteine Glycine Proline



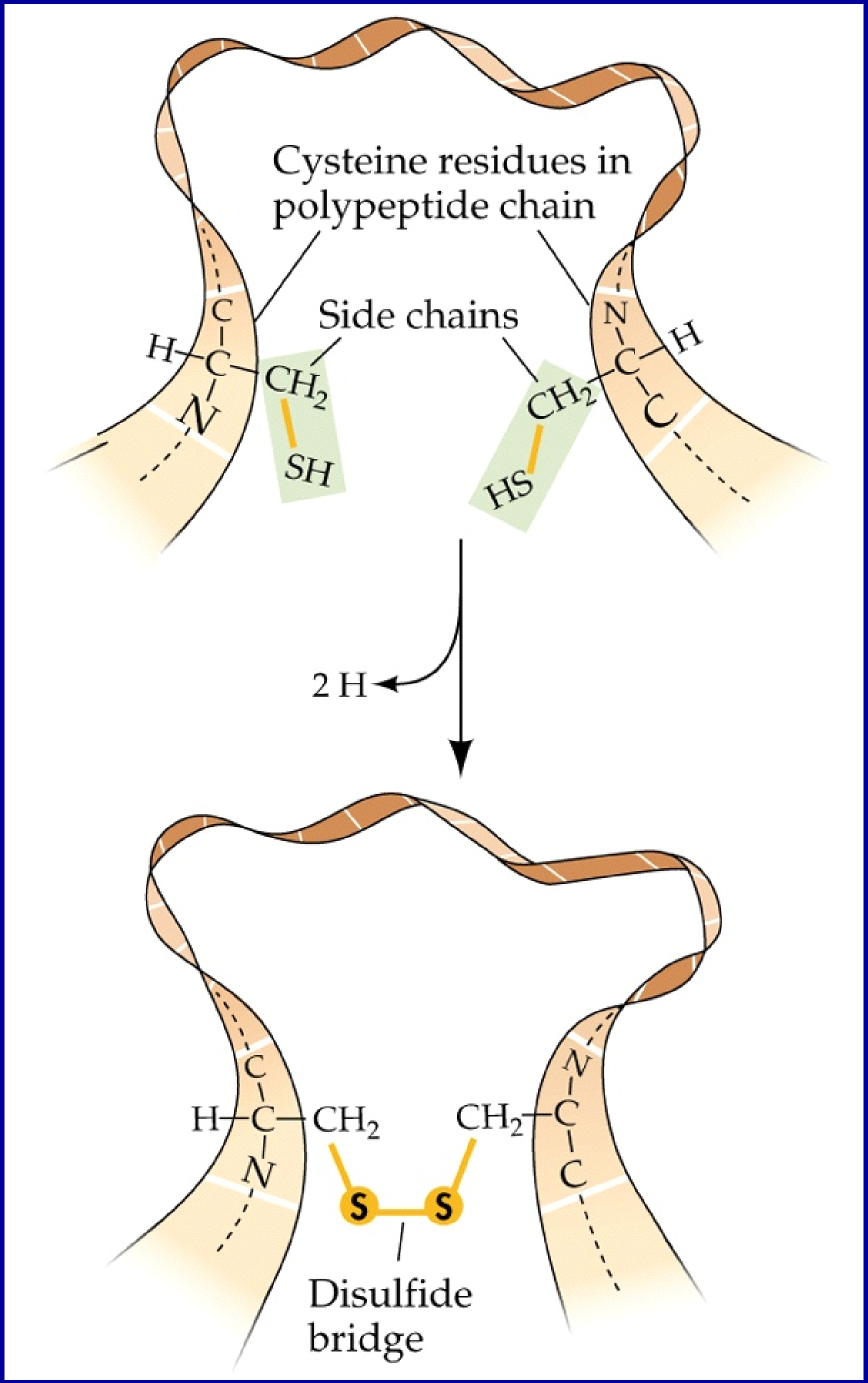
3.2 **Twenty Amino Acids Found in Proteins**

D. *Amino acids with hydrophobic side chains*



E. Proteins: Amazing Polymers of Amino Acids

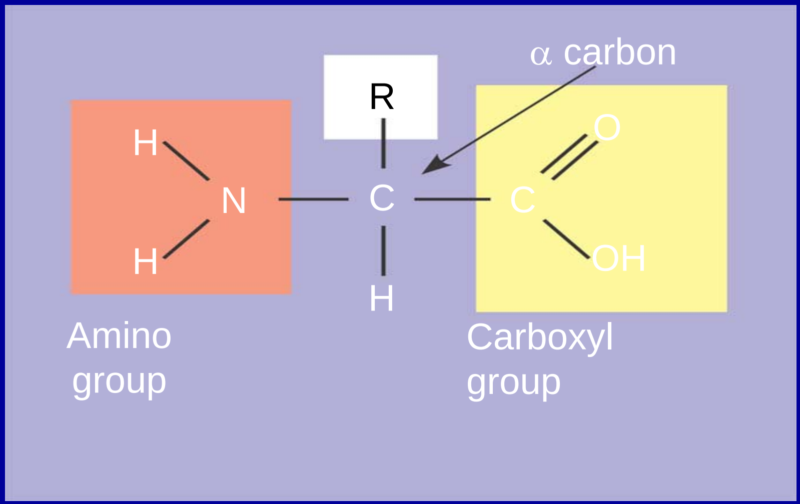
- Side chains of amino acids may be charged, polar, or hydrophobic. SH groups can form disulfide bridges.



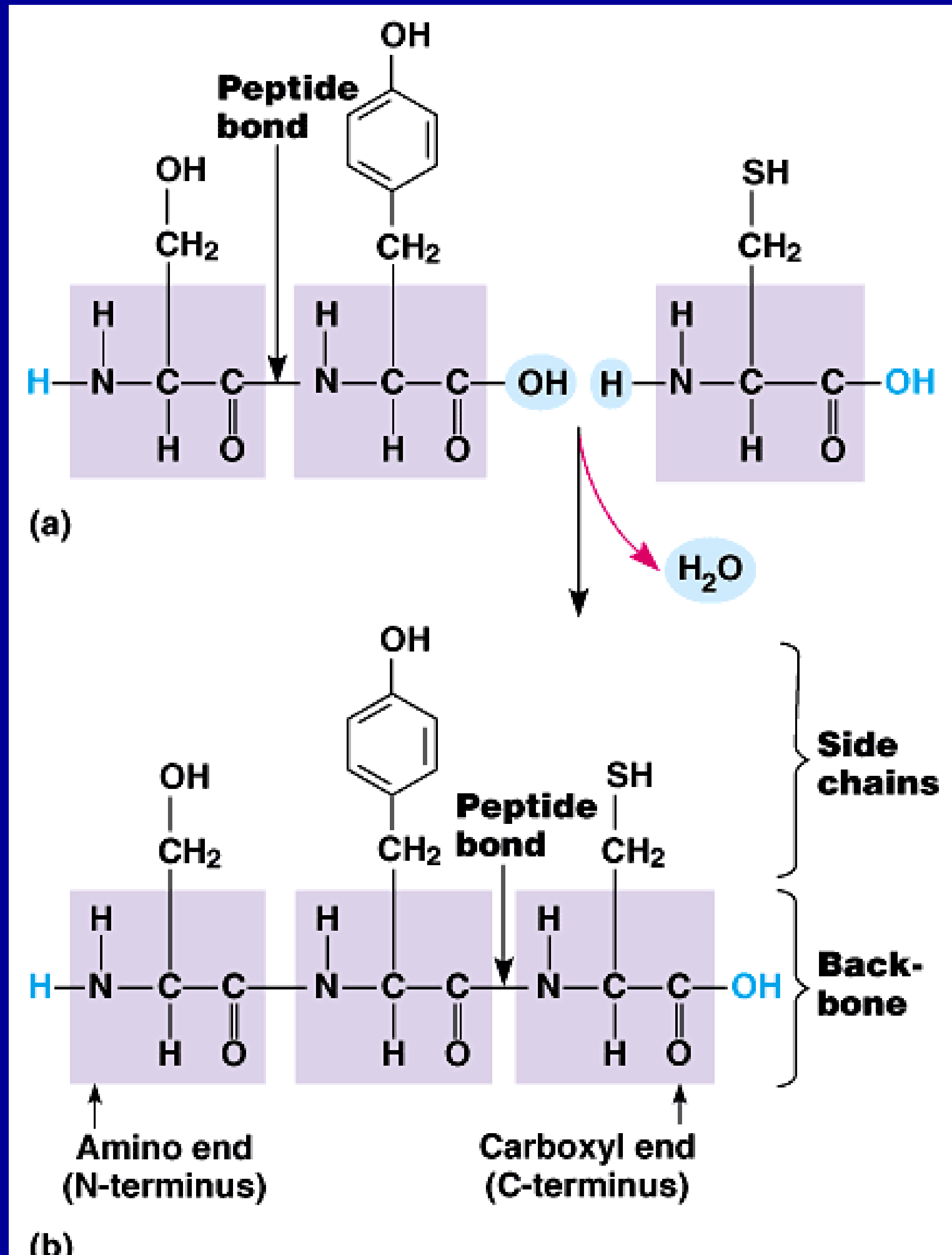
Cysteine residues can form a covalently linked disulfide bridge

E. Proteins: Amazing Polymers of Amino Acids

- Amino acids are covalently bonded together by peptide linkages.



Making a polypeptide chain

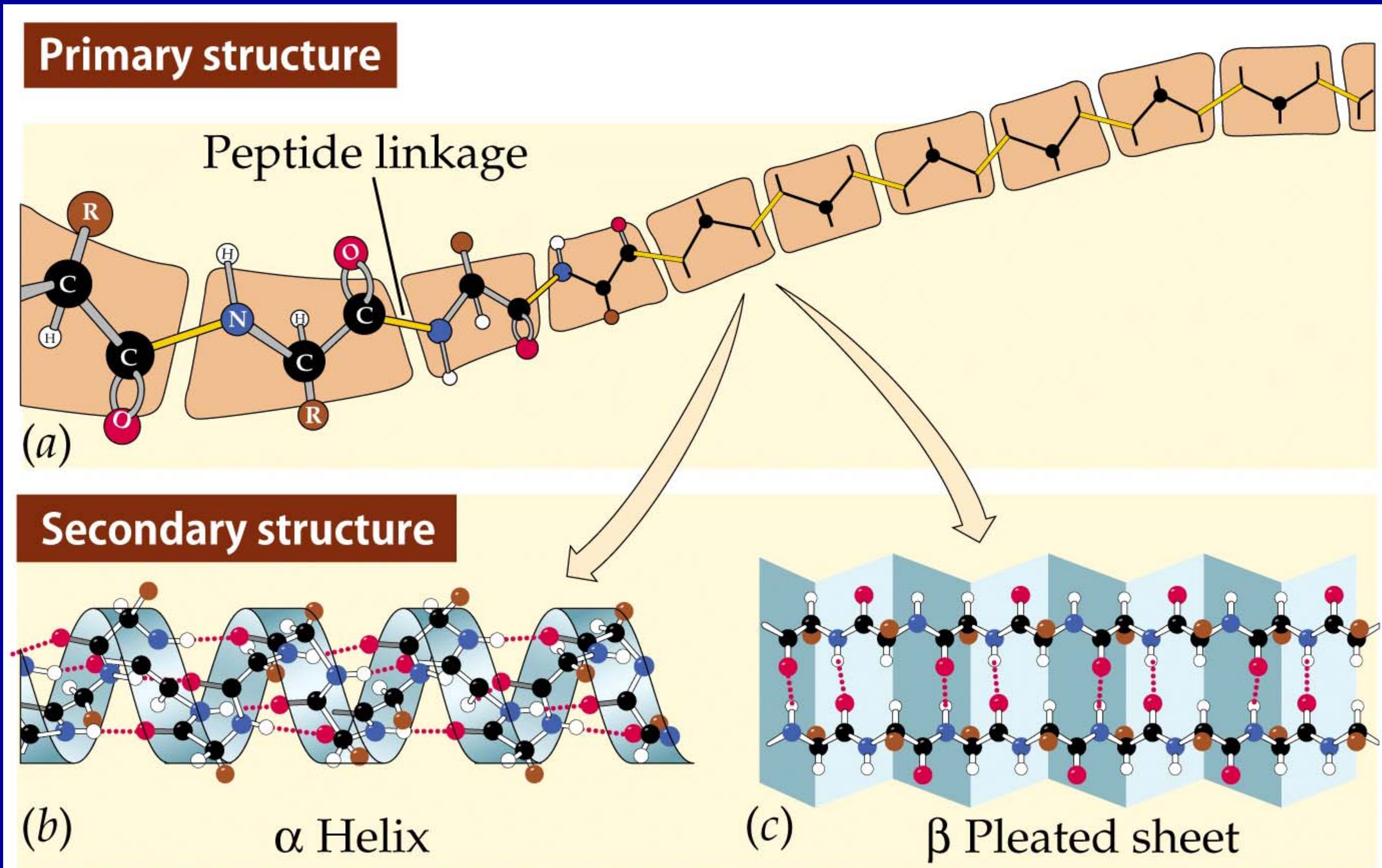


E. Proteins: Amazing Polymers of Amino Acids

- Polypeptide chains of proteins are folded into specific three-dimensional shapes. Primary, secondary, tertiary, and quaternary structures are possible.

E. Proteins: Amazing Polymers of Amino Acids

- The primary structure of a protein is the sequence of amino acids bonded by peptide linkages.
- Secondary structures are maintained by hydrogen bonds between atoms of the amino acid residues.



Primary structure
Peptide linkage
R
H
O
C
N
(a)
Secondary structure
(b)
α Helix
(c)
β Pleated sheet

Abdominal glands of the spider secrete silk fibers that form the web

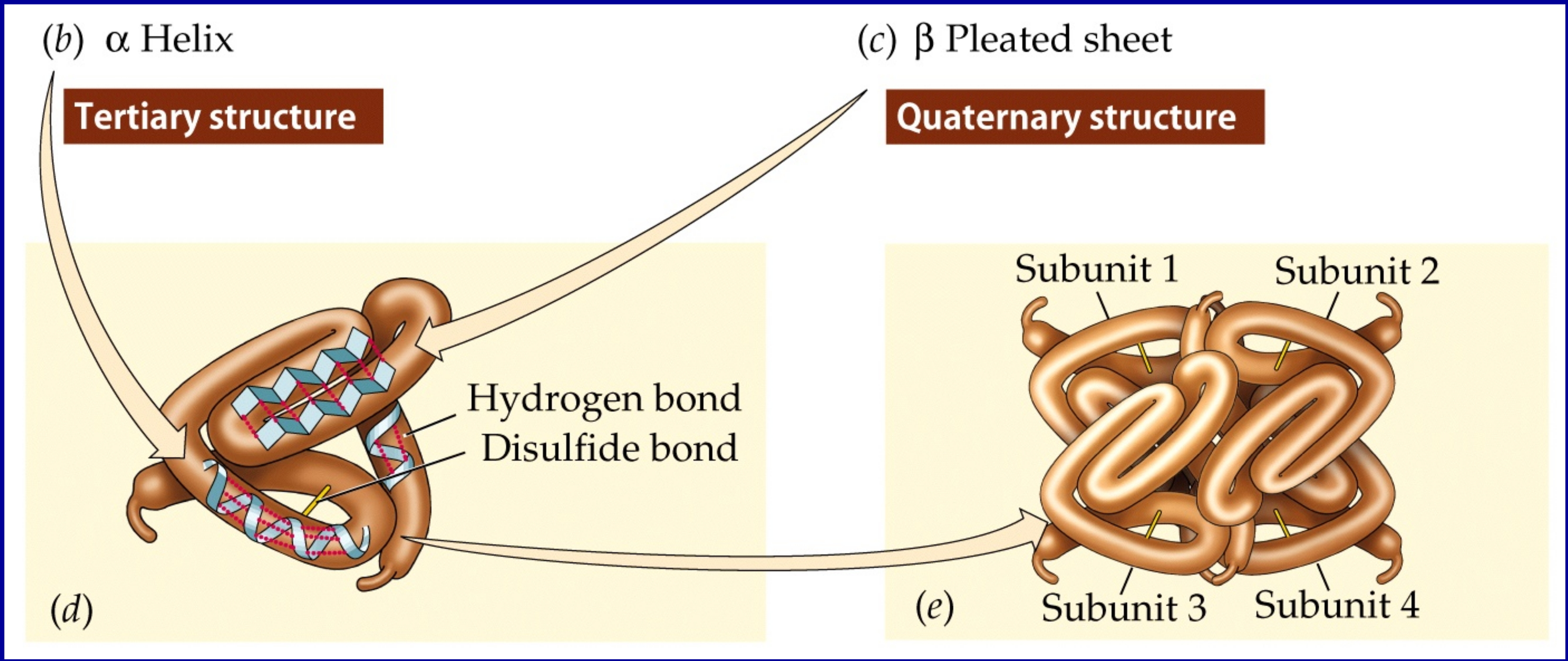
The radiating strands, made of dry silk fibers maintained the shape of the web

The spiral strands (capture strands) are elastic, stretching in response to wind, rain, and the touch of insects

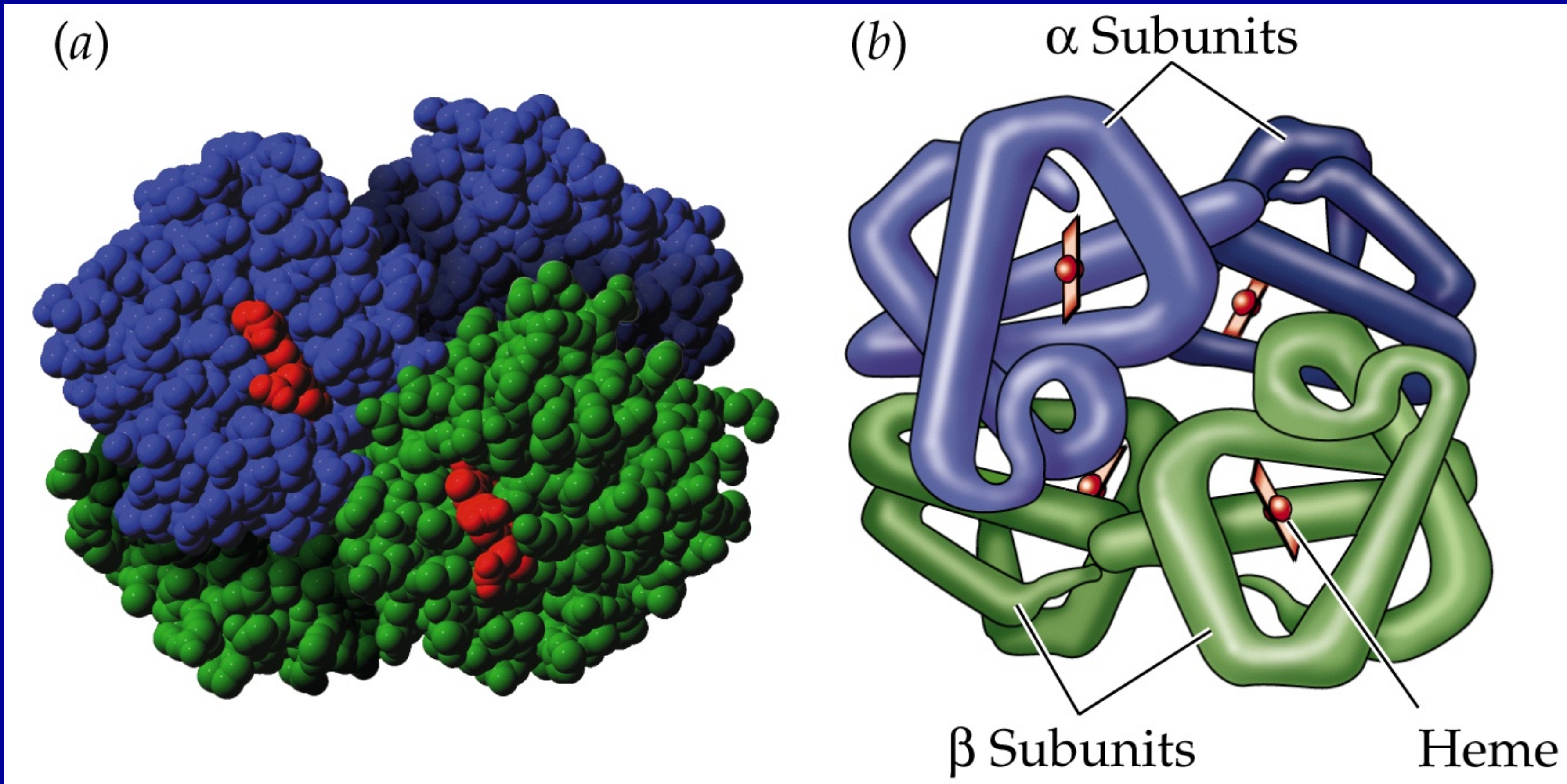
Spider silk: a structural protein containing β pleated sheets

E. Proteins: Amazing Polymers of Amino Acids

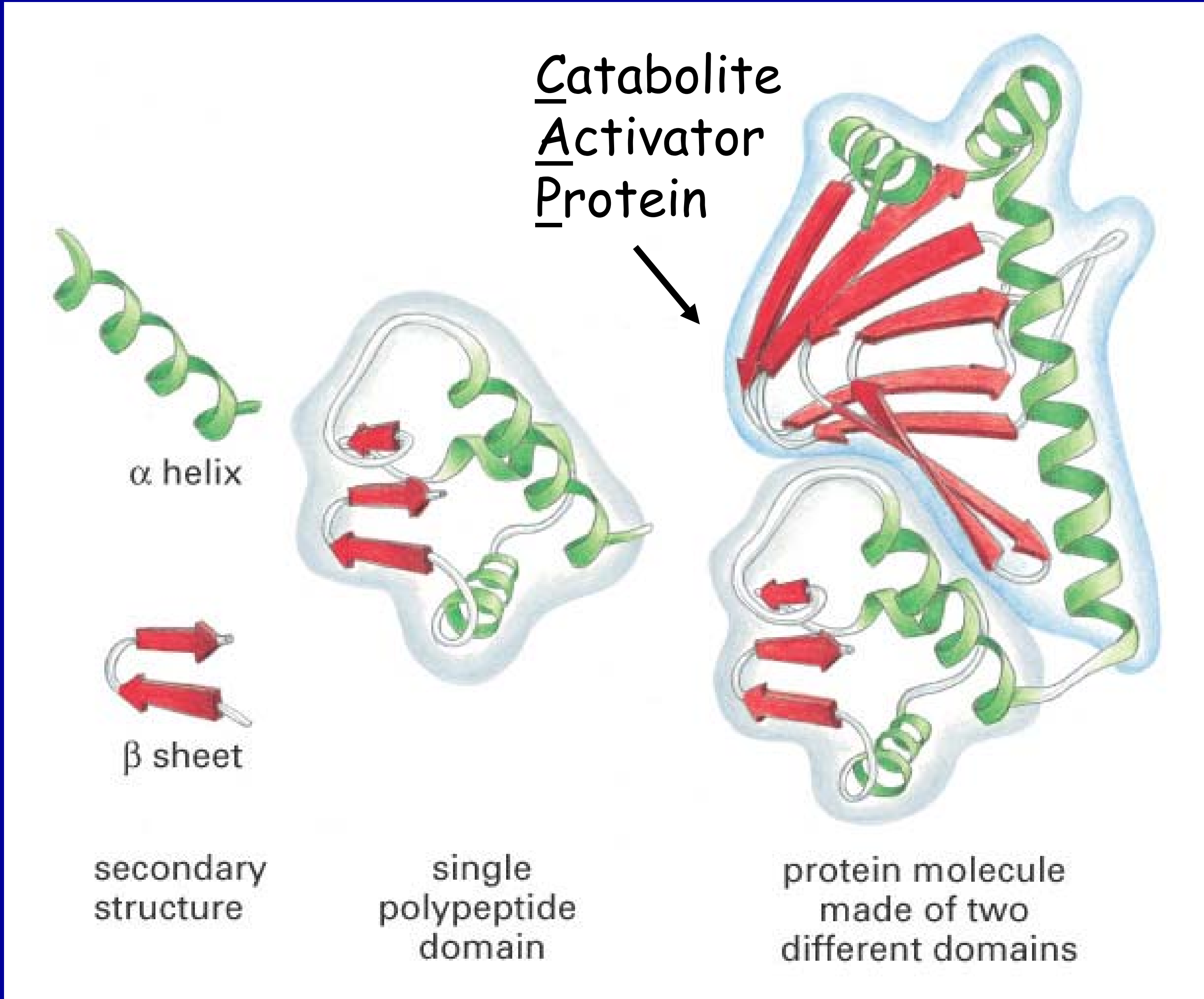
- The tertiary structure is generated by bending and folding of the polypeptide chain. This results from interactions between amino acids and R groups.
- The quaternary structure is the arrangement of polypeptides in a single functional unit consisting of more than one polypeptide subunit.


(b) α Helix
(c) β Pleated sheet
Tertiary structure
Quaternary structure
Hydrogen bond
Disulfide bond
Subunit 1
Subunit 2
Subunit 3
Subunit 4
(d)
(e)

Quaternary Structure

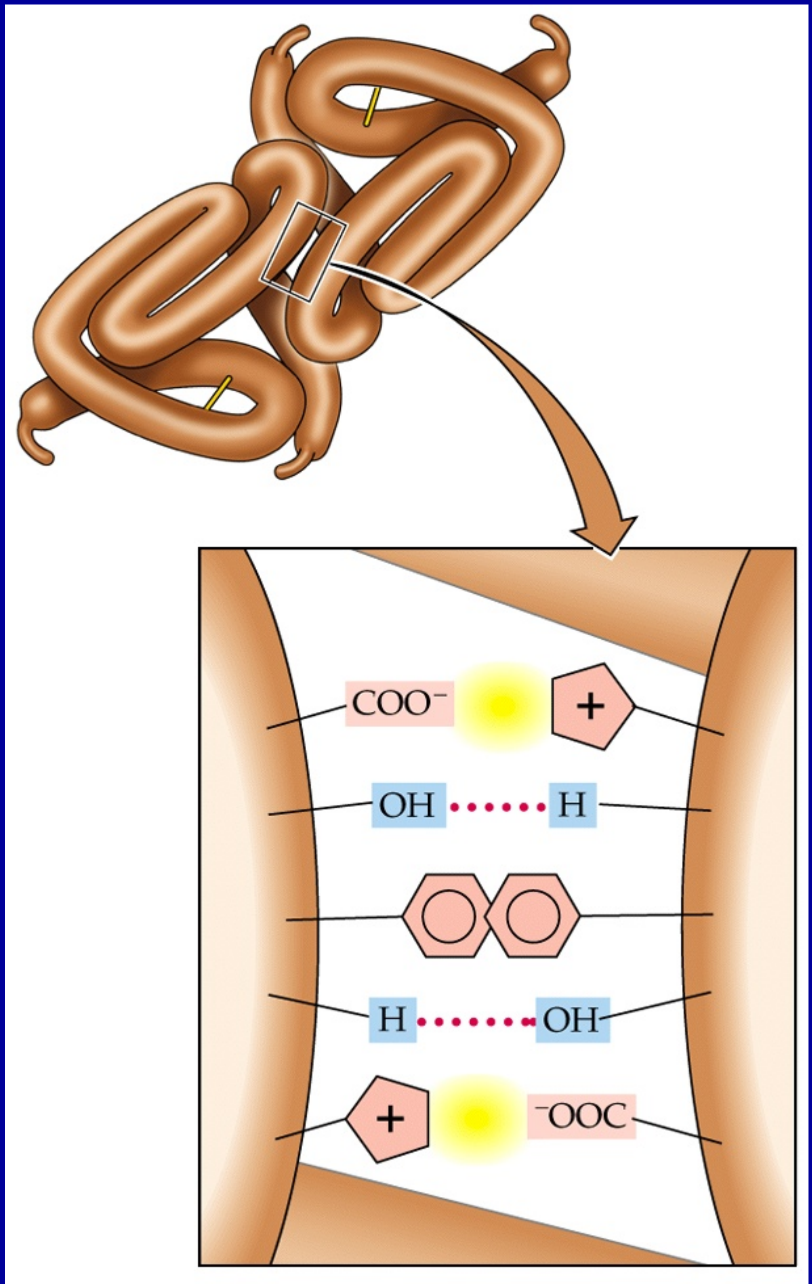


Domains

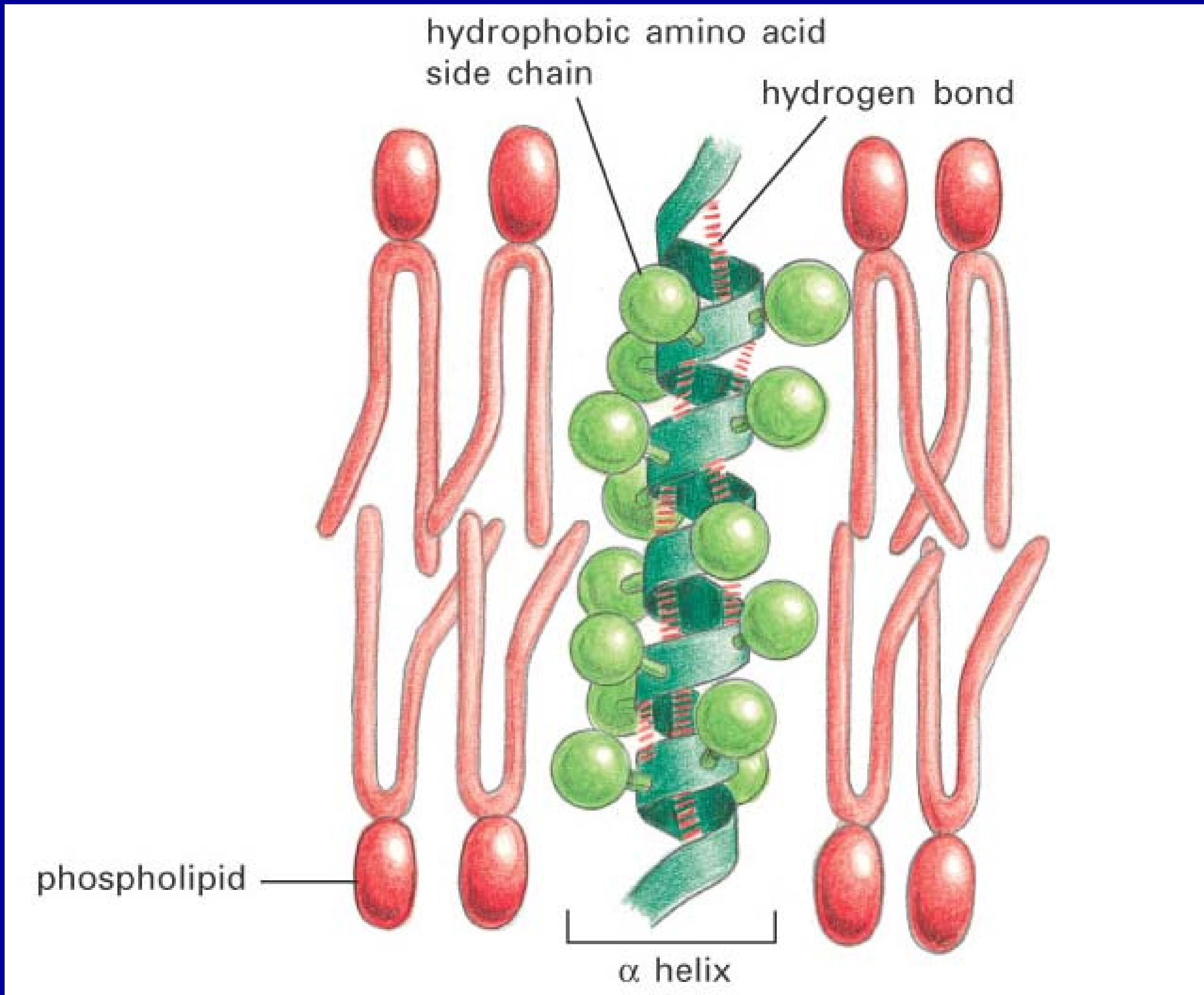

Catabolite
Activator
Protein
α helix
β sheet
secondary structure
single polypeptide domain
protein molecule made of two different domains

E. Proteins: Amazing Polymers of Amino Acids

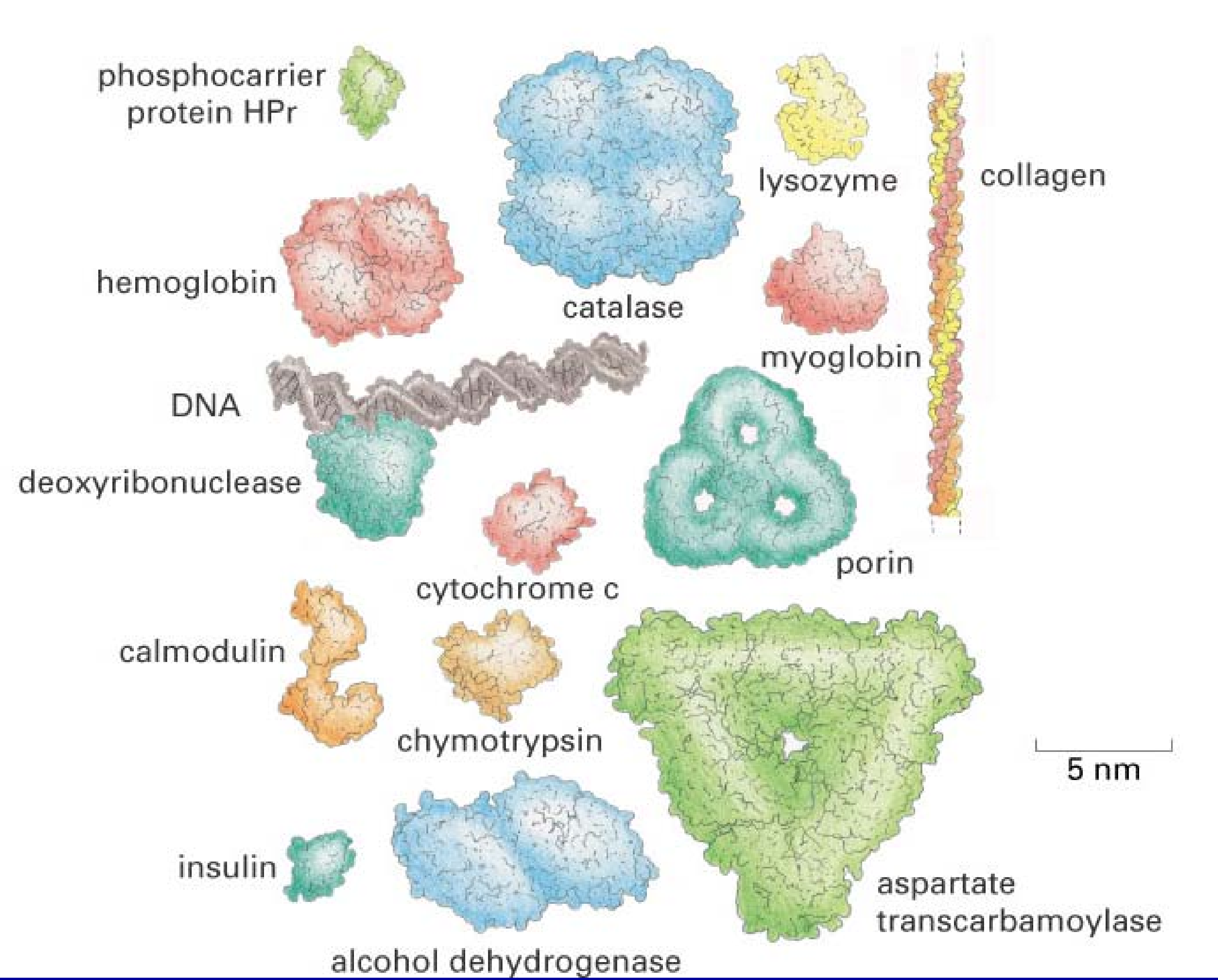
- Weak chemical interactions are important in the binding of proteins to other molecules.
- Any molecule that binds to a protein is called a ligand (e.g., antibodies to antigens).
- Proteins denatured by heat, acid, or chemicals lose tertiary and possibly secondary structure and lose biological function.



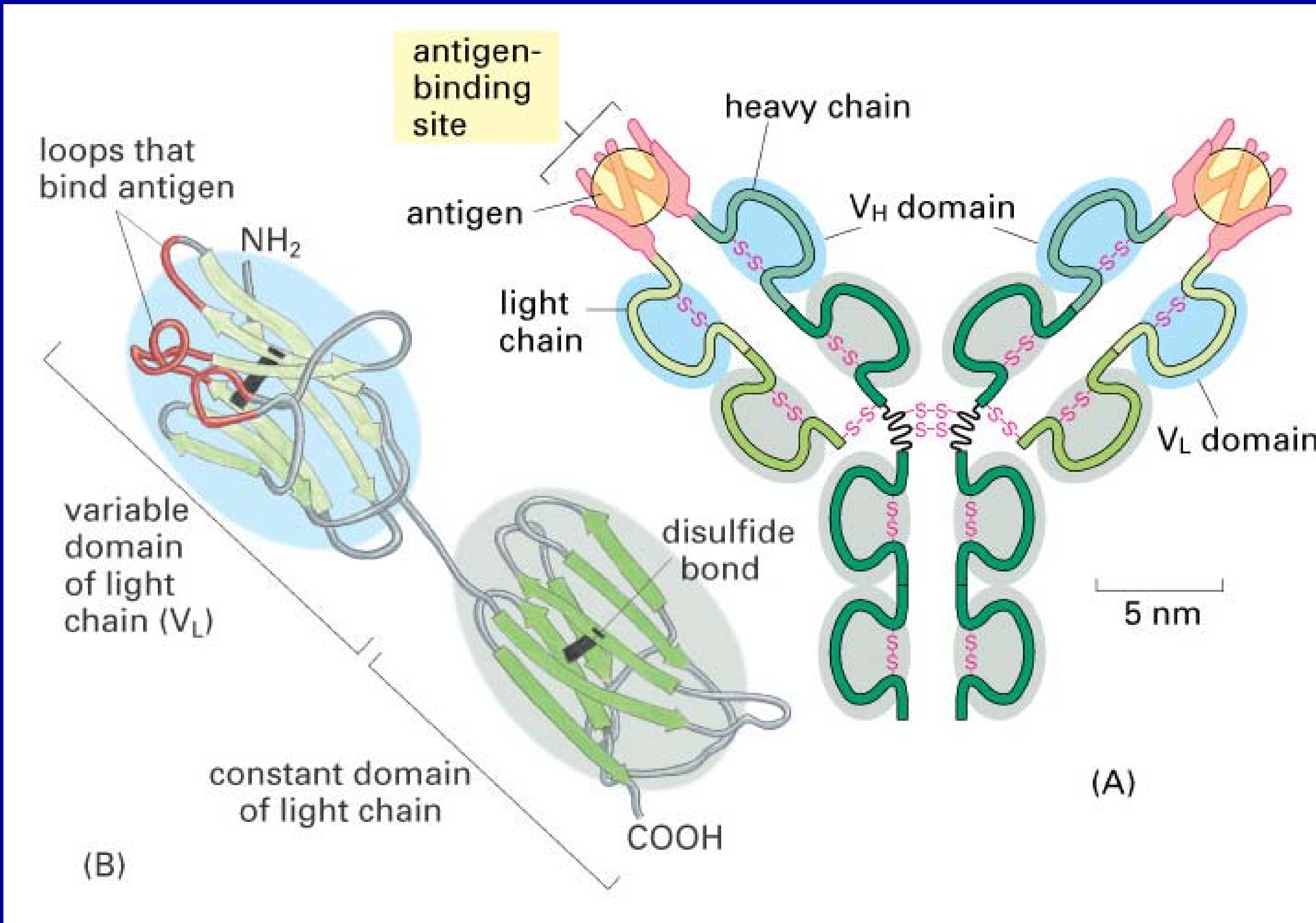
Noncovalent interactions can occur between proteins and other molecules


hydrophobic amino acid side chain
hydrogen bond
phospholipid
α helix

Extreme Diversity

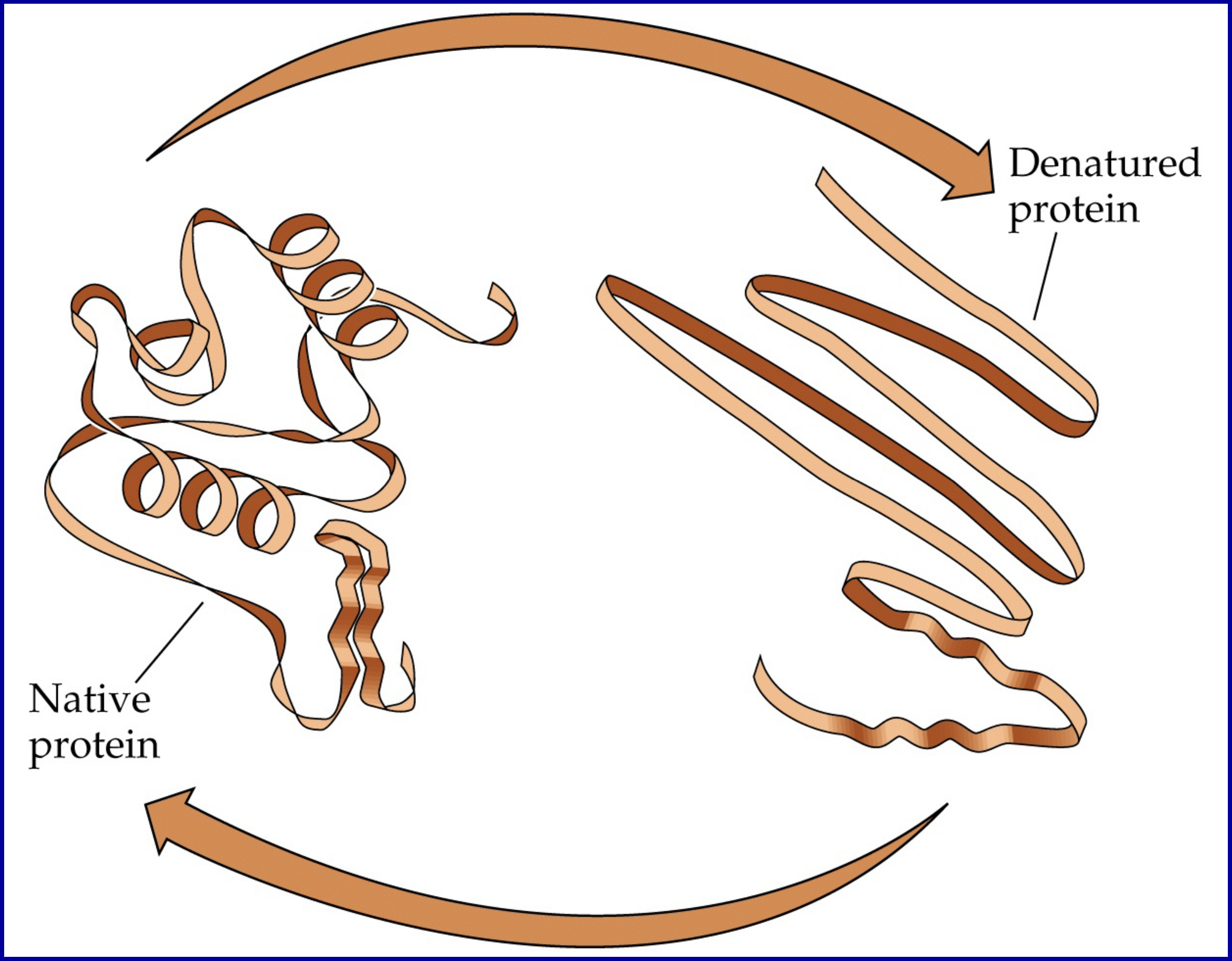


Antibodies



antigen-binding site
heavy chain
loops that bind antigen
antigen
V_H domain
NH_2
light chain
S-S
variable domain of light chain (V_L)
disulfide bond
V_L domain
5 nm
constant domain of light chain
COOH
(A)
(B)

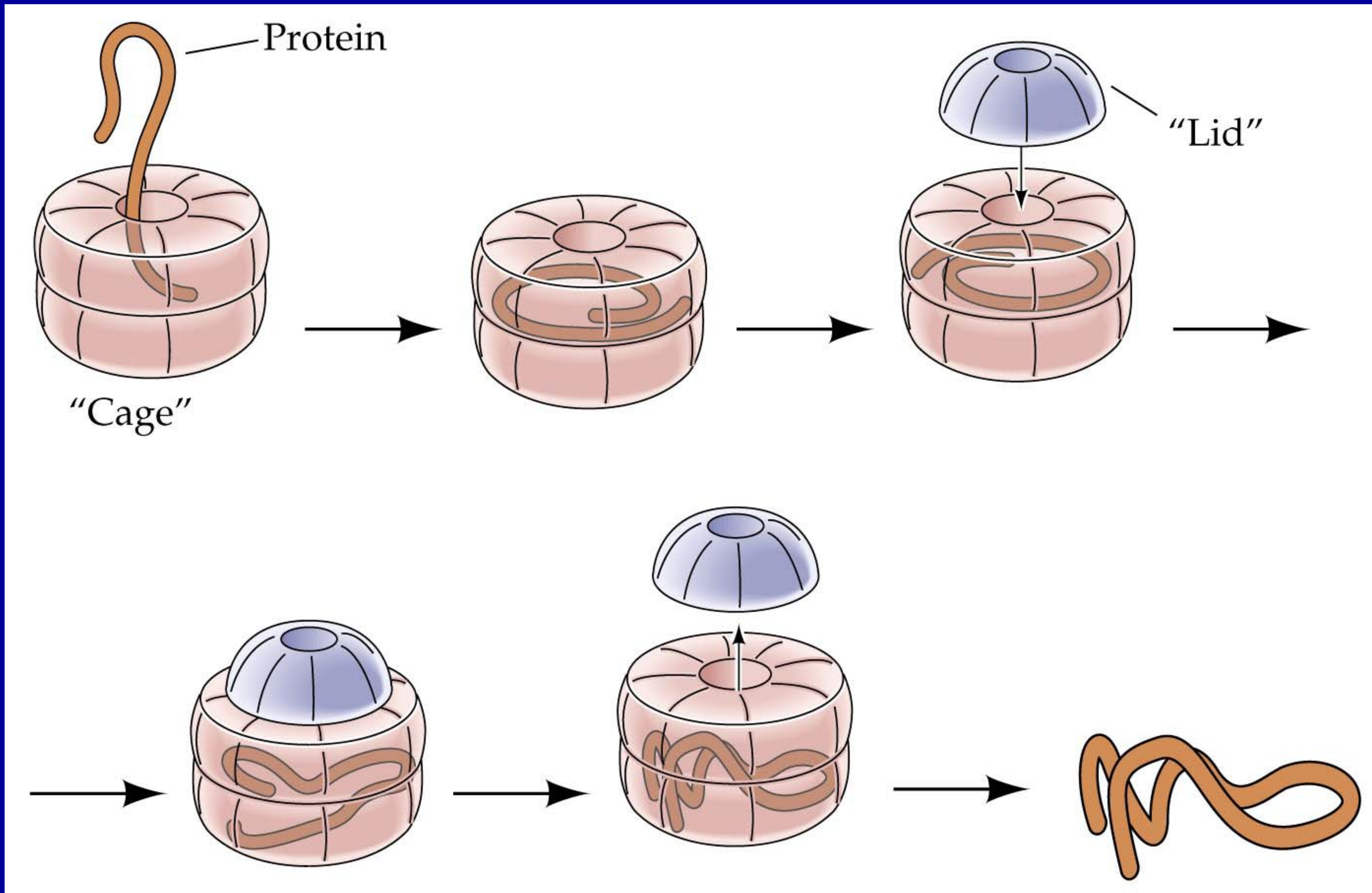
Denaturation is the loss of Tertiary Structure and Function



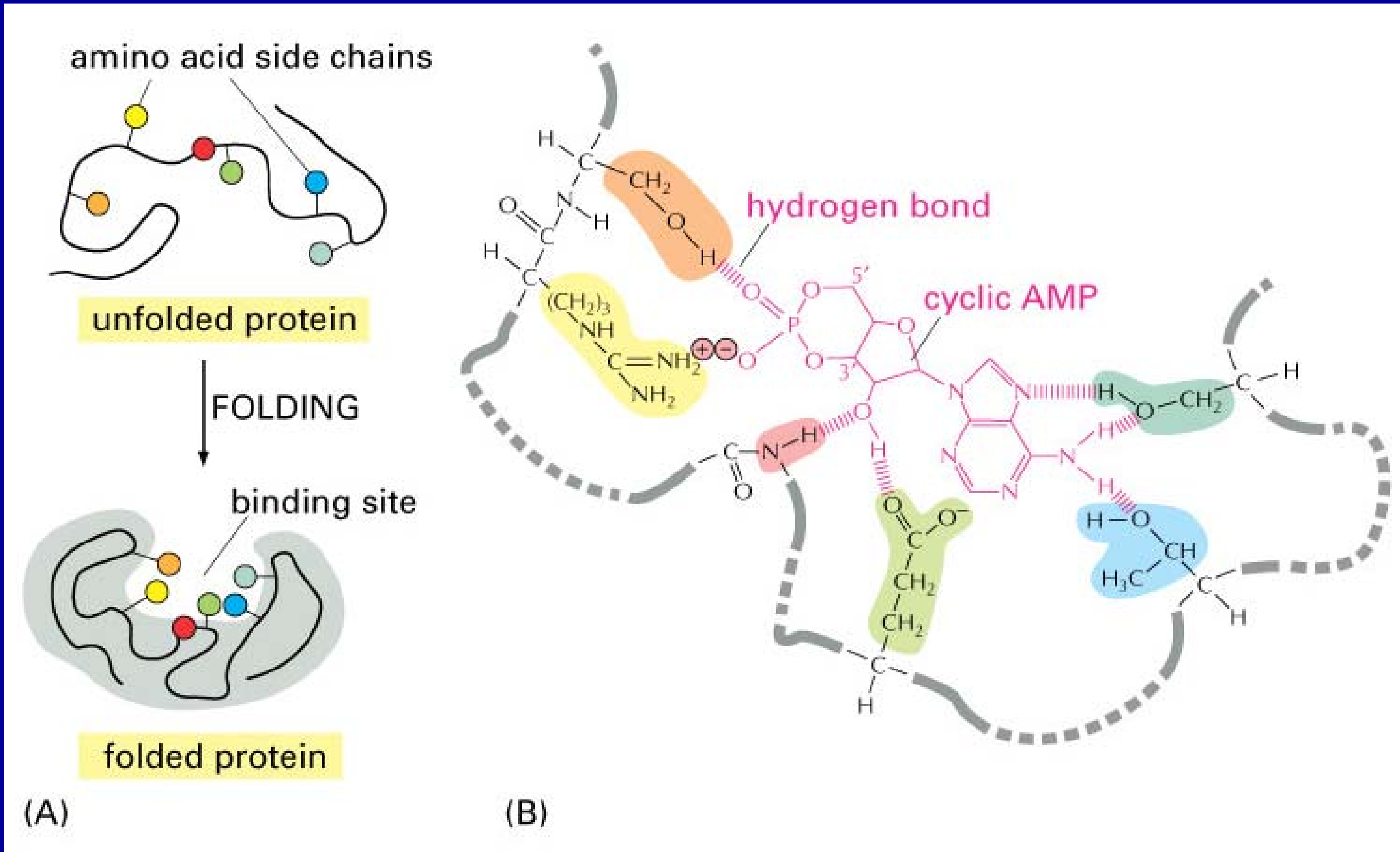
E. Proteins: Amazing Polymers of Amino Acids

- Chaperonins assist protein folding by preventing binding to inappropriate ligands.
- They also help to shape proteins with special needs regarding hydrophobic and hydrophilic interactions.

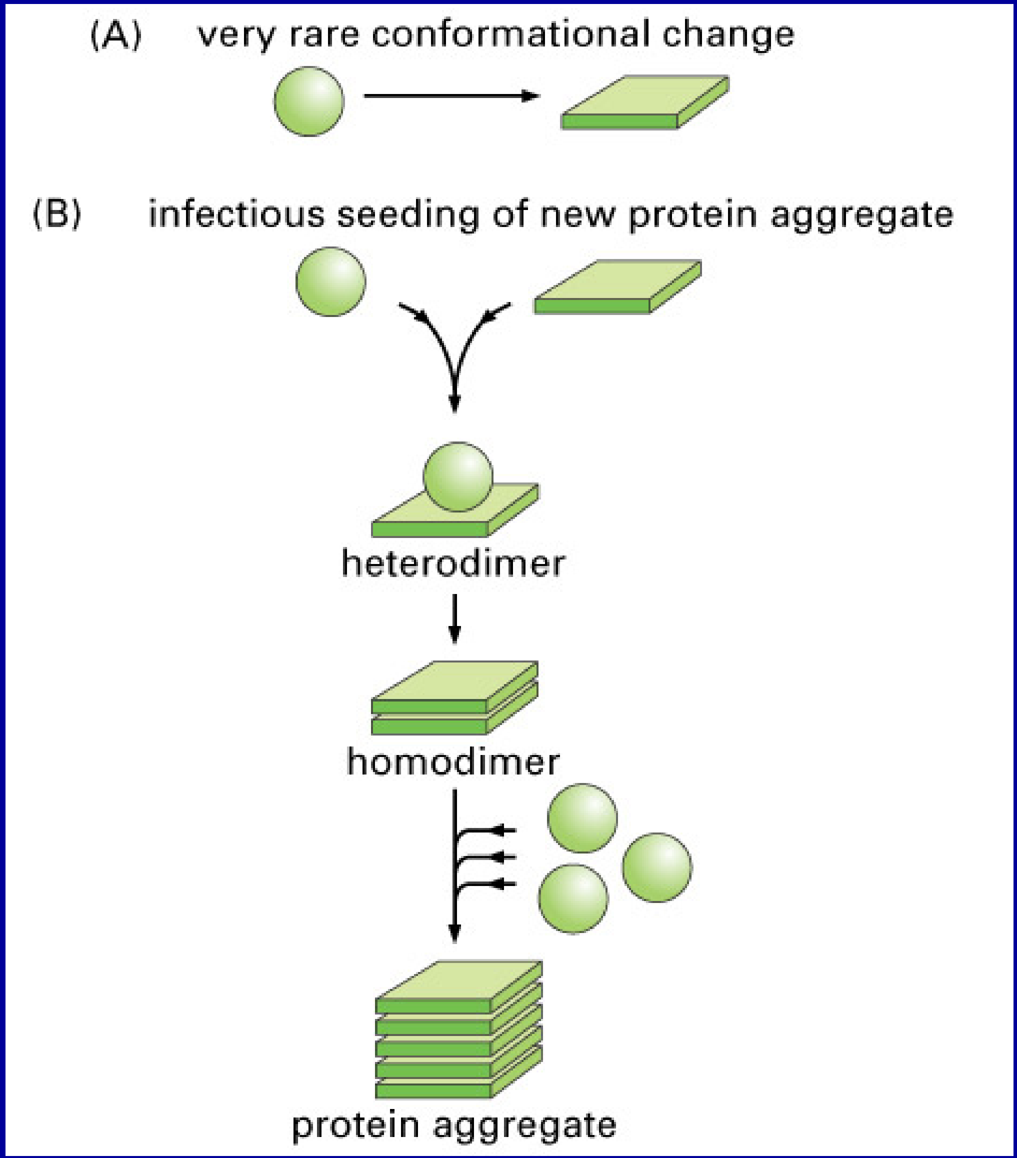
Chaperonins aid in Folding through Protection



Binding to specific ligands



Prion diseases



F. The Interactions with other Macromolecules

- Glycoproteins contain an oligosaccharide "label" that directs the protein to the proper cell destination. The carbohydrate groups of glycolipids are on the cell's outer surface, serving as recognition signals.
- An example of emergent properties where greater complexity is exhibited.