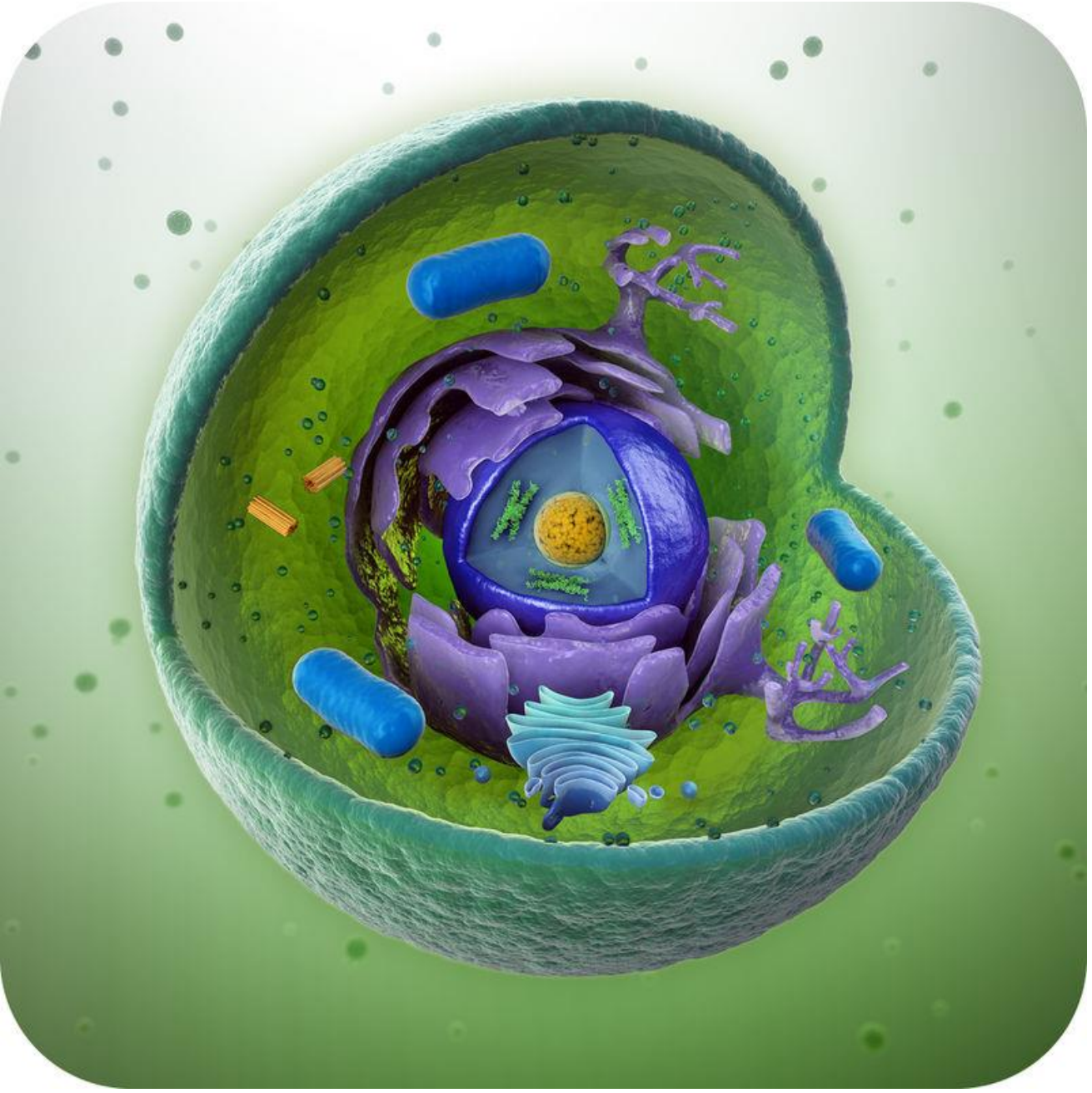

Cell biology Introduction

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Course parts

Cell biology

Molecular biology

Syllabus for cell biology section

Part I: Cell Biology
Overview of macromolecules, intermolecular forces and interactions, and protein structure and function with emphasis on enzyme, Introduction into basic cell structure, and introduction into cell biology and eukaryotic cell organelles
Biomembranes and membrane proteins and their role in plasma membrane transport
Protein sorting and transport, and endoplasmic reticulum
The Golgi apparatus and vesicular transport
Lysosome, endocytosis, endocytosis, and lysosomal storage diseases
Mitochondria and mitochondrial diseases
Peroxisomes
The nucleus
The actin cytoskeleton and cell movement
Microtubules and intermediate filaments
The extracellular matrix
Cell signaling
The cell cycle
Cell proliferation
Cell differentiation
Cell death

Main Reference

The Cell: A Molecular Approach, Geoffrey M. Cooper and Robert E. Hausmann, 7th edition, Sinauer Associates, 2018.

Exams

Evaluation	Point %	Date
Midterm Exam	40%	TBD
Final Exam	60%	TBD

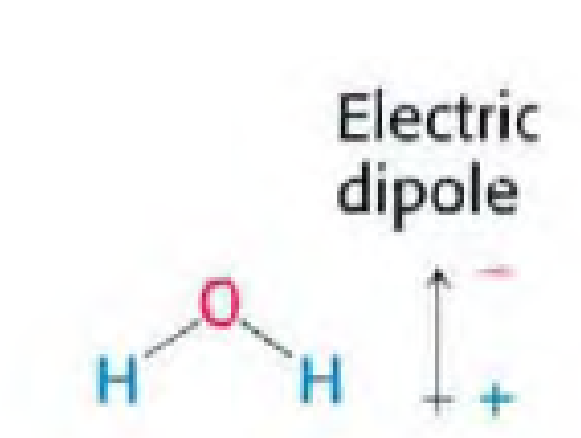
Cells are extremely complex and diverse structures.

Yet, they obey the same laws of chemistry and physics that determine the behaviour of non-living systems.

Types of molecules in the cell

- Water molecules (70% of total cell mass)
- Organic molecules (carbon-containing)
  Proteins, carbohydrates, nucleic acids and lipids (80-90% of dry cell mass)
- Inorganic molecules (<1% of total cell mass)
  Na^{+}, K^{+}, Mg^{+2}, Ca^{+2}, Cl^{-}, HCO_3^{-}, HPO_4^{-2}

Polarity



If straight?

CO_2 has polar bonds but is nonpolar

δ- δ+ δ-

O = C = O

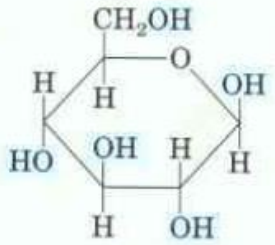
Linear- no dipole moment

Polarity

TABLE 2–2 Some Examples of Polar, Nonpolar, and Amphipathic Biomolecules (Shown as Ionic Forms at pH 7)

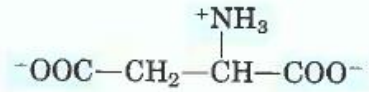
Polar

Glucose

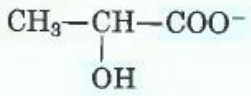


Glycine

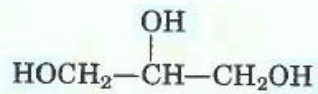
Aspartate



Lactate

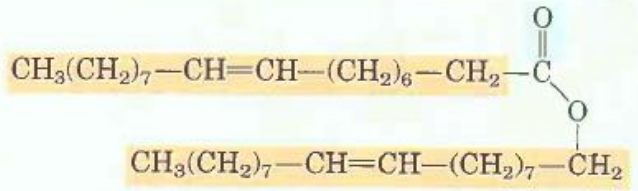


Glycerol



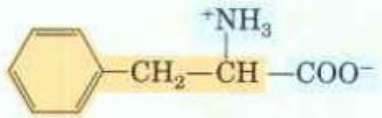
Nonpolar

Typical wax

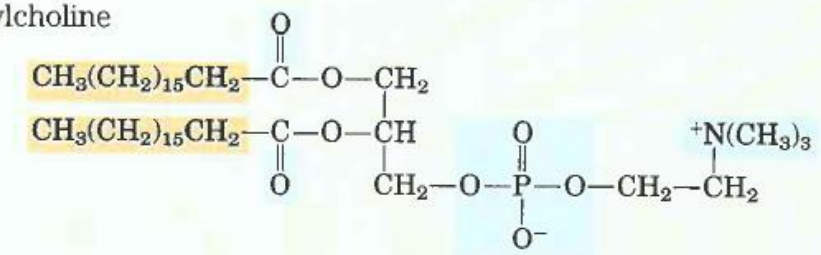


Amphipathic

Phenylalanine



Phosphatidylcholine



Polar groups Nonpolar groups

Noncovalent Interactions

Electrostatic, or ionic interactions (salt bridges)

- Interactions between oppositely charged groups

Van der Waals forces

- Attractions between transient dipoles generated by the rapid movement of electrons of all neutral atoms. 1-5 kj/mole

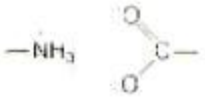
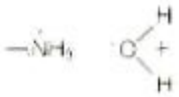
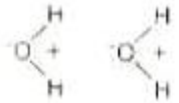
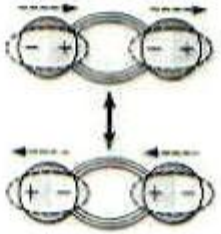
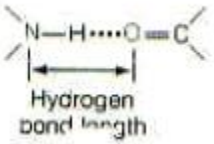
Hydrophobic interactions 5-30 kj/mole

- Self-association of nonpolar compounds in an aqueous environment.
- Minimize unfavorable interactions between nonpolar groups and water

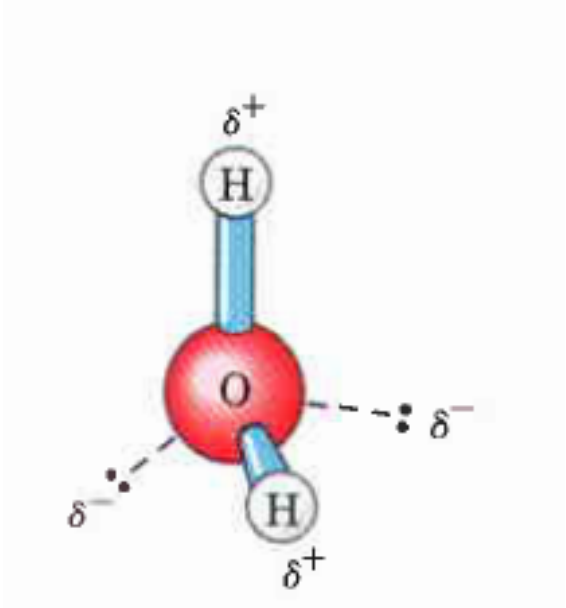
Hydrogen bonds

- The two strands of the DNA helix. 10-30 kj/mole

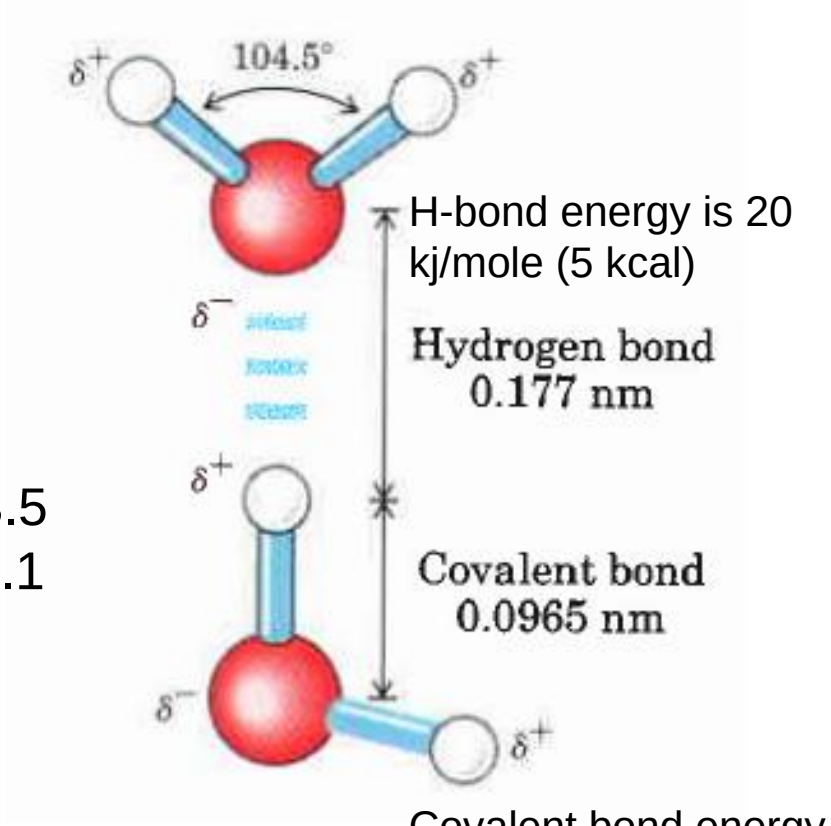
Types of noncovalent interactions

TYPE OF INTERACTION	MODEL	EXAMPLE	DEPENDENCE OF ENERGY ON DISTANCE	COMMENT
(a) Charge–charge			$1/r$	Longest-range force; nondirectional
(b) Charge–dipole			$1/r^2$	Depends on orientation of dipole
(c) Dipole–dipole			$1/r^3$	Depends on *mutual* orientation of dipoles
(d) Charge–induced dipole			$1/r^4$	Depends on polarizability of molecule in which dipole is induced
(e) Dipole–induced dipole			$1/r^5$	Depends on polarizability of molecule in which dipole is induced
(f) Dispersion			$1/r^6$	Involves mutual synchronization of fluctuating charges
(g) Hydrogen bond	DONOR—H···· ACCEPTOR	 Hydrogen bond length	Length of bond fixed	Depends on donor–acceptor pair

Hydrogen bond



Electronegativity of O atom is 3.5
Electronegativity of H atom is 2.1



H-bond energy is 20 kj/mole (5 kcal)

Covalent bond energy is 460 kj/mole (110 kcal)

Lehninger 5th edition

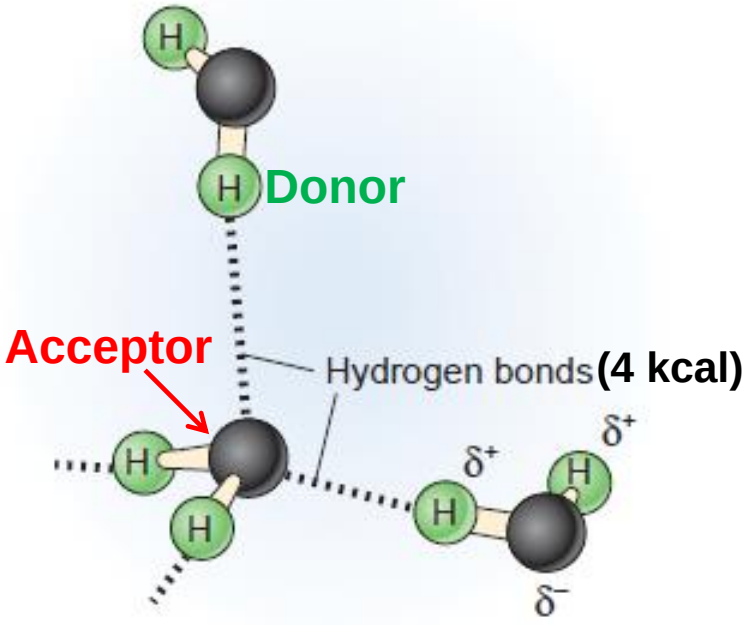
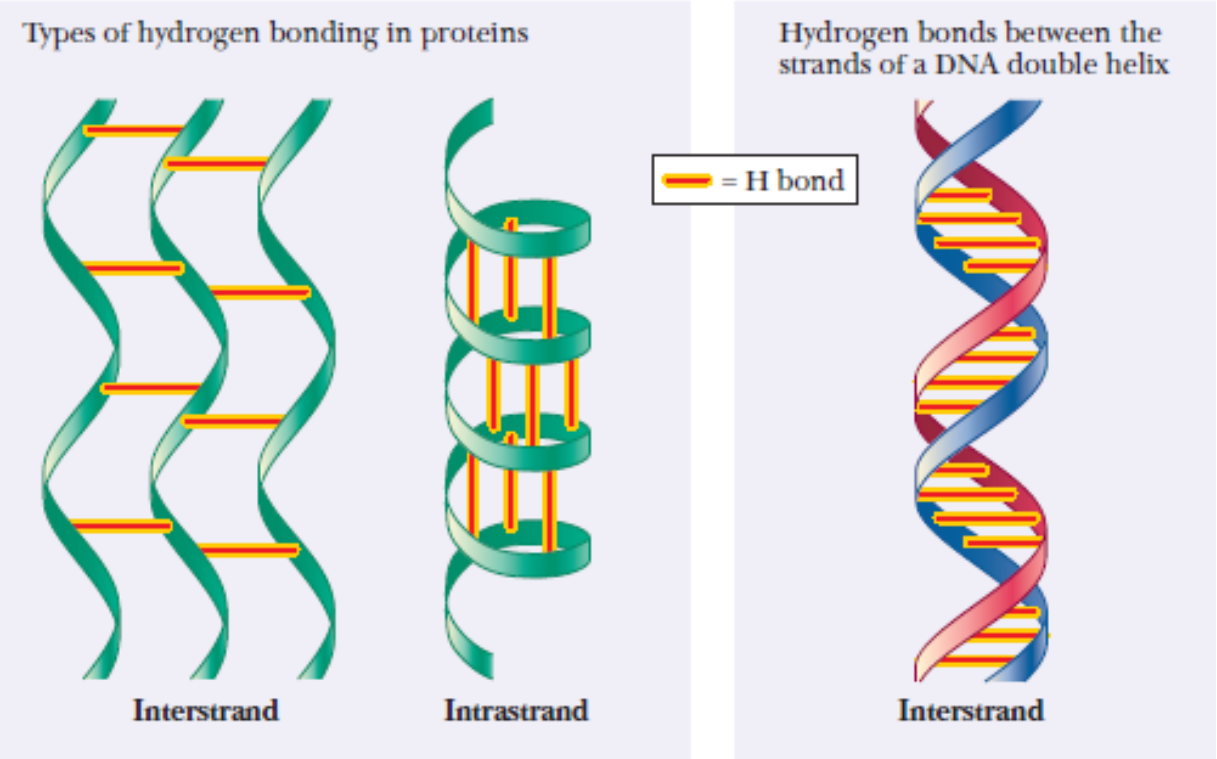


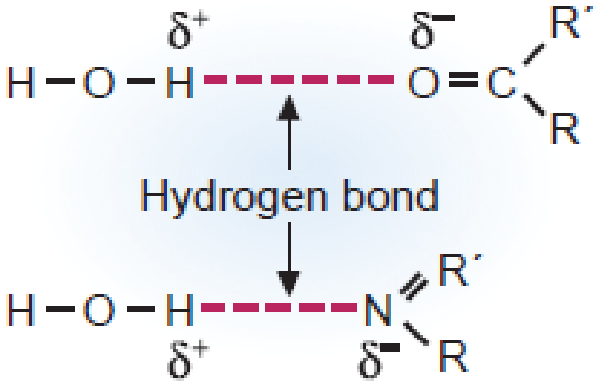
FIG. 4.3. Hydrogen bonds between water molecules. The oxygen atoms are shown in *black*.

Mark's 2012

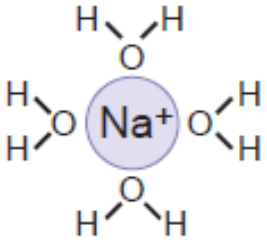
Noncovalent Interactions

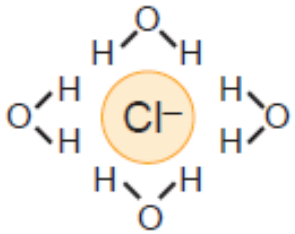


Water as a solvent



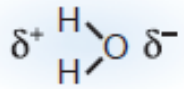
H-bonds between water and polar molecules. *R denotes additional atoms*.

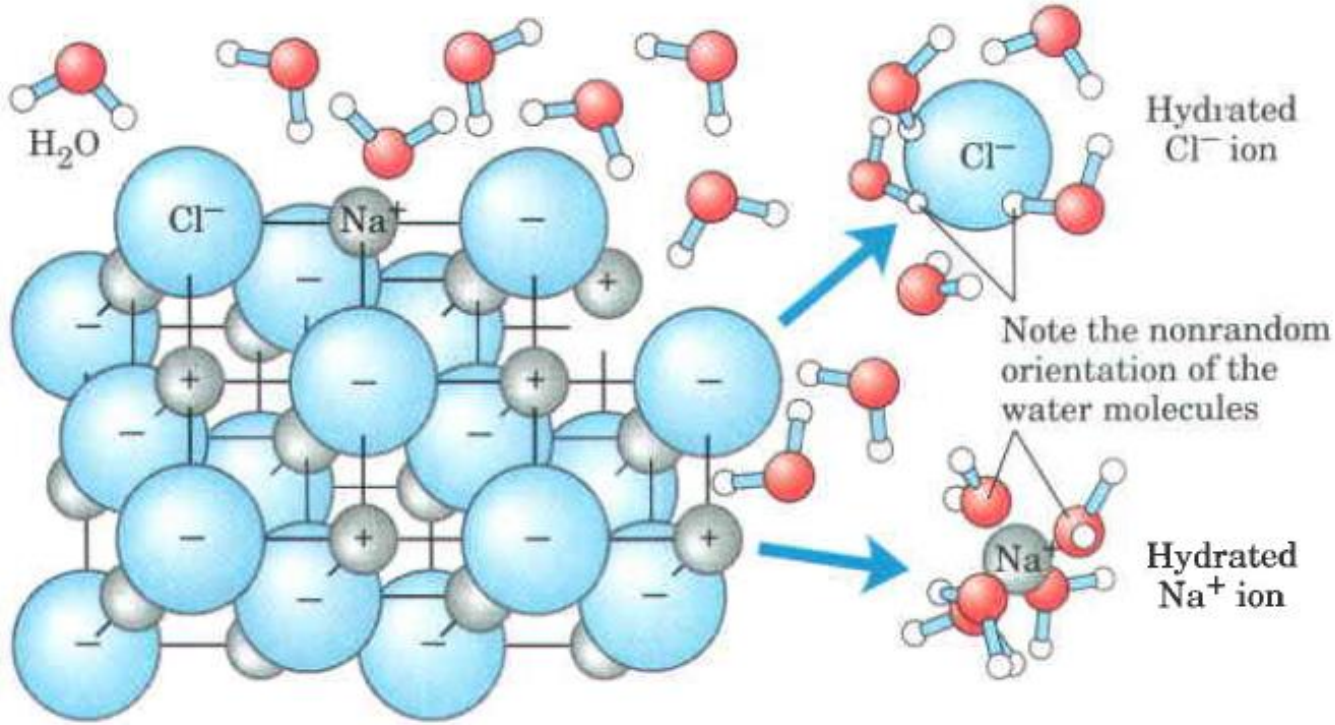




Hydration shells surrounding anions and cations.

where water is





Properties of Noncovalent Interactions

1. Reversible

2. Relatively weak. 1-30 kj/mole vs. 350 kj/mole in C–C bond

3. Molecules interact and bind specifically.

Noncovalent Interactions

-Noncovalent forces significantly contribute to the structure, stability, and functional competence of macromolecules in living cells.

- Can be either attractive or repulsive.

-Involve interactions both within the biomolecule and between it and the water of the surrounding environment.

Covalent vs Noncovalent bonds

Table 2.3

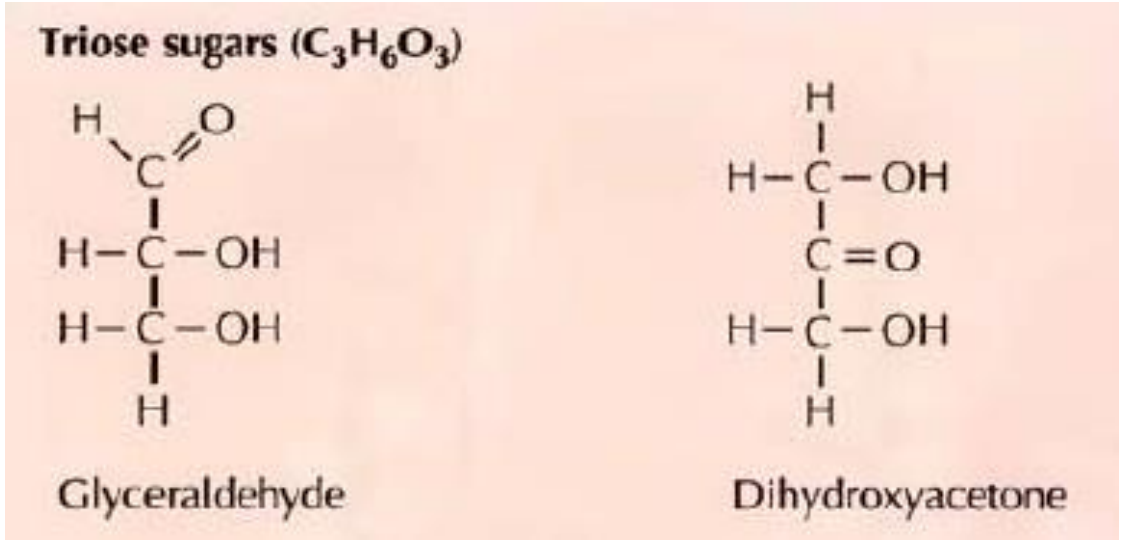
Some Bond Energies

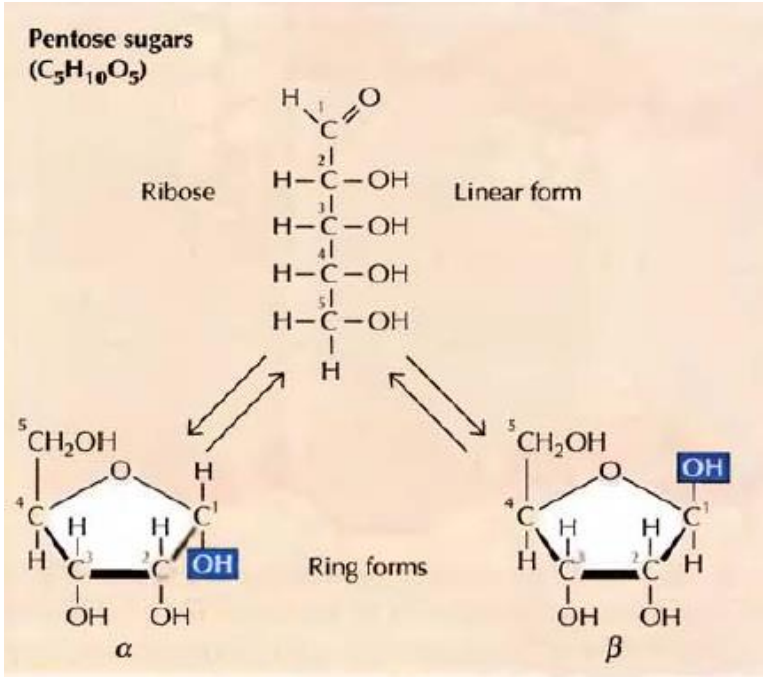
	Type of Bond	Energy ($kJ\ mol^{-1}$)	Energy ($kcal\ mol^{-1}$)
Covalent Bonds (Strong)	O—H	460	110
	H—H	416	100
	C—H	413	105
Noncovalent Bonds (Weaker)	Hydrogen bond	20	5
	Ion–dipole interaction	20	5
	Hydrophobic interaction	4–12	1–3
	Van der Waals interactions	4	1

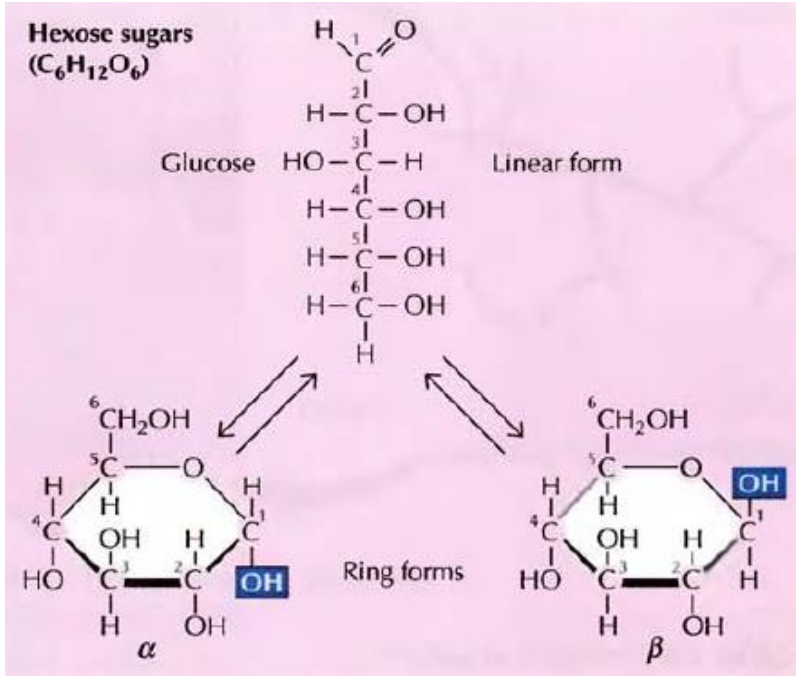
*Note that two units of energy are used throughout this text. The kilocalorie (kcal) is a commonly used unit in the biochemical literature. The kilojoule (kJ) is an SI unit and will come into wider use as time goes on. The kcal is the same as the "Calorie" reported on food labels.

Carbohydrates

- ✓ Include both simple monosaccharides and the complex polysaccharides
- ✓ General formula for simple sugars $(CH_2O)_n$, n=3-7 mostly
- ✓ 3, 5, 6 are the most common
- ✓ Cyclization
- ✓ α and β forms on carbon 1

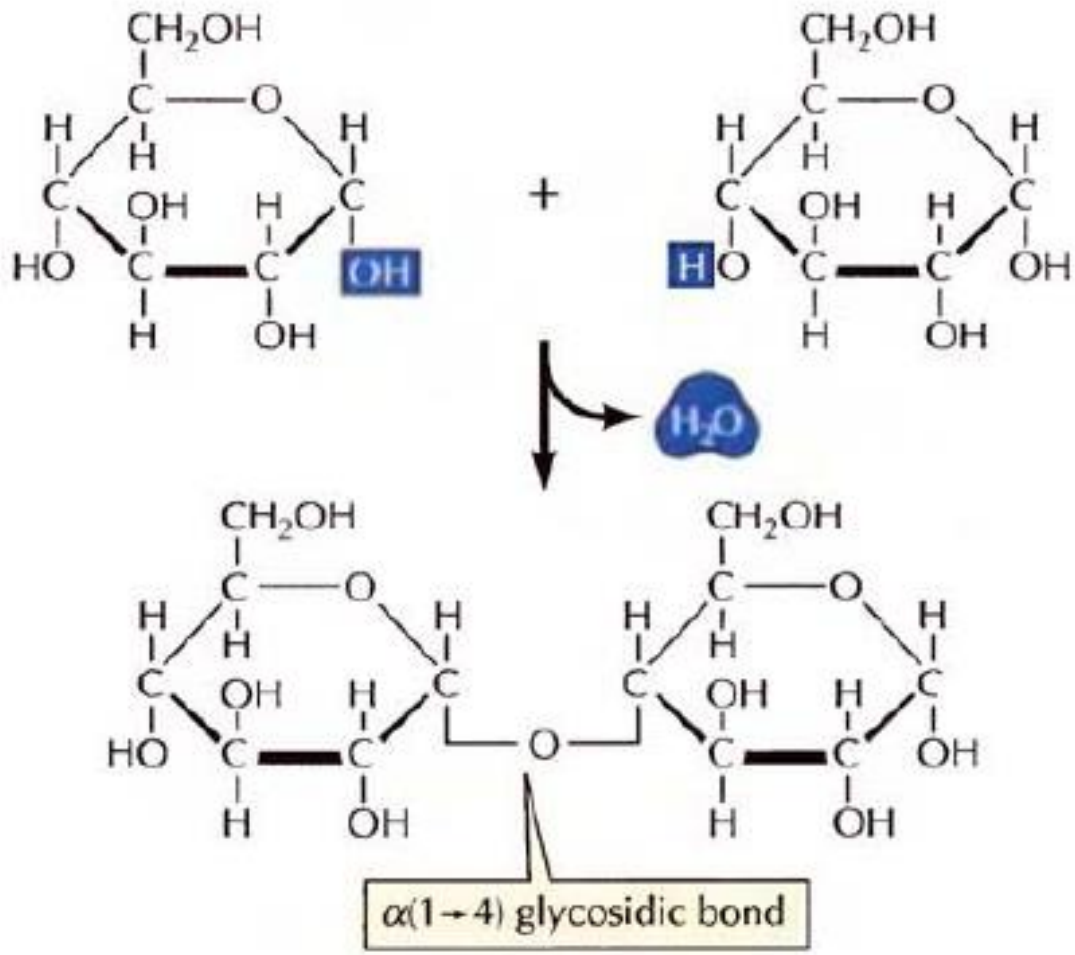






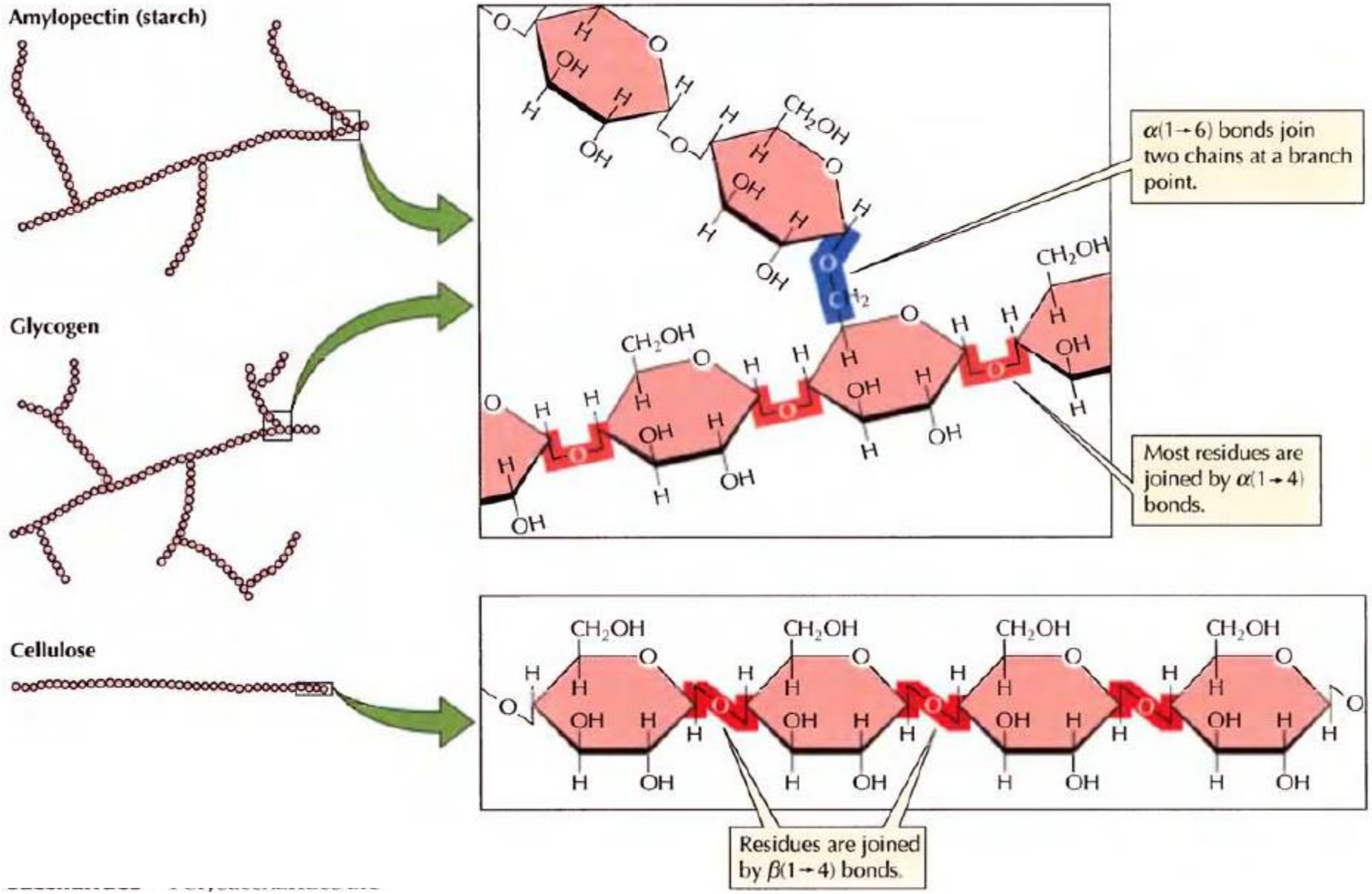
Linkage of carbohydrates to form larger molecules
Formation of a glycosidic bond

- ✓ Dehydration reaction
- ✓ 2 residues=disaccharide
- ✓ A few residues=oligosaccharide
- ✓ Hundreds or thousands residues=polysaccharide

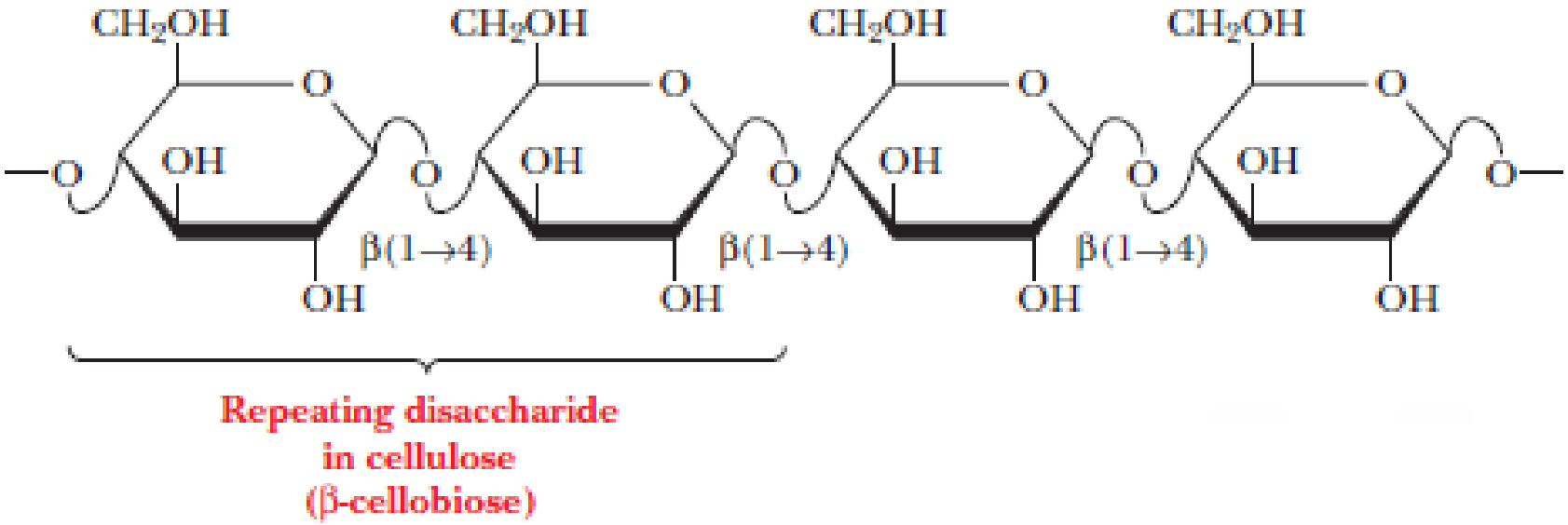


Polysaccharides

- ✓ Storage polysaccharides are starch (plants) and glycogen (animal)
- ✓ Cellulose is a structural sugar



Cellulose

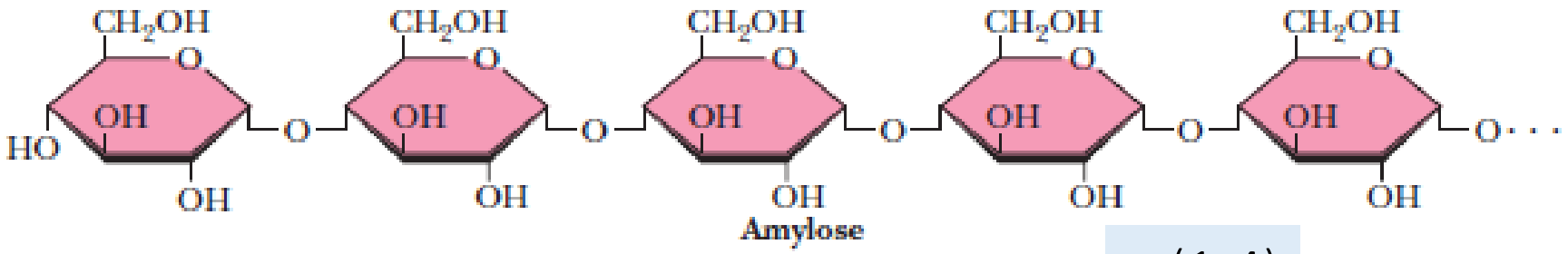


- Animals lack cellulases enzymes that hydrolyze cellulose to glucose.
- Cellulases are found in the bacteria that inhabit the digestive tracts of insects and grazing animals, such as cattle and horses.

Starch

Types of starches

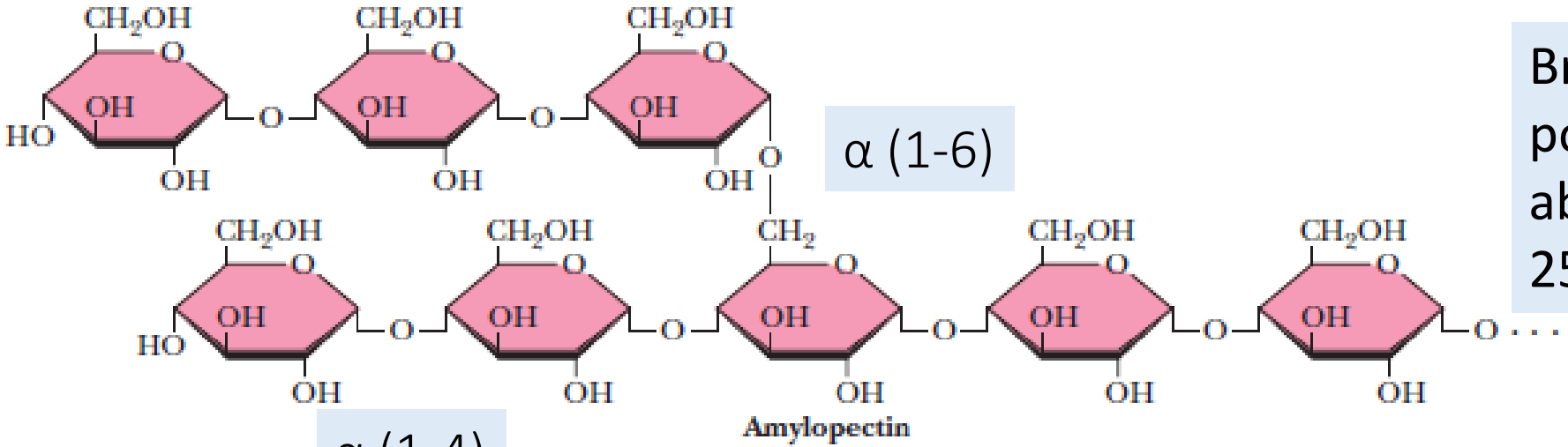
Amylose



No branching

α (1-4)

Amylopectin



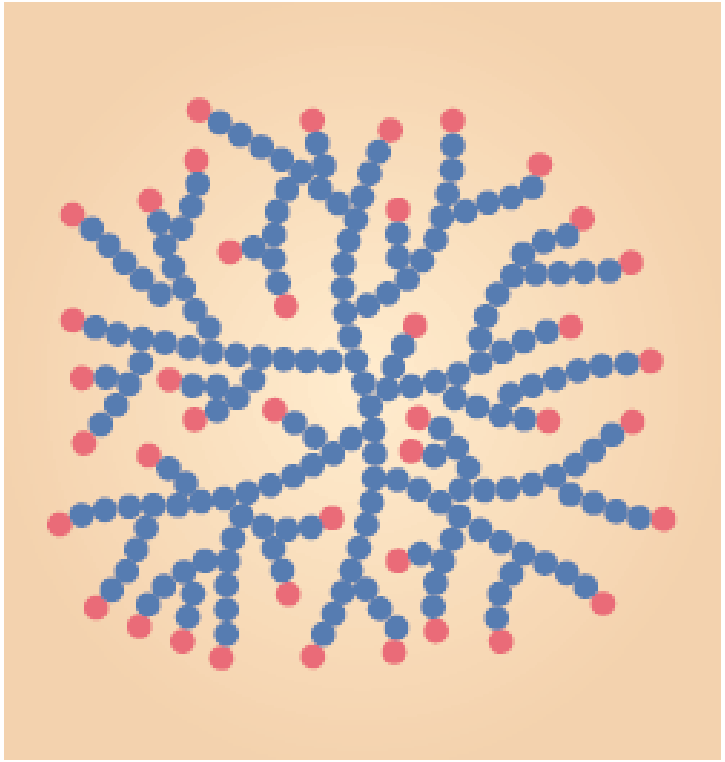
α (1-6)

Branch points occur about every 25 residues

α (1-4)

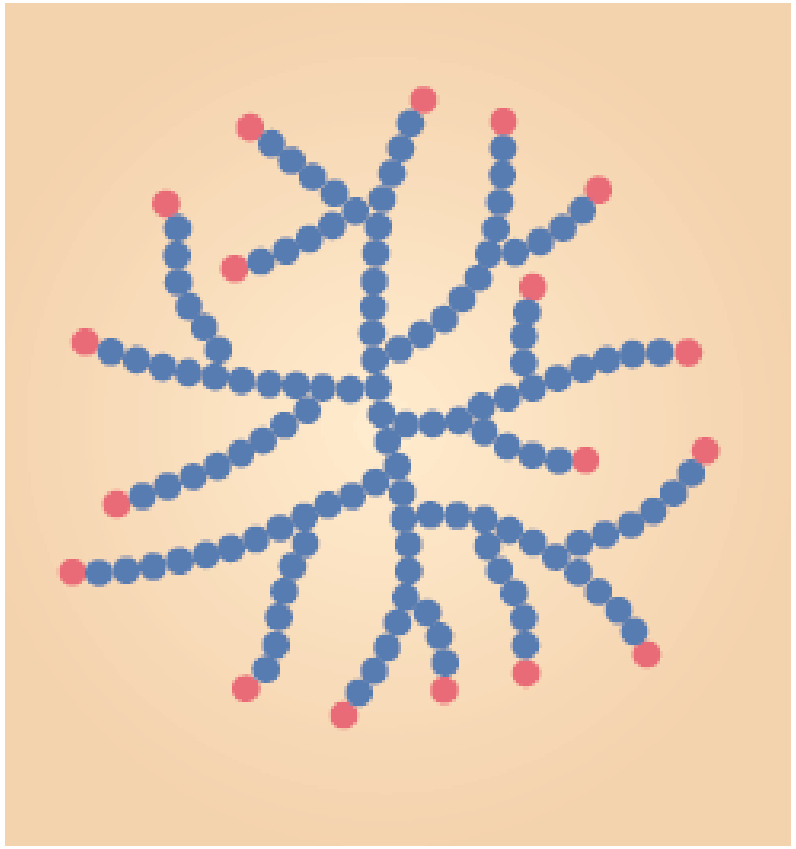
Glycogen

- Glycogen is more branched than starch
- Branch points occur about every 10 residues in glycogen
- α (1-4) linkage in main chain
- α (1-6) linkage at branches
- The average chain length is 13 glucose residues
- 12 layers of branching

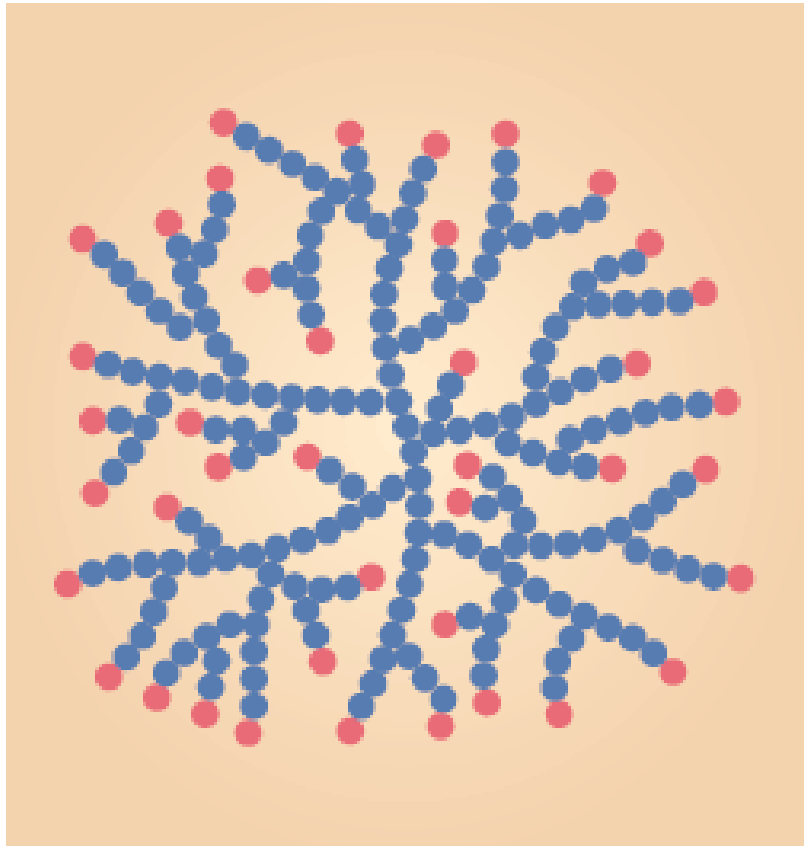


Glycogen

Amylopectin versus glycogen



Amylopectin



Glycogen

- Branching
- Source

Roles of Carbohydrates

Major energy sources

Starting material for the **synthesis of other cell constituents**

Major **nutrients** of the cells

Oligosaccharides play a key role in **cell–cell interactions, adhesion, immune recognition, protein targeting and protein folding.**

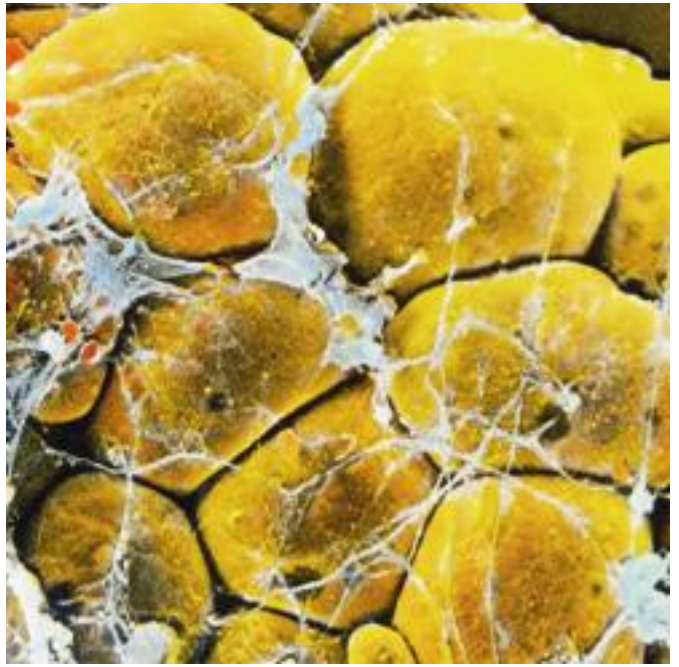
Polysaccharides are essential **structural components** of several classes of organisms such as cellulose (a major component of grass and trees)

Lipids

Naturally occurring organic molecules that are nonpolar and therefore dissolve in nonpolar organic solvents but not in water.

Major role of lipids

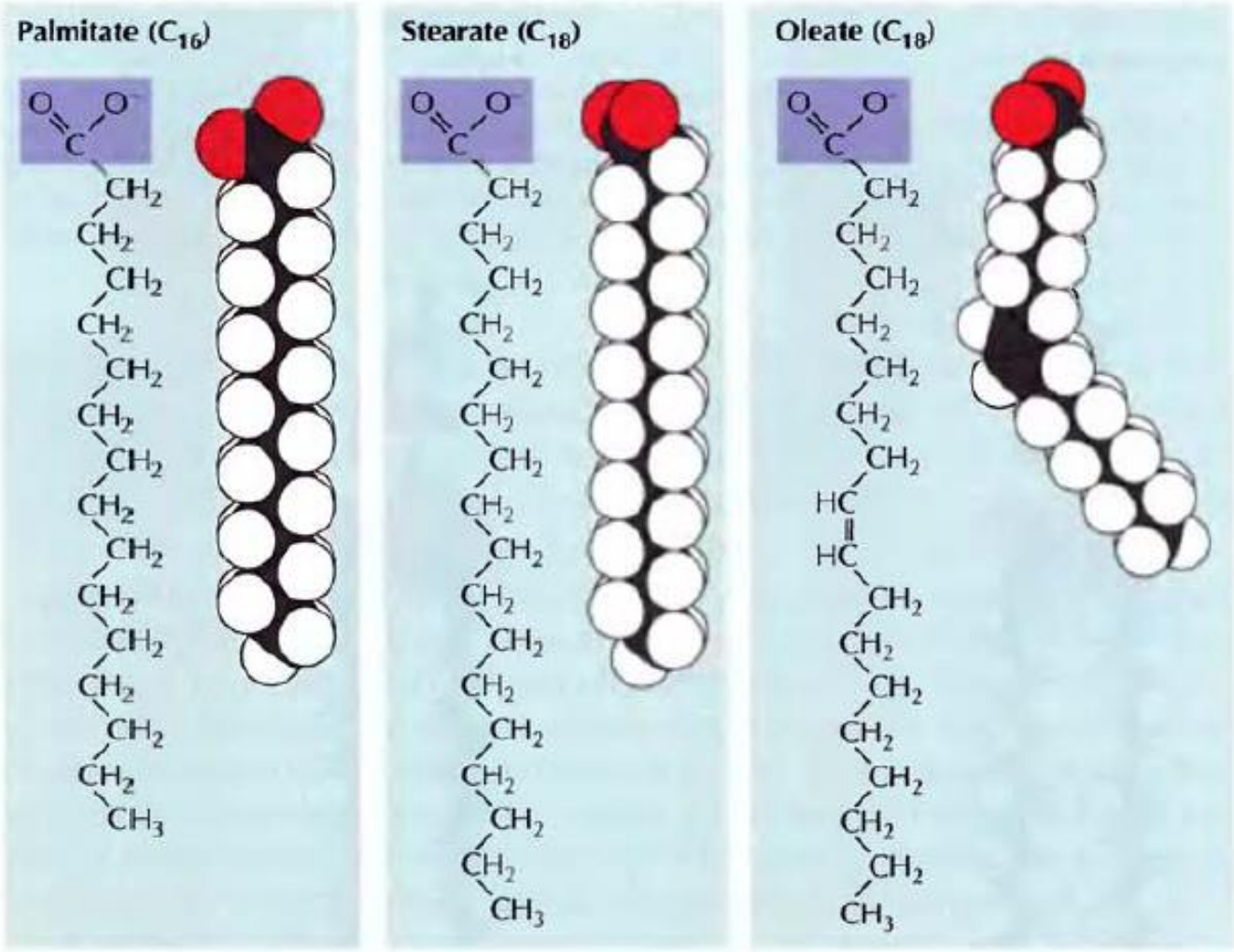
- Energy storage from metabolism of food within fat cells (adipocytes).
- Major components of cell membranes.
- Major role in cell signaling via steroid hormones and chemical messengers.



Fat cells

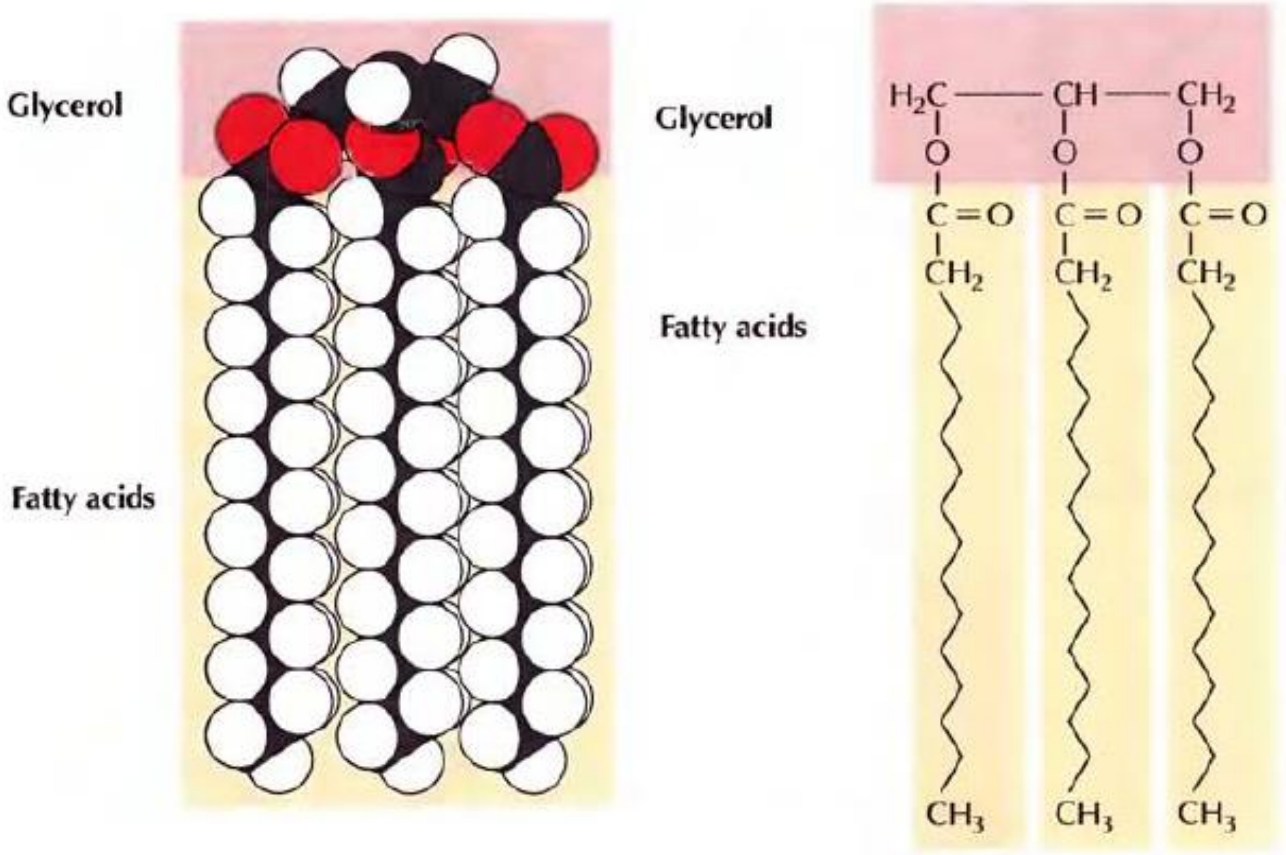
Lipids-Fatty acids (FAs)

- Simplest lipids
- Consist of long unbranched hydrocarbon chains mostly of 16 or 18 carbons with a COO^- group on one end.
- Hydrophobic
- Most have even numbers of carbon atoms.
- May or may not contain carbon-carbon double bonds.
- **Saturated fatty acids (**without double bonds)
- **Unsaturated (one or more double bond)**



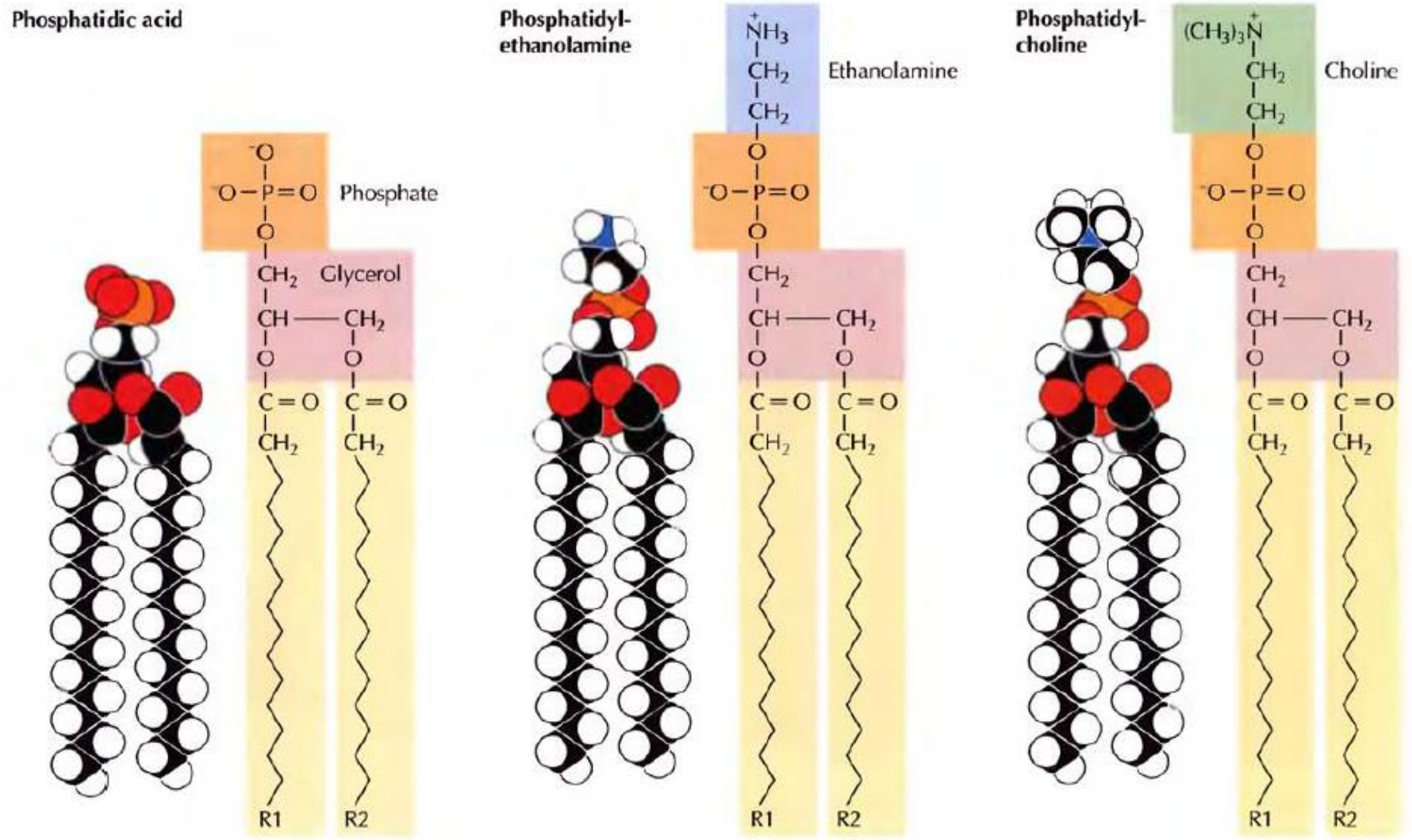
Lipids-Triacylglycerols (TAGs)

- Storage form of fatty acids
- Insoluble in water
- Accumulate in fat droplet in the cytoplasm of fat cells
- Can be broken down to generate energy
- Store energy more efficiently than carbohydrates

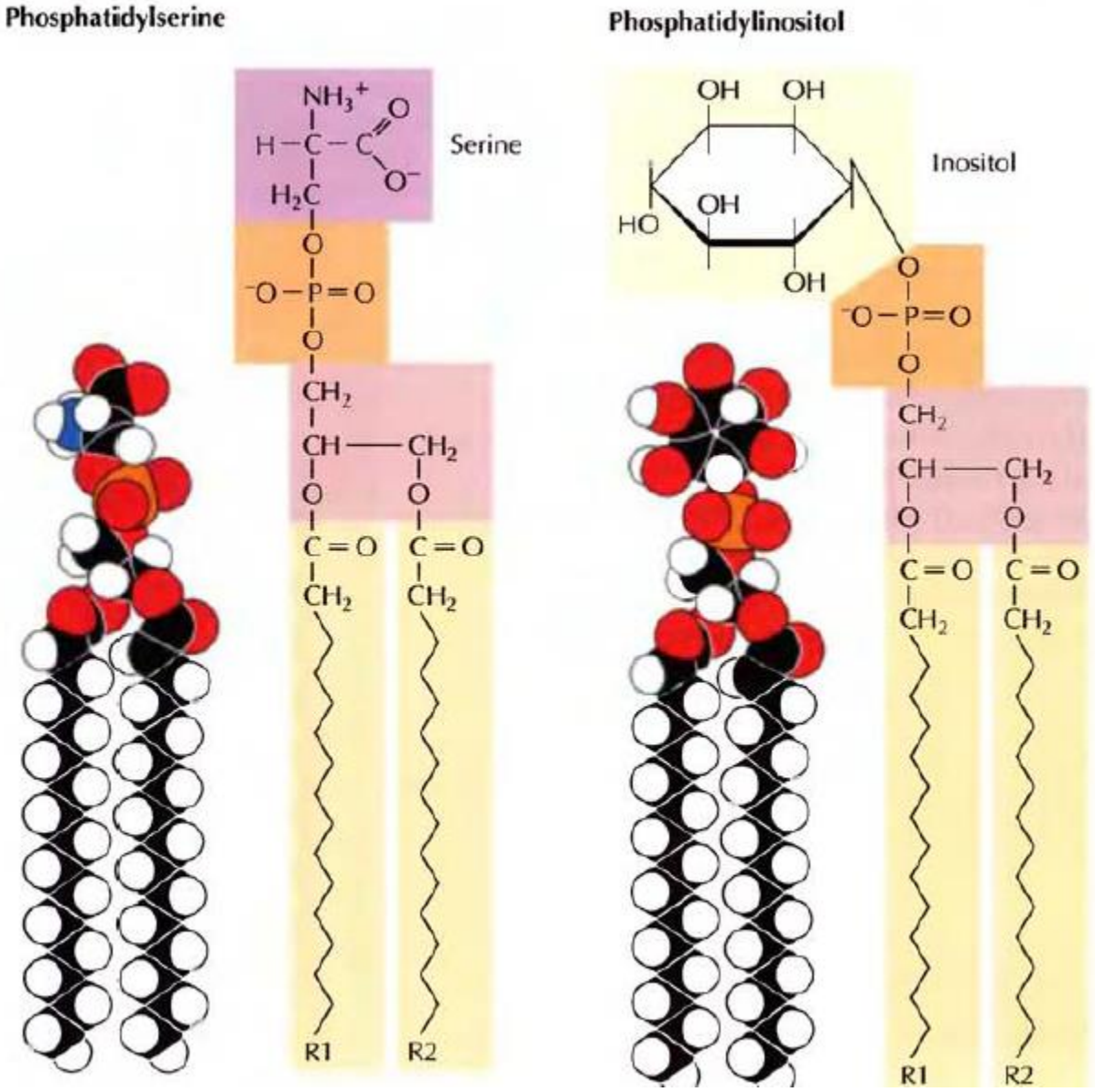


Lipids-Phospholipids

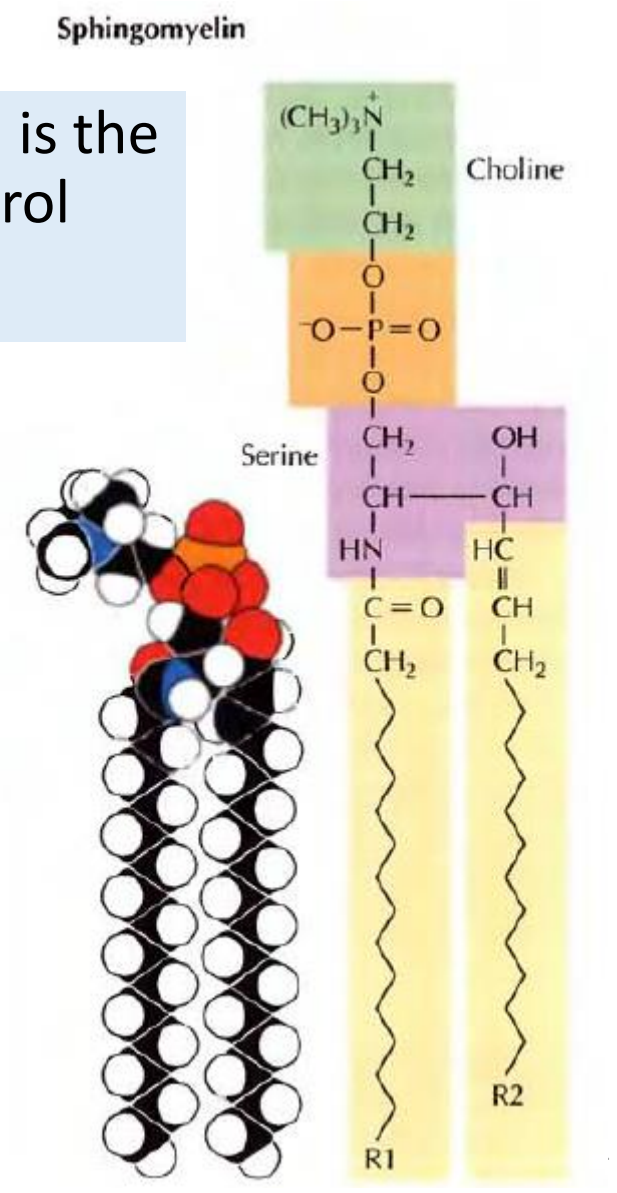
- Principal component of cell membranes
- Consist of 2 fatty acids connected to a polar head group
- Amphipathic molecules
- The polar head contains a phosphate group connected to another polar small molecule such as choline, ethanolamine, inositol, or serine.



Lipids-Phospholipids

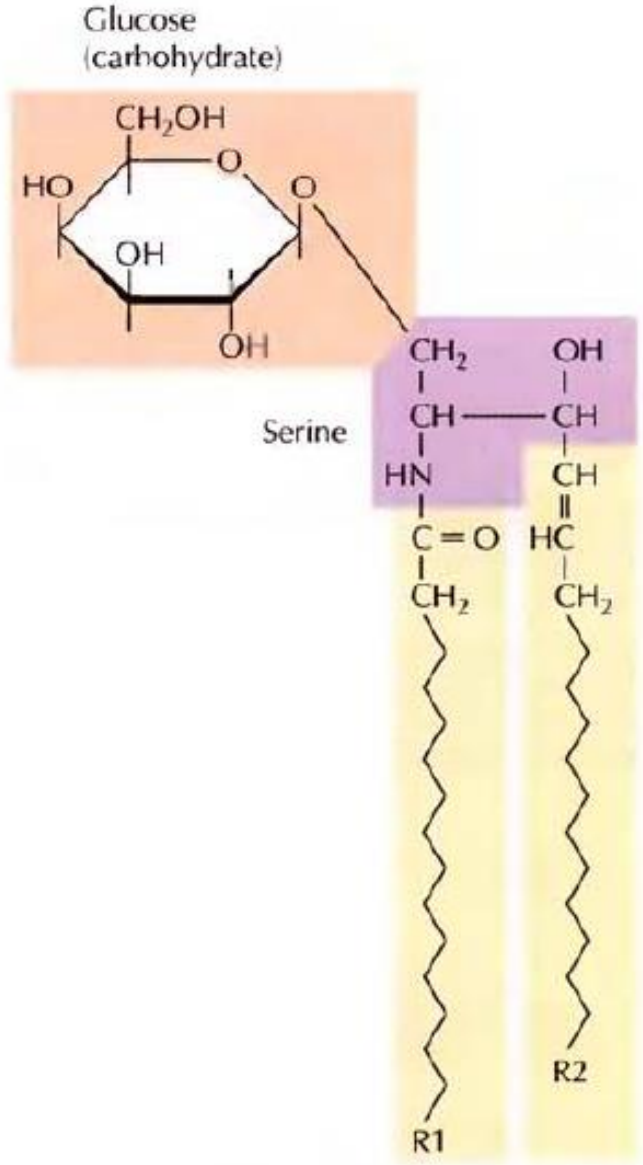


Sphingomyelin is the only non-glycerol phospholipid



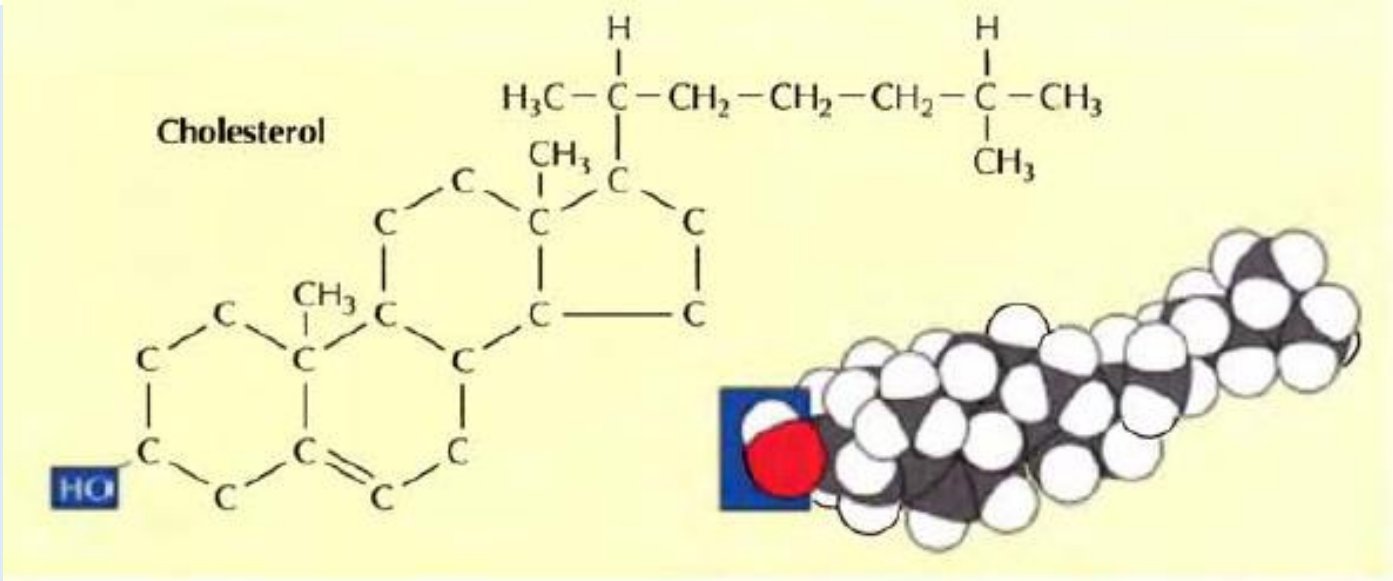
Lipids-Glyolipids

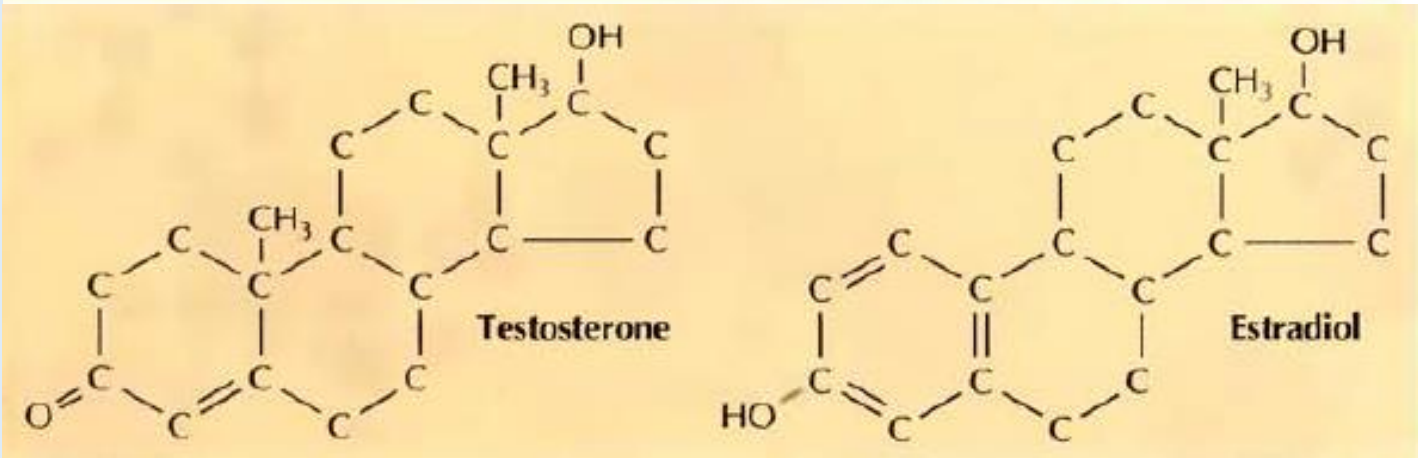
- Consist of 2 hydrocarbon chains connected to a polar head group that contain sugar
- Amphipathic molecules
- Sugars can be monosaccharides or larger



Lipids-Cholesterol

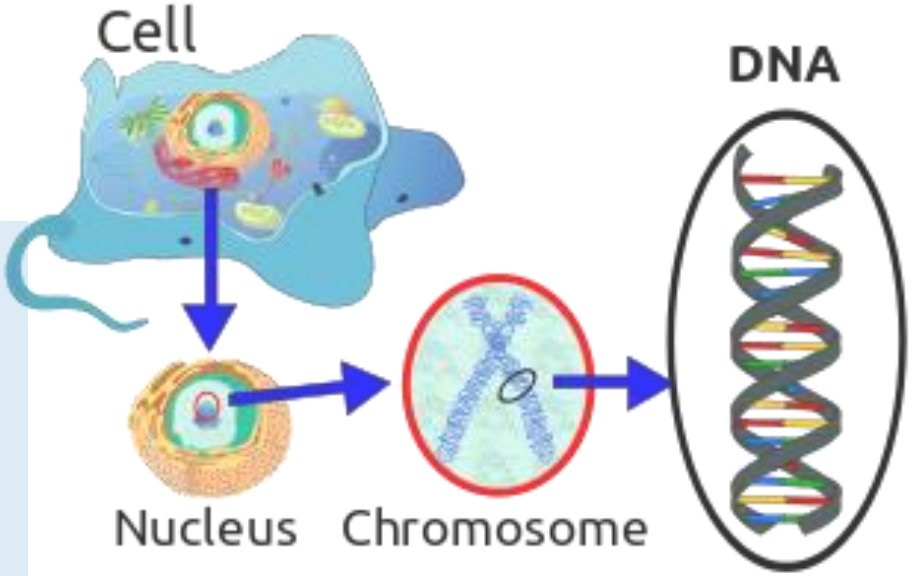
- Consist of 4 fused hydrocarbon rings
- Rings are hydrophobic but OH group is hydrophilic
- Cholesterol is amphipathic
- A component of cell membranes
- A precursor of steroid hormones and vitamin D3.
- Is modified in liver cells to produce bile acids, essential in the digestion of dietary fats.

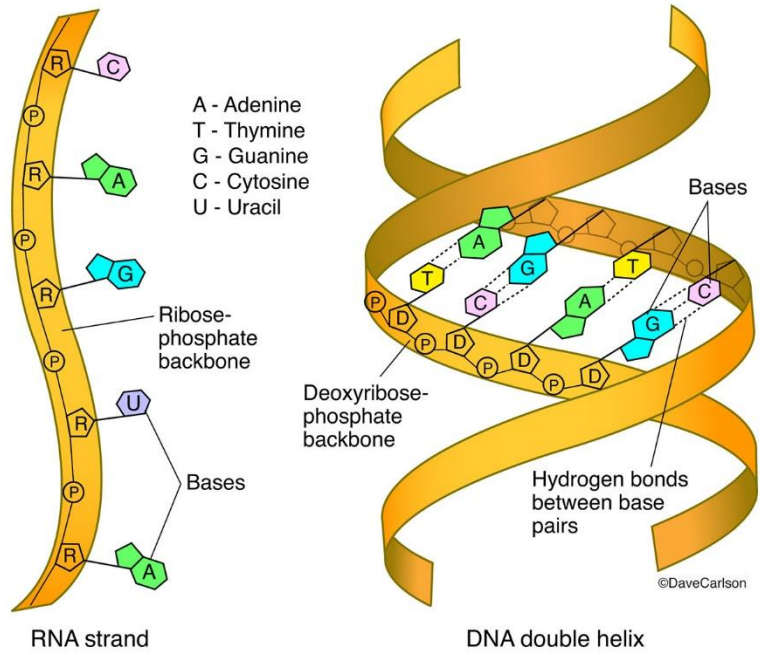




Nucleic acids

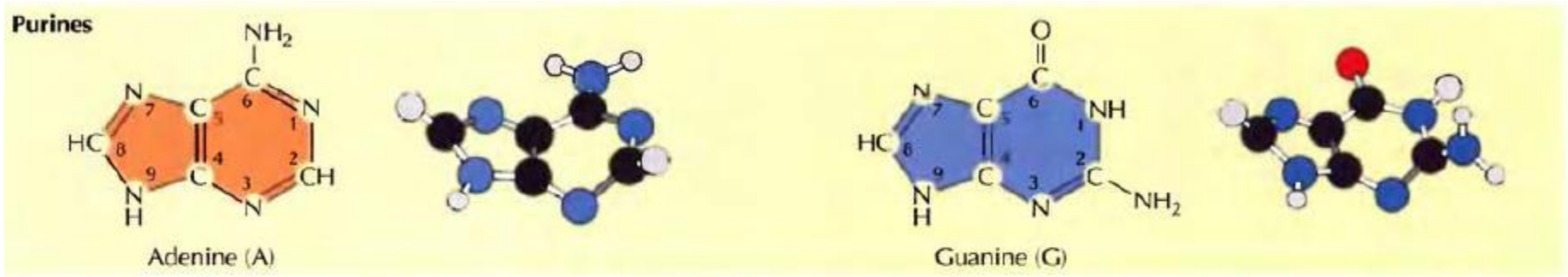
- DNA (deoxyribonucleic acid) and RNA (ribonucleic acid)
- Informational molecules of the cell
- DNA is the genetic material in the nucleus of a cell
- RNA has several types and roles
- mRNA carries information from DNA to ribosomes to make proteins
- rRNA makes the structure of ribosomes
- tRNA carries amino acids during protein synthesis or translation
- Other types such as microRNA, small nuclear RNA…etc
- DNA and RNA are made of nucleotides

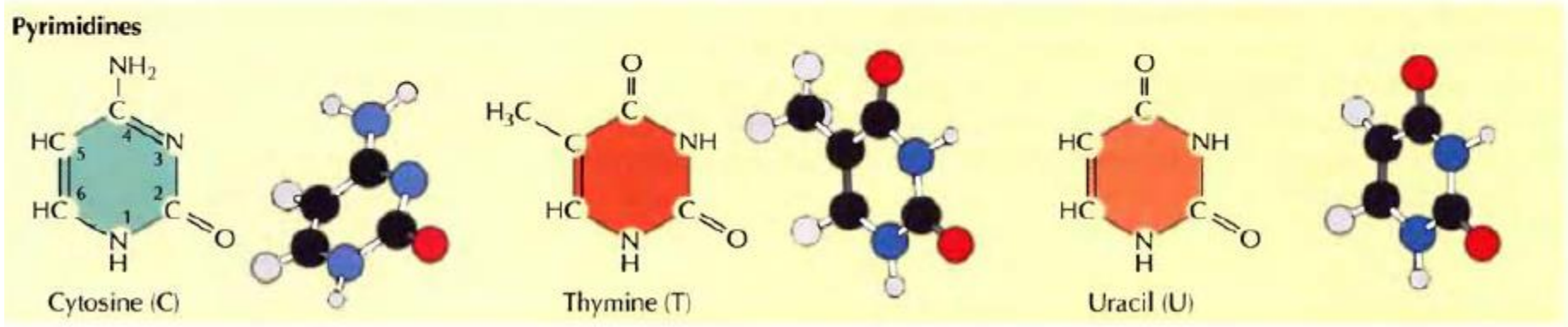




Nucleotide structure

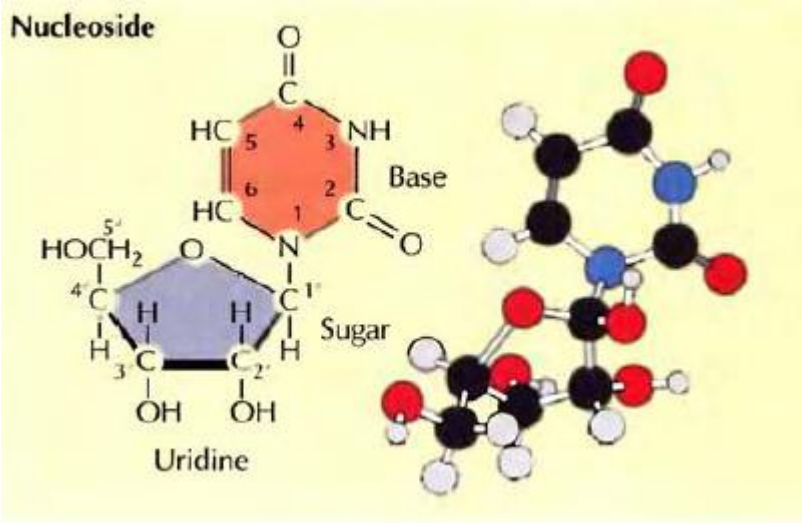
- Pentose sugar + phosphate group + nitrogenous base
- Nitrogenous bases are either purines or pyrimidines

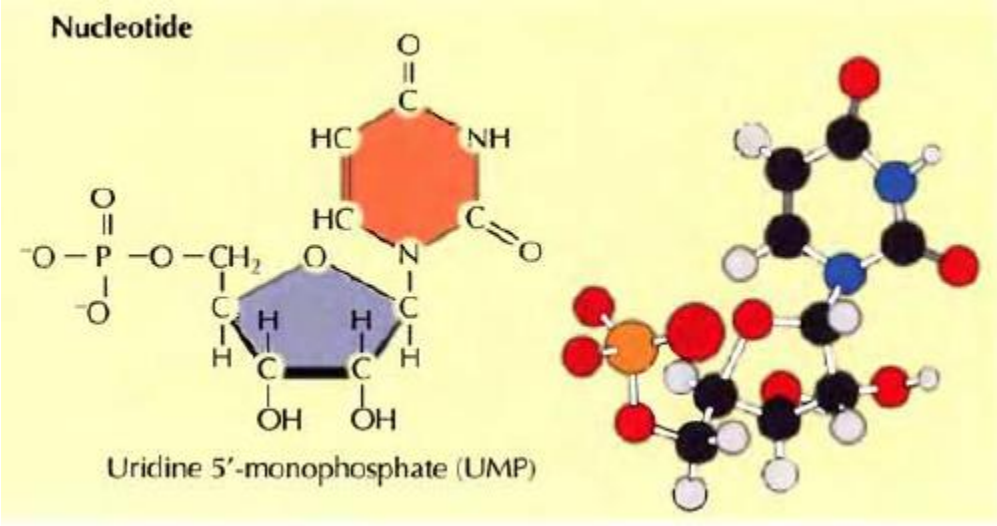




- Sugars are either ribose or 2-deoxyribose

Nucleotide structure



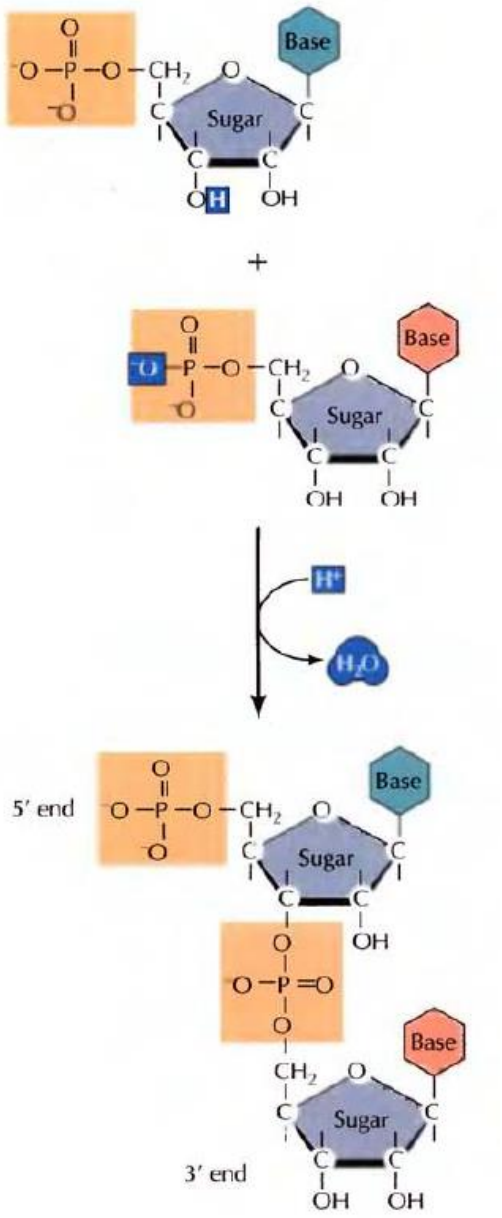


- DNA has A, G, C, T
- RNA has A, G, C, U

Nucleotide Roles

- Essential for RNA and DNA synthesis.
- They serve as carriers of activated intermediates in the synthesis of some carbohydrates, lipids, and conjugated proteins, such as, UDP-glucose and CDP-choline
- They are structural components of several essential coenzymes, such as coenzyme A, FAD, NAD+, and NADP+.
- They serve as second messengers in signal transduction pathways, such as cAMP and cGMP
- They are “energy currency” in the cell such as ATP molecule
- They act as regulatory compounds for many metabolic pathways by inhibiting or activating key enzymes.

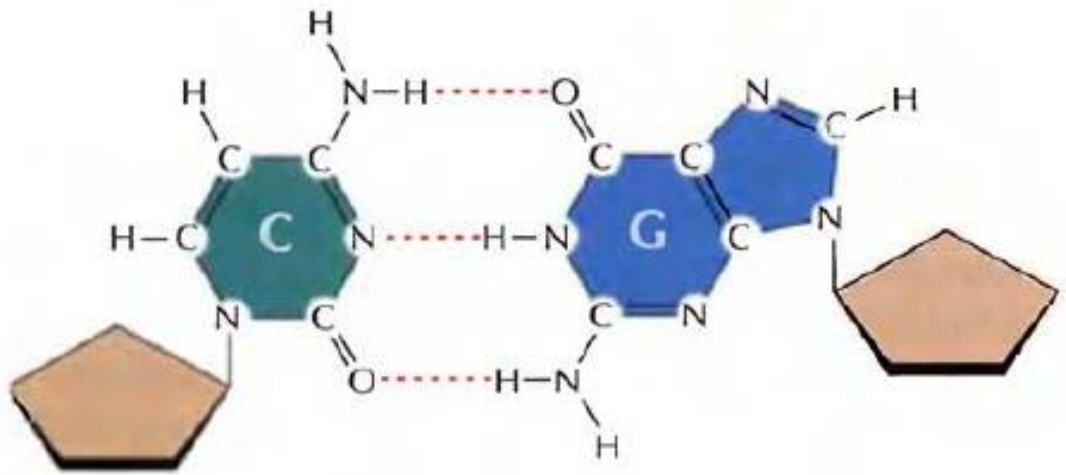
Formation of nucleic acids

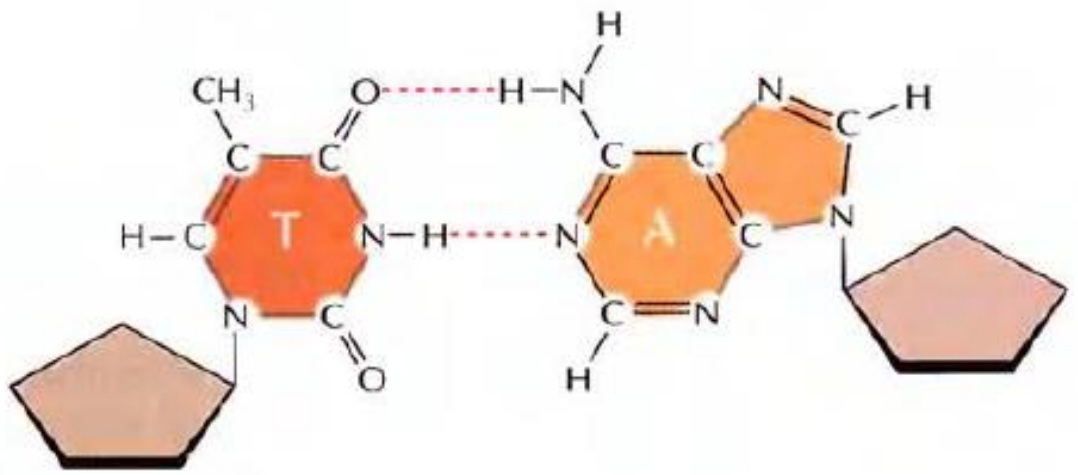


- Polymerization involves the formation of phosphodiester bond between 5’phosphate of one nucleotide and the 3’hydroxyl group of the next nucleotide
- Polynucleotides are synthesized 5’ to 3’
- The sequence of bases is written 5’ to 3’
- The information in DNA or RNA are conveyed by the order of the bases

DNA structure and the complementarity of strands

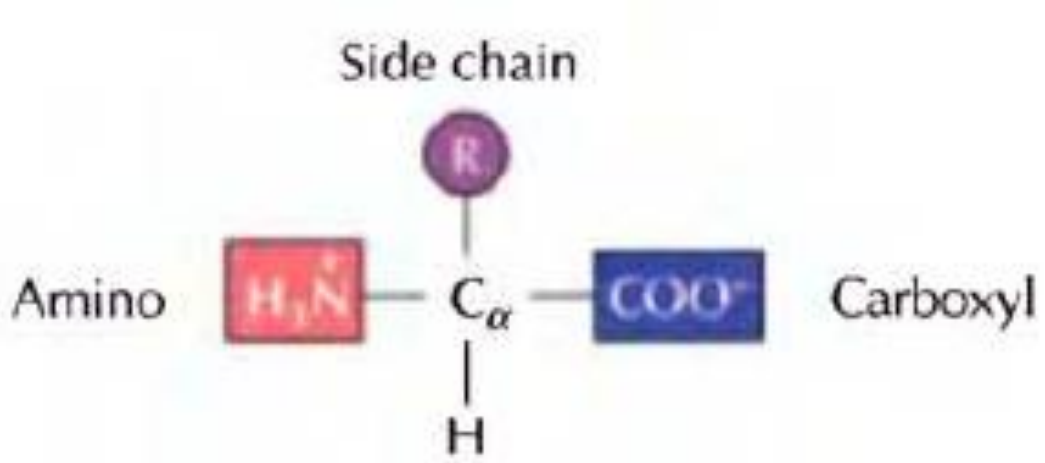
- DNA is double stranded with the strands running in opposite directions
- The bases are directed to the inside of the molecule and are linked in the 2 chains via hydrogen bonds
- Complementary base pairing is important to guide self replication



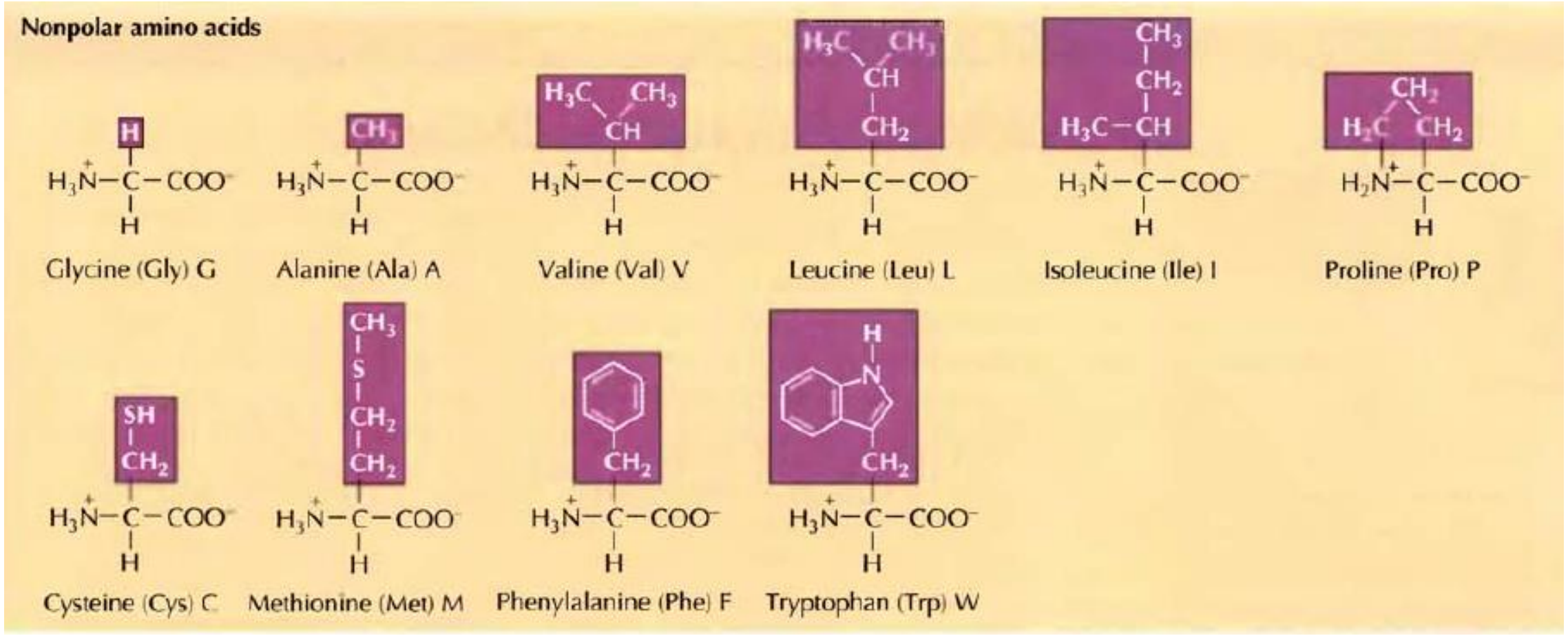


Proteins

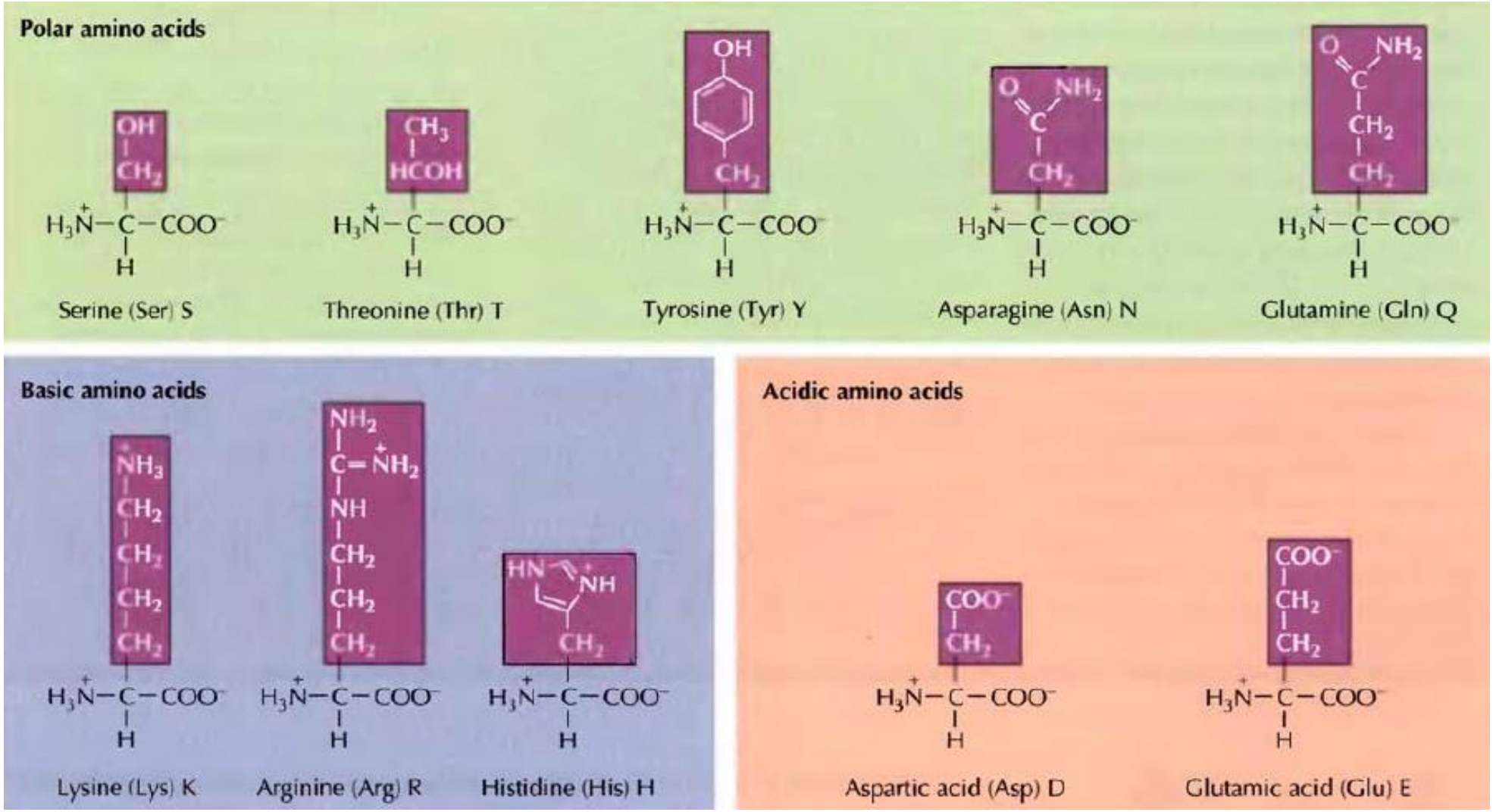
- The most diverse group of all macromolecules
- They execute the tasks directed by genetic information
- Are polymers of 20 different amino acids



Amino acids

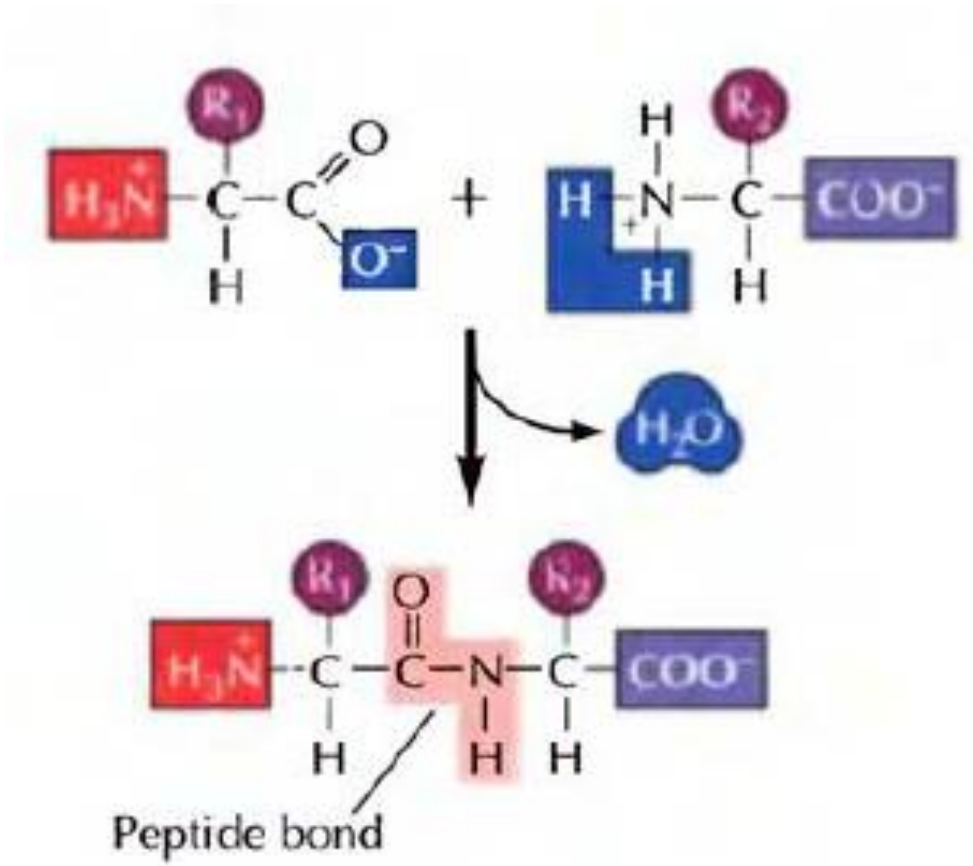

Nonpolar amino acids
Glycine (Gly) G
Alanine (Ala) A
Valine (Val) V
Leucine (Leu) L
Isoleucine (Ile) I
Proline (Pro) P
Cysteine (Cys) C
Methionine (Met) M
Phenylalanine (Phe) F
Tryptophan (Trp) W

Amino acids


Polar amino acids
Serine (Ser) S
Threonine (Thr) T
Tyrosine (Tyr) Y
Asparagine (Asn) N
Glutamine (Gln) Q
Basic amino acids
Lysine (Lys) K
Arginine (Arg) R
Histidine (His) H
Acidic amino acids
Aspartic acid (Asp) D
Glutamic acid (Glu) E

Formation of peptide bond

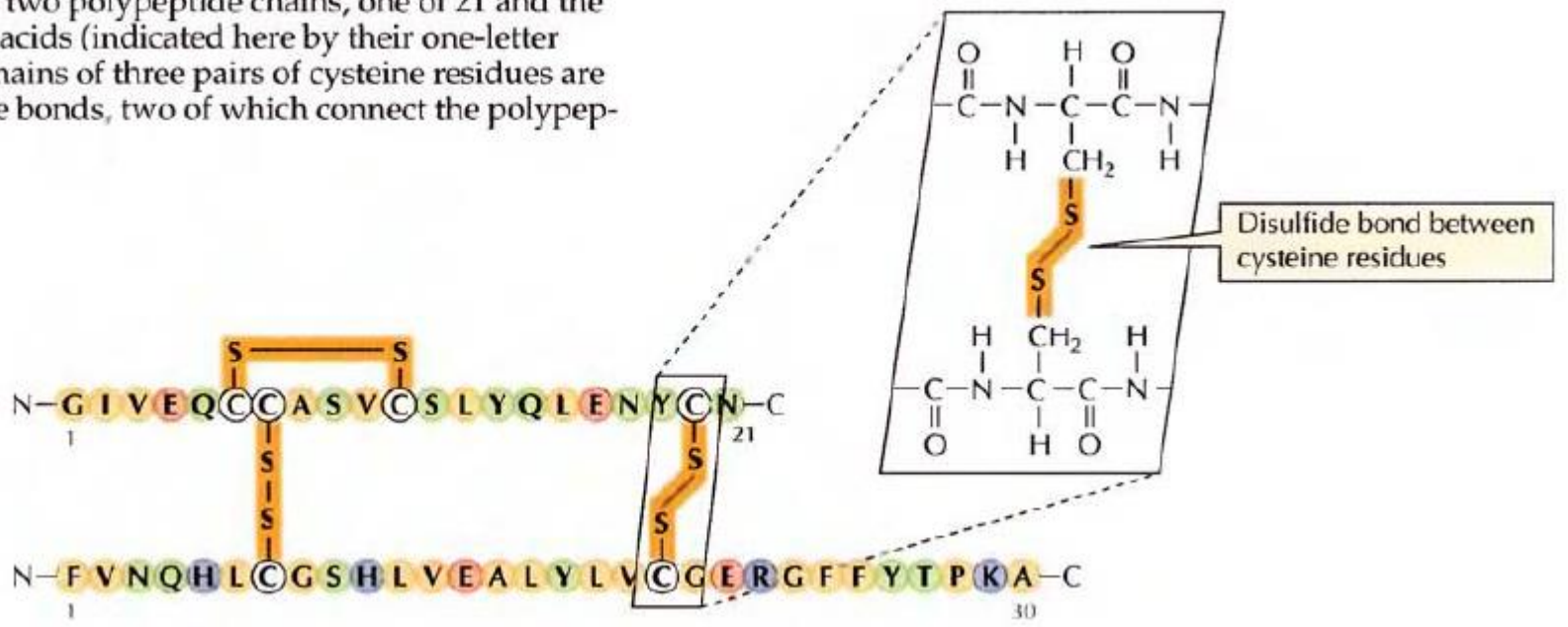
- Dehydration reaction
- Polypeptides are linear chains of amino acids (hundreds or thousands in length)
- Has an N terminus (beginning) and C terminus (end)



Protein structure

- Primary structure (sequence)
- Primary structure determines its 3D shape

FIGURE 2.16 Amino acid sequence of insulin
Insulin consists of two polypeptide chains, one of 21 and the other of 30 amino acids (indicated here by their one-letter codes). The side chains of three pairs of cysteine residues are joined by disulfide bonds, two of which connect the polypeptide chains.

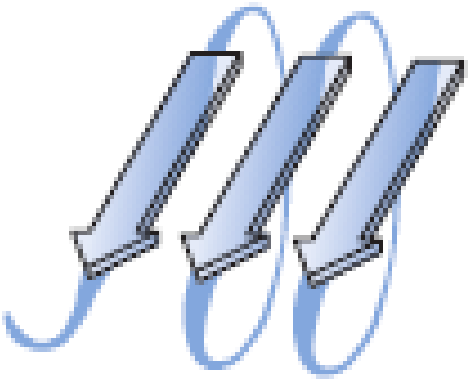


Protein structure

Secondary structure

- The hydrogen-bonded arrangement of the backbone of the protein, the polypeptide chain.
- Is the arrangement in space of the polypeptide chain, which includes regular repeating patterns
- Two kinds of repeating patterns: the **alpha-helix (α-helix), and the beta-sheet (β-sheet)**
- **Also includes turns and loops**
- Is The H-bond connects the carbonyl oxygen of one peptide unit with the amide hydrogen of another peptide unit

α-helix

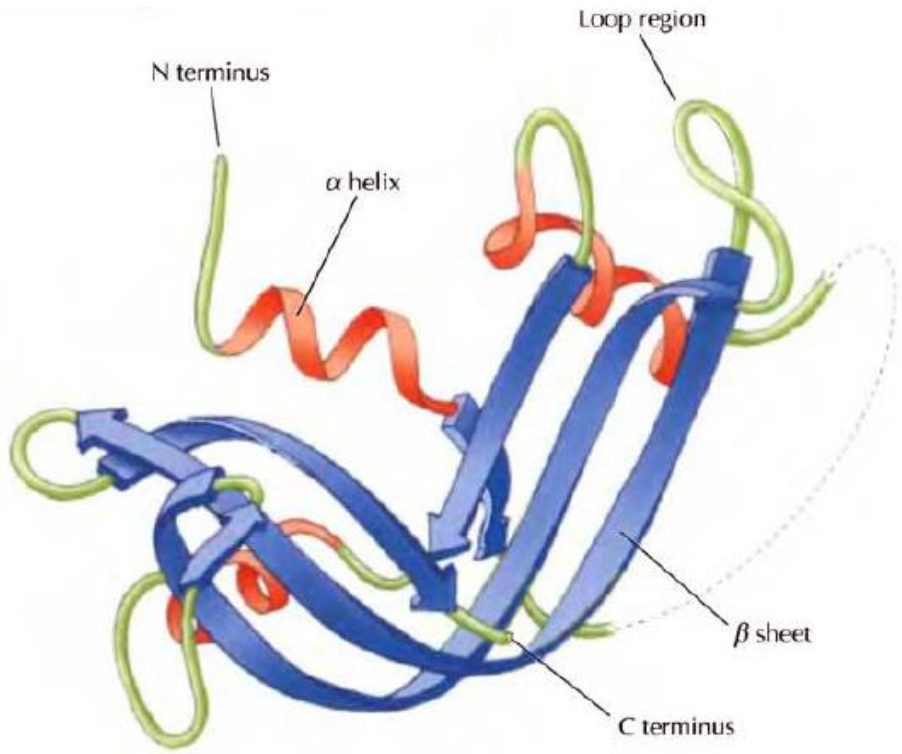


β-sheet

Protein structure

Tertiary structure

- The folding of the polypeptide chain as a result of interactions between side chains of amino acids that lie in different regions of the primary sequence.
- Composed of domains that are folded compacted globular structures that are composed of combinations of alpha helices and beta sheets connected by loop regions

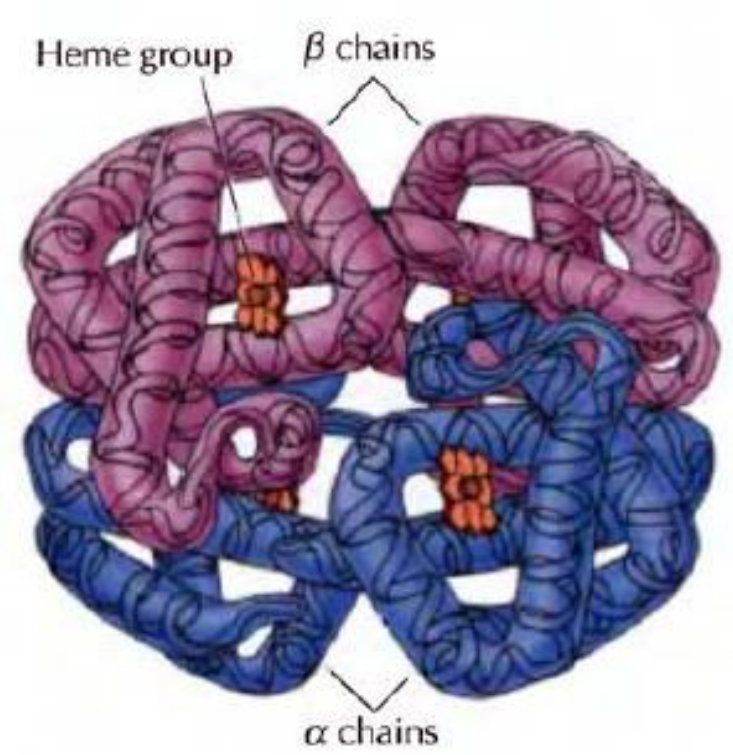


- Hydrophobic amino acids are mainly interior whereas hydrophilic amino acids are on the surface.
- Form due to the non covalent interactions between side chains in addition to the covalent disulfide bridge.

Protein structure

Quaternary structure

- Consists of interactions between several polypeptide chains
- Held together by the same interactions the maintain the tertiary structure
- Not present in all proteins



Protein classification by function

TABLE 18.2 Classification of Proteins by Function

TYPE	FUNCTION	EXAMPLE
Enzymes	Catalysts	*Amylase*—begins digestion of carbohydrates by hydrolysis
Hormones	Regulate body functions by carrying messages to receptors	*Insulin*—facilitates use of glucose for energy generation
Storage proteins	Make essential substances available when needed	*Myoglobin*—stores oxygen in muscles
Transport proteins	Carry substances through body fluids	*Serum albumin*—carries fatty acids in blood
Structural proteins	Provide mechanical shape and support	*Collagen*—provides structure to tendons and cartilage
Protective proteins	Defend the body against foreign matter	*Immunoglobulin*—aids in destruction of invading bacteria
Contractile proteins	Do mechanical work	*Myosin and actin*—govern muscle movement