Chemical Composition of the Cell

B. Balen

Table 2–2 The Approximate Chemical Composition of a Bacterial Cell

	PERCENT OF TOTAL CELL WEIGHT	NUMBER OF TYPES OF EACH MOLECULE
Water	70	1
Inorganic ions	1	20
Sugars and precursors	1	250
Amino acids and precursors	0.4	100
Nucleotides and precursors	0.4	100
Fatty acids and precursors	1	50
Other small molecules	0.2	~300
Macromolecules (proteins, nucleic acids, and polysaccharides)	26	~3000

Table 2-2 *Molecular Biology of the Cell* (© Garland Science 2008)

1. Water

- ✓ the most abundant substance in the cell!
- ✓ Where did it come from?
- several hypothesis:
  - condensation from the primary atmosphere
  - release of gases from the Earth interior
  - extraterrestrial origin

- ✓ accounts for about 70% of a cell’s weight
- ✓ most intracellular reactions occur in an aqueous environment
- ✓ Oceans → beginning of the life on Earth
- ✓ life is dependent on the properties of water

2. Small organic molecules

- ✓ carbon-based compounds – up to 30 C atoms
- ✓ molecular weight 100 - 1000 kDa
- ✓ usually found free in solution
- ✓ many different fates :
    - monomer subunits for building macromolecules
    - source of energy for intracellular metabolic pathways

✓ much less abundant that the organic macromolecules – only about 1/10 of the total mass of organic matter in the cell (Table 2-2).

✓ around 1000 different kinds of these molecules in a typical cell

Four main types of small organic molecules:

- ✓ sugars
- ✓ fatty acids (lipids)
- ✓ amino acids
- ✓ nucleotides

Energy source

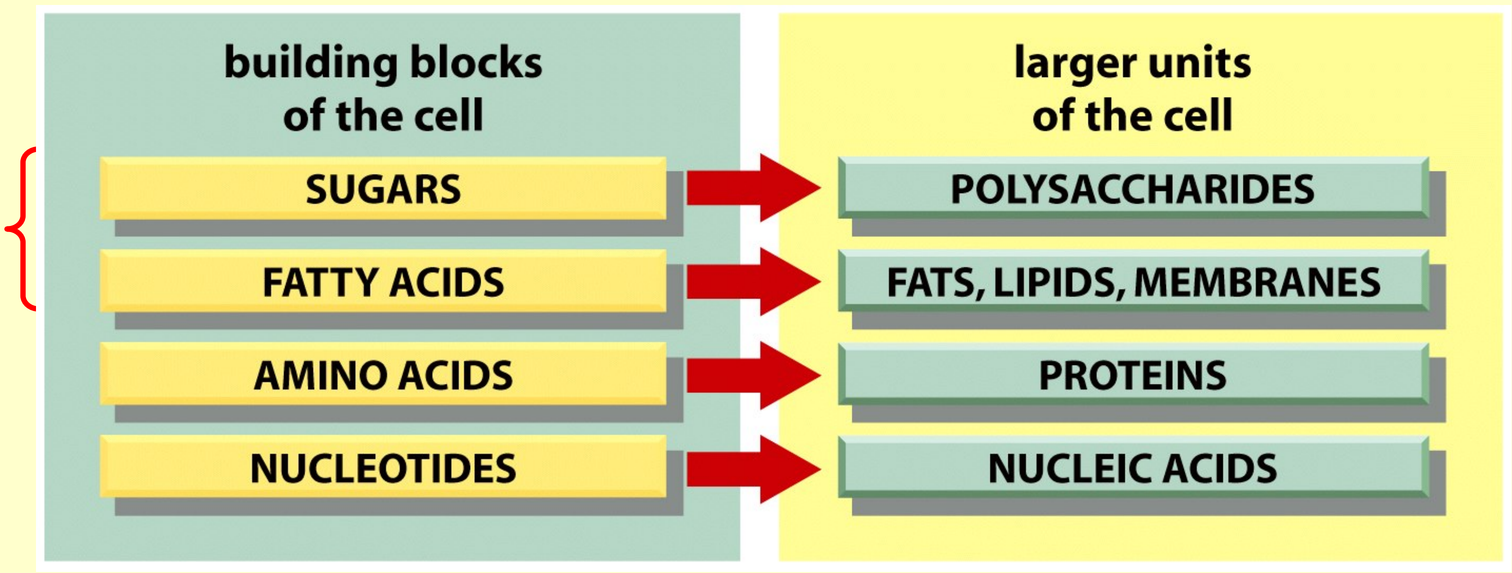


Figure 2-17 *Molecular Biology of the Cell* (© Garland Science 2008)

2.1. Sugars

✓monosaccharides

– the simplest sugars

– general formula $(CH_2O)n$, n = 3, 4, 5, 6, 7 ili 8

– carbohydrates

– glucose $C_6H_{12}O_6$

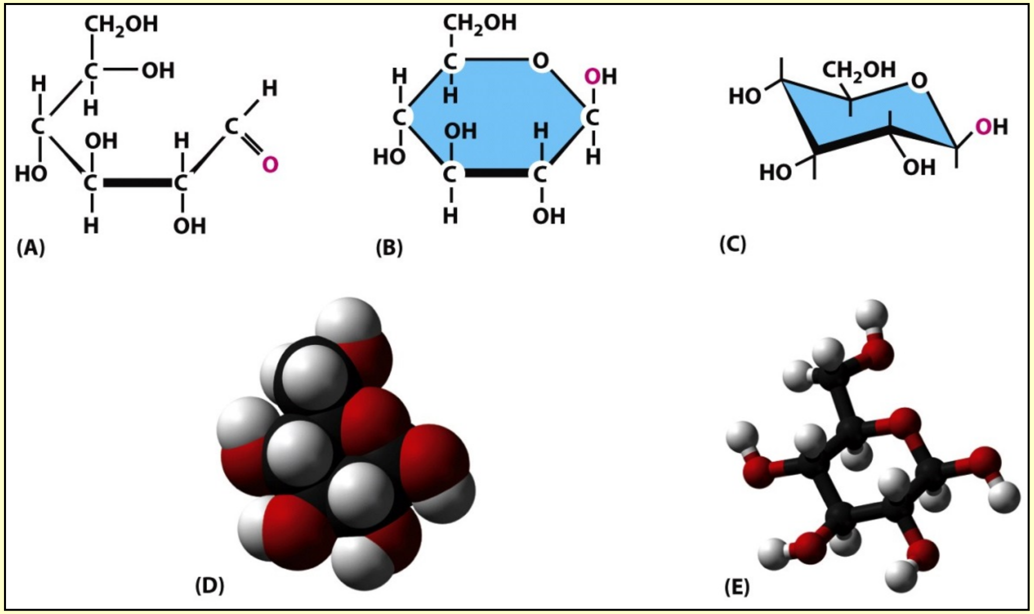


Figure 2-18 *Molecular Biology of the Cell* (© Garland Science 2008)

– the formula does not fully define the molecule – variety of ways in which C, H and O atoms can be joined together by covalent bonds → structures with different shapes

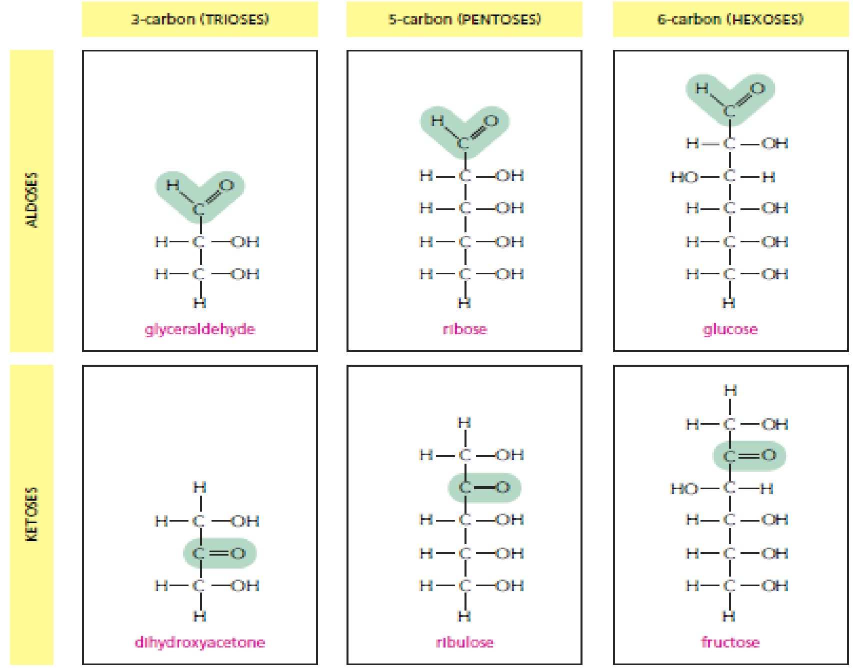
– changing the orientation of specific –OH group glucose is converted to mannose or galactose → **isomers**

– each of these sugars can exist in either two forms L- and D-forms → mirror images of each other → **optical isomers**

✓monosaccharides

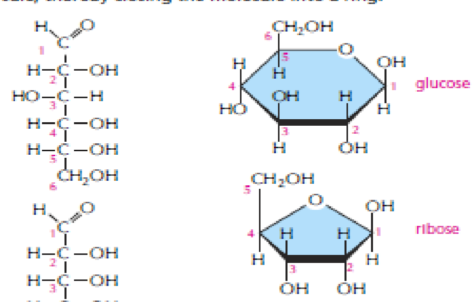
MONOSACCHARIDES

Monosaccharides usually have the general formula $(CH_2O)_n$, where *n* can be 3, 4, 5, 6, 7, or 8, and have two or more hydroxyl groups. They either contain an aldehyde group ($-C\overset{O}{\underset{H}{\lessgtr}}$) and are called aldoses or a ketone group ($>C{=}O$) and are called ketoses.



RING FORMATION

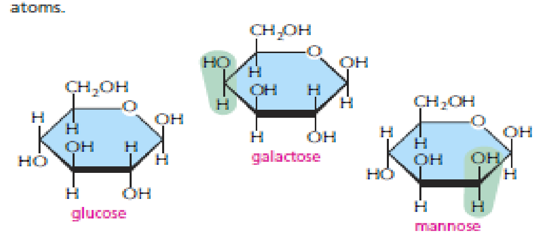
In aqueous solution, the aldehyde or ketone group of a sugar molecule tends to react with a hydroxyl group of the same molecule, thereby closing the molecule into a ring.



Note that each carbon atom has a number.

ISOMERS

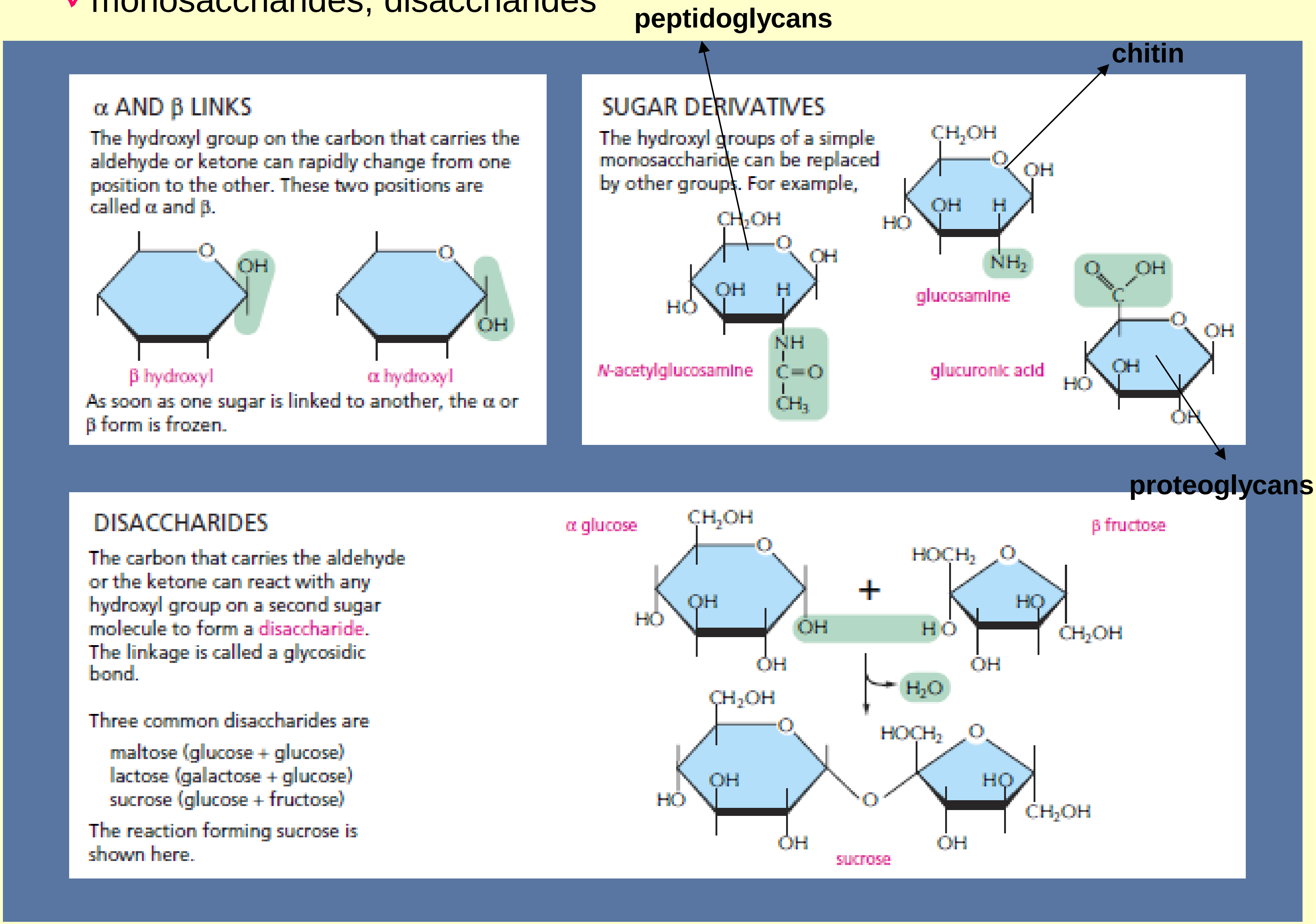
Many monosaccharides differ only in the spatial arrangement of atoms—that is, they are isomers. For example, glucose, galactose, and mannose have the same formula ($C_6H_{12}O_6$) but differ in the arrangement of groups around one or two carbon atoms.



These small differences make only minor changes in the chemical properties of the sugars. But they are recognized by enzymes and other proteins and therefore can have important biological effects.

Panel 2-4 *Molecular Biology of the Cell* (© Garland Science 2008)

✓monosaccharides, disaccharides

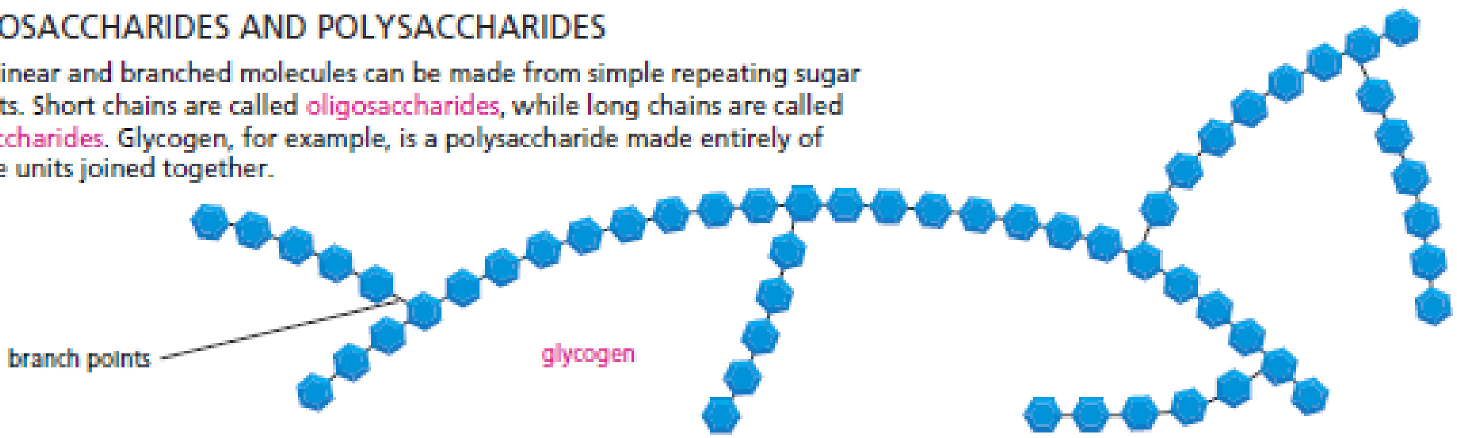


Panel 2-4 *Molecular Biology of the Cell* (© Garland Science 2008)

✓ oligosaccharides, polysaccharides

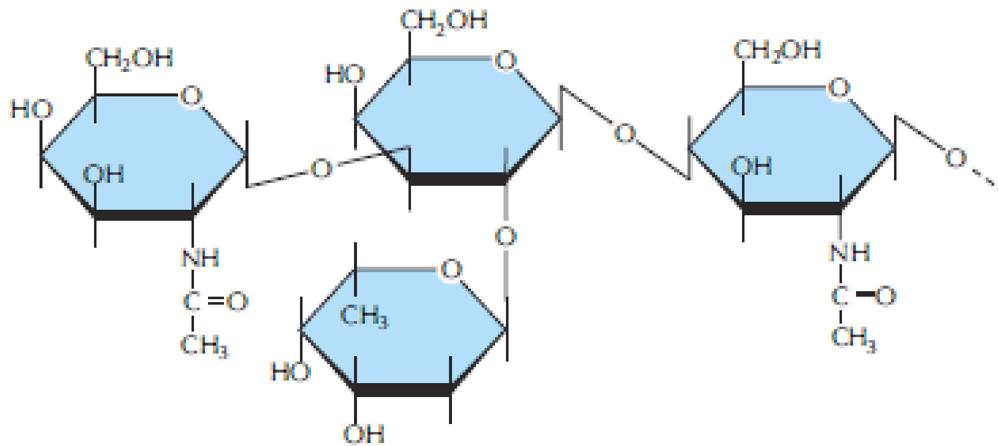
OLIGOSACCHARIDES AND POLYSACCHARIDES

Large linear and branched molecules can be made from simple repeating sugar subunits. Short chains are called oligosaccharides, while long chains are called polysaccharides. Glycogen, for example, is a polysaccharide made entirely of glucose units joined together.

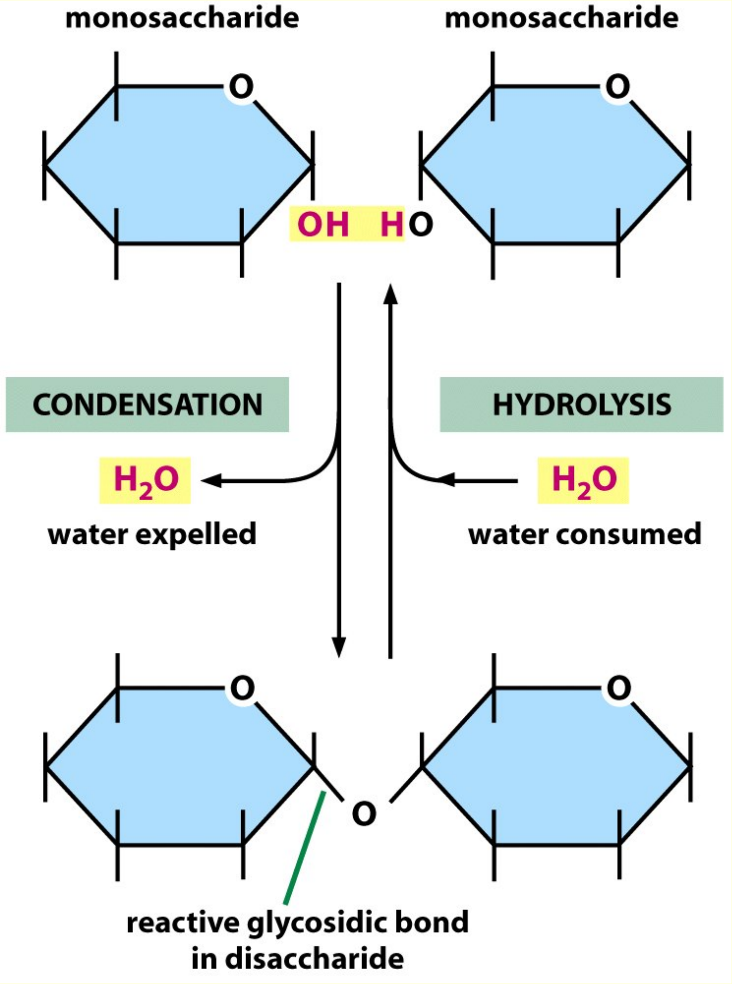


COMPLEX OLIGOSACCHARIDES

In many cases a sugar sequence is nonrepetitive. Many different molecules are possible. Such complex oligosaccharides are usually linked to proteins or to lipids, as is this oligosaccharide, which is part of a cell-surface molecule that defines a particular blood group.



✓ the reaction of two monosaccharides to form a disaccharide



- <u>condensation</u> – two monosaccharides are joined together as a loss of one H_2O molecule

- <u>hydrolysis</u> – reverse reaction in which H_2O is added

Figure 2-19 *Molecular Biology of the Cell* (© Garland Science 2008)

Importance:

✓ energy sources

- glucose – key energy source for cells → in a series of reactions is broken down to smaller molecules to release the energy

- cells use simple polysaccharides composed only of glucose units → glycogen (animal cells) and starch (plant cells)

✓ mechanical support

- **cellulose** – glucose polysaccharide (the most abundant organic chemical on Earth!)

- **chitin** – linear polymer of N-acetylglucosamine

✓ molecular markers

- glycoproteins and glycolipids of the cell membrane → selective recognition by other cells

- human blood groups

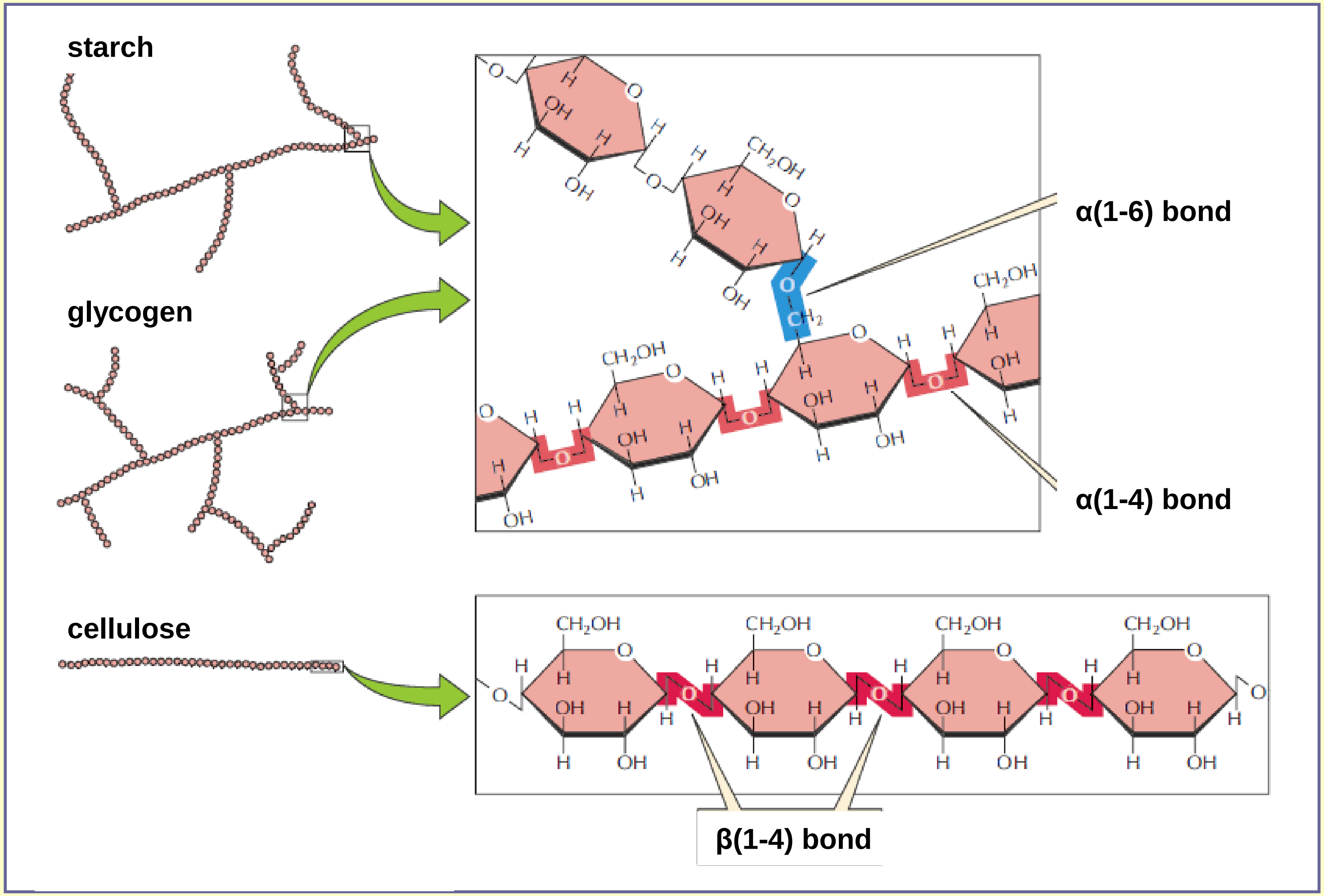
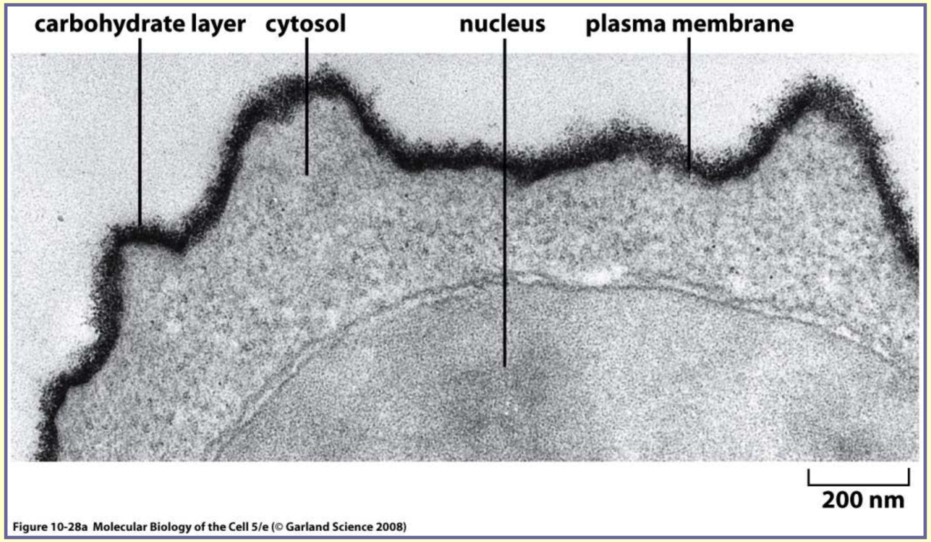
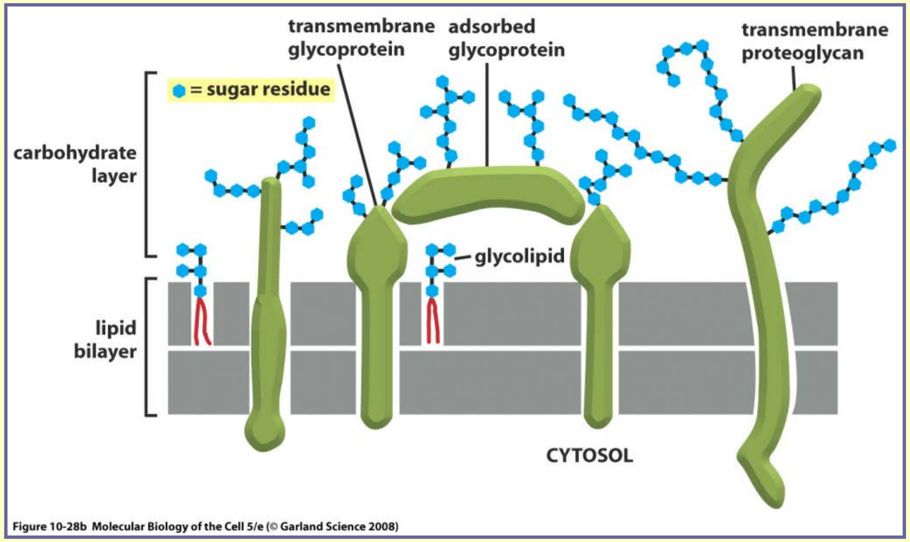


Figure 2-4. The Cell; Cooper 2000

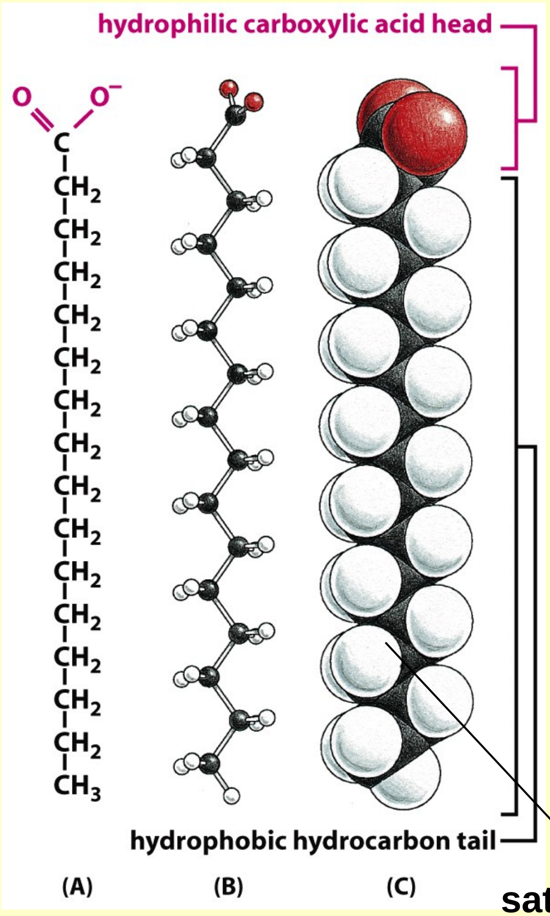




Electron micrograph of a surface of lymphocite – extracellular carbohydrate layer - **glycocalyx**

Glycocalyx – simplifed diagram

2.2. Fatty acids (lipids)



saturated chain

palmitic acid

✓ Lipids
→ fatty acid and their derivatives
→ water insoluble; soluble in fats and organic solvents

✓ two different structural parts:

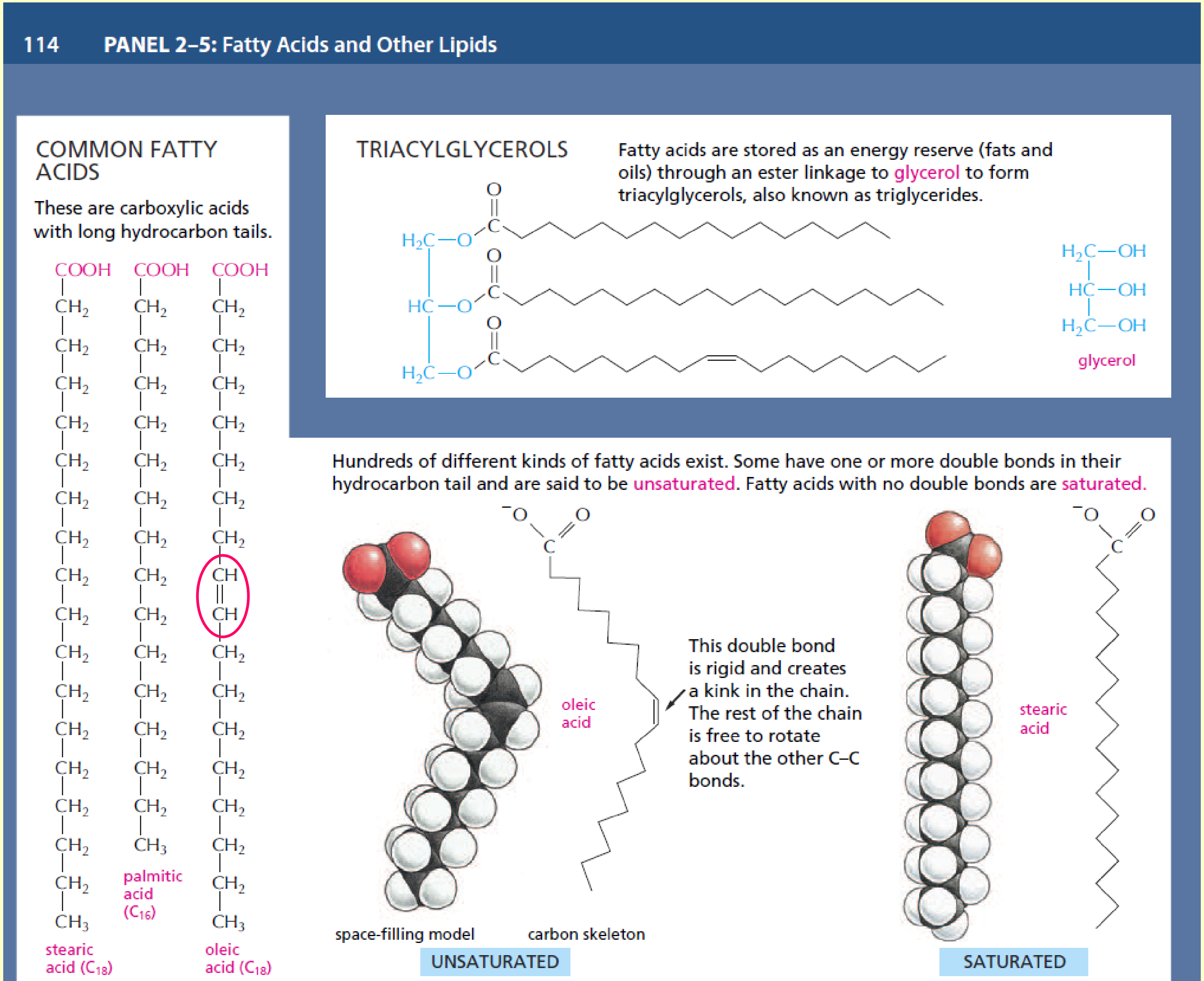
• hydrophilic head – chemically active

• hydrophobic tail – differences between hydrocarbon chains – not very active chemically

• almost all fatty acids are covalently linked to other molecules by their carboxylic acid group

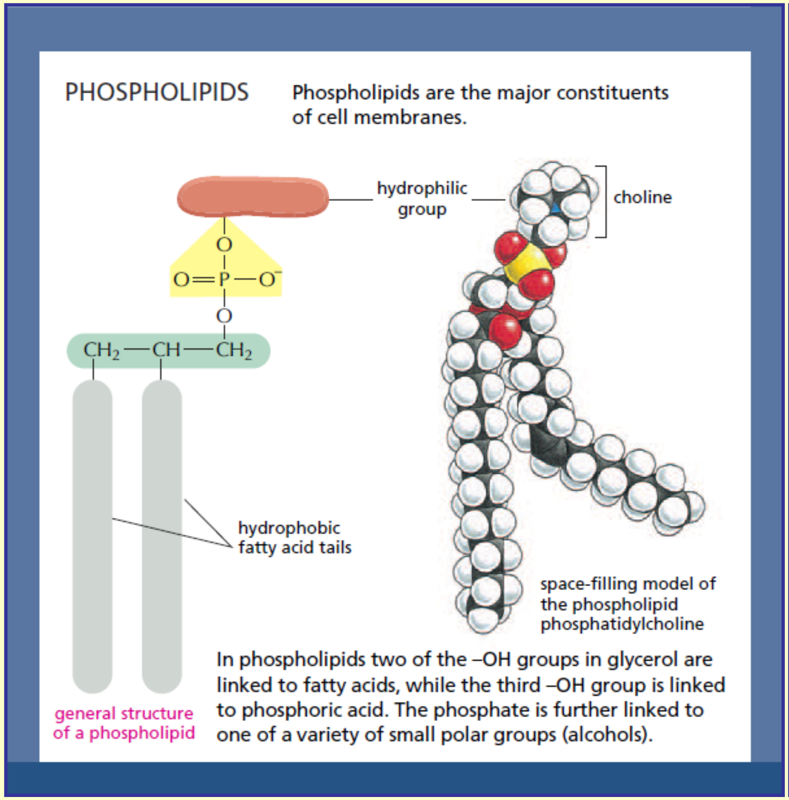
Figure 2-21 *Molecular Biology of the Cell* (© Garland Science 2008)

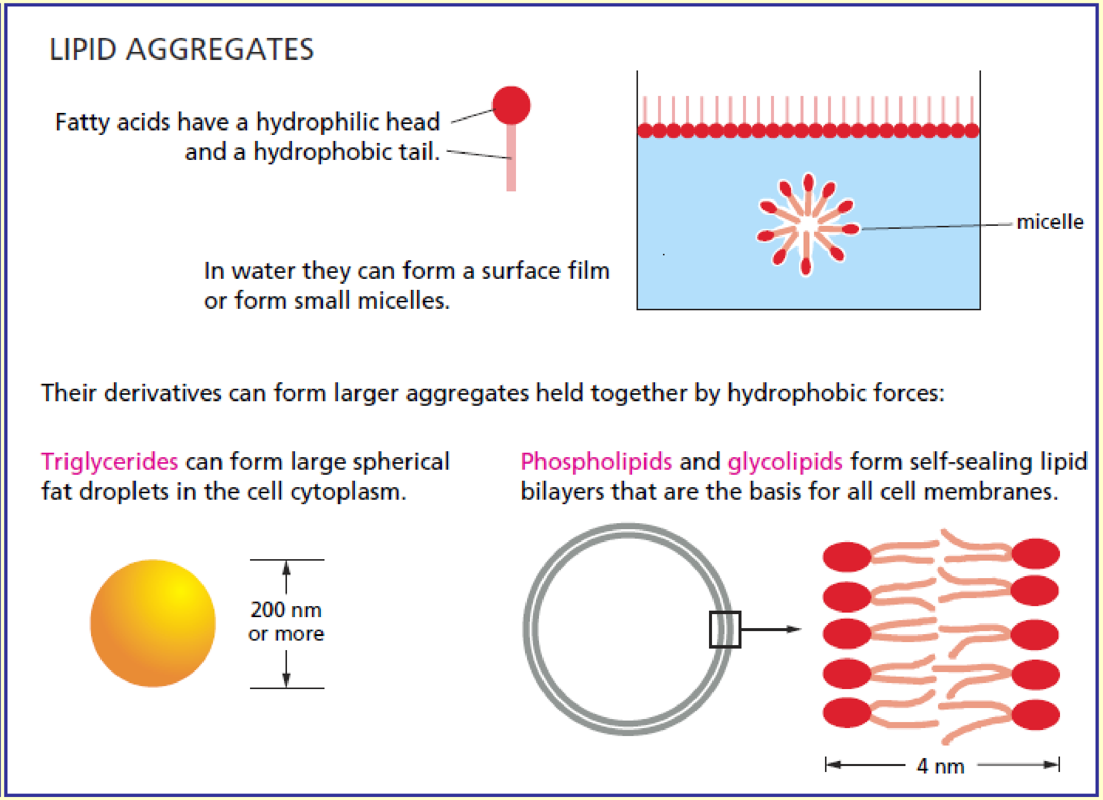
✓ fatty acids



Panel 2-5 *Molecular Biology of the Cell* (© Garland Science 2008)

✓ phospholipids



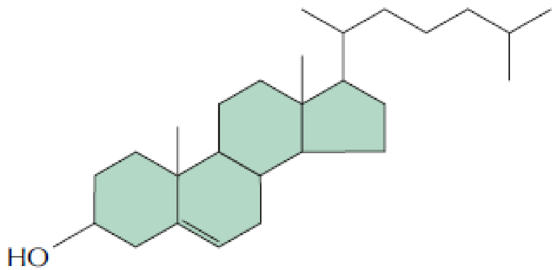


Panel 2-5 *Molecular Biology of the Cell* (© Garland Science 2008)

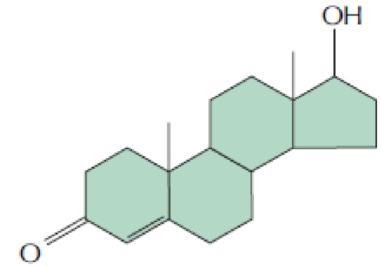
✓ other lipids

STEROIDS

Steroids have a common multiple-ring structure.



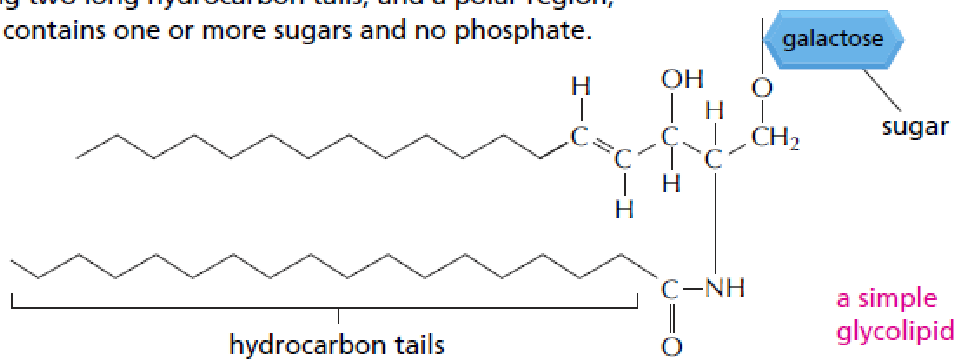
cholesterol—found in many membranes



testosterone—male steroid hormone

GLYCOLIPIDS

Like phospholipids, these compounds are composed of a hydrophobic region, containing two long hydrocarbon tails, and a polar region, which, however, contains one or more sugars and no phosphate.



a simple glycolipid

Panel 2-5 *Molecular Biology of the Cell* (© Garland Science 2008)

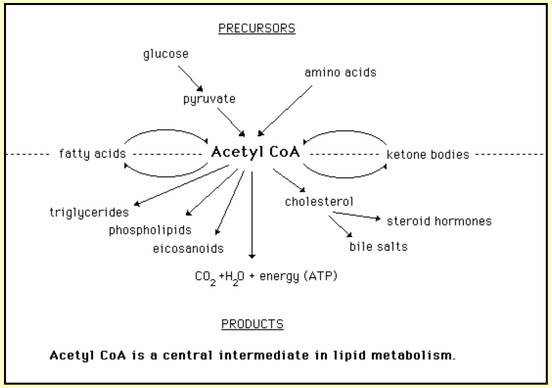
Importance

✓ energy source

- stored in the cytoplasm of many cells in the form of droplets of triacylglycerol molecules

• animal fats (meat, butter and cream)

• plant oils (corn and olive oil)



✓construction of biological membranes

- Cell and organelle membranes

• phospholipids

• glycolipids

• cholesterol

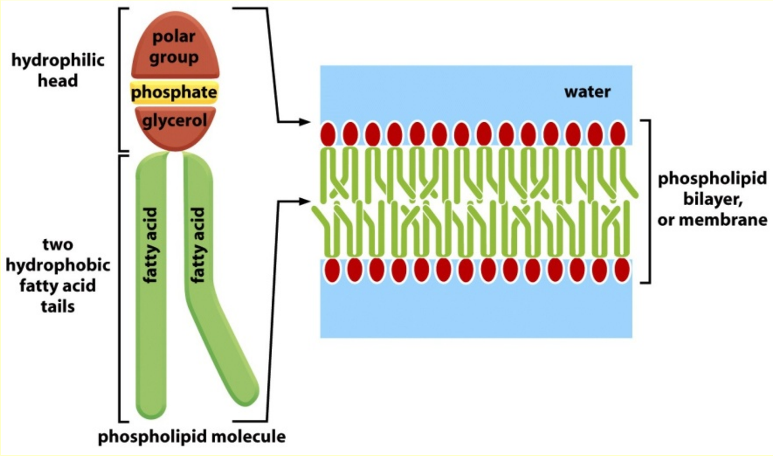
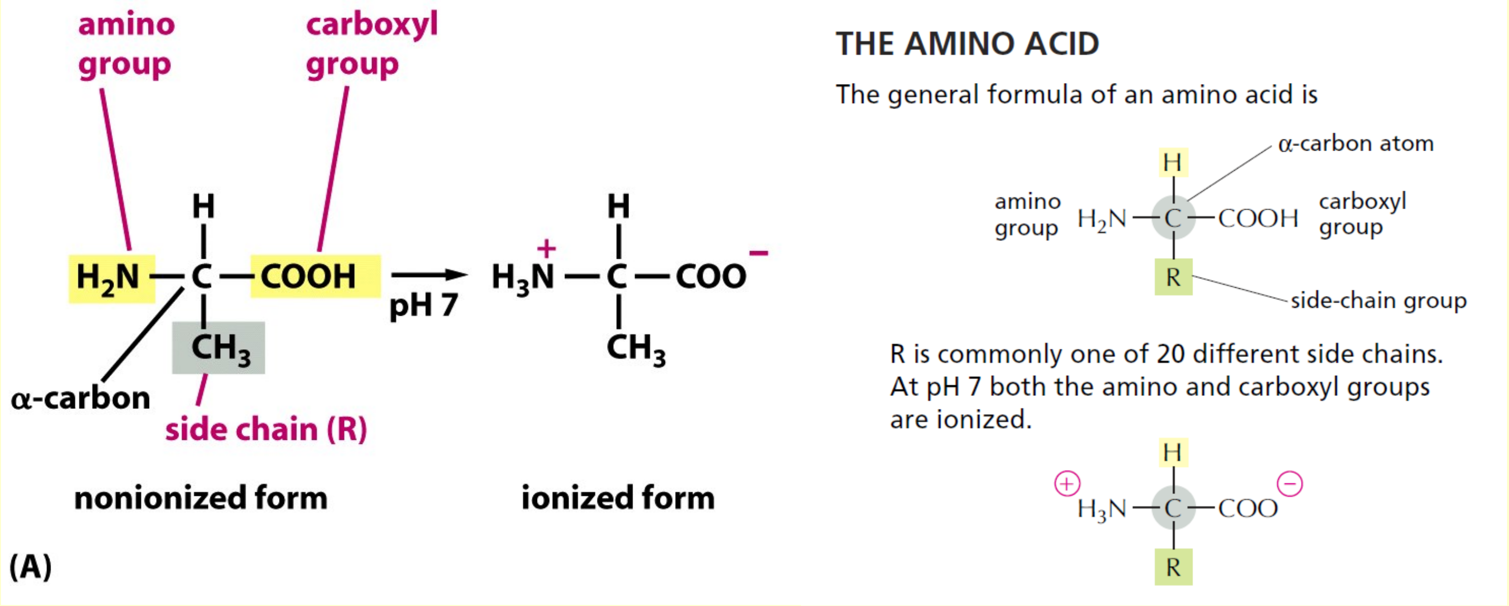


Figure 2-22 *Molecular Biology of the Cell* (© Garland Science 2008)

2.3. Amino acids

✓ all have carboxylic acid group (COOH) and amino group (NH_2) both linked to a single C-atom (α-carbon)

✓ chemical variety → side chain attached to the α-C



Ala

Figure 2-23 *Molecular Biology of the Cell* (© Garland Science 2008)

✓ amino acids linked together – peptid bond

✓ polypeptide or protein – two chemically distinct ends:

- NH_2 (N-terminus)
- COOH (C-terminus)

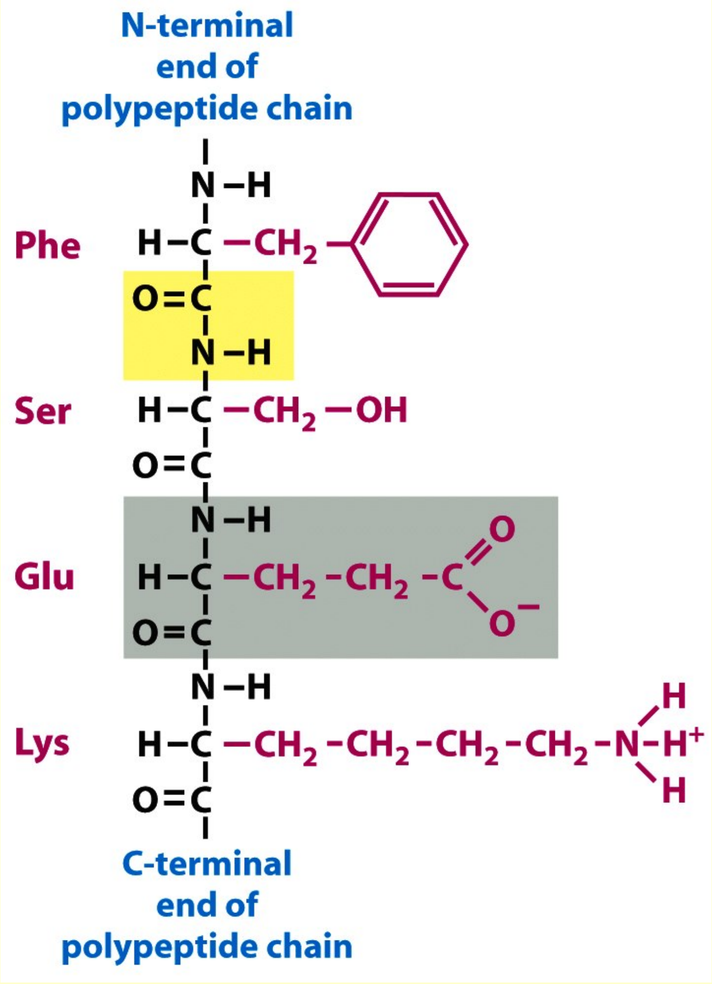


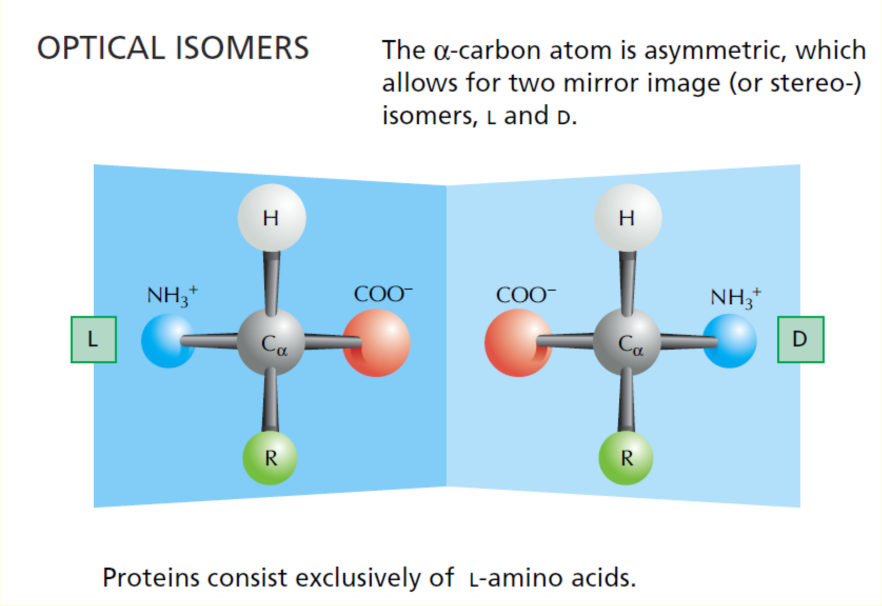
Figure 2-24 *Molecular Biology of the Cell* (© Garland Science 2008)

✓ 20 types of aa in proteins of bacteria and eukaryotic cells

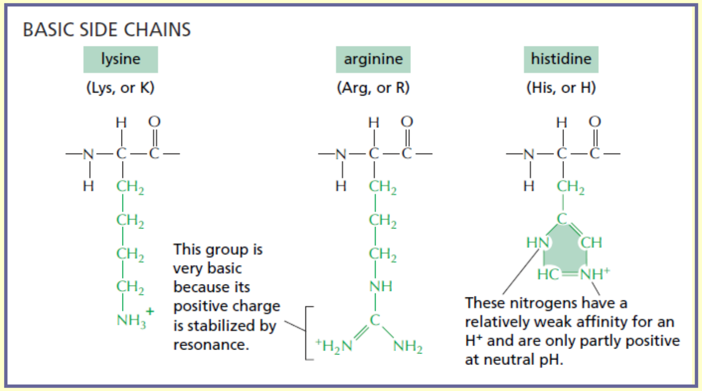
✓ Why? Evolutionary mistery! – no obvious chemical reason!

✓ All aa except Gly exist as optical isomers (D- and L-form)

✓ Only L-forms are ever found in proteins!
(D-aa occur as part of bacterial cell wall and in some antibiotics)
Another evolutionary mistery!

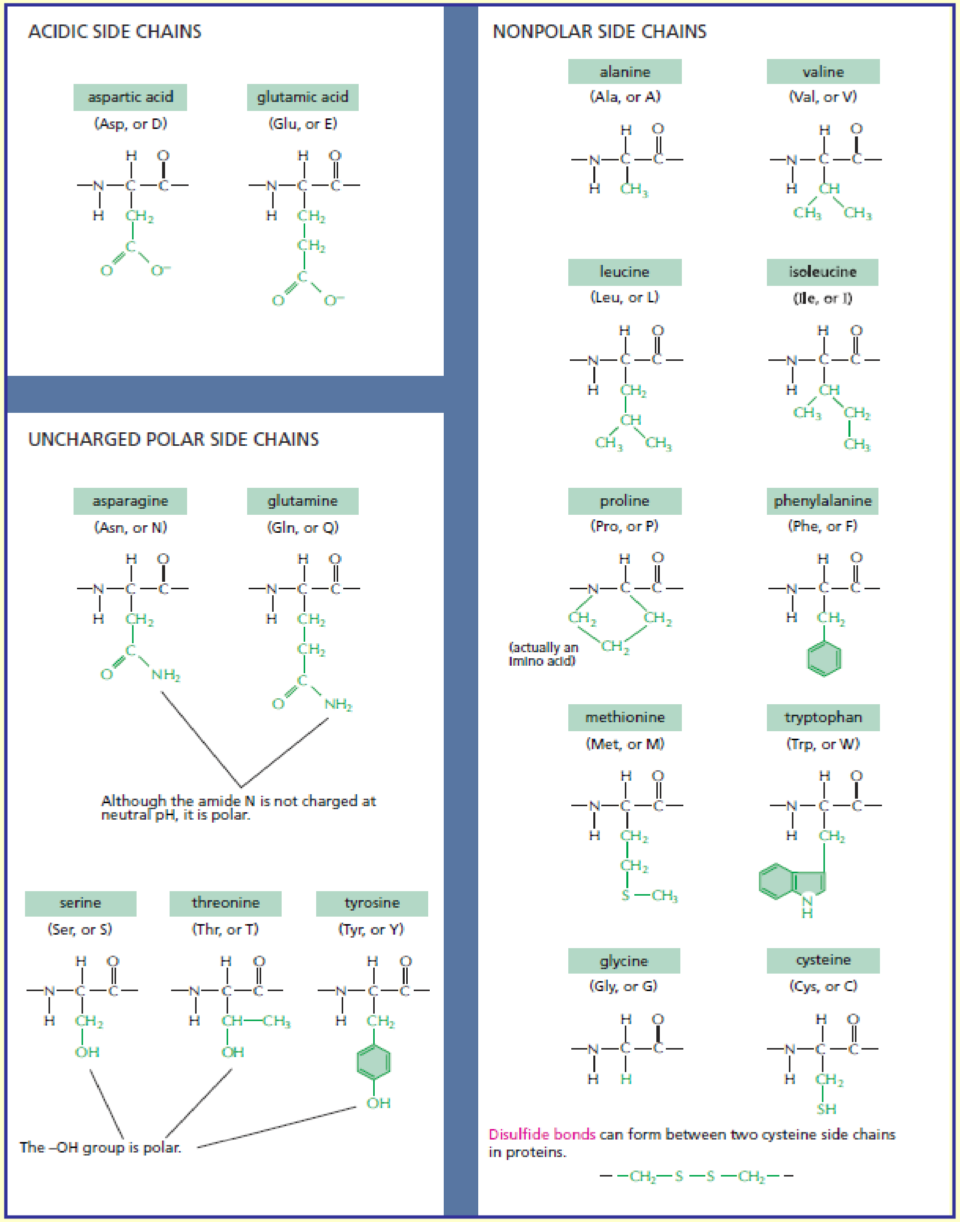


Panel 3-1 *Molecular Biology of the Cell* (© Garland Science 2008)



Amino acid chains:

- **basic**
- **acidic**
- **uncharged polar**
- **nonpolar**



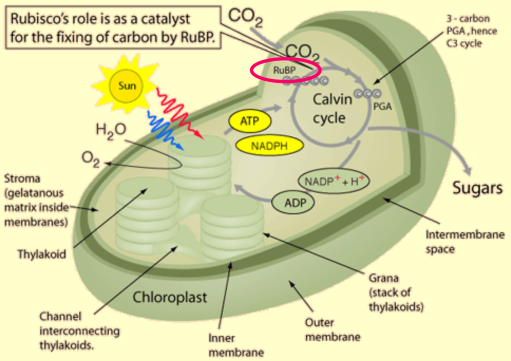
Panel 3-1 *Molecular Biology of the Cell* (© Garland Science 2008)

Amino acids are subunits of proteins

✓Particulary abundant and versatile

✓Responsible for thousands of distinct functions in cells

- Enzymes – catalysts that direct many reaction in cells



- Structural proteins
  - **tubulin** – microtubules
  - **histones** – chromosomes

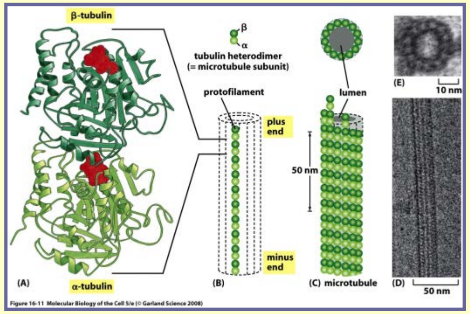
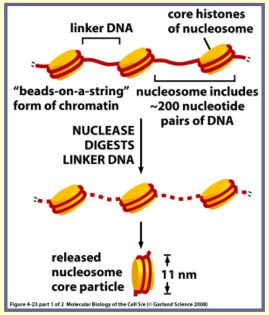


Figure 16-11 Molecular Biology of the Cell 5/e (© Garland Science 2008)



- Molecular motors
  - movements of cells and cell structures
  - **myosin** in muscles

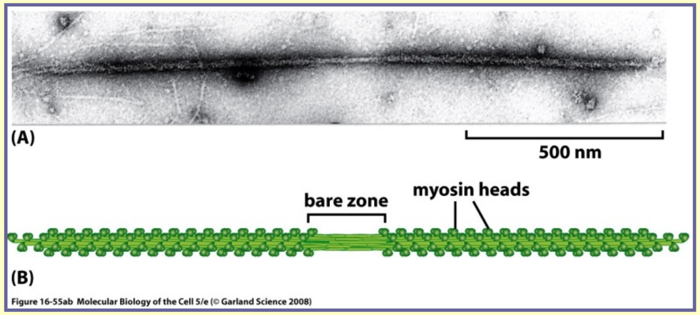


Figure 16-55ab Molecular Biology of the Cell 5/e (© Garland Science 2008)

2.4. Nucleotides

- <u>pentose sugar</u>

- ribose → ribonucleotides

- deoxyribose → deoxyribonucleotides

- <u>one or more phosphate groups</u>

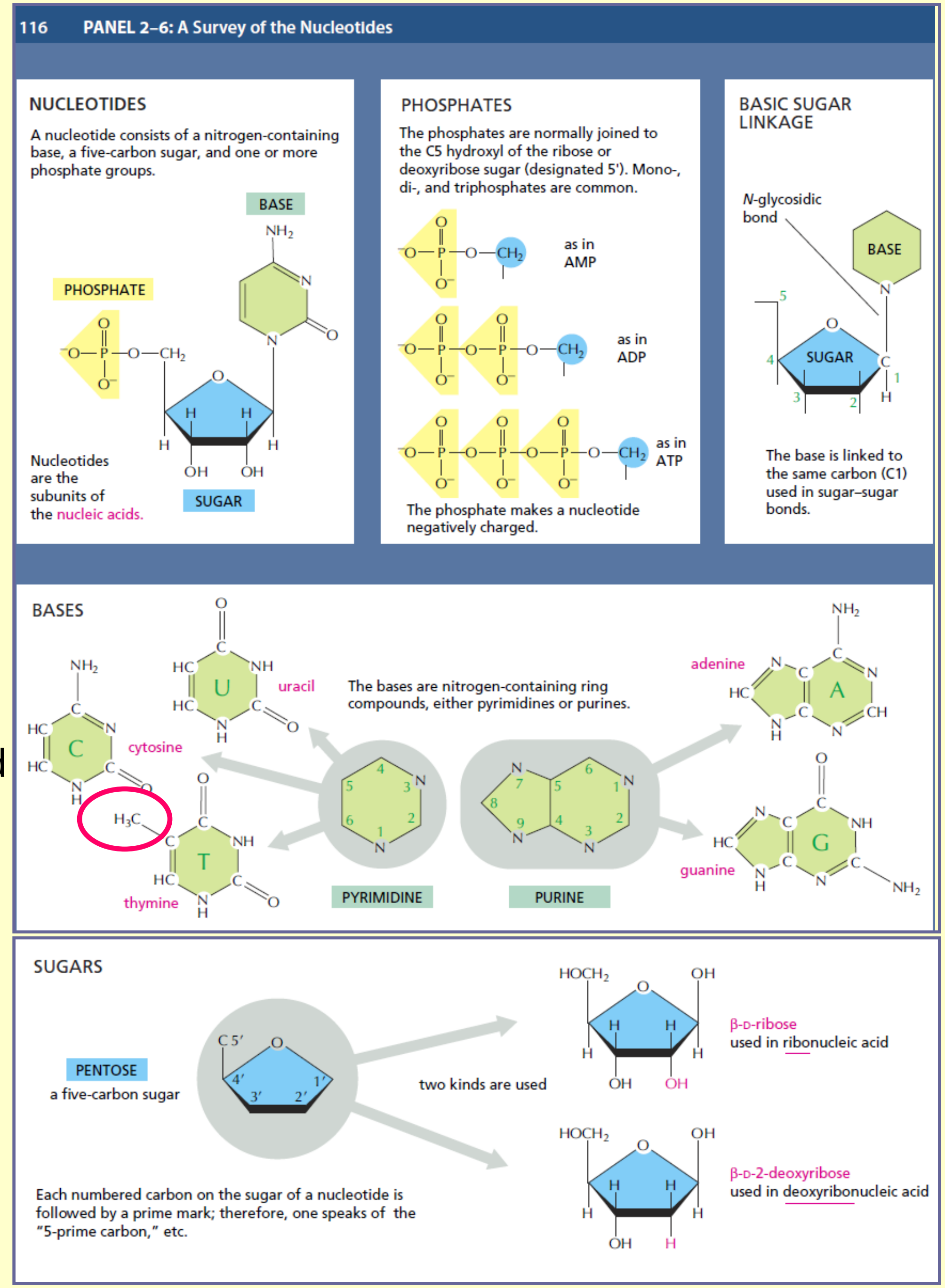
- <u>bases</u>

pyrimidines – they all derive from six-membered pyrimidine ring

- cytosine (C), thymine (T) and uracil (U)

purines – they have a second, five-membered ring fused to the six-membered ring

- adenine (A) and guanine (G)



Panel 2-6 *Molecular Biology of the Cell* (© Garland Science 2008)

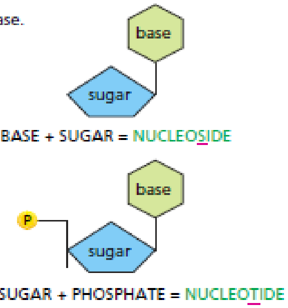
NOMENCLATURE

A nucleoside or nucleotide is named according to its nitrogenous base.

BASE	NUCLEOSIDE	ABBR.
adenine	adenosine	A
guanine	guanosine	G
cytosine	cytidine	C
uracil	uridine	U
thymine	thymidine	T

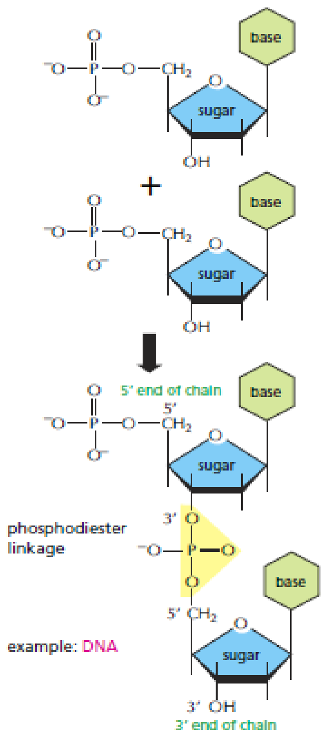
Single letter abbreviations are used variously as shorthand for (1) the base alone, (2) the nucleoside, or (3) the whole nucleotide—the context will usually make clear which of the three entities is meant. When the context is not sufficient, we will add the terms "base", "nucleoside", "nucleotide", or—as in the examples below—use the full 3-letter nucleotide code.

AMP = adenosine monophosphate
dAMP = deoxyadenosine monophosphate
UDP = uridine diphosphate
ATP = adenosine triphosphate



NUCLEIC ACIDS

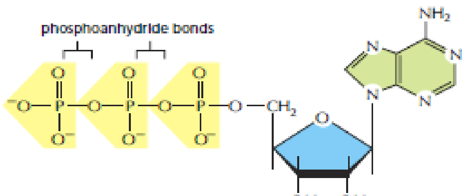
Nucleotides are joined together by a phosphodiester linkage between 5′ and 3′ carbon atoms to form nucleic acids. The linear sequence of nucleotides in a nucleic acid chain is commonly abbreviated by a one-letter code, A—G—C—T—T—A—C—A, with the 5′ end of the chain at the left.



example: DNA

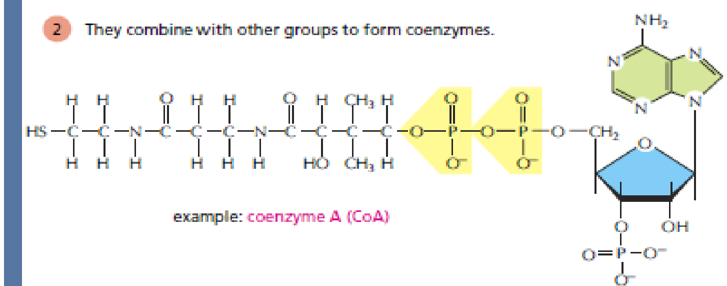
NUCLEOTIDES HAVE MANY OTHER FUNCTIONS

1 They carry chemical energy in their easily hydrolyzed phosphoanhydride bonds.



example: ATP (or ATP)

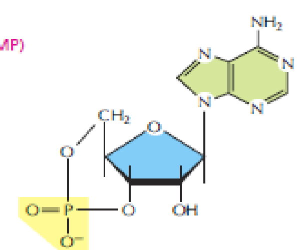
2 They combine with other groups to form coenzymes.



example: coenzyme A (CoA)

3 They are used as specific signaling molecules in the cell.

example: cyclic AMP (cAMP)



Panel 2-6 *Molecular Biology of the Cell* (© Garland Science 2008)

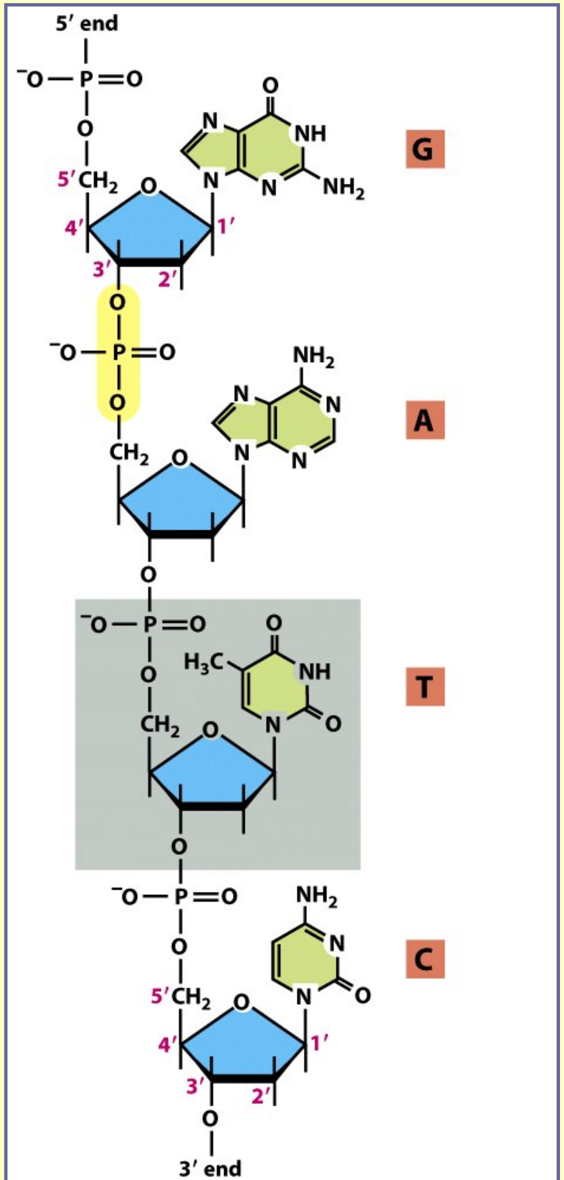


Figure 2-28 Molecular Biology of the Cell 5/e (© Garlan

✓ the most important role → storage of biological information

✓building blocks of nucleic acid → nucleotides covalently linked by the formation of phosphodiester bond

✓ phosphodiester bond– linkage between phosphate group attached to the sugar of one nucleotide and a hydroxyl group on the sugar of the next nucleotide

✓ two types of nucleic acids:

- RNA – ribose + A, G, C i U; mostly single-stranded
- DNA – deoxyribose + A, G, C i T; double stranded helix

DNA and its building blocks

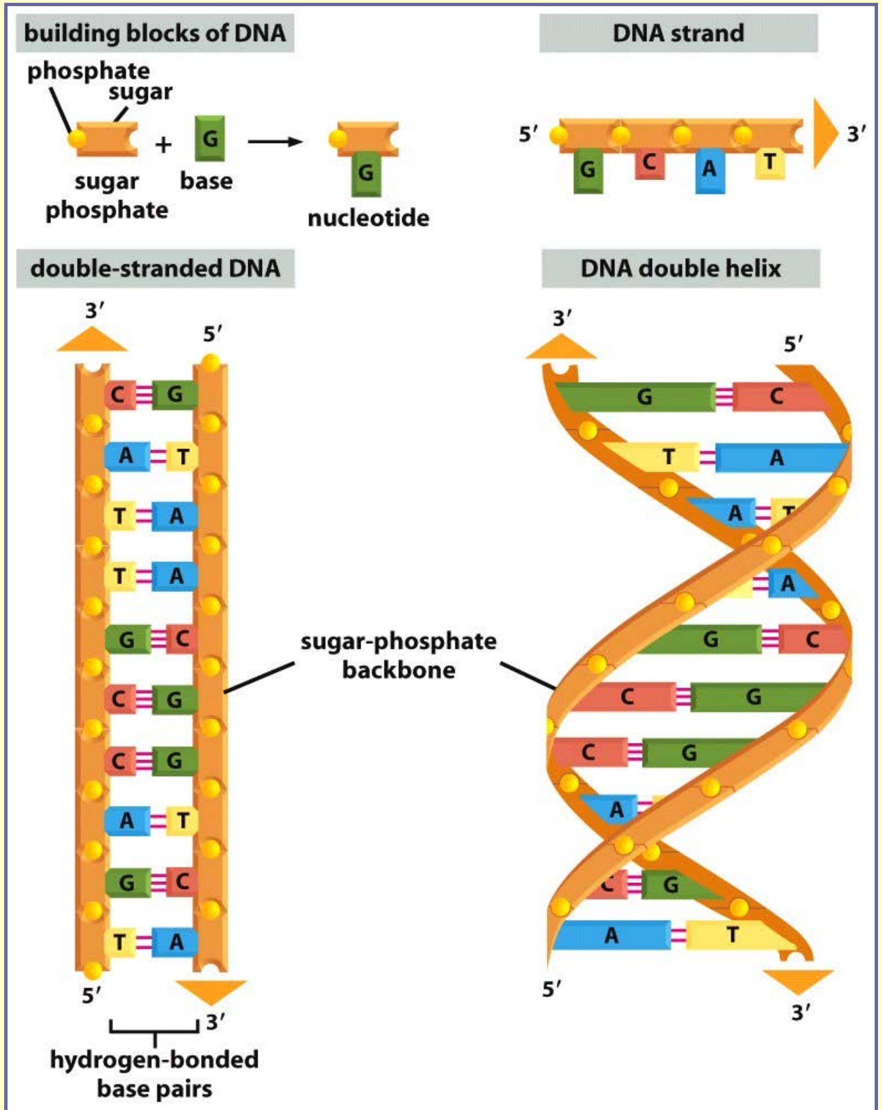


Figure 4-3 Molecular Biology of the Cell 5/e (© Garland Science 2008)

Complementary base pairs in the DNA double helix

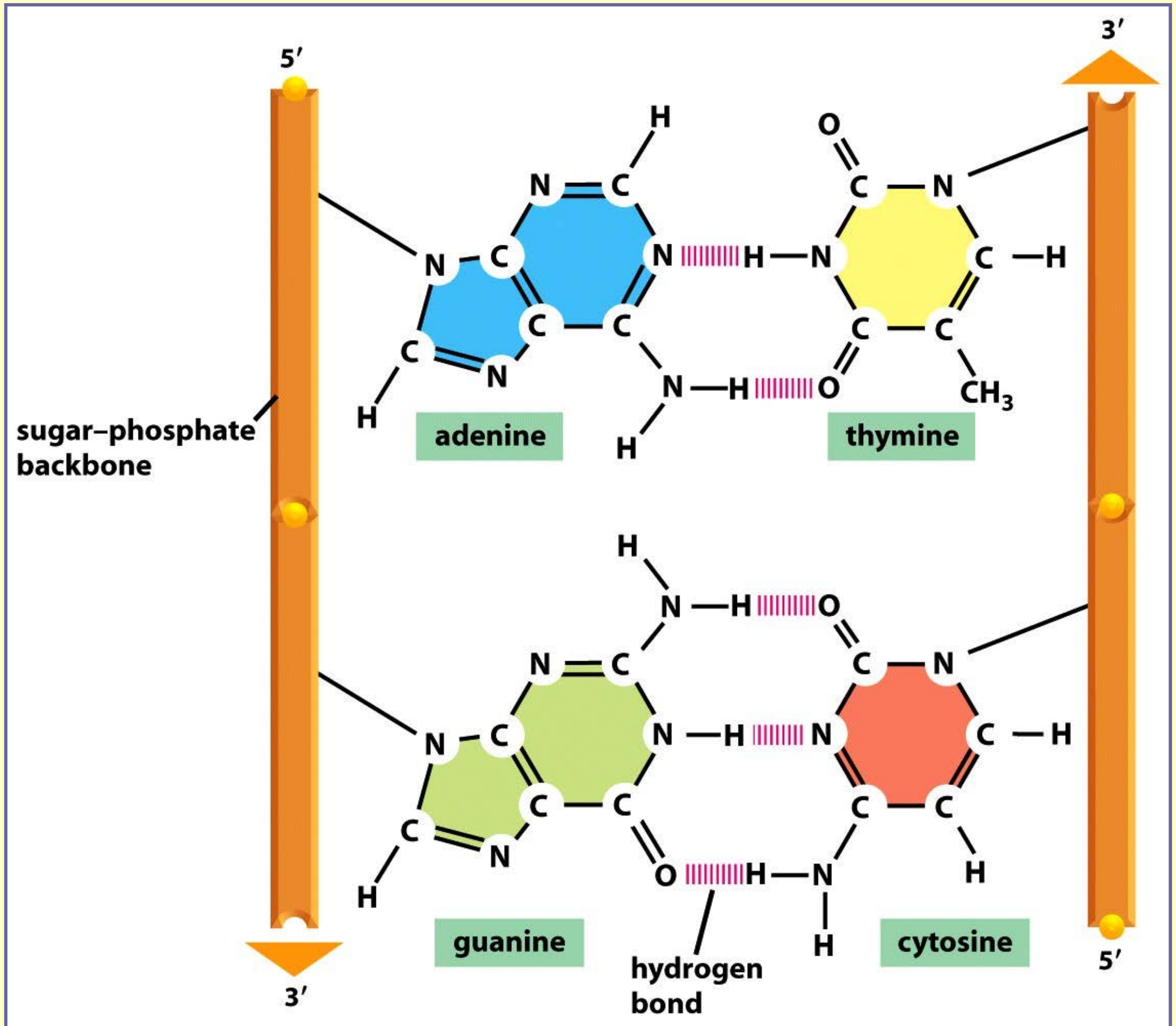


Figure 4-4 Molecular Biology of the Cell 5/e (© Garland Science 2008)

The synthesis of polysaccharides, proteins and nucleic acids

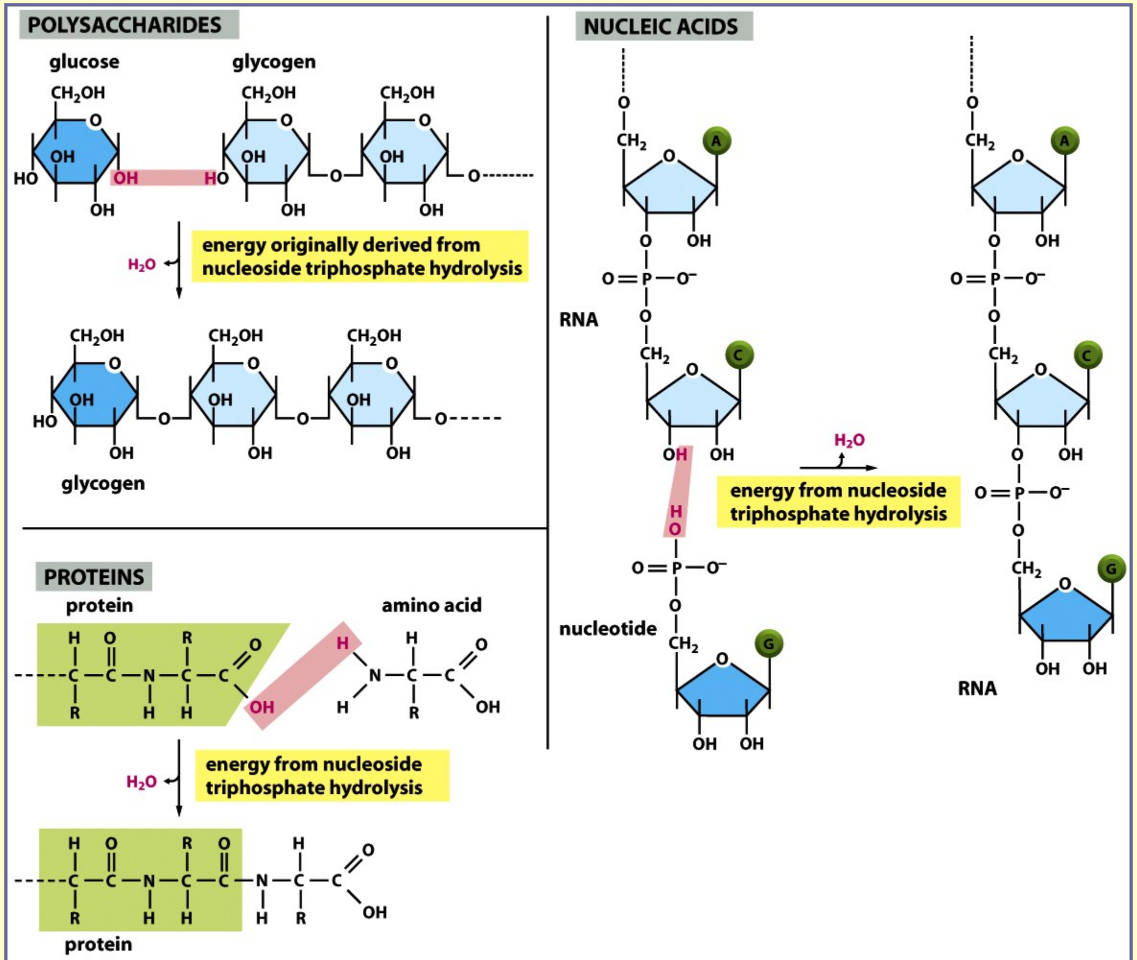


Figure 2-65 Molecular Biology of the Cell 5/e (© Garland Science 2008)

✓Synthesis of each polymer involves the loss of water in a condensation reaction

✓Consumption of high-energy nucleoside triphospahte is required (activate each monomer before its addition)

✓ Hydrolysis – the reverse reaction – breakdown of polymers (water addition)