Chemistry of Organic Molecules

3 February 2012

Outline

- Organic vs. Inorganic
- Functional Groups and Isomers
- Macromolecules
  - Carbohydrates
  - Lipids
  - Proteins
  - Nucleic Acids

Organic Molecules

- **Organic molecules** contain carbon and hydrogen atoms bonded to other atoms
- Organic molecules are a diverse group
- Four types of organic molecules (biomolecules) exist in organisms**:**
  - **Carbohydrates**
  - **Lipids**
  - **Proteins**
  - **Nucleic Acids**

Organic versus Inorganic Molecules

TABLE 3.1

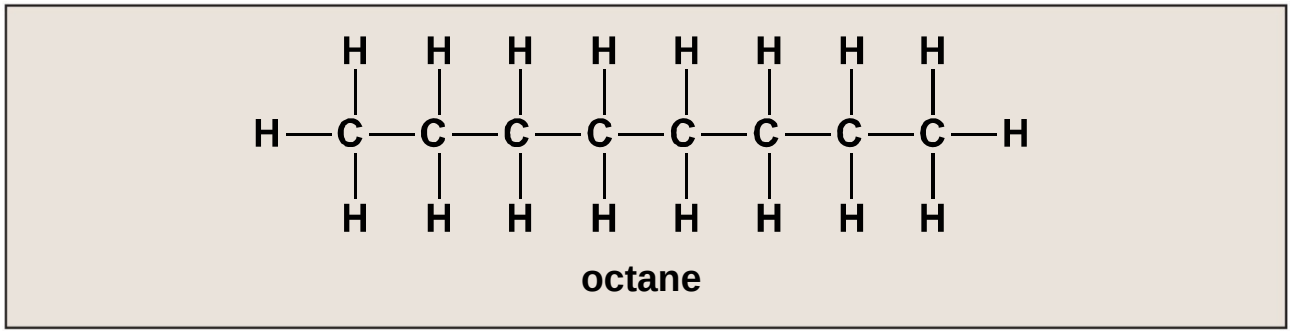
Inorganic Versus Organic Molecules

Inorganic Molecules	*Organic Molecules*
Usually contain positive and negative ions	Always contain carbon and hydrogen
Usually ionic bonding	Always covalent bonding
Always contain a small number of atoms	Often quite large, with many atoms
Often associated with nonliving matter	Usually associated with living organisms

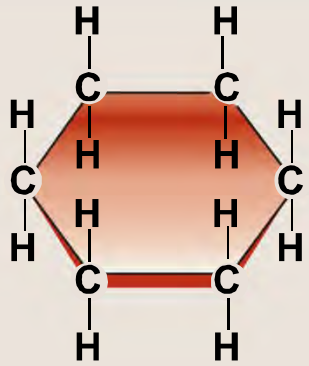
Carbon Atom

- Carbon atoms:
  - Contain a total of 6 electrons
  - Only four electrons in the outer shell
  - Very diverse as one atom can bond with up to four other atoms
- Often bonds with other carbon atoms to make hydrocarbons
  - Can produce long carbon chains like octane
  - Can produce ring forms like cyclohexane

Octane & Cyclohexane



octane

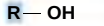
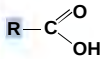
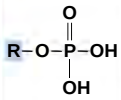


cyclohexane

Functional Groups

- **Functional groups** are clusters of specific atoms bonded to the carbon skeleton with characteristic structure and functions
  - Always react in the same manner, regardless of where attached
  - Determine activity and polarity of large organic molecules
- Many functional groups, but only a few are of major biological importance
- Depending on its functional groups, an organic molecule may be both acidic and hydrophilic
- Nonpolar organic molecules are **hydrophobic** (cannot dissolve in water) unless they contain a polar functional group

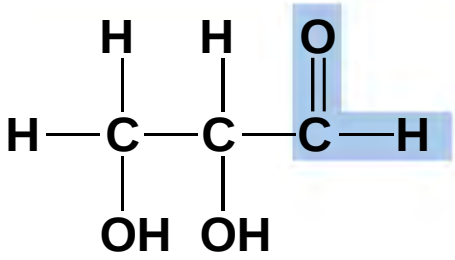
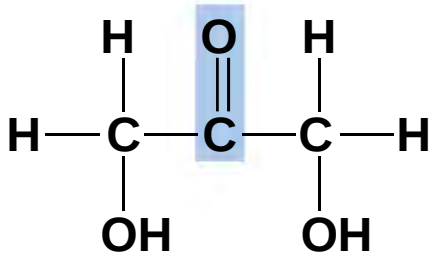
Biologically Important Functional Groups

Functional Groups			
Group	**Structure**	**Compound**	**Significance**
Hydroxyl		Alcohol as in ethanol	Polar, forms hydrogen bond Present in sugars, some amino acids
Carbonyl	 	Aldehyde as in formaldehyde Ketone as in acetone	Polar Present in sugars Polar Present in sugars
Carboxyl (acidic)		Carboxylic acid as in acetic acid	Polar, acidic Present in fatty acids, amino acids
Amino		Amine as in tryptophan	Polar, basic, forms hydrogen bonds Present in amino acids
Sulfhydryl		Thiol as in ethanethiol	Forms disulfide bonds Present in some amino acids
Phosphate		Organic phosphate as in phosphorylated molecules	Polar, acidic Present in nucleotides, phospholipids

R = remainder of molecule

Isomers

- Isomers - organic molecules that have:
  - Identical molecular formulas, but
  - Differing internal arrangement of atoms

glyceraldehyde	dihydroxyacetone
	

Macromolecules

- Carbohydrates, lipids, proteins, and nucleic acids are called **macromolecules** because of their large size.
  - Usually consist of many repeating units
    - Resulting molecule is a polymer (many parts)
    - Repeating units are called monomers
    - E.g. amino acids (monomer) are linked to form a **protein** (polymer)
- Some examples:

Category	*Example*	*Subunit(s)*
Lipids	**Fat**	**Glycerol & fatty acids**
Carbohydrates	**Polysaccharide**	**Monosaccharide**
Proteins	**Polypeptide**	**Amino acid**
Nucleic Acids	**DNA, RNA**	**Nucleotide**

Common Foods

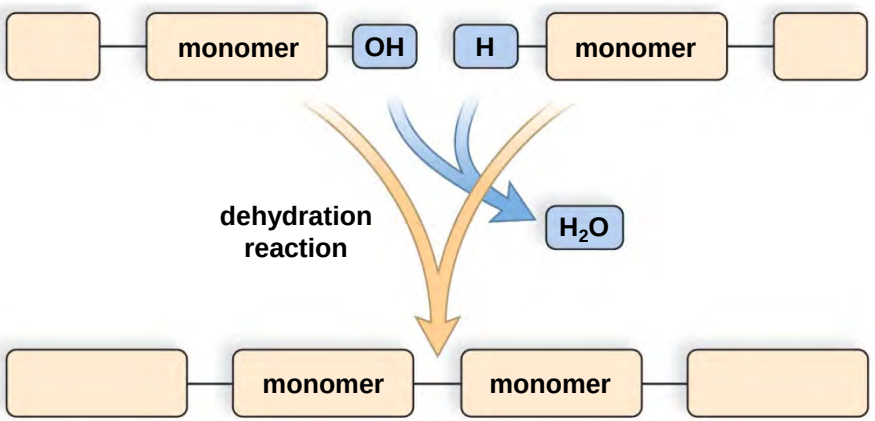
Dehydration and Hydrolysis

- Dehydration - Removal of water molecule
  - Used to connect monomers together to make polymers
  - Polymerization of glucose monomers to make starch
- Hydrolysis - Addition of water molecule
  - Used to disassemble polymers into monomer parts
  - Digestion of starch into glucose monomers
- Specific enzymes required for each reaction
  - Accelerate reaction
  - Are not used in the reaction
  - Are not changed by the reaction

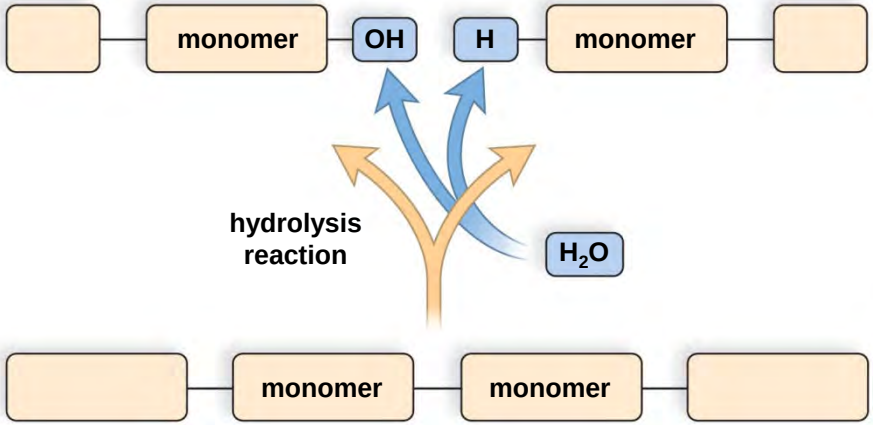
Synthesis and Degradation of Polymers

Synthesis

Degradation



a. Synthesis of a biomolecule

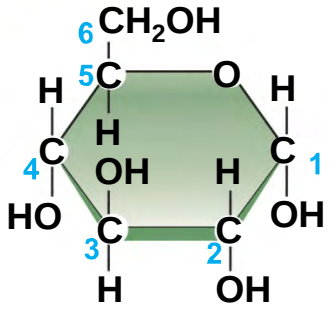


b. Degradation of a biomolecule

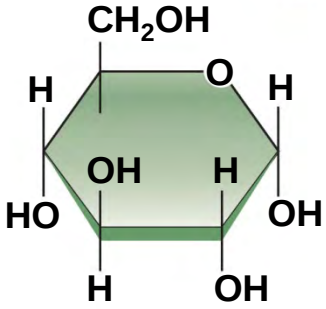
Carbohydrates

- Monosaccharides:
  - Are a single sugar molecule such as glucose, ribose, deoxyribose
  - Are with a backbone of 3 to 7 carbon atoms (most have 6 carbon).
- Disaccharides:
  - Contain two monosaccharides joined by dehydration reaction
    - **Lactose** is composed of galactose and glucose and is found in milk.
    - **Sucrose** (table sugar) is composed of glucose and fructose
- Polysaccharides - Are polymers of monosaccharides
  - Polysaccharides as Energy Storage Molecules
    - Starch, Glycogen
  - Polysaccharides as Structural Molecules
    - Cellulose, Chitin

Popular Models for Representing Glucose Molecules

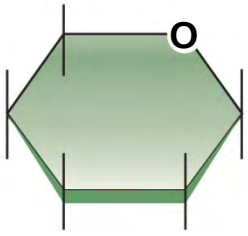


a.

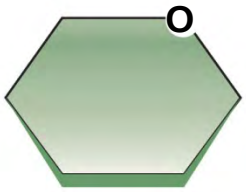


b.

$C_6H_{12}O_6$

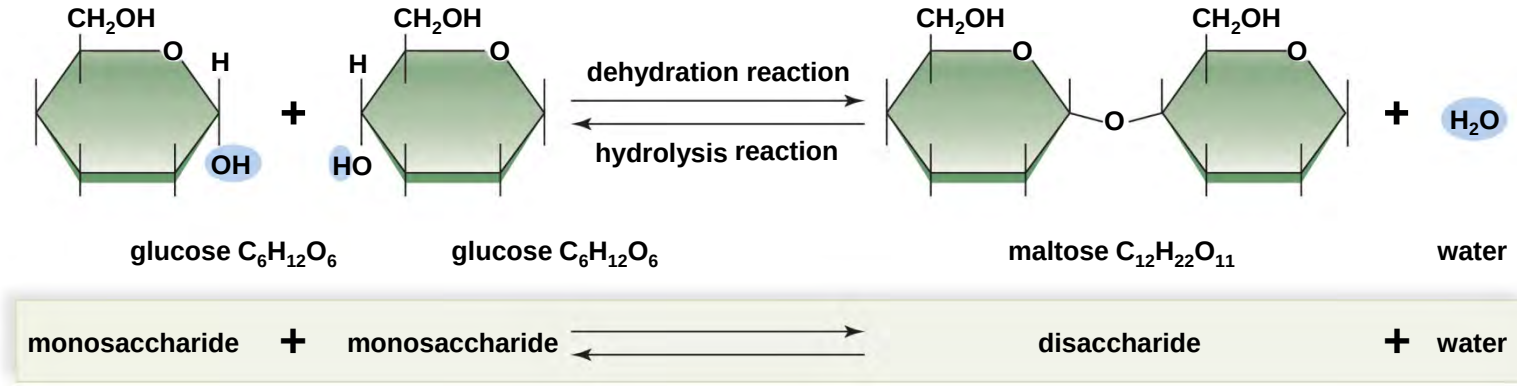


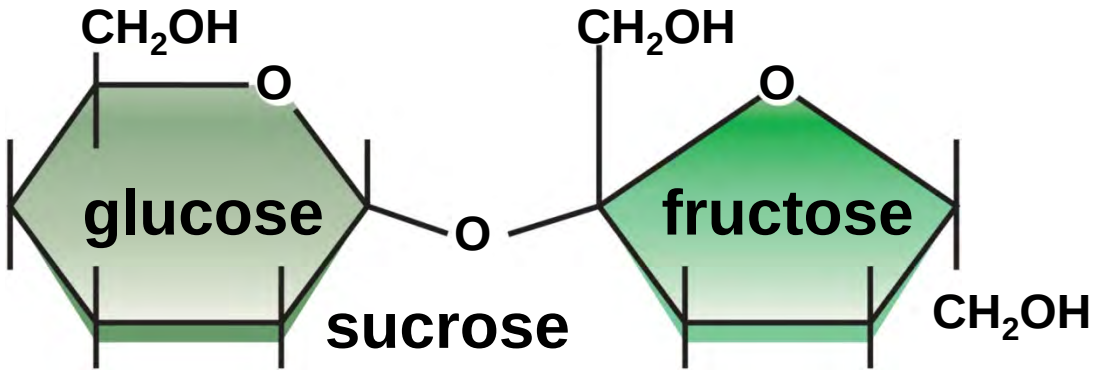
c.



d.

Synthesis and Degradation of Maltose, a Disaccharide





Carbohydrates: Monosaccharides

- Single sugar molecules
- Quite soluble and sweet to taste
- Examples
  - Glucose (blood), fructose (fruit) and galactose
    - Hexoses - Six carbon atoms
    - Isomers of $C_6H_{12}O_6$
  - Ribose and deoxyribose (in nucleotides)
    - Pentoses – Five carbon atoms
    - $C_5H_{10}O_5$ & $C_5H_{10}O_4$

Carbohydrates: Disaccharides

- Contain two monosaccharides joined by dehydration reaction
- Soluble and sweet to taste
- Examples
  - Lactose is composed of galactose and glucose and is found in milk
  - Sucrose (table sugar) is composed of glucose and fructose
  - Maltose is composed of two glucose molecules

Carbohydrates: Polysaccharides

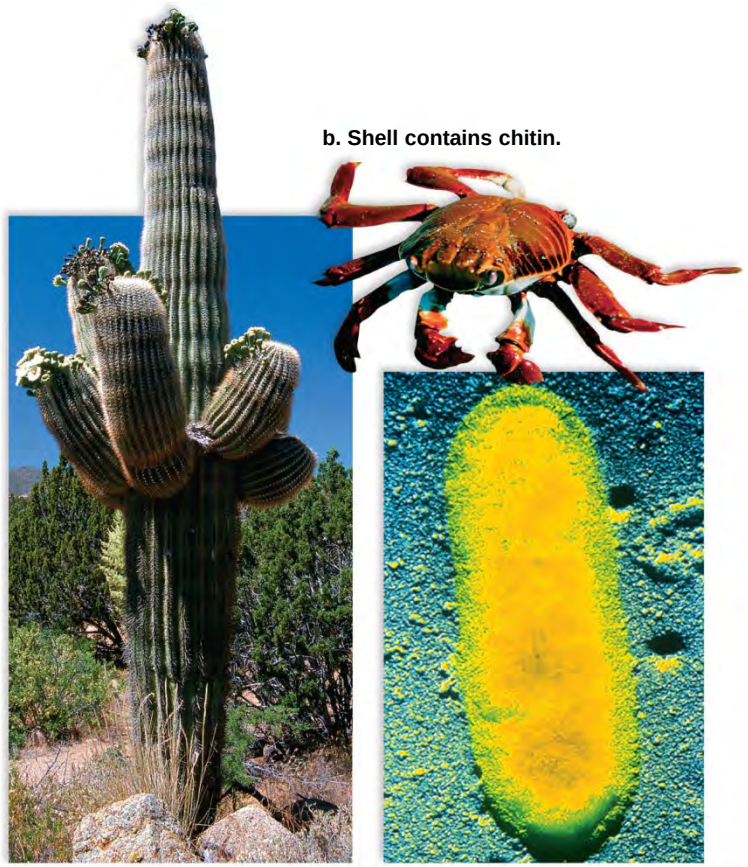
- Polymers of monosaccharides
- Low solubility; not sweet to taste
- Polysaccharides as Energy Storage Molecules
  - Starch found in plant
    - Polymer of glucose
    - Few side branches
    - Used for short-term energy storage
    - *Amylose* and *amylopectin* are the two forms of starch found in plants
  - Glycogen is the storage form of glucose in animals.
    - Highly branched polymer of glucose with many side branches
    - Glycogen in liver and muscles

Carbohydrates: Polysaccharides

- Polysaccharides as Structural Molecules
  - Cellulose is a polymer of glucose which forms microfibrils
    - Primary constituent of plant cell walls
    - Main component of wood and many natural fibers
    - Indigestible by most animals
  - Chitin is a polymer of glucose with an amino group attached to each glucose
    - Very resistant to wear and digestion
    - Primary constituent of arthropod exoskeletons (e.g. Crab) and cell walls of fungi

Carbohydrates as Structural Materials

- Plants cell wall consist of cellulose
- Cell wall of fungi and shell of crab contain chitin
- Bacterial cell wall contain peptidoglycan



b. Shell contains chitin.

a. Cell walls contain cellulose.

c. Cell walls contain peptidoglycan.

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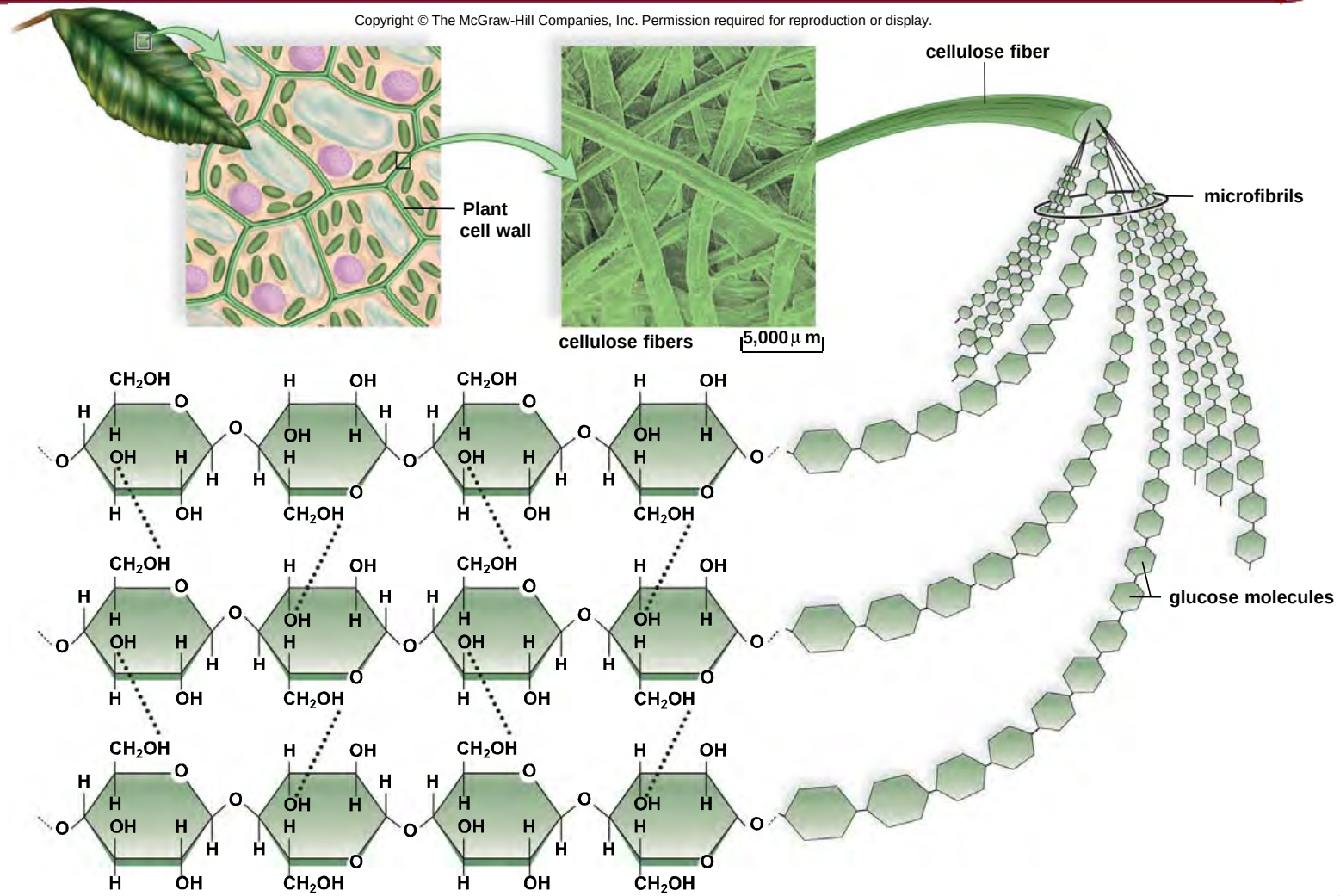
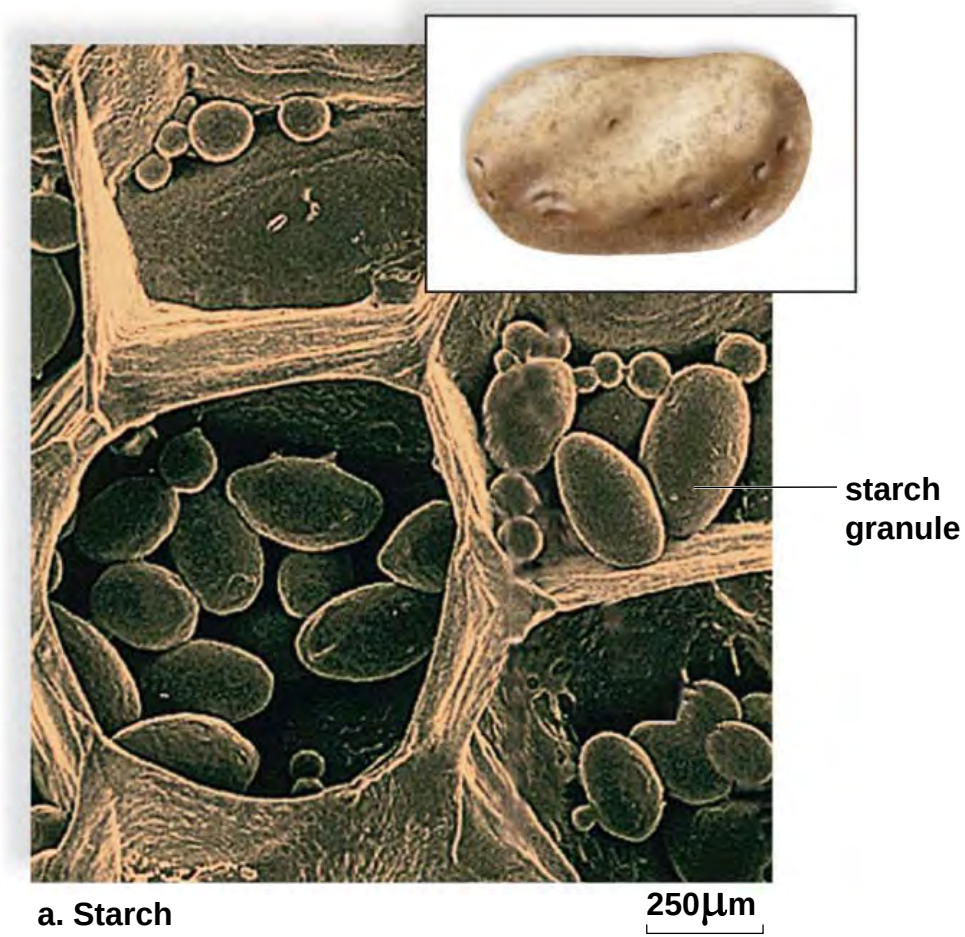
Cellulose Structure and Function



Starch Structure and Function



a. Starch

Lipids

- Lipids are varied in structure
- Insoluble in water
  - Long chains of repeating CH_2 units
  - Renders molecule nonpolar
  - Lack polar groups
- **Fat** provides insulation and energy storage in animals

© Paul Nicklen/National Geographic/Getty

Types of Lipids

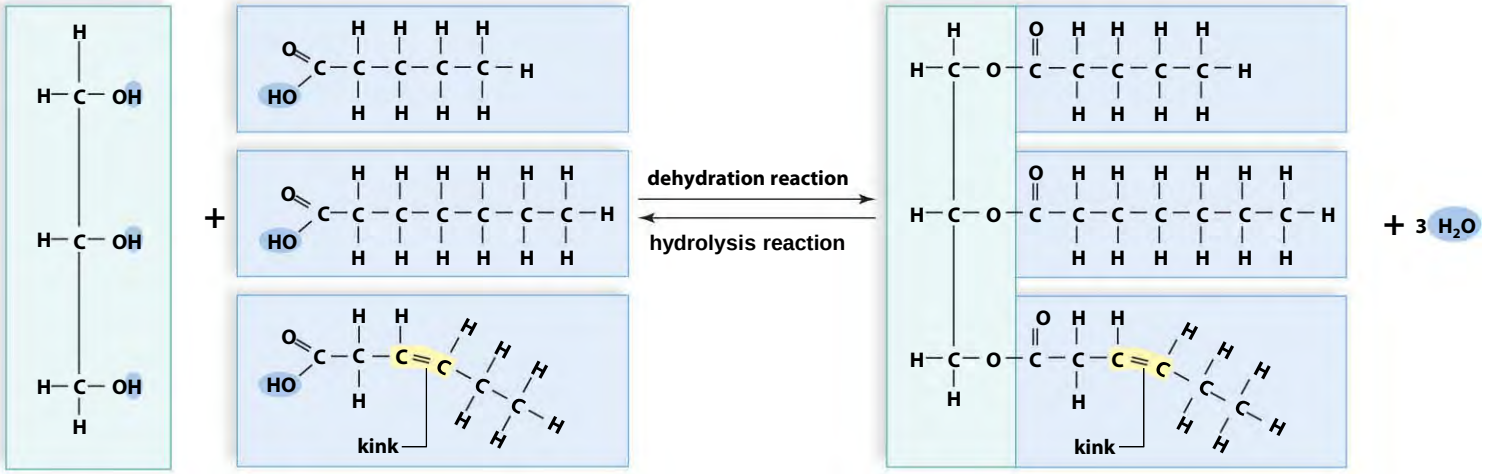
TABLE 3.2

Lipids

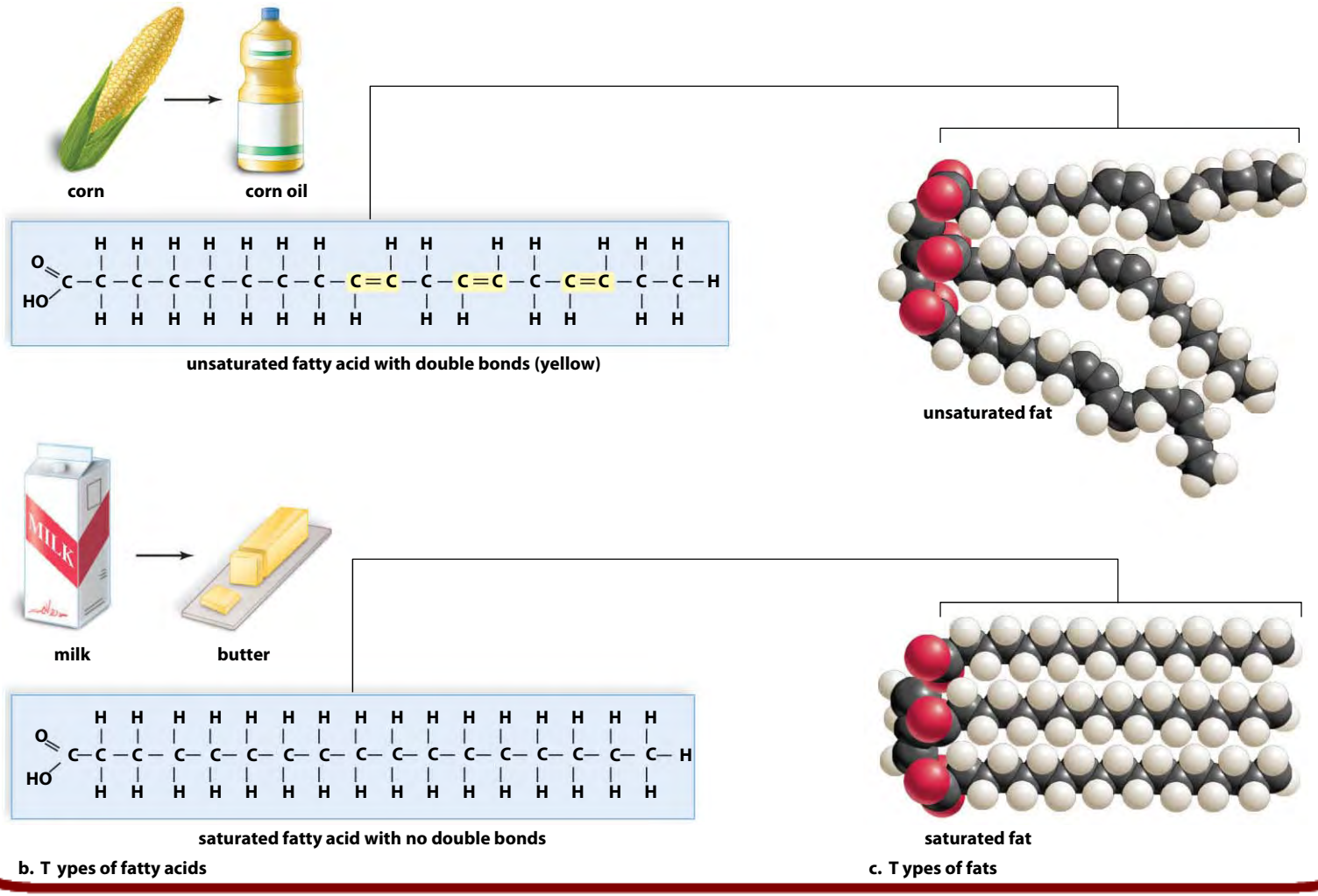
Type	*Functions*	*Human Uses*
Fats	Long-term energy storage and insulation in animals	Butter, lard
Oils	Long-term energy storage in plants and their seeds	Cooking oils
Phospholipids	Component of plasma membrane	—
Steroids	Component of plasma membrane (cholesterol), sex hormones	Medicines
Waxes	Protection, prevent water loss (cuticle of plant surfaces), beeswax, earwax	Candles, polishes

Types of Lipids: Triglycerides

- **Fats** and **oils** contain two molecular units: glycerol and fatty acids.
- Dehydration Synthesis of Triglyceride from Glycerol and Three Fatty Acids



Types of Lipids: Triglycerides



Types of Lipids: Triglycerides

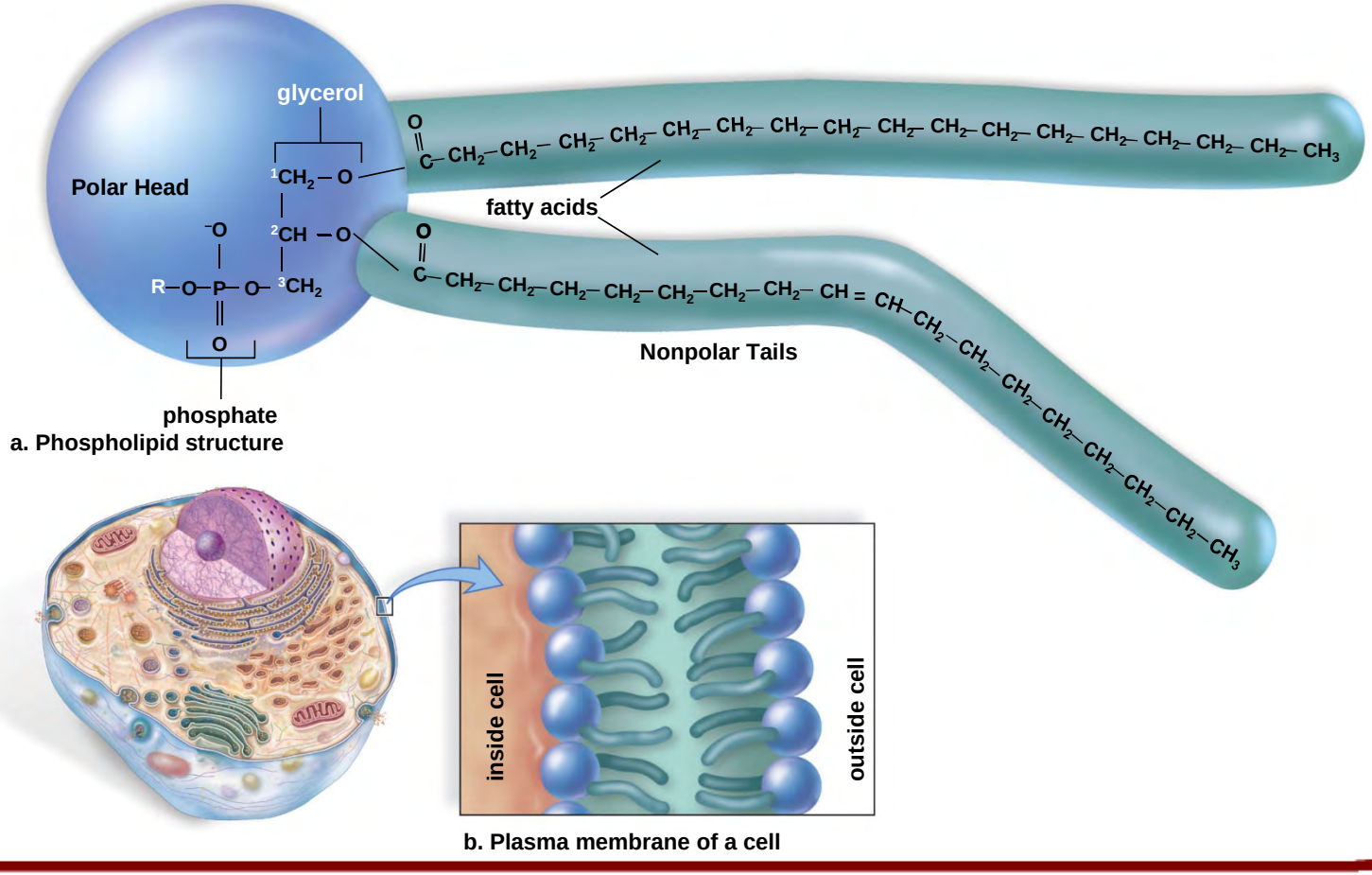
- Triglycerides (Fats)
  - Long-term energy storage
  - Consist of a backbone of one glycerol molecule
    - Glycerol is a water-soluble compound with three hydroxyl groups.
  - Three fatty acids attached to each glycerol molecule
    - Long hydrocarbon chain
      - Saturated - no double bonds between carbons e.g. in fats (butter)
      - Unsaturated - 1 or more than1 double bonds between carbons e.g. in oils
    - Carboxylic acid at one end
    - Carboxylic acid connects to –OH on glycerol in dehydration reaction

Types of Lipids: Phospholipids

- Phospholipids
- Derived from triglycerides
  - Glycerol backbone
  - Two fatty acids attached instead of three
  - Third fatty acid replaced by phosphate group
    - The fatty acids are nonpolar and hydrophobic
    - The phosphate group is polar and hydrophilic
- Molecules self arrange when placed in water
  - Polar phosphate “heads” next to water
  - Nonpolar fatty acid “tails” overlap and exclude water
  - Spontaneously form double layer & a sphere

Types of Lipids: Phospholipids

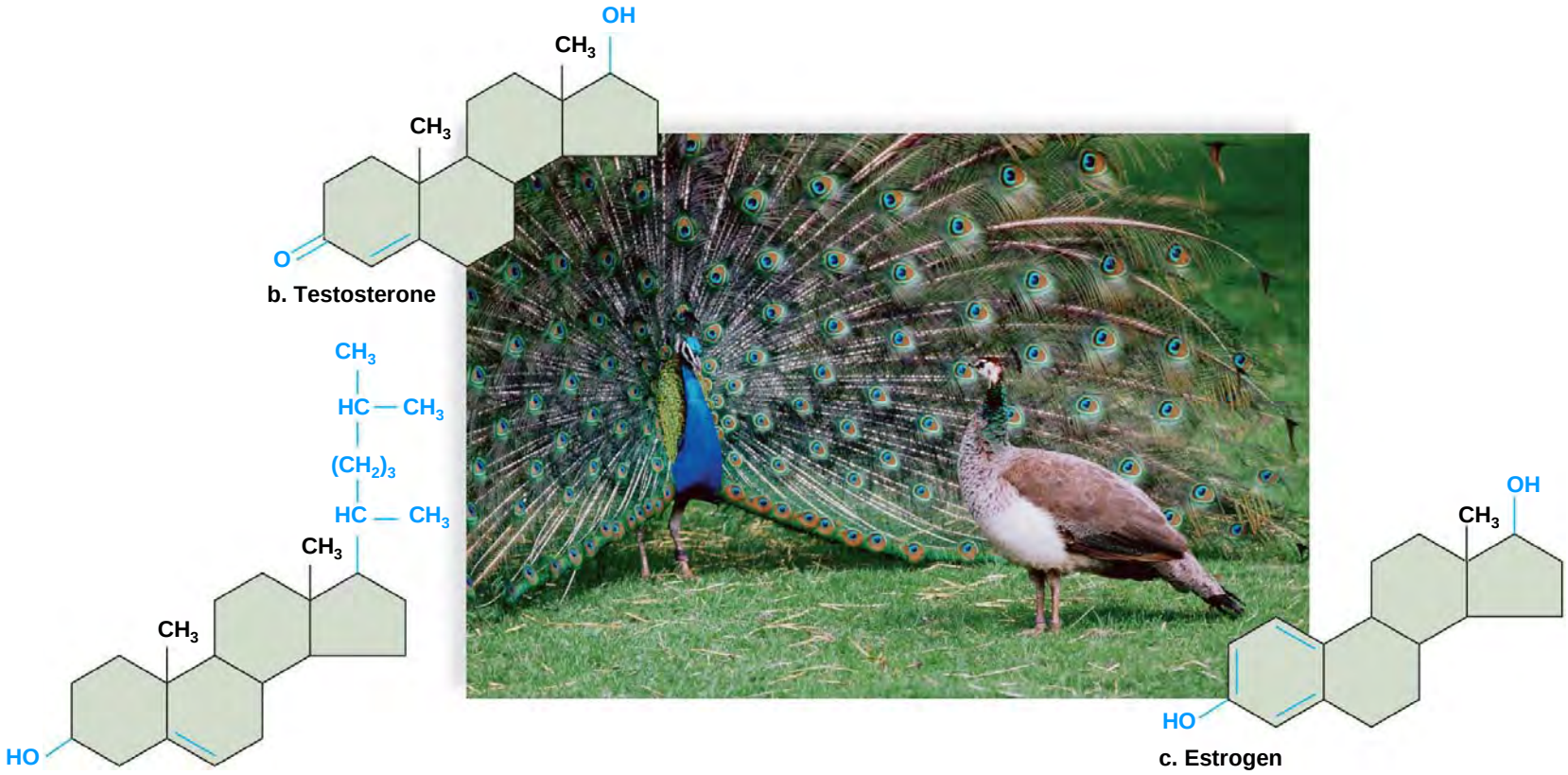
- Phospholipids Form Membranes



Types of Lipids: Steroids & Waxes

- Steroids
  - Cholesterol, testosterone, estrogen
  - Skeletons of four fused carbon rings
- Waxes
  - Long-chain fatty acid bonded to a long-chain alcohol
    - High melting point
    - Waterproof
    - Resistant to degradation

Steroid Diversity



Waxes

a.

b.

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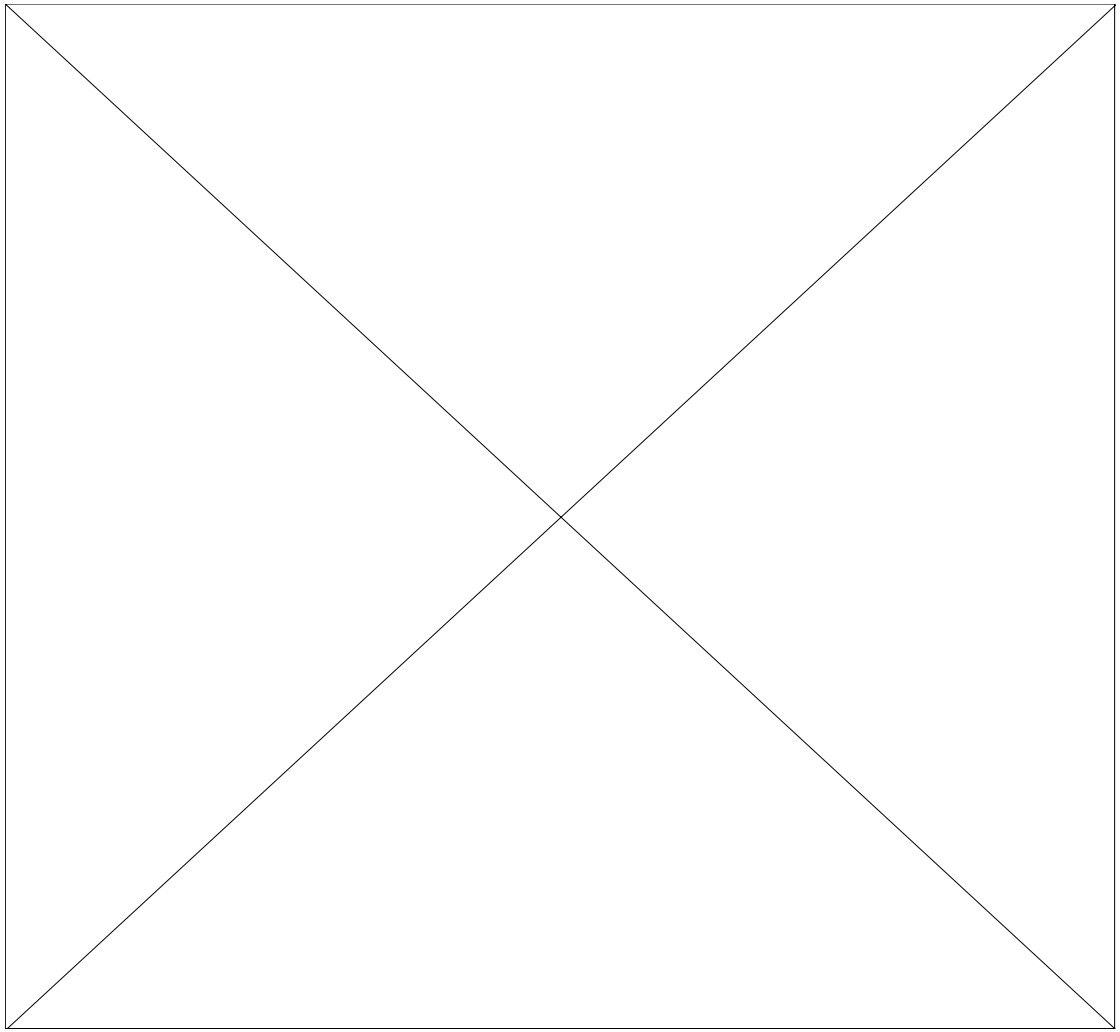
Proteins

- Functions
  - Support proteins
    - Keratin - makes up hair and nails
    - Collagen - support many of the body's structures e.g. tendons, skin
  - Enzymes – Almost all enzymes are proteins
    - Acts as organic catalysts to accelerate chemical reactions within cells
  - Transport – Hemoglobin; membrane proteins
  - Defense – Antibodies
  - Hormones are regulatory proteins that influence the metabolism of cells e.g. insulin
  - Motion – Muscle proteins, microtubules

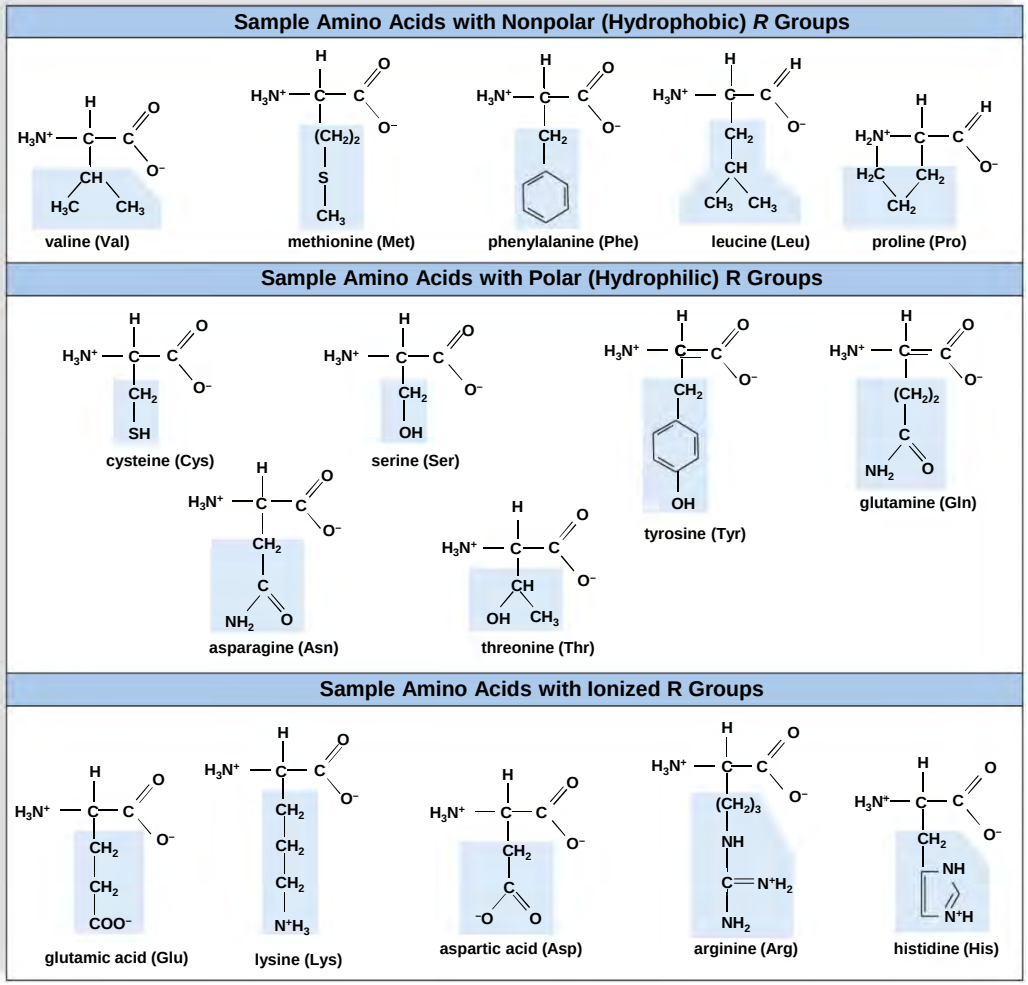
Protein Subunits: The Amino Acids

- Proteins are polymers of amino acids
- Each amino acid has a central carbon atom (the alpha carbon) to which are attached
  - a hydrogen atom,
  - an amino group $–NH_2$,
  - A carboxylic acid group –COOH,
  - and one of 20 different types of *–R* (remainder) groups
- There are 20 different amino acids that make up proteins
- Amino acids differ according to their particular R group

Animation



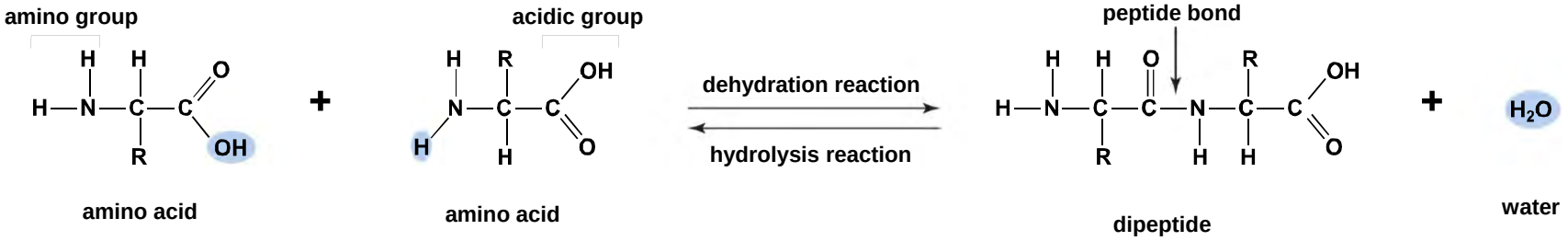
Structural Formulas for the 20 Amino Acids



Proteins: The Polypeptide Backbone

- A **peptide bond** is a covalent bond between two amino acids (AA)
  - COOH of one AA covalently bonds to the NH_2 of the next AA
    - Two AAs bonded together – Dipeptide
    - Three AAs bonded together – Tripeptide
    - Many AAs bonded together – Polypeptide
  - Characteristics of a protein determined by composition and sequence of AA's
  - A **protein** may contain more than one polypeptide chain
  - Virtually unlimited number of proteins

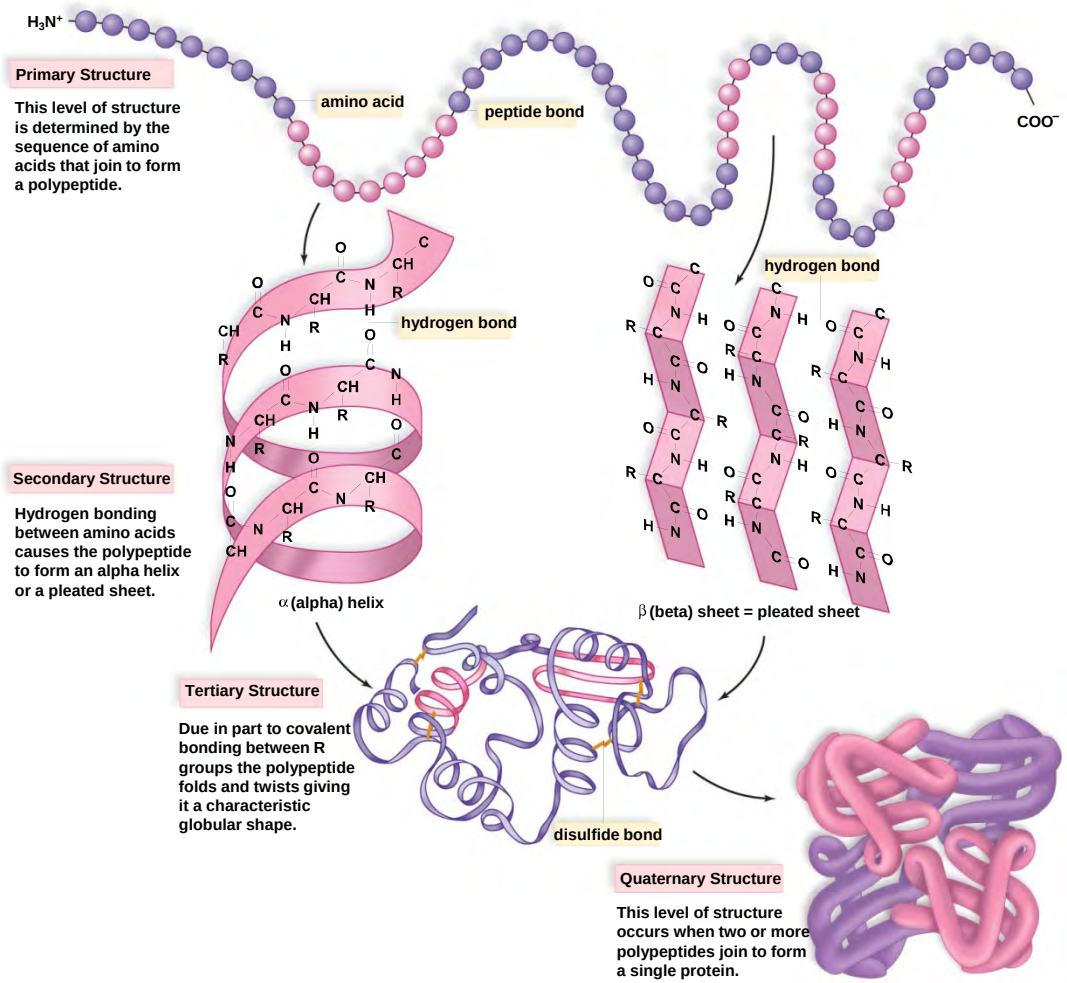
Synthesis and Degradation of a Peptide



Protein: Levels of Structure

- Protein shape (3-D structure) determines the function of the protein in the organism
- Proteins can have up to four levels of structure
  - Primary:
    - Literally, the sequence of amino acids
    - A string of beads (up to 20 different colors)
  - Secondary:
    - The way the amino acid chain coils or folds
    - Describing the way a knot is tied
  - Tertiary:
    - Overall three-dimensional shape of a polypeptide
    - Describing what a knot looks like from the outside
  - Quaternary:
    - Consists of more than one polypeptide
    - Like several completed knots glued together

Levels of Protein Organization



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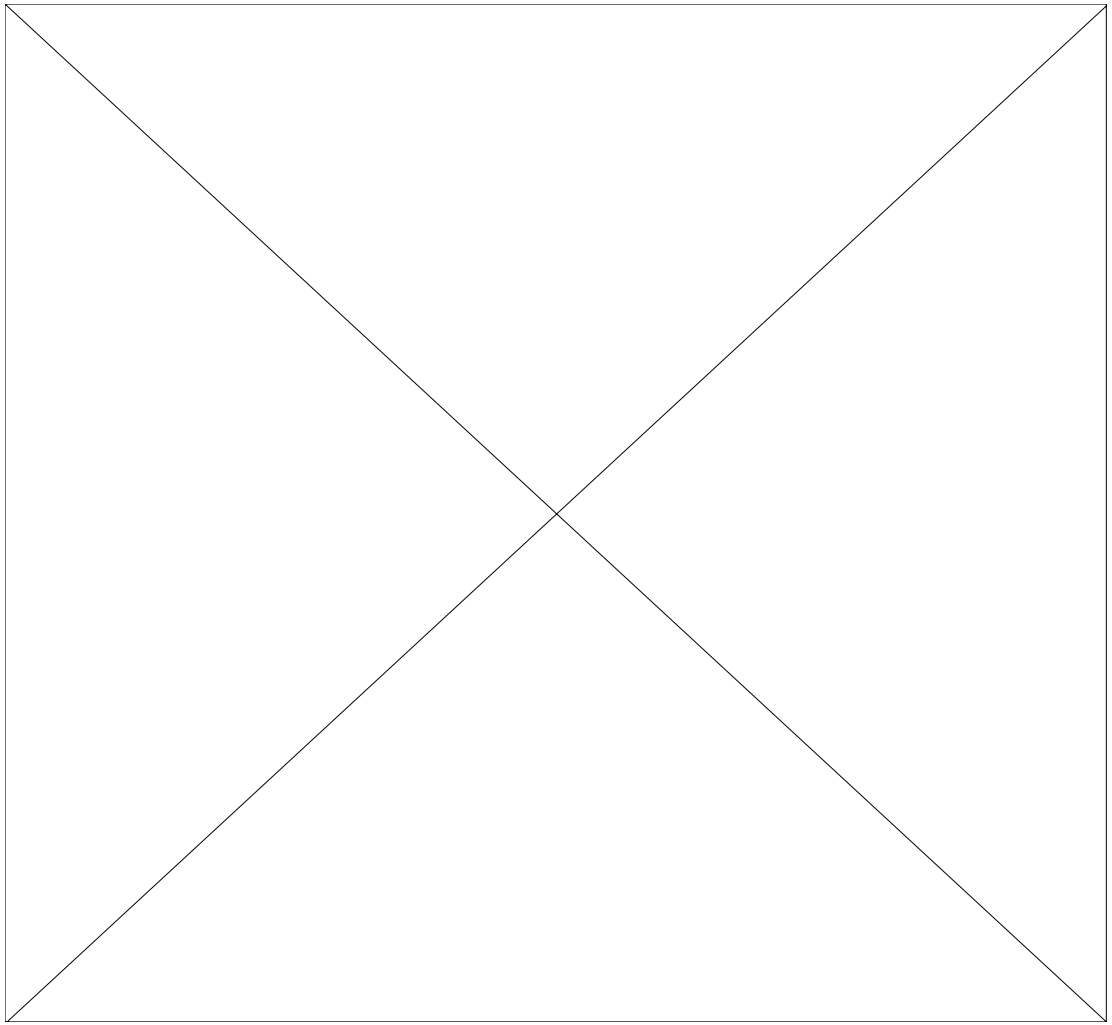

Examples of Fibrous Proteins

a. **b.** **c.**

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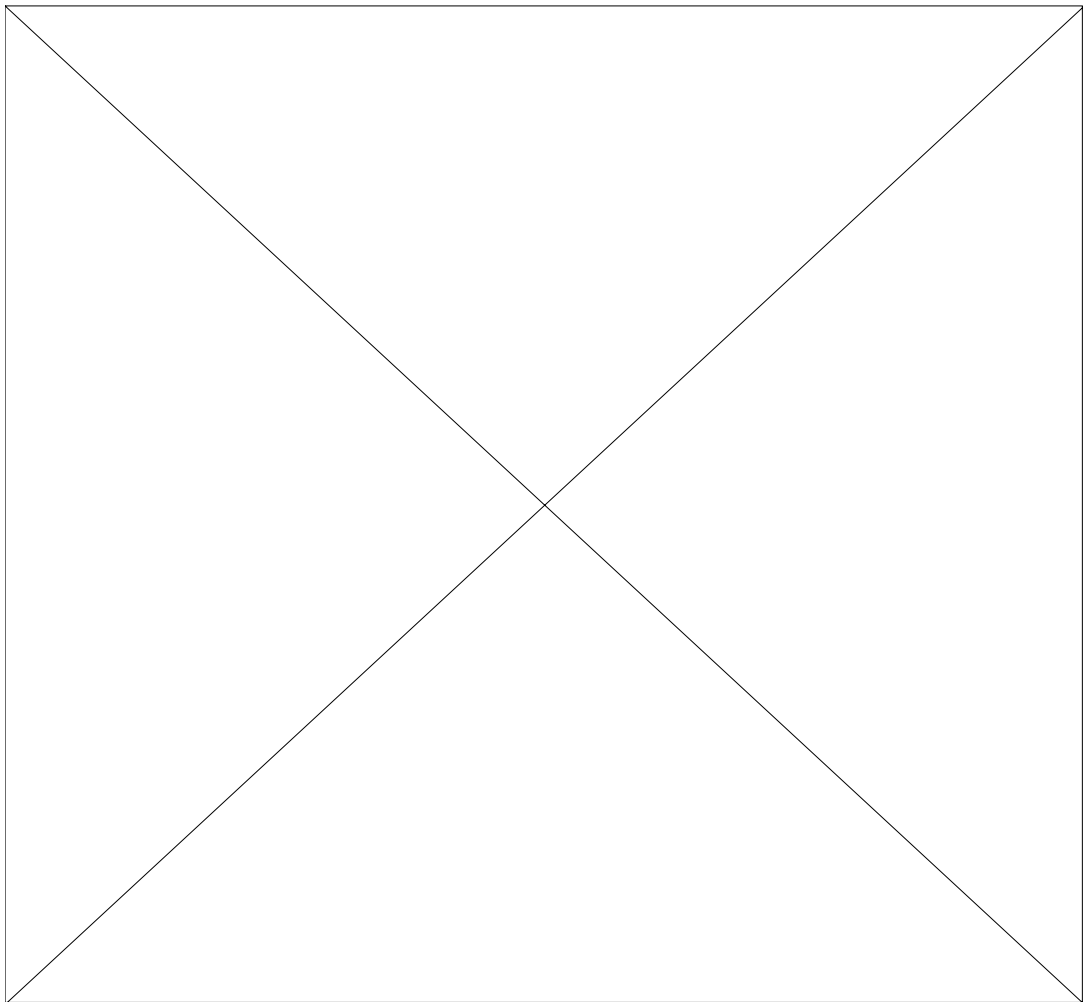
Animation



Protein-folding Diseases

- Assembly of AA's into protein extremely complex
- Process overseen by "chaperone" molecules
  - Inhibit incorrect interactions between *R* groups as polypeptide grows
  - Defects in these chaperones can corrupt the tertiary structure of proteins
  - Mad cow disease could be due to mis-folded proteins called prions

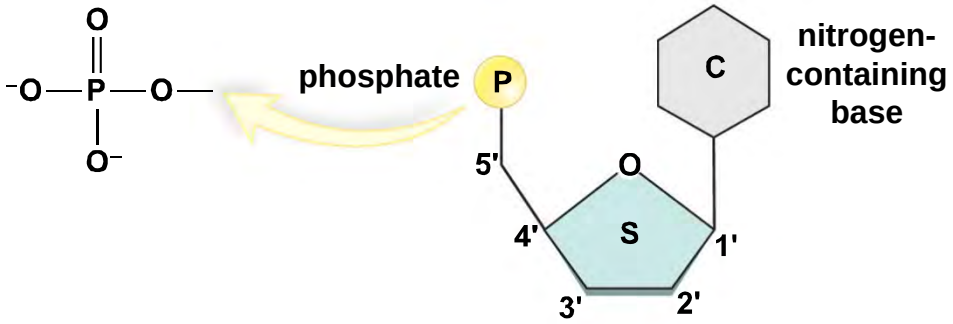
Nucleic Acids

- Polymers of nucleotides
- Very specific cell functions
  - DNA (deoxyribonucleic acid)
    - Double-stranded helical spiral (twisted ladder)
    - Serves as genetic information center
    - In chromosomes
  - RNA (ribonucleic acid)
    - Part single-stranded, part double-stranded
    - Serves primarily in assembly of proteins
    - In nucleus and cytoplasm of cell

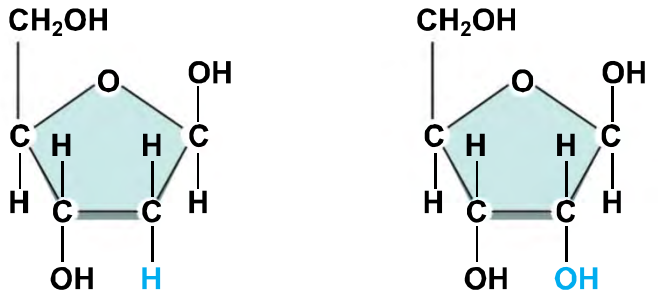
The Nucleotides of Nucleic Acids

- Three components:
  - A phosphate group,
  - A pentose sugar (ribose or deoxyribose), and
  - A nitrogenous base (4 kinds in DNA, 3 kinds in RNA, 3 common to both
- Nucleotide subunits connected end-to-end to make nucleic acid
- Sugar of one connected to the phosphate of the next
- Sugar-phosphate backbone

Nucleotides

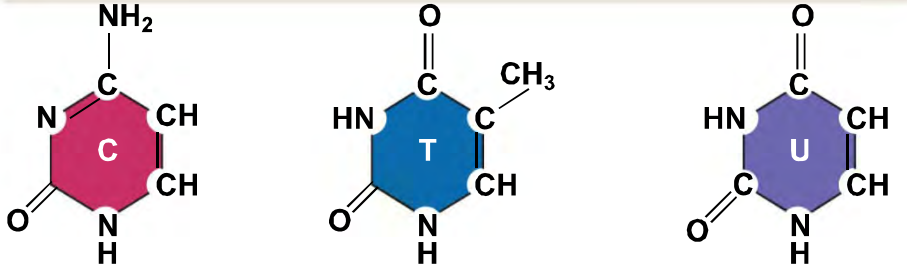


a. Nucleotide structure

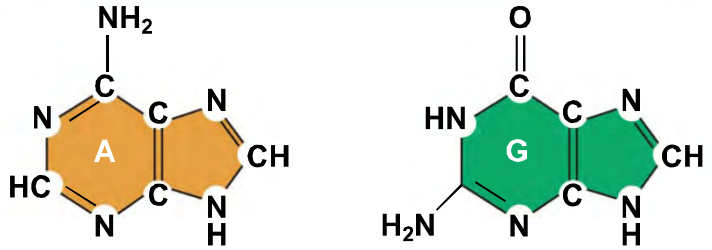


b. Deoxyribose versus ribose

Pyrimidines



Purines

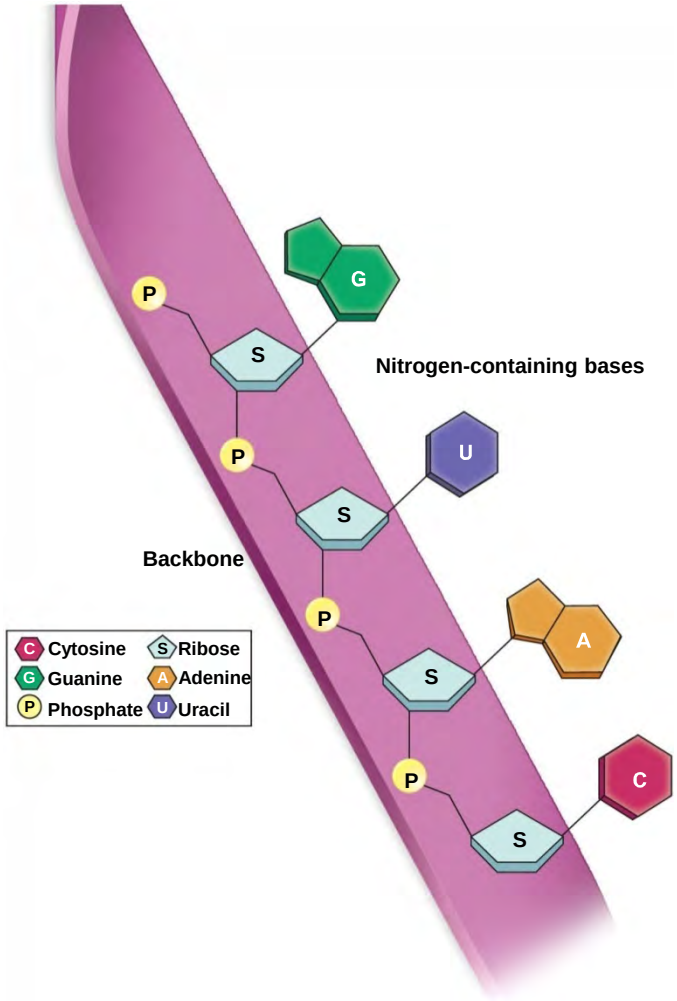


c. Pyrimidines versus purines

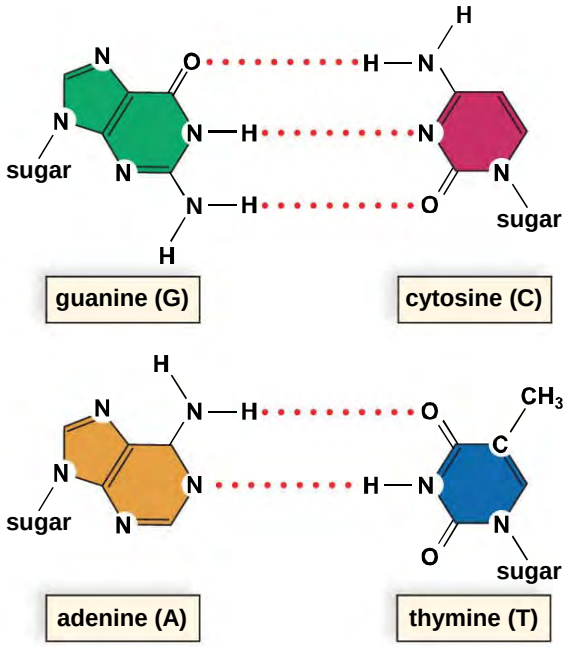
DNA Structure

a. Space-filling model b. Double helix

RNA Structure



Complementary Base Pairing



c. Complementary base pairing

Comparison of DNA & RNA

TABLE 3.4

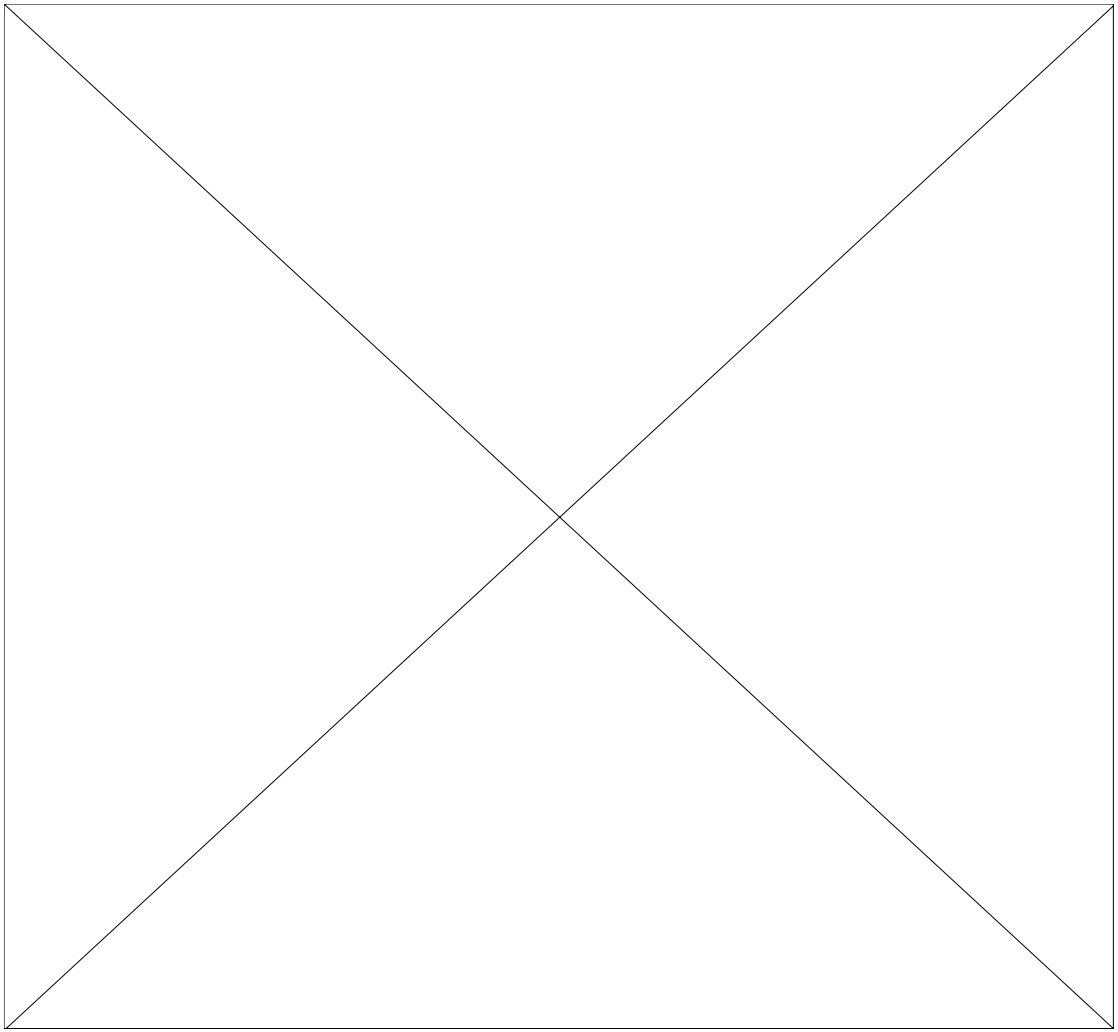
Organic Compounds in Cells

	Categories	*Elements*	*Examples*	*Functions*
Carbohydrates	Monosaccharides 6-carbon sugar 5-carbon sugar	C, H, O	 Glucose Deoxyribose, ribose	 Immediate energy source Found in DNA, RNA
	Disaccharides 12-carbon sugar	C, H, O	Sucrose	Transport sugar in plants
	Polysaccharides Polymer of glucose	C, H, O	Starch, glycogen, Cellulose	Energy storage in plants, animals Plant cell wall structure
Lipids	Triglycerides 1 glycerol + 3 fatty acids	C, H, O	Fats, oils	Long-term energy storage
	Phospholipids Like triglyceride except the head group contains phosphate	C, H, O, P	Lecithin	Plasma membrane phospholipid bilayer
	Steroids Backbone of 4 fused rings	C, H, O	Cholesterol, Testosterone, estrogen	Plasma membrane component Sex hormones
	Waxes Fatty acid + alcohol	C, H, O	Cuticle Earwax	Protective covering in plants Protective wax in ears
Proteins	Polypeptides Polymer of amino acids	C, H, O, N, S	Enzymes Myosinand actin Insulin Hemoglobin Collagen	Speed cellular reactions Movement of muscle cells Hormonal control of blood sugar Transport of oxygen in blood Fibrous support of body parts
Nucleic Acids	Nucleic acids Polymer of nucleotides	C, H, O, N, P	DNA, RNA	Genetic material Protein synthesis
	Nucleotides		ATP Coenzymes	Energy carrier Assist enzymes

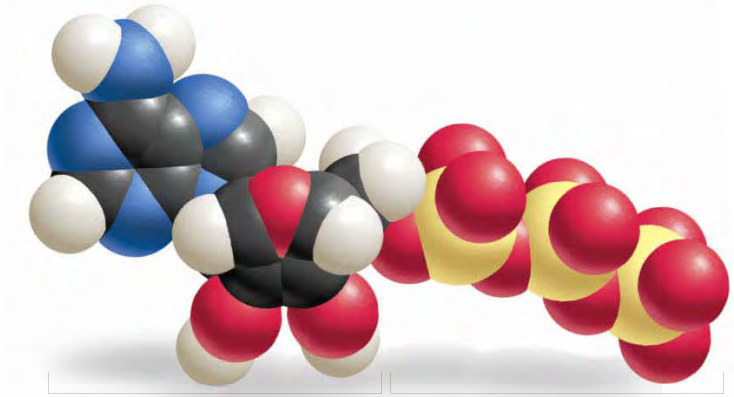
Other Nucleic Acids

- ATP (adenosine triphosphate) is composed of adenine, ribose, and three phosphates
- In cells, one phosphate bond is hydrolyzed – Yields:
  - The molecule ADP (adenosine diphosphate)
  - An inorganic phosphate molecule p_i
  - Energy
- Other energy sources used to put ADP and p_i back together again

Animation

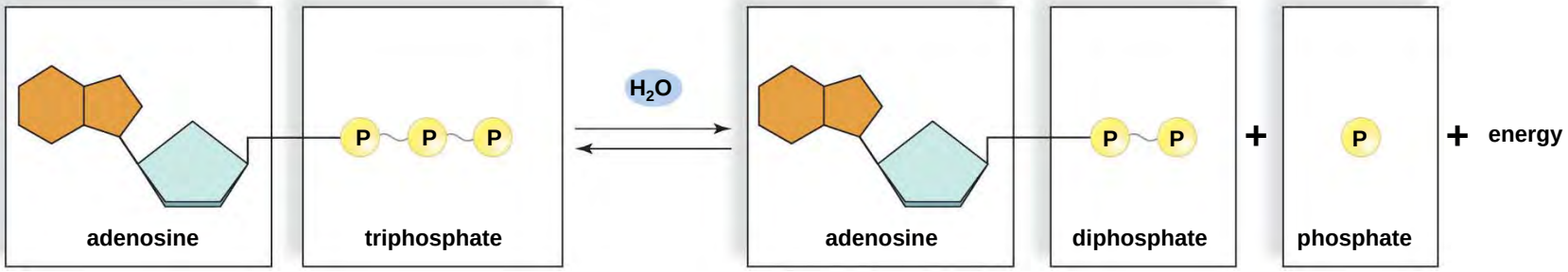


ATP



a. adenosine triphosphate

c.



b. ATP ADP

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