The Molecules of Cells

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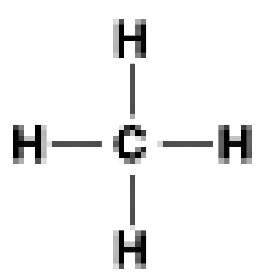
Introduction

- Living cells are formed from a small number of different types of molecules that make up the earth.
- Life’s structural and functional diversity results from a great variety of molecules

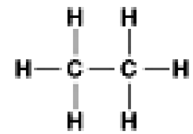
Introduction

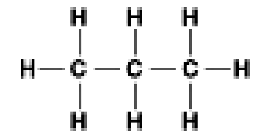
- All **biomolecules** contain carbon atoms.
- Atoms that are commonly found in covalent linkage to carbon are carbon itself, hydrogen, oxygen, and nitrogen.
- A carbon atom forms four covalent bonds
- It can join with other carbon atoms to make chains or rings that are the backbones of all biomolecules.



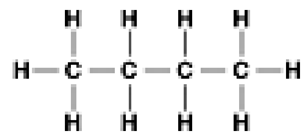
Introduction

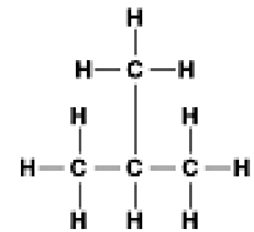
- Carbon skeletons vary in many ways


Ethane

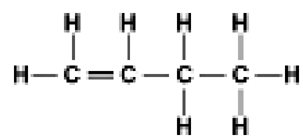

Propane

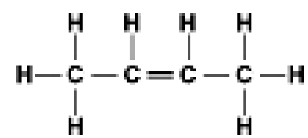
Carbon skeletons vary in length.


Butane

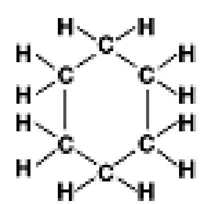

Isobutane

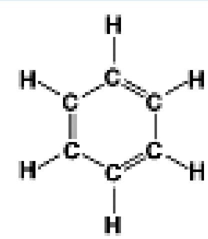
Skeletons may be unbranched or branched.


1-Butene


2-Butene

Skeletons may have double bonds, which can vary in location.


Cyclohexane

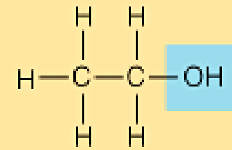
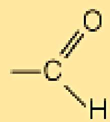
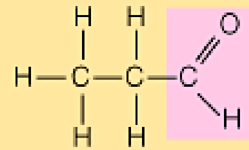
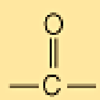
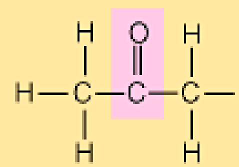
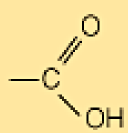
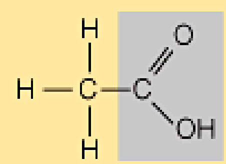
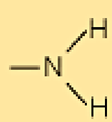
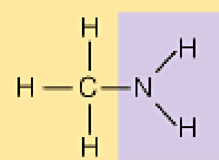

Benzene

Skeletons may be arranged in rings.

Introduction

- Functional groups are the groups of atoms that participate in chemical reactions
- Functional groups help to determine the properties of organic compounds
  - Hydroxyl groups are characteristic of alcohols
  - The carboxyl group acts as an acid

SOME COMMON FUNCTIONAL GROUPS

Functional Group	General Formula	Name of Compounds	Example	Where Else Found
Hydroxyl —OH (or HO—)	—O—H	Alcohols	 Ethanol	Sugars; water-soluble vitamins
Carbonyl >CO		Aldehydes	 Propanal	Some sugars; formaldehyde (a preservative)
		Ketones	 Acetone	Some sugars; "ketone bodies" in urine (from fat breakdown)
Carboxyl —COOH		Carboxylic acids	 Acetic acid	Amino acids; proteins; some vitamins; fatty acids
Amino $—NH_2$ (or H_2N —)		Amines	 Methylamine	Amino acids; proteins; urea in urine (from protein breakdown)

Introduction

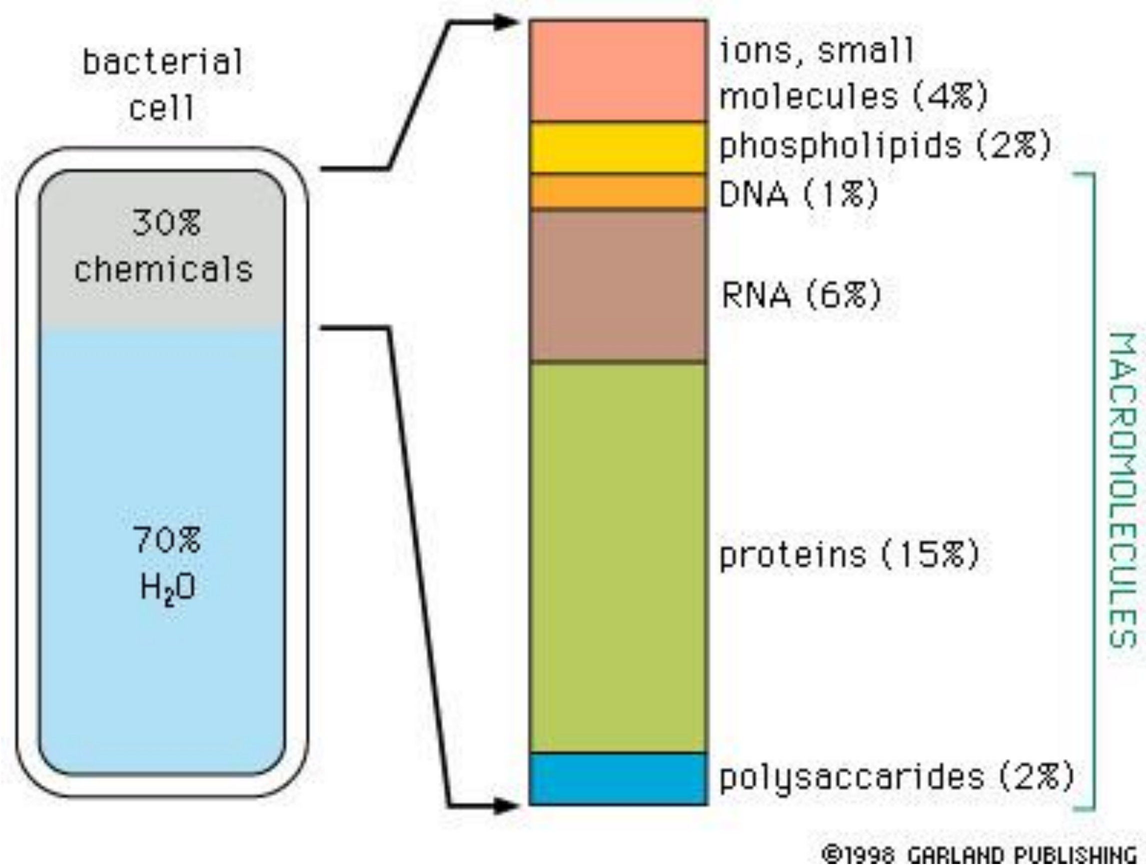
- Phosphorus (as phosphate —OPO_3^{2-} derivatives) and sulfur, also play important roles in biomolecules.
  - DNA
  - RNA
  - ATP

Introduction

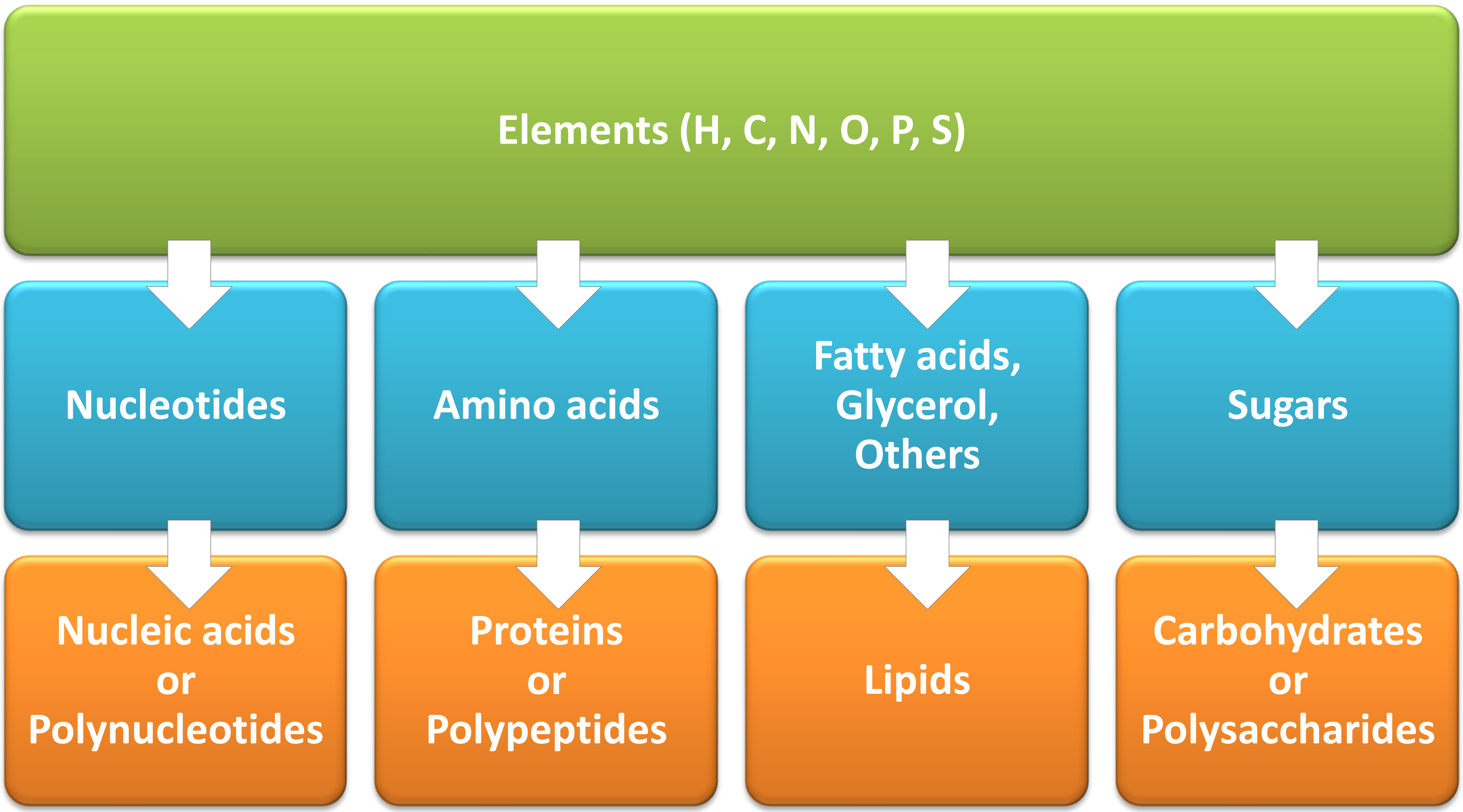
- There are three levels of organisation to describe biomolecules.
- The simplest level is the individual **elements** such as carbon or nitrogen.
- The basic elements can be arranged into a series of small molecules known as **building blocks**. Building blocks include compounds such as amino acids and sugars.
- The building blocks are organised into larger compounds, known as **macromolecules**. Macromolecules interact to form larger cell structures such as membranes, ribosomes, and chromosomes.

Introduction

- Macromolecules are abundant in cells



Introduction

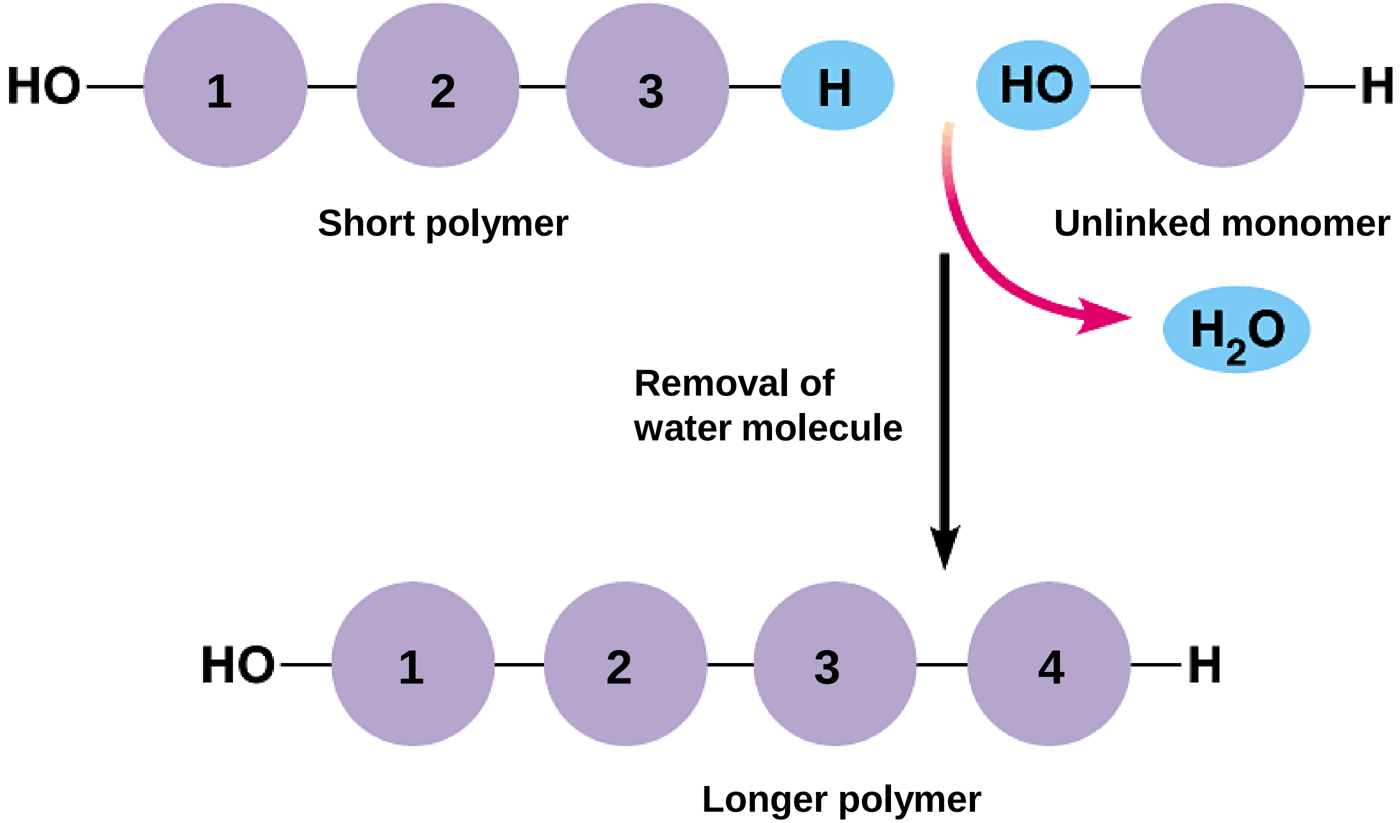


Introduction

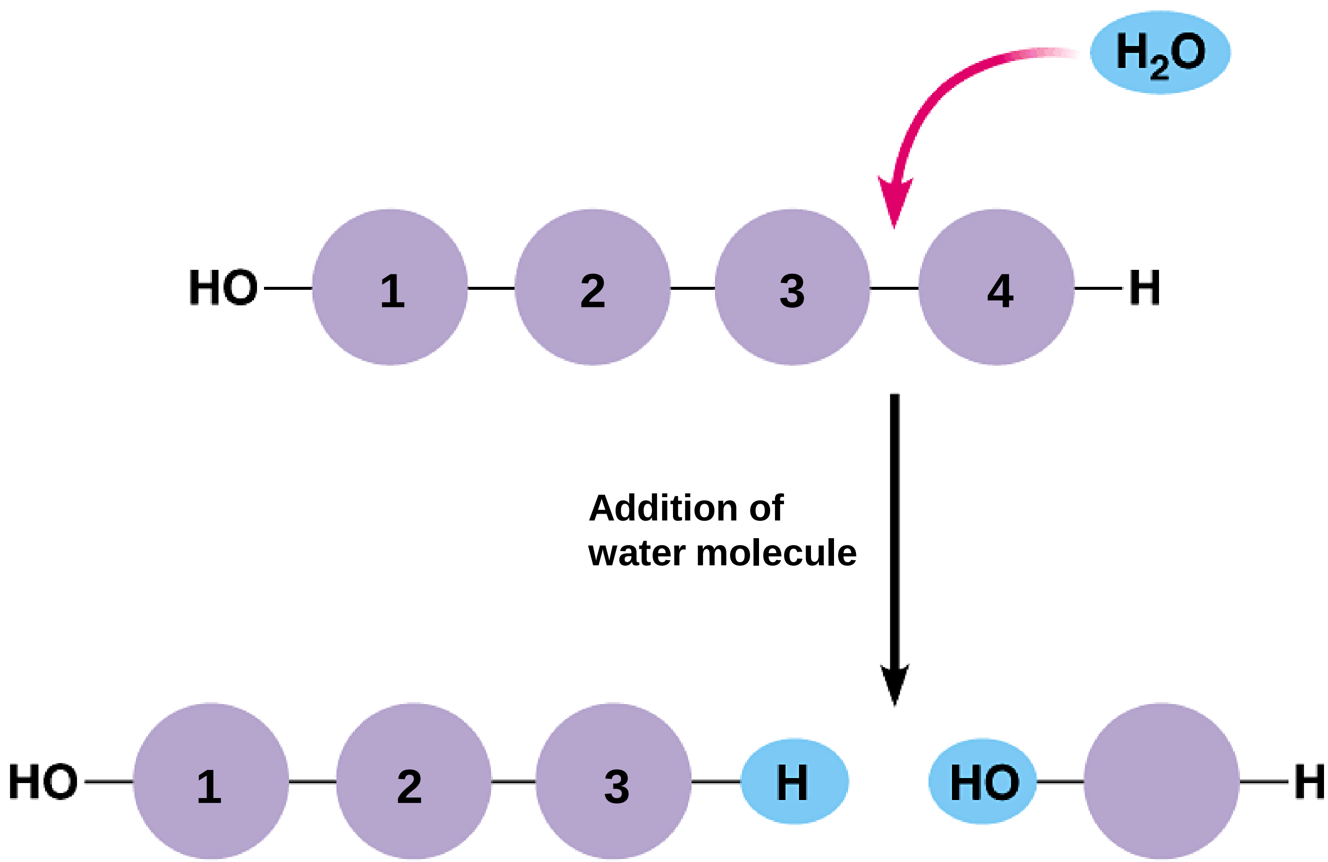
- Biological macromolecules are **polymers** formed by linking building blocks, or monomers, together.
  - Polymers are long chains of smaller molecular units called monomers
- Most of the large molecules in living things are macromolecules called polymers
  - A huge number of different polymers can be made from a small number of monomers

Introduction

- The covalent bond between the building blocks is formed by **dehydration synthesis** (also called **condensation reaction**), an energy-requiring process that creates a water molecule for every bond formed.



- Breaking the bond between building blocks requires the returning of a water molecule with a subsequent release of energy, a process called **hydrolysis**.



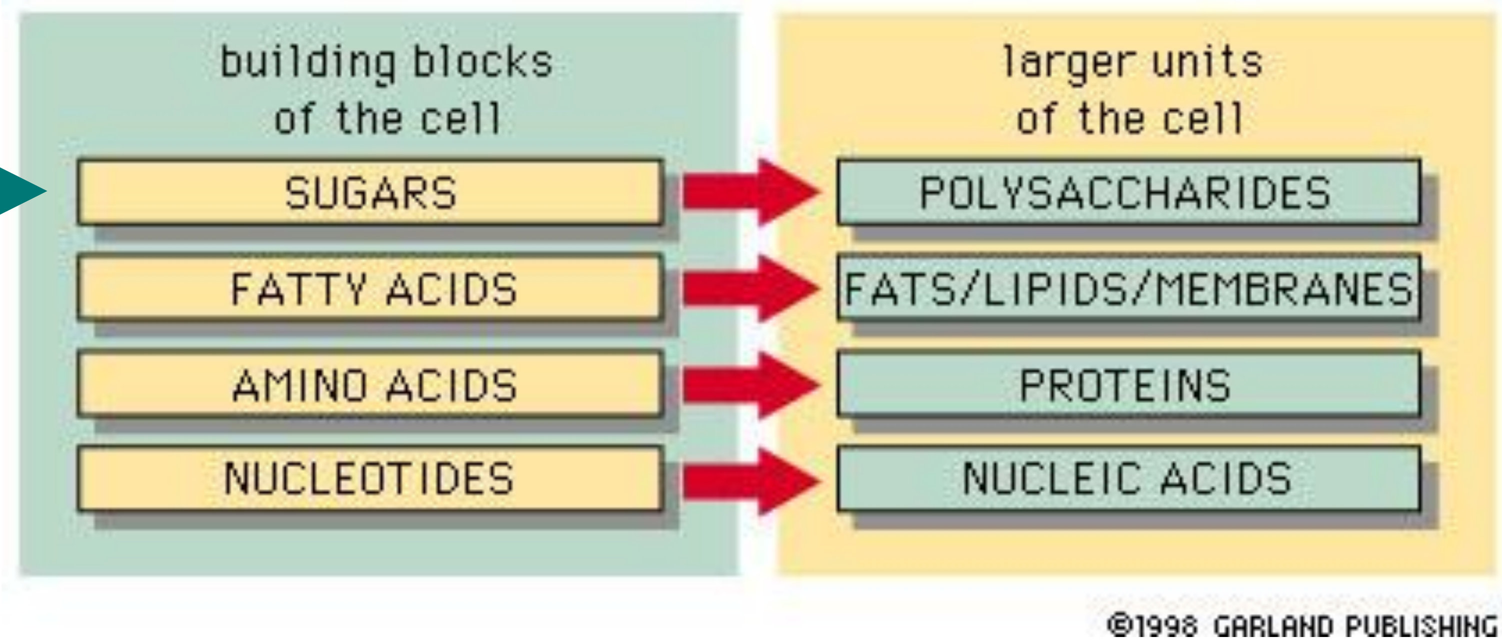
Carbohydrates

- **Carbohydrates** are the single most abundant class of organic molecules found in nature.
- Carbohydrates are a class of molecules
  - They range from small sugars to large polysaccharides
  - Polysaccharides are long polymers of monomers

Carbohydrates

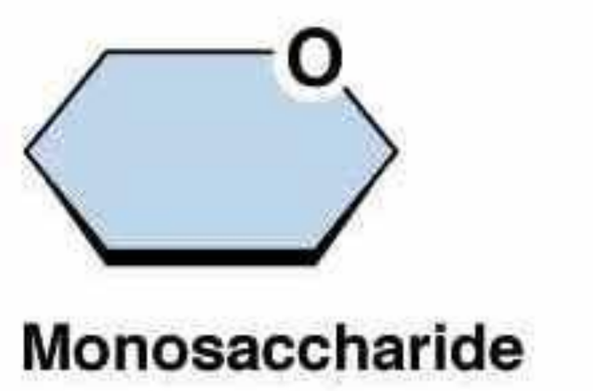
- The name *carbohydrate* arises from the basic molecular formula $(CH_2O)_n$, which shows that these substances resemble hydrates of carbon, where $n = 3$ or more.
- Carbohydrates function
  - **energy-storage molecules**
  - **structural components**
  - **recognition elements**

The four main families of small organic molecules in cells



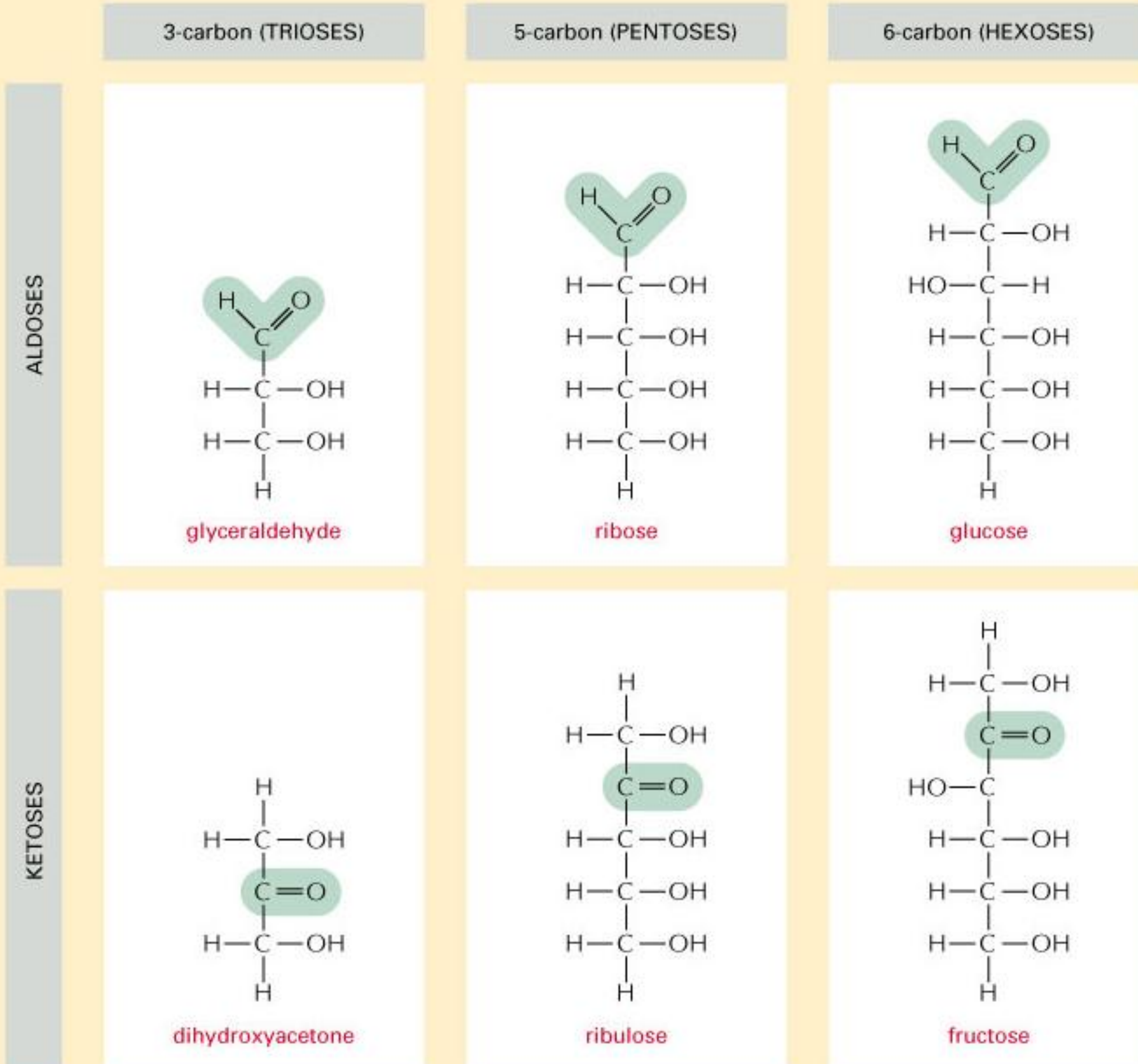
Carbohydrates

- The simplest of the carbohydrates are the simple sugars, or **monosaccharides**.
- Monosaccharides are single-unit sugars
- Each molecule contains hydroxyl groups and a carbonyl group
- Monosaccharides are the fuels for cellular work



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 ($-\mathrm{C}{\overset{\mathrm{O}}{\underset{\mathrm{H}}{<}}}$) and are called aldoses or a ketone group ($>\mathrm{C}=\mathrm{O}$) and are called ketoses.



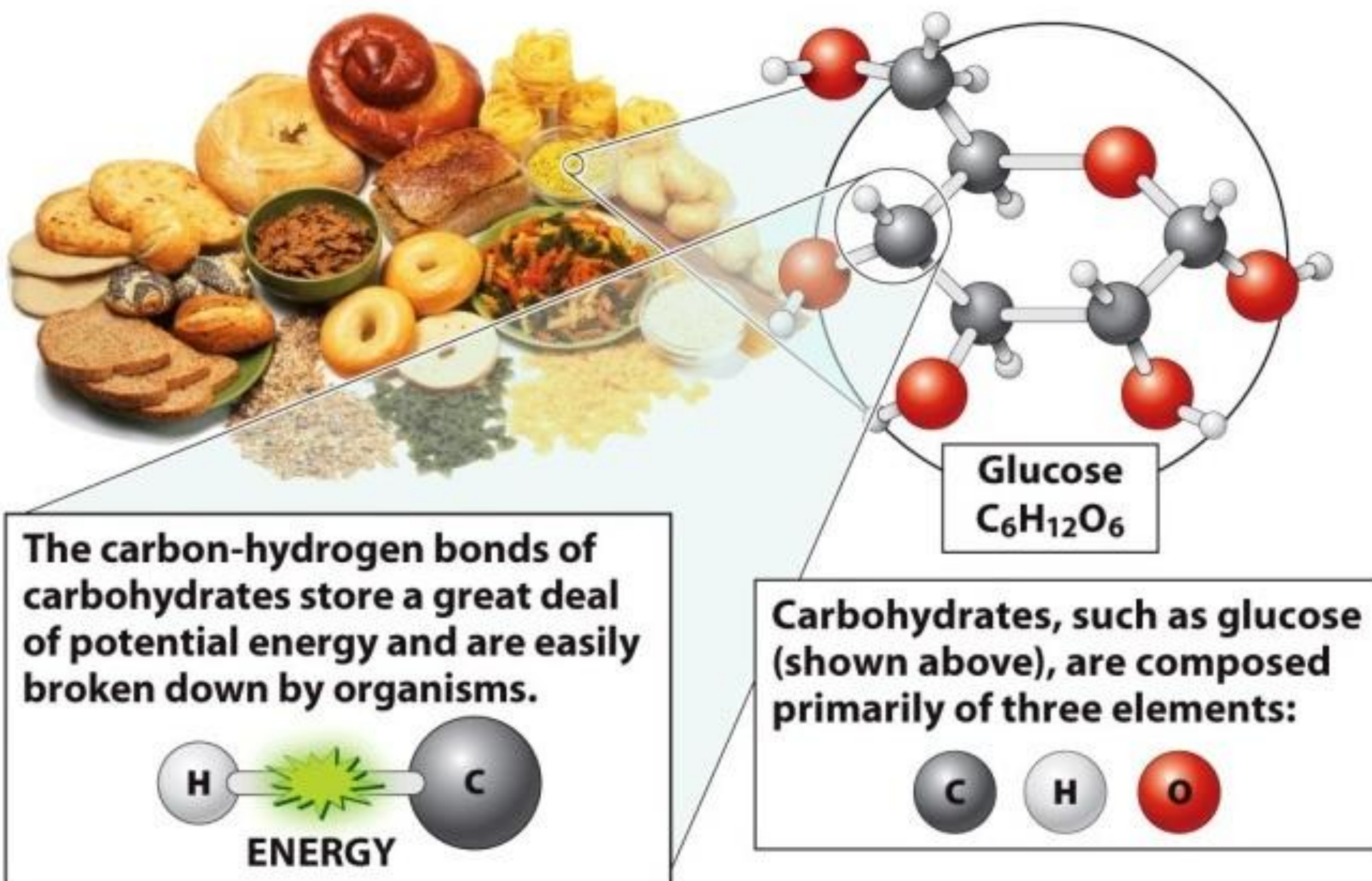
Carbohydrates

- Monosaccharides may contain as few as three carbon atoms, but those that play the central role in energy storage have six.
- The most important of these for energy storage is **glucose**, a six-carbon sugar which has seven energy storing C—H bonds.
- Some five-carbon sugars are of little importance as a source of energy but are essential constituents of nucleic acids.

Carbohydrates

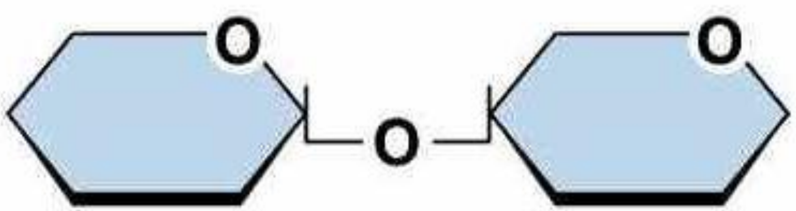
- When the bonds are broken down in a series of reactions, energy is released.
- Cells use carbohydrates mainly as a source of energy because drawing the energy from carbohydrate molecules is quicker and easier than it is for other biomolecules.
- The heat of combustion for one gram of carbohydrate generally represents **4.2 kcal**.

Carbohydrates



Carbohydrates

- **Disaccharides** are *double sugars* formed by the covalent joining of two monosaccharide units.
- Disaccharides often play a role in the transport of sugars in plants.
- **Sucrose** is composed of a glucose and a fructose unit and extracted from sugar cane or sugar beet.
- **Lactose**, which is another disaccharide, is the principal sugar in milk (in the lactating mammary gland).



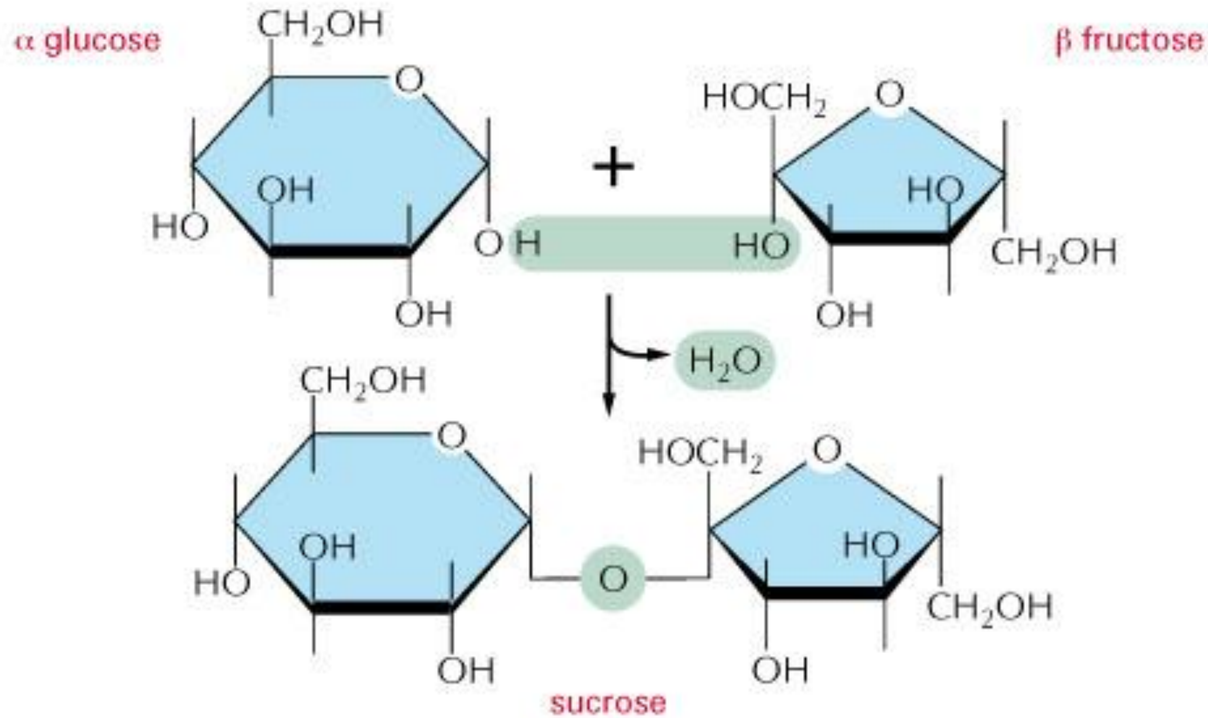
Disaccharide

DISACCHARIDES

The carbon that carries the aldehyde or the ketone can react with any hydroxyl group on a second sugar molecule to form a disaccharide. Three common disaccharides are

maltose (glucose + glucose)
lactose (galactose + glucose)
sucrose (glucose + fructose)

The reaction forming sucrose is shown here.



Carbohydrates

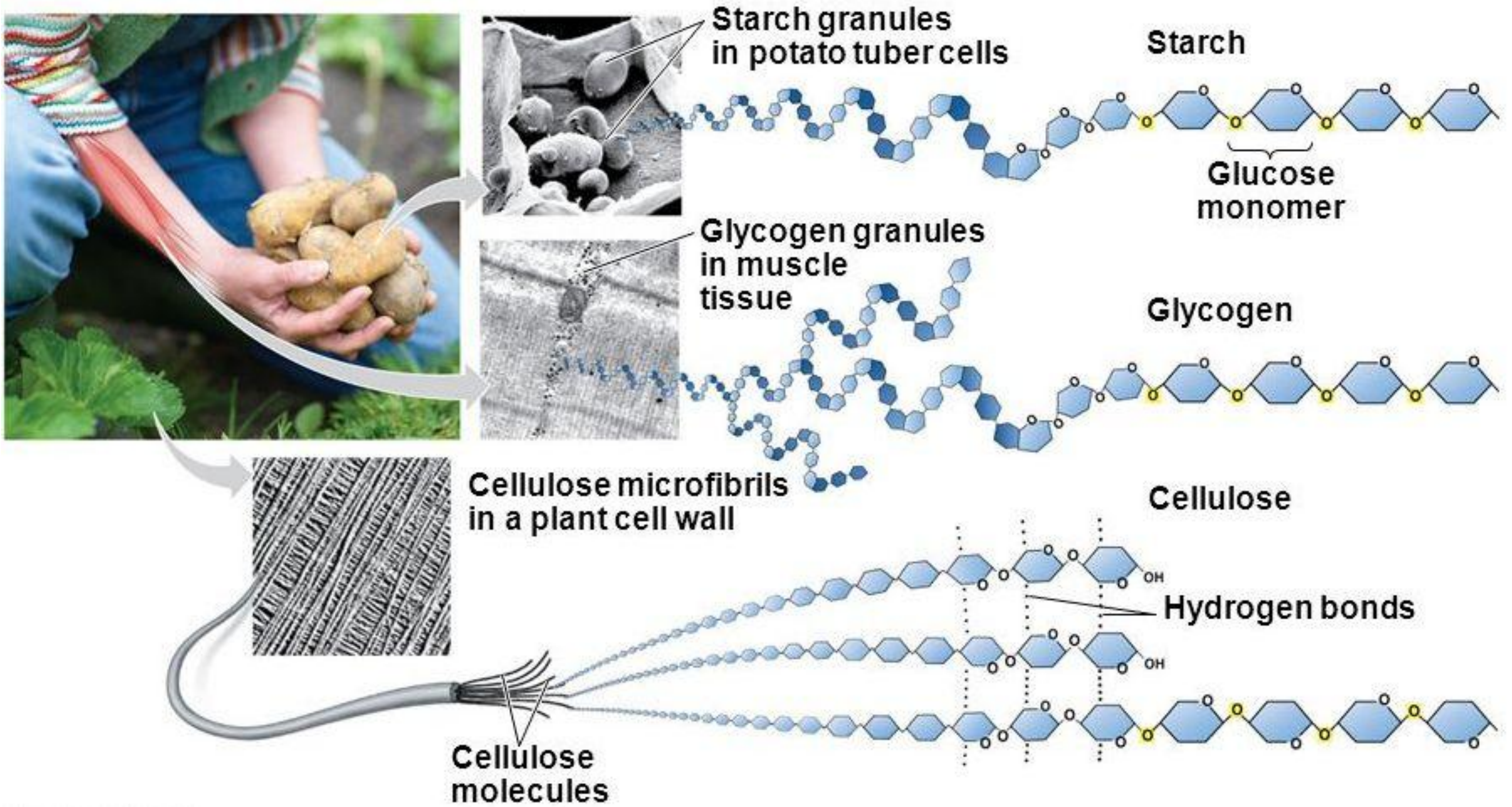
- Glucose and fructose are readily soluble in water and cannot be stored.
- Cells use insoluble, long polymers of monosaccharides, called **polysaccharides**, as long-term stores of energy.
- **Polysaccharides** are polymers of hundreds or thousands of monosaccharides linked by dehydration synthesis
- The principal storage polysaccharides are **starch** (in plant cells) and **glycogen** (in animal cells), both of which are composed of many glucose units.
- Both starch and glycogen constitute good storage products because the bonds linking the glucose molecules are easily broken when needed, providing readily available energy.

Carbohydrates

- Unlike storage polysaccharides, structural polysaccharides are very difficult to digest by most organisms.
- **Cellulose** consists of long chains of covalently linked glucose units and provides strength and support to the cell walls of plants and many microscopic algae.

Carbohydrates

- Starch and glycogen are polysaccharides that store sugar for later use
- Cellulose is a polysaccharide in plant cell walls

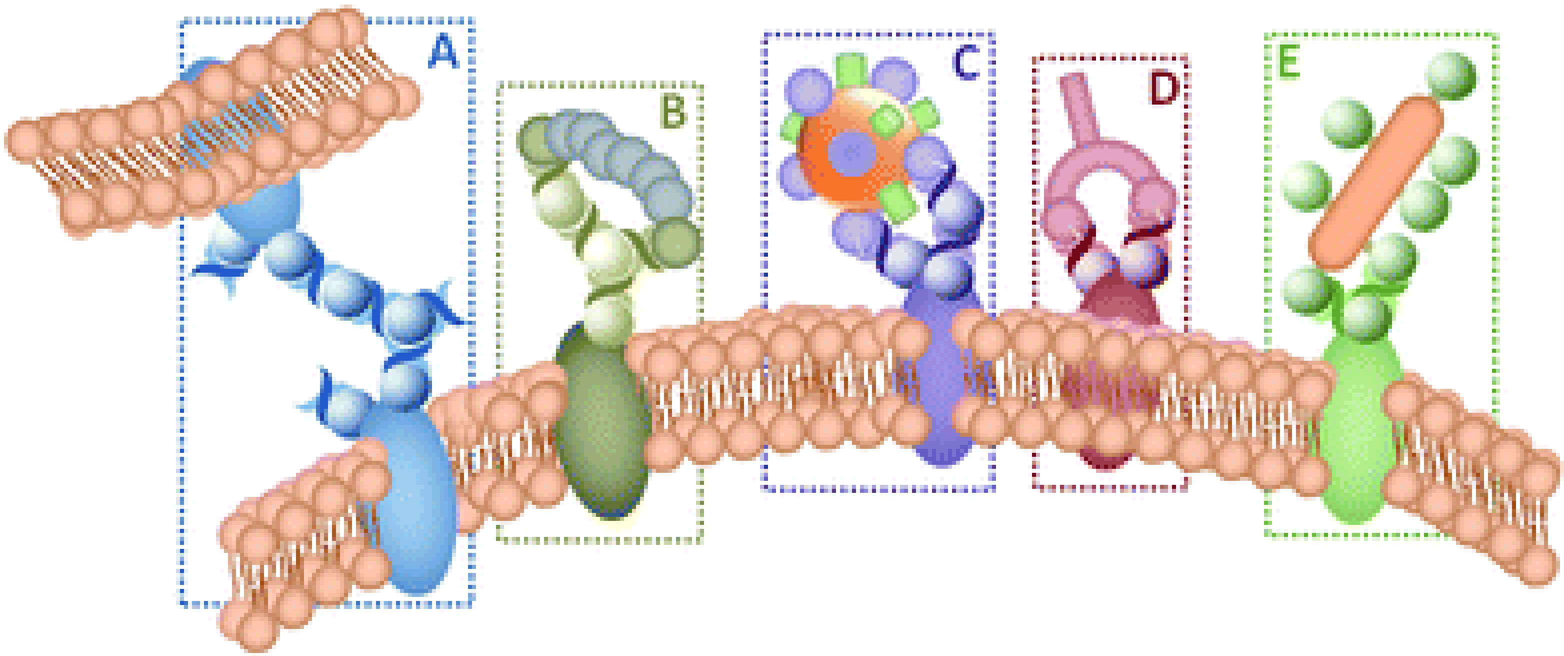


Carbohydrates

- **Oligosaccharides** are short chains of carbohydrates that contain from three to approximately ten monosaccharide units.
- In animal cells, cell surface recognition (of other cells and pathogens), and cellular adhesion are mediated by oligosaccharides that are attached to membrane proteins and lipids.

Carbohydrates

another cell toxins viruses antibodies bacteria



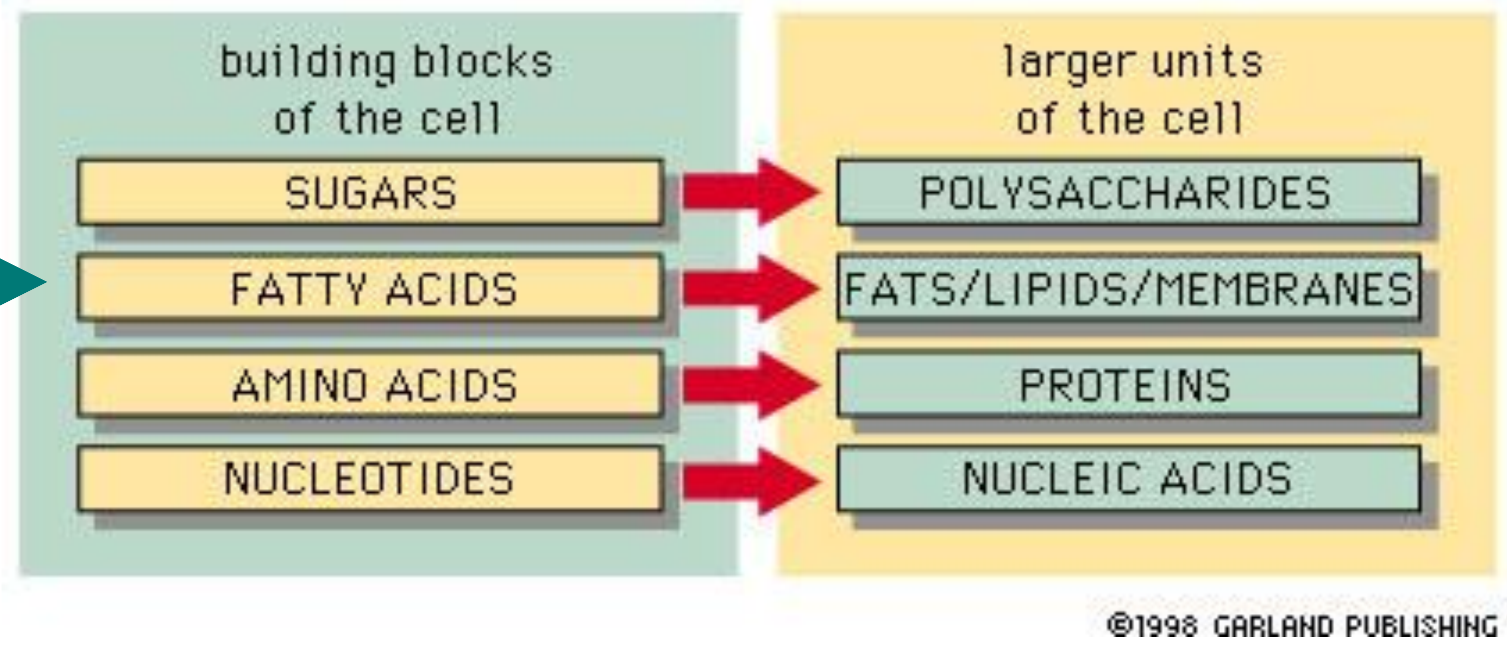
Lipids

- The term **lipid** is derived from the Greek word *lipos*, meaning fat.
- Lipids are a loosely defined group of molecules with one main characteristic: they are insoluble in water (owing to their very high proportion of nonpolar C—H bonds).
- The main groups of compounds classified as lipids are **triglycerides**, **phospholipids**, **steroids**, **prostaglandins**, and **waxes**.

Lipids

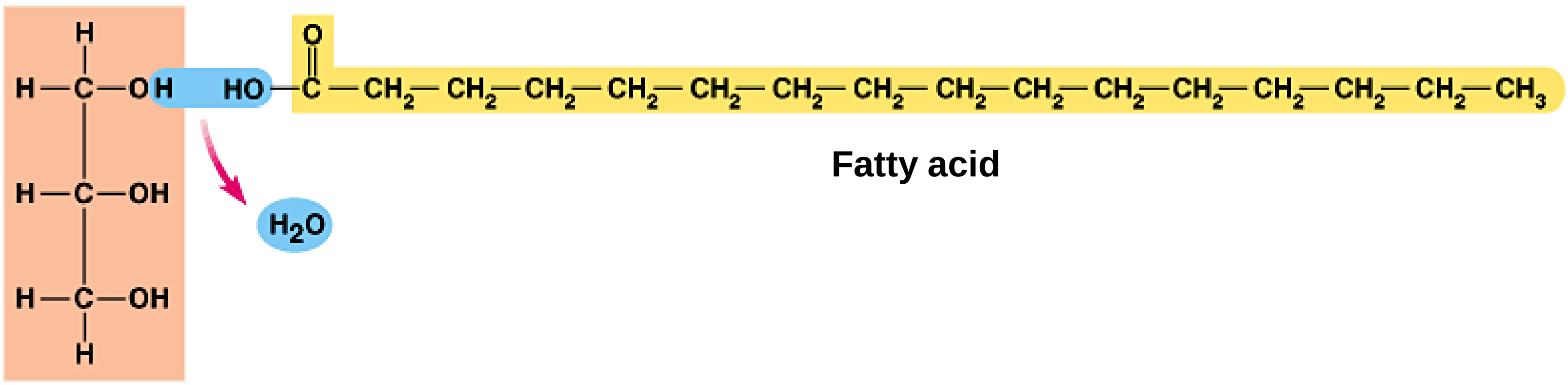
- Lipids function mainly as
  - nutrient stores
  - cell components
  - cell secretions

The four main families of small organic molecules in cells



Lipids

- **Triglycerides** are a category that includes **fats** and **oils**
- They are the important storage lipids.
- Triglycerides are composed of a single molecule of **glycerol** (a three-carbon alcohol) bound to three **fatty acids** (hydrocarbon chains ending in a carboxyl group).
- A triglyceride molecule consists of one glycerol molecule linked to three fatty acids



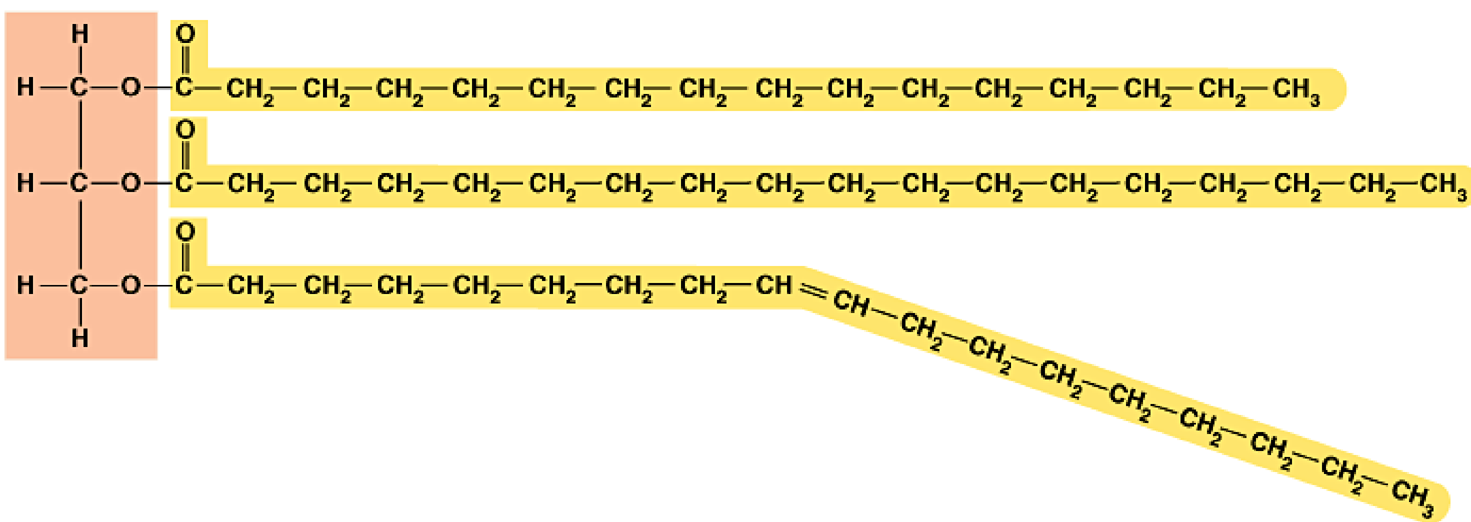
Lipids

- Fats are lipids whose main function is energy storage

- Most fats are rich in **saturated** fatty acids and are semisolid at room temperature.

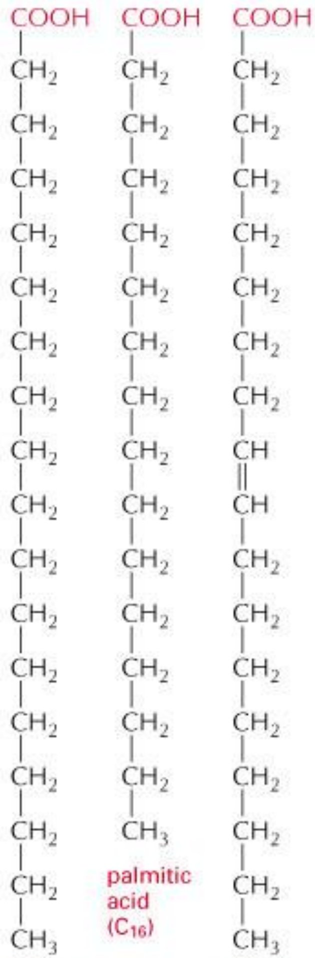
Lipids

- The fatty acids of unsaturated fats (plant oils) contain double bonds
  - These prevent them from solidifying at room temperature
- Saturated fats (lard) lack double bonds
  - They are solid at room temperature
- Oils are rich in **unsaturated** fatty acids and are usually liquid at room temperature.



COMMON FATTY ACIDS

These are carboxylic acids with long hydrocarbon tails.

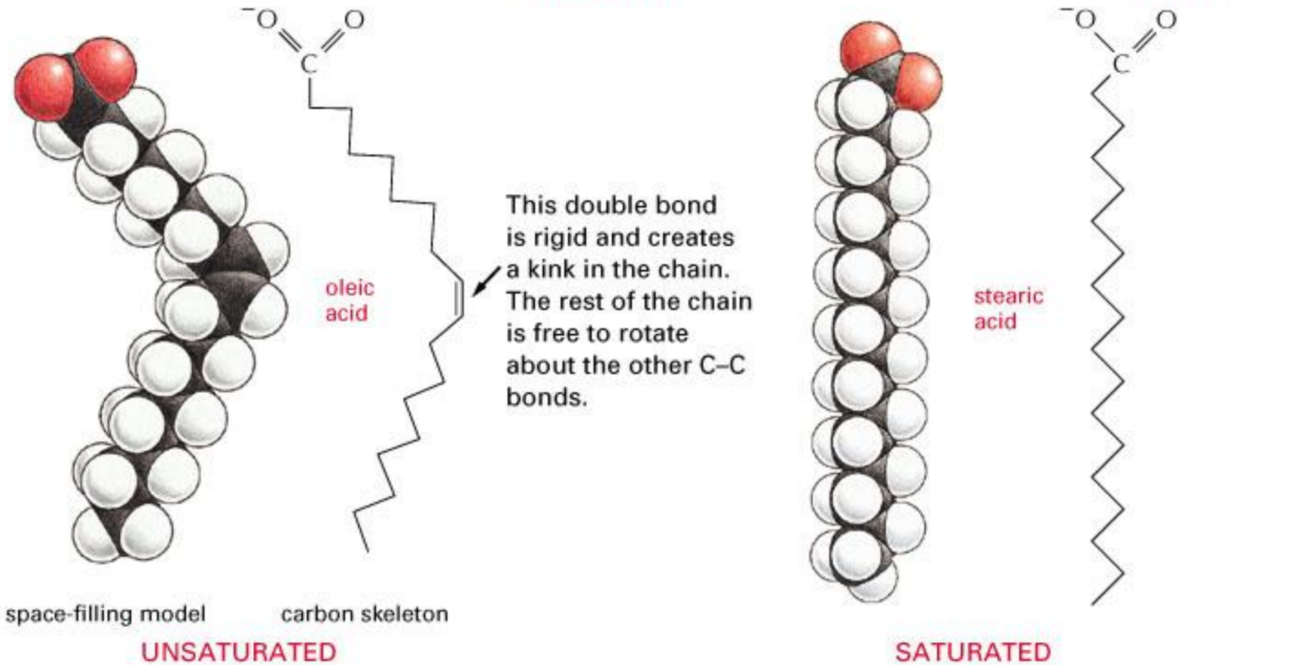


stearic acid (C_{18})

palmitic acid (C_{16})

oleic acid (C_{18})

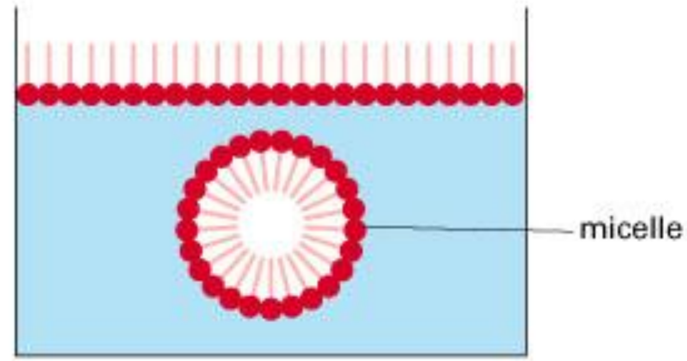
Hundreds of different kinds of fatty acids exist. Some have one or more double bonds in their hydrocarbon tail and are said to be unsaturated. Fatty acids with no double bonds are saturated.



LIPID AGGREGATES

Fatty acids have a hydrophilic head
and a hydrophobic tail.

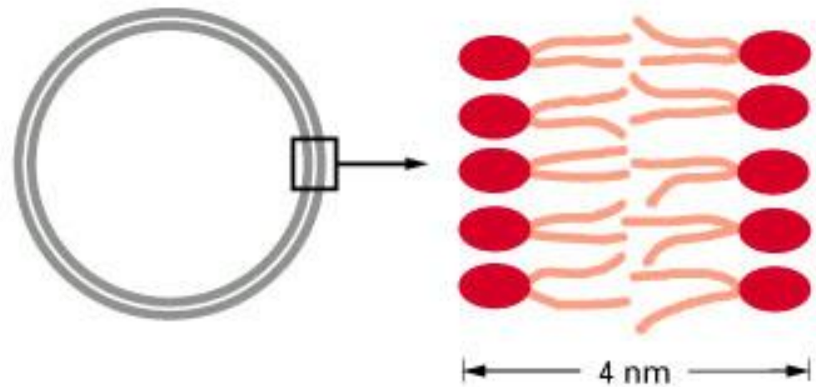
In water they can form a surface film
or form small micelles.



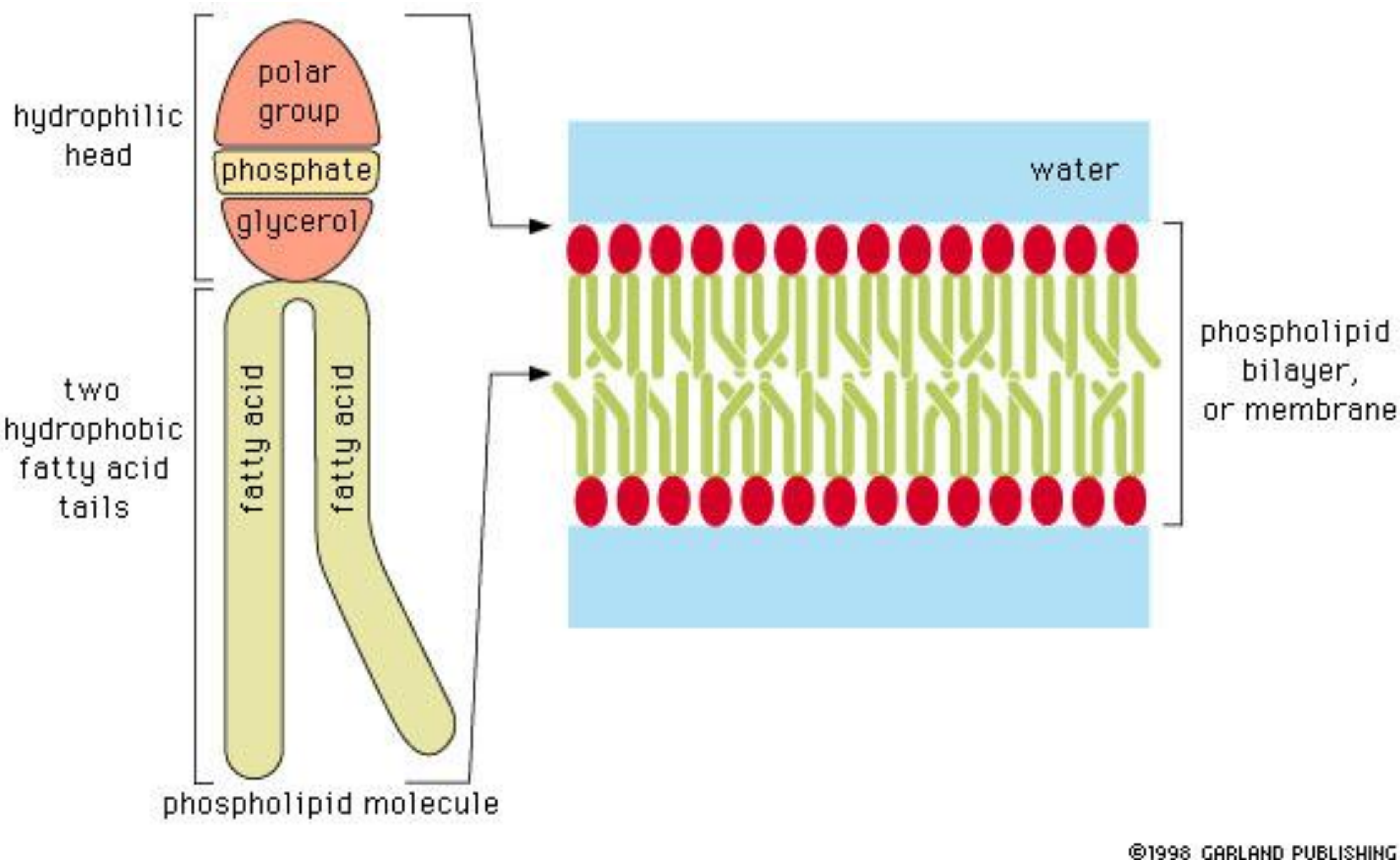
Their derivatives can form larger aggregates held together by hydrophobic forces:

Triglycerides form large spherical fat droplets in the cell cytoplasm.

Phospholipids and glycolipids form self-sealing lipid bilayers that are the basis for all cellular membranes.



Phospholipid structure and orientation of phospholipids in membranes

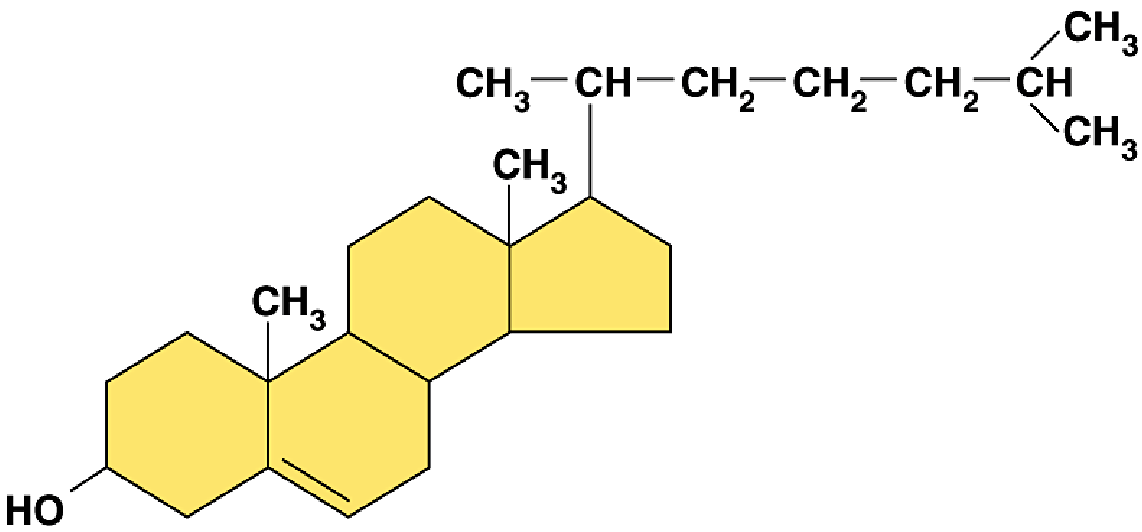


Lipids

- The average heat of combustion for lipid is **9.4 kcal** per gram.
- Triglycerides can be stored in the body in almost unlimited amounts in contrast to carbohydrates.
- Stored triglycerides are utilised when the liver is empty of glycogen.
- In higher animals, triglycerides are found in the adipose tissue and around various organs, where they serve as thermal and mechanical insulators.

Lipids

- **Steroids** are ring-shaped carbon compounds with no fatty acid tails.
- Most animal cell membranes contain **cholesterol** as steroid.
- Other steroids, such as **testosterone** and **oestrogen**, function in multicellular organisms as hormones.

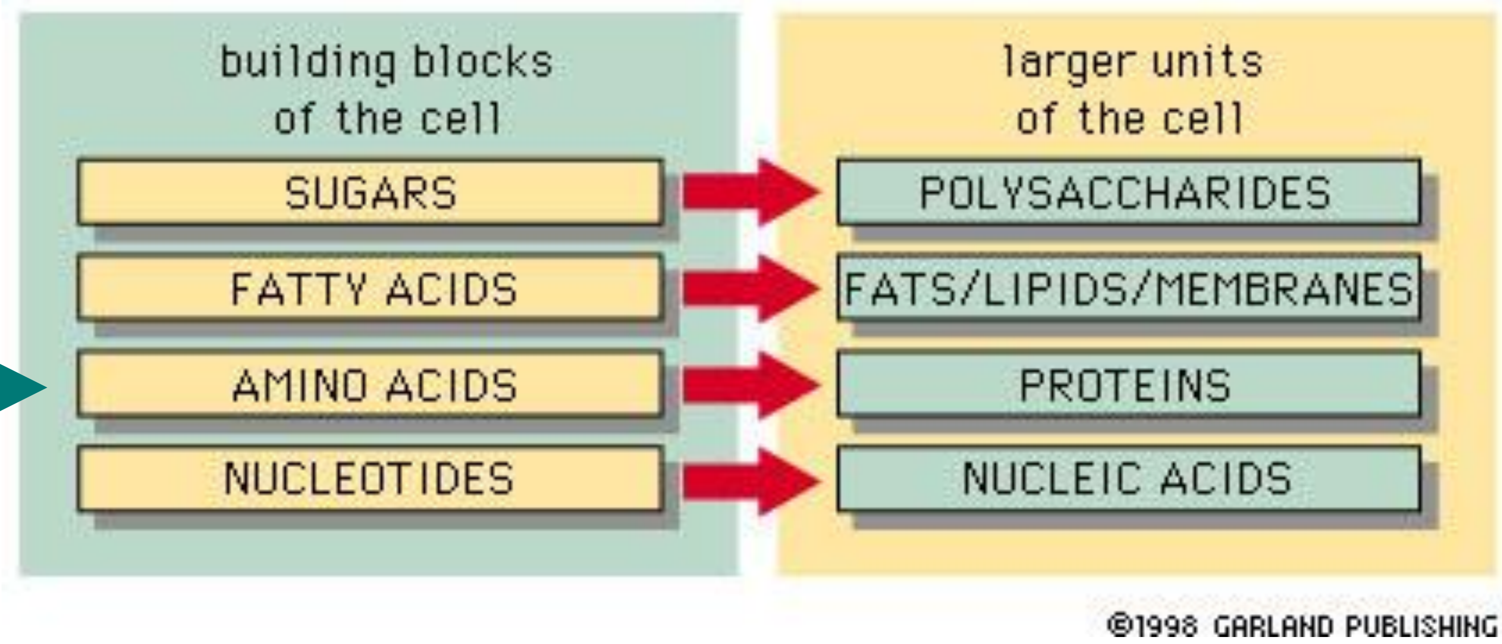


Lipids

- **Prostaglandins** are fatty acid derivatives found in small amounts.

- They act as local chemical messengers, mediating inflammatory and allergic reactions, blood clotting, and smooth muscle contraction.

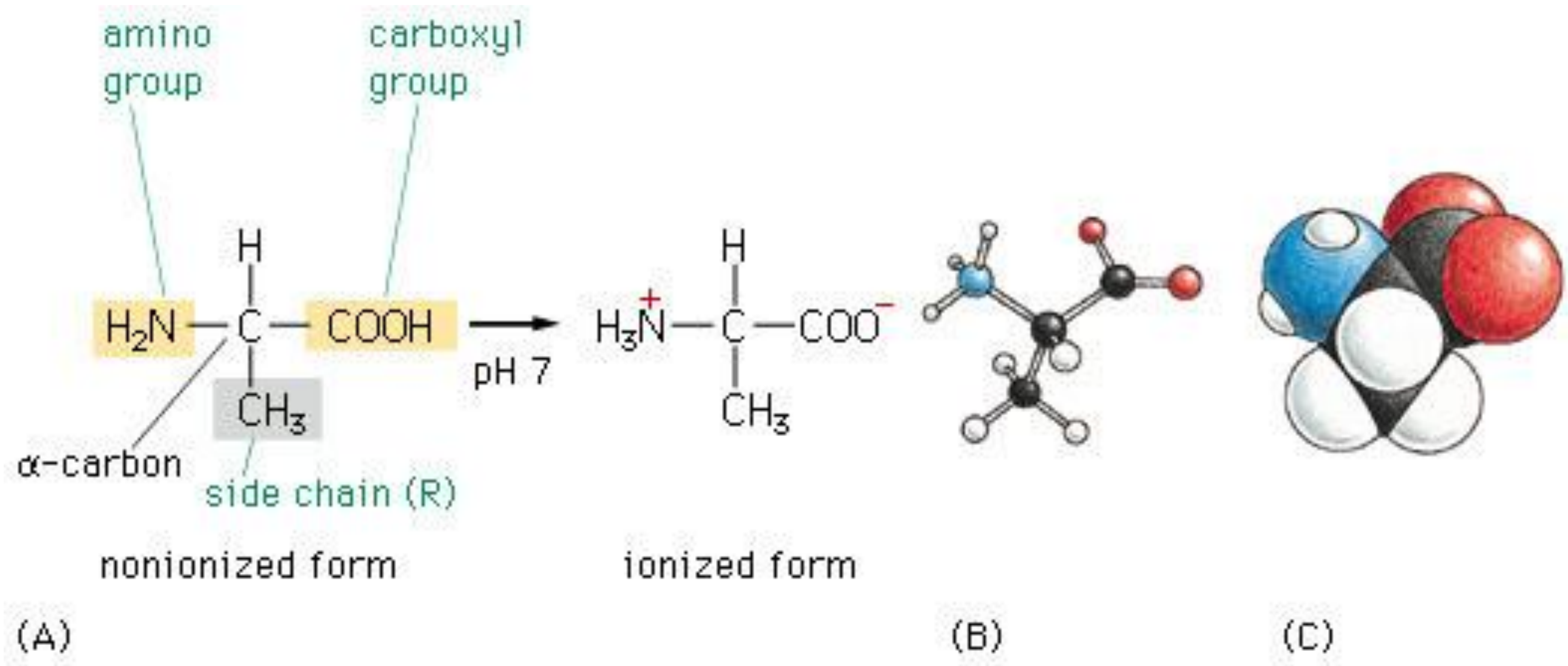
The four main families of small organic molecules in cells



Proteins

- The main organic molecules in cells are **proteins**
- The building blocks of proteins are **amino acids**, which exist in 20 different naturally occurring forms.
- Amino acids have a basic skeleton consisting of
  - a central carbon atom linked
  - a basic amino group ($—NH_2$)
  - an acidic carboxyl group ($—COOH$)
  - a hydrogen atom
  - a variable group ($—R$).

A simple amino acid: alanine



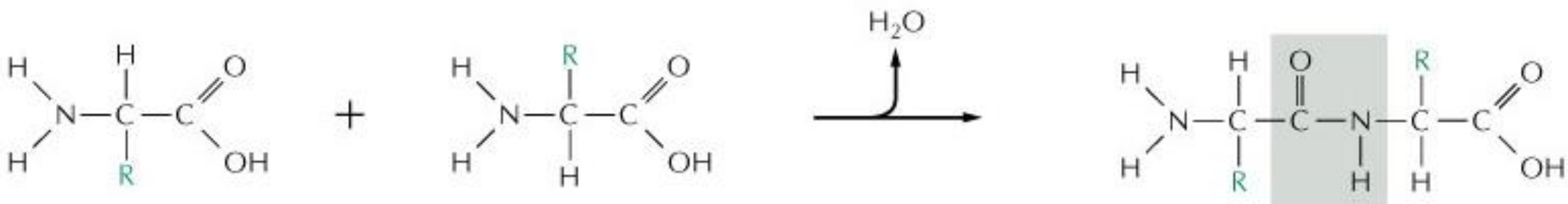
Proteins

- The amino and carboxyl groups on a pair of amino acids can undergo a condensation reaction, losing a molecule of water and forming a covalent bond: peptides.
- **Peptide** usually refers to a molecule composed of short chains of amino acids, such as a dipeptide (two amino acids), a tripeptide (three), and a tetrapeptide (four).
- A protein is composed of one or more long chains, or **polypeptides**, composed of amino acids linked by covalent bonds.

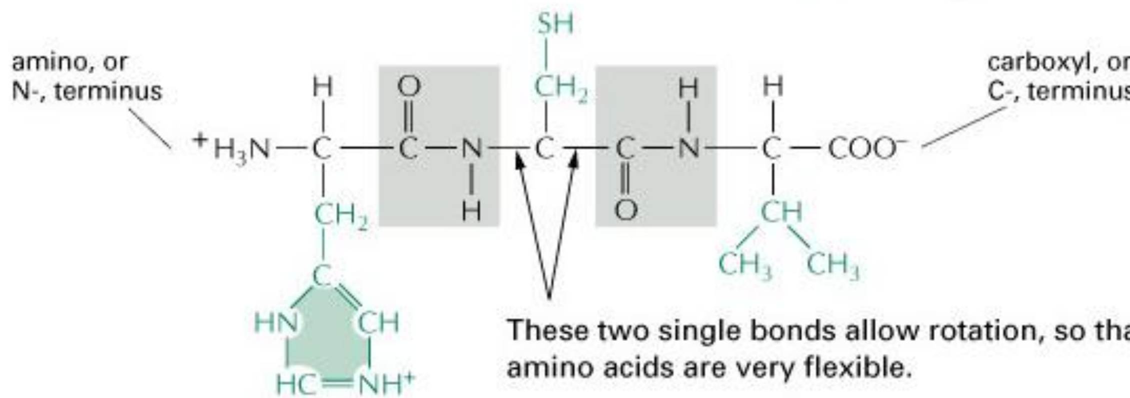
PEPTIDE BONDS

Amino acids are commonly joined together by an amide linkage, called a peptide bond.

Peptide bond: The four atoms in each *gray box* form a rigid planar unit. There is no rotation around the C–N bond.



Proteins are long polymers of amino acids linked by peptide bonds, and they are always written with the N-terminus toward the left. The sequence of this tripeptide is histidine-cysteine-valine.



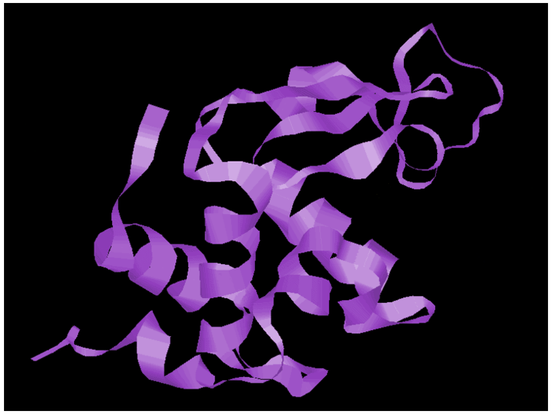
These two single bonds allow rotation, so that long chains of amino acids are very flexible.

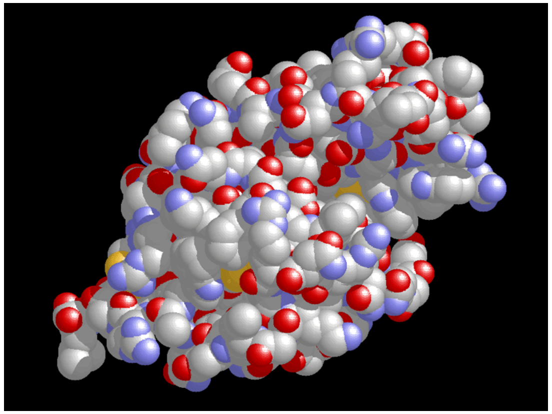
Proteins

- Proteins are the end-products of the decoding process that starts with the information in the cell's hereditary material.
- This information is required to arrange amino acids into particular sequences in proteins.
- All the information necessary for a protein molecule to achieve its complex architecture is contained within the amino acid sequence of its polypeptide chain(s).
- The **shape** of a protein is very important because it determines the protein's function.

Proteins

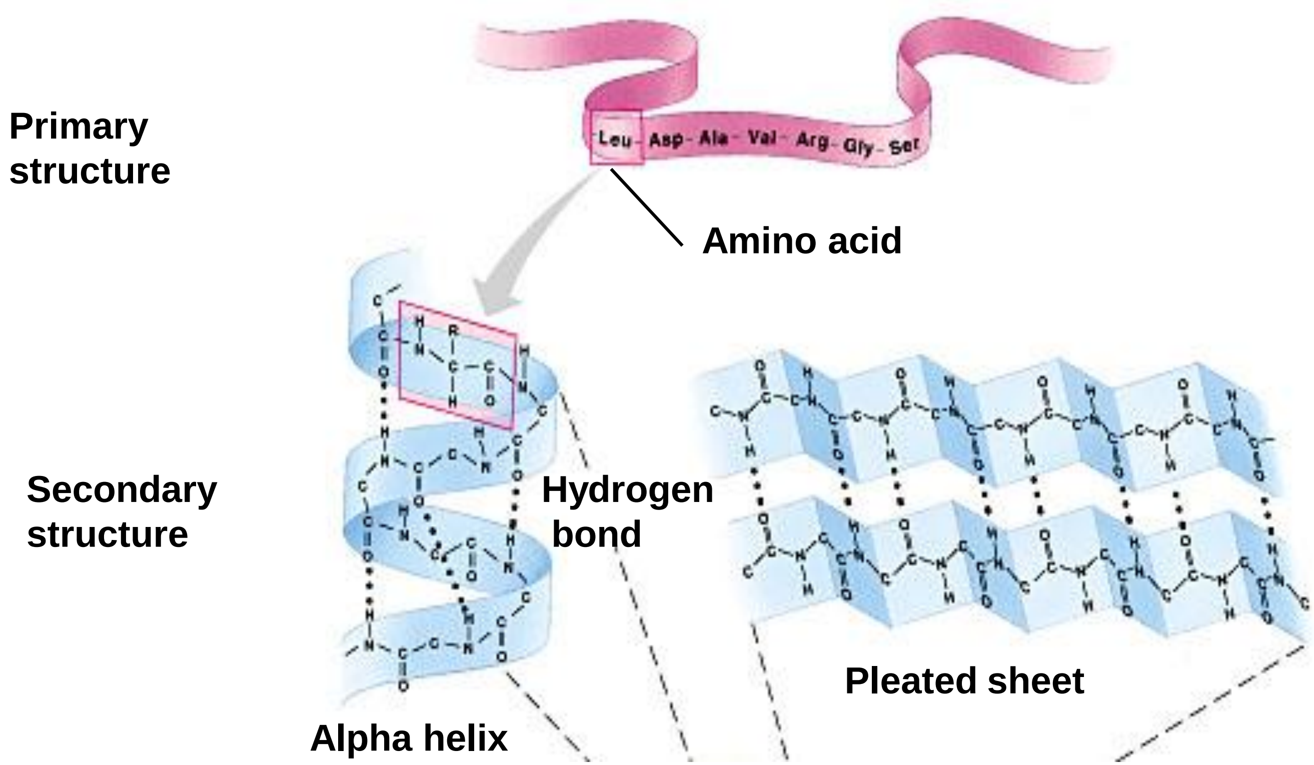
- A protein, such as lysozyme, consists of polypeptide chains folded into a unique shape
  - The shape determines the protein's function
  - A protein loses its specific function when its polypeptides unravel





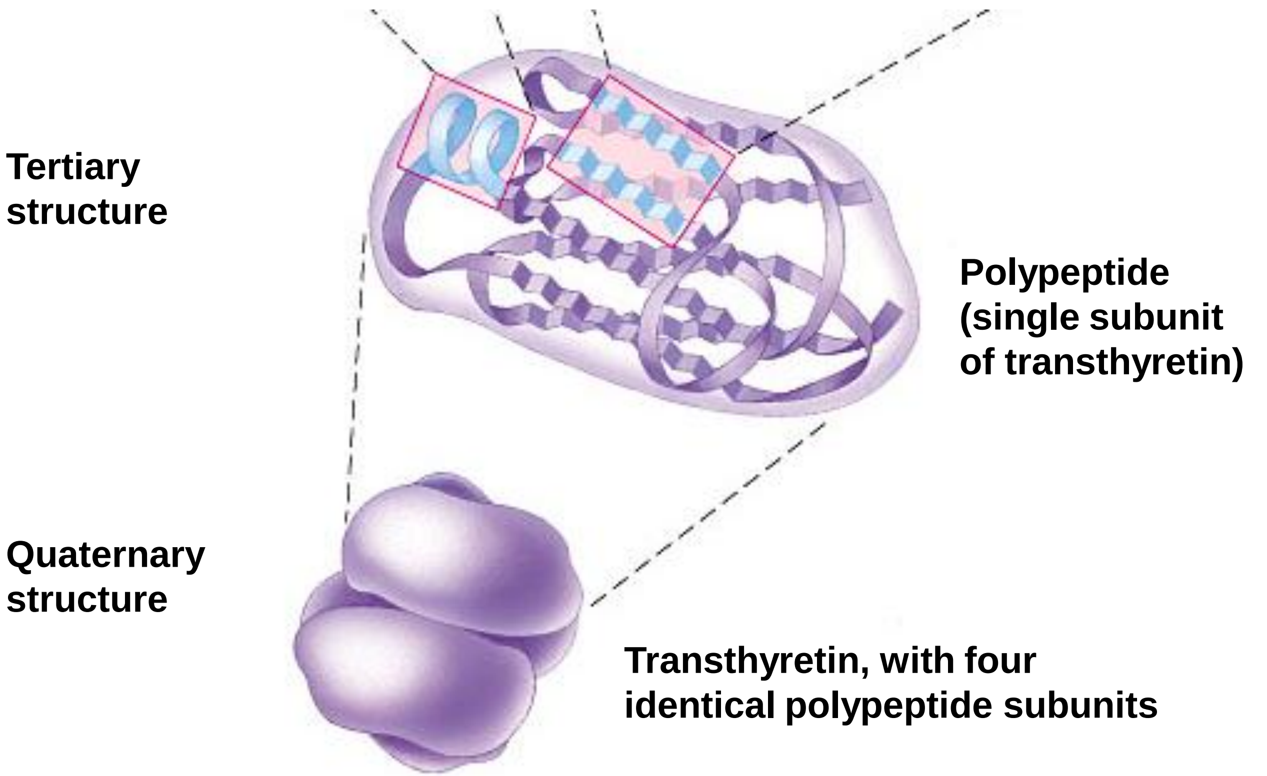
Proteins

- A protein's primary structure is its amino acid sequence
- Secondary structure is polypeptide coiling or folding produced by hydrogen bonding



Proteins

- Tertiary structure is the overall shape of a polypeptide
- Quaternary structure is the relationship among multiple polypeptides of a protein



Proteins

- Owing to their structural diversity, proteins carry out a diverse array of functions in the cell, such as catalysis, defense, transport of substances, motion, and regulation of cell and body functions.
- Proteins do not represent a main energy source (though under certain conditions they can be catabolised to supply energy).
- The heat of combustion for protein averages **5.65 kcal** per gram.

Proteins

Functional class	Description	Examples
Enzymes	Act as catalysts that accelerate the rates of biological reactions	Amylase Trypsin
Control and regulatory proteins	Promote or inhibit the activity of other cellular molecules	Insulin *lac* repressor
Transport proteins	Function to transport specific substances from one place to another	Haemoglobin Glucose transporter
Storage proteins	Hold amino acids and other substances in stored form	Ovalbumin Casein
Contractile and motile proteins	Provide cells with unique capabilities for movement	Actin Tubulin
Structural or supportive proteins	Provide strength and protection to cells and tissues	Keratin Collagen

Proteins

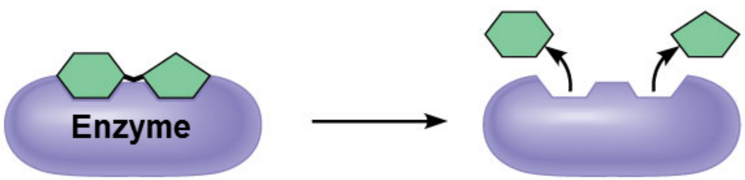
Functional class	Description	Examples
Scaffold or adaptor proteins	Recognise and bind certain structural elements in other proteins	Shc Stat
Protective and exploitative proteins	Have biologically active role in cell defense, protection, or exploitation (in contrast to the passive protective nature of some structural proteins)	Immunoglobulins Fibrin Snake or bee venom Antifreeze proteins
Exotic proteins	Different functions compared to the other classifications	Monellin- sweetener Resilin- movement of wings

Proteins

Enzymatic proteins

Function: Selective acceleration of chemical reactions

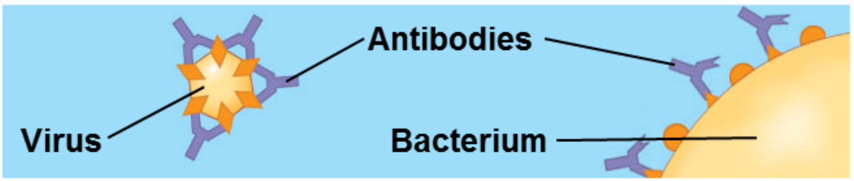
Example: Digestive enzymes catalyze the hydrolysis of bonds in food molecules.



Defensive proteins

Function: Protection against disease

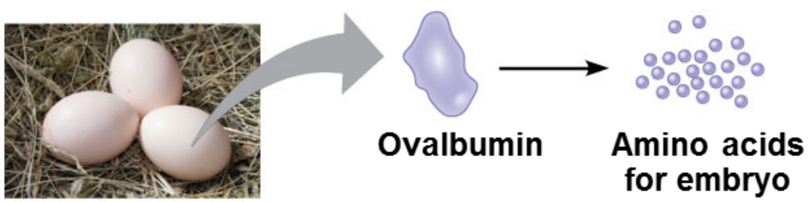
Example: Antibodies inactivate and help destroy viruses and bacteria.



Storage proteins

Function: Storage of amino acids

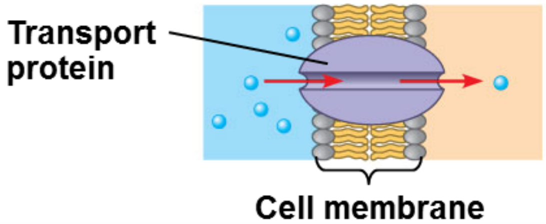
Examples: Casein, the protein of milk, is the major source of amino acids for baby mammals. Plants have storage proteins in their seeds. Ovalbumin is the protein of egg white, used as an amino acid source for the developing embryo.



Transport proteins

Function: Transport of substances

Examples: Hemoglobin, the iron-containing protein of vertebrate blood, transports oxygen from the lungs to other parts of the body. Other proteins transport molecules across cell membranes.



Proteins

Hormonal proteins

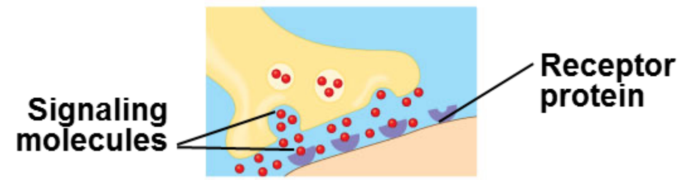
Function: Coordination of an organism's activities

Example: Insulin, a hormone secreted by the pancreas, causes other tissues to take up glucose, thus regulating blood sugar concentration

Receptor proteins

Function: Response of cell to chemical stimuli

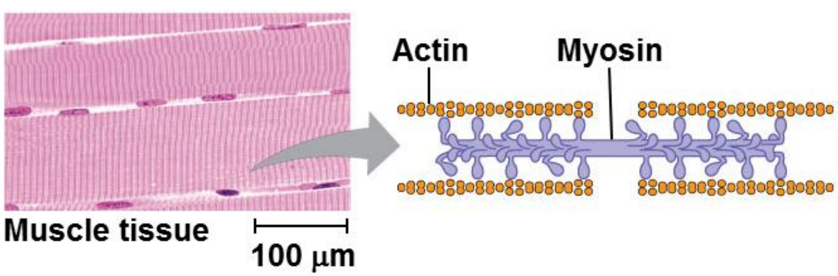
Example: Receptors built into the membrane of a nerve cell detect signaling molecules released by other nerve cells.



Contractile and motor proteins

Function: Movement

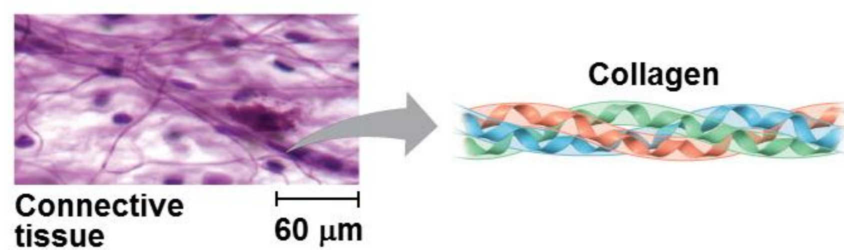
Examples: Motor proteins are responsible for the undulations of cilia and flagella. Actin and myosin proteins are responsible for the contraction of muscles.



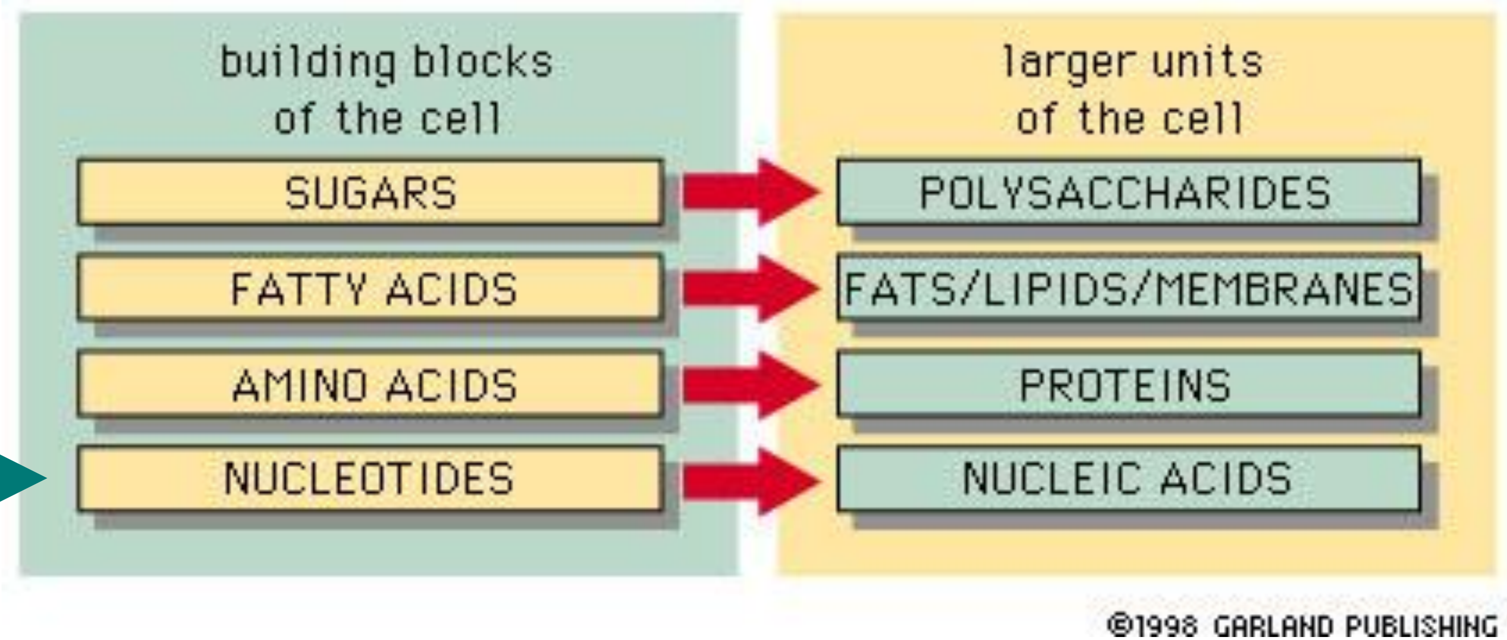
Structural proteins

Function: Support

Examples: Keratin is the protein of hair, horns, feathers, and other skin appendages. Insects and spiders use silk fibers to make their cocoons and webs, respectively. Collagen and elastin proteins provide a fibrous framework in animal connective tissues.



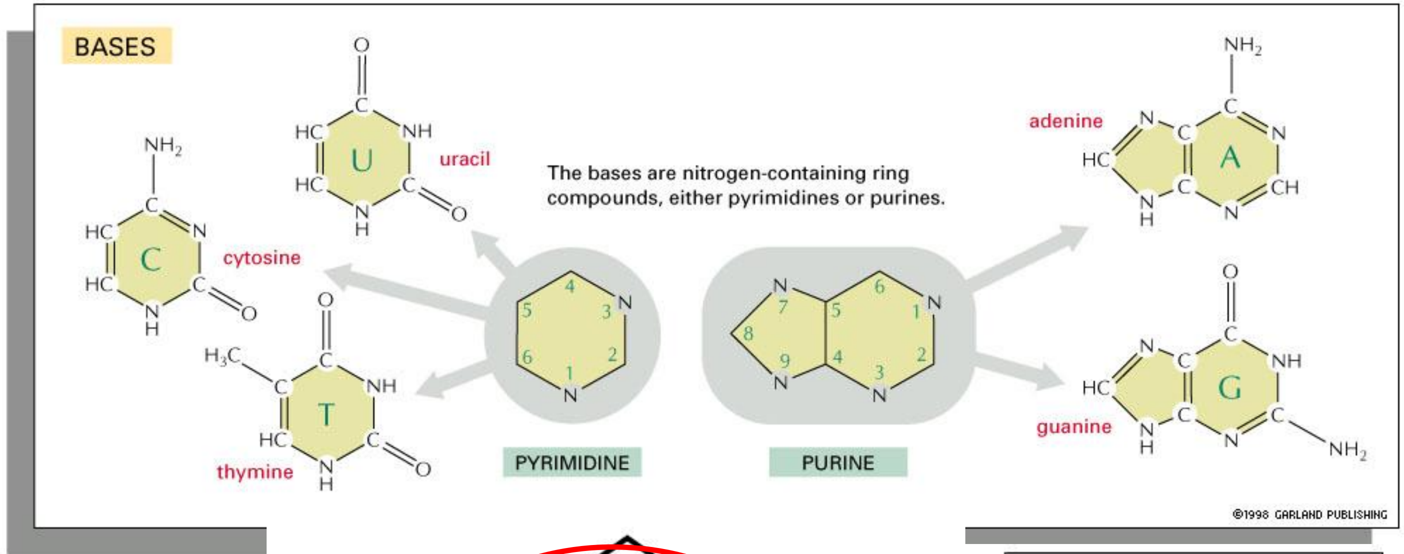
The four main families of small organic molecules in cells

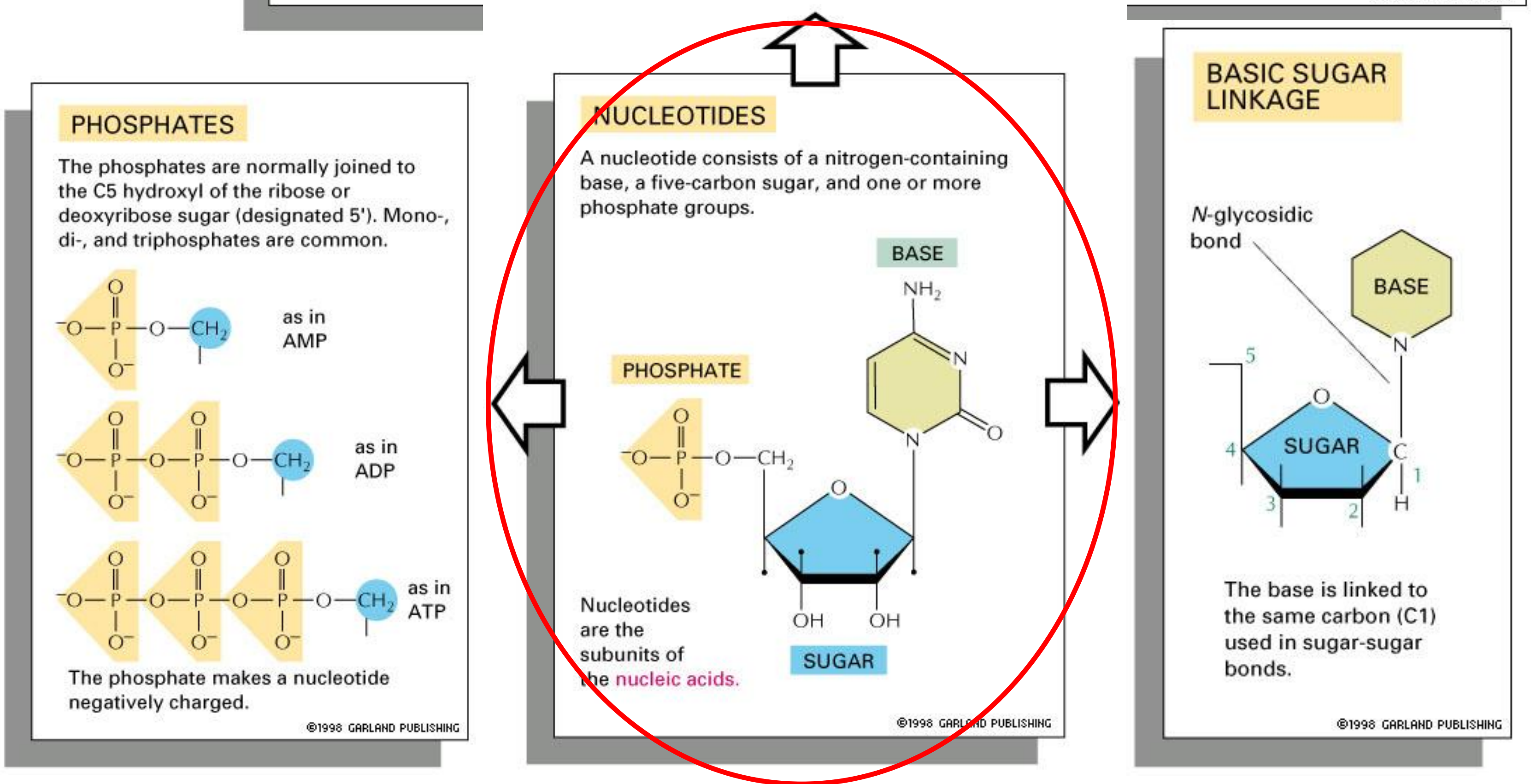


Nucleic Acids

- Nucleic acids
  - **Store**
  - **Transmit**
  - **express** genetic information
- There are two varieties of nucleic acids:
  - **deoxyribonucleic acid (DNA)**
  - **ribonucleic acid (RNA)**.
- Both nucleic acids are long polymers of repeating building blocks called **nucleotides**.

•Each nucleotide consists of three components: a five-carbon **sugar**; a **phosphate group**; and an organic nitrogen-containing **base**.





Nucleic Acids

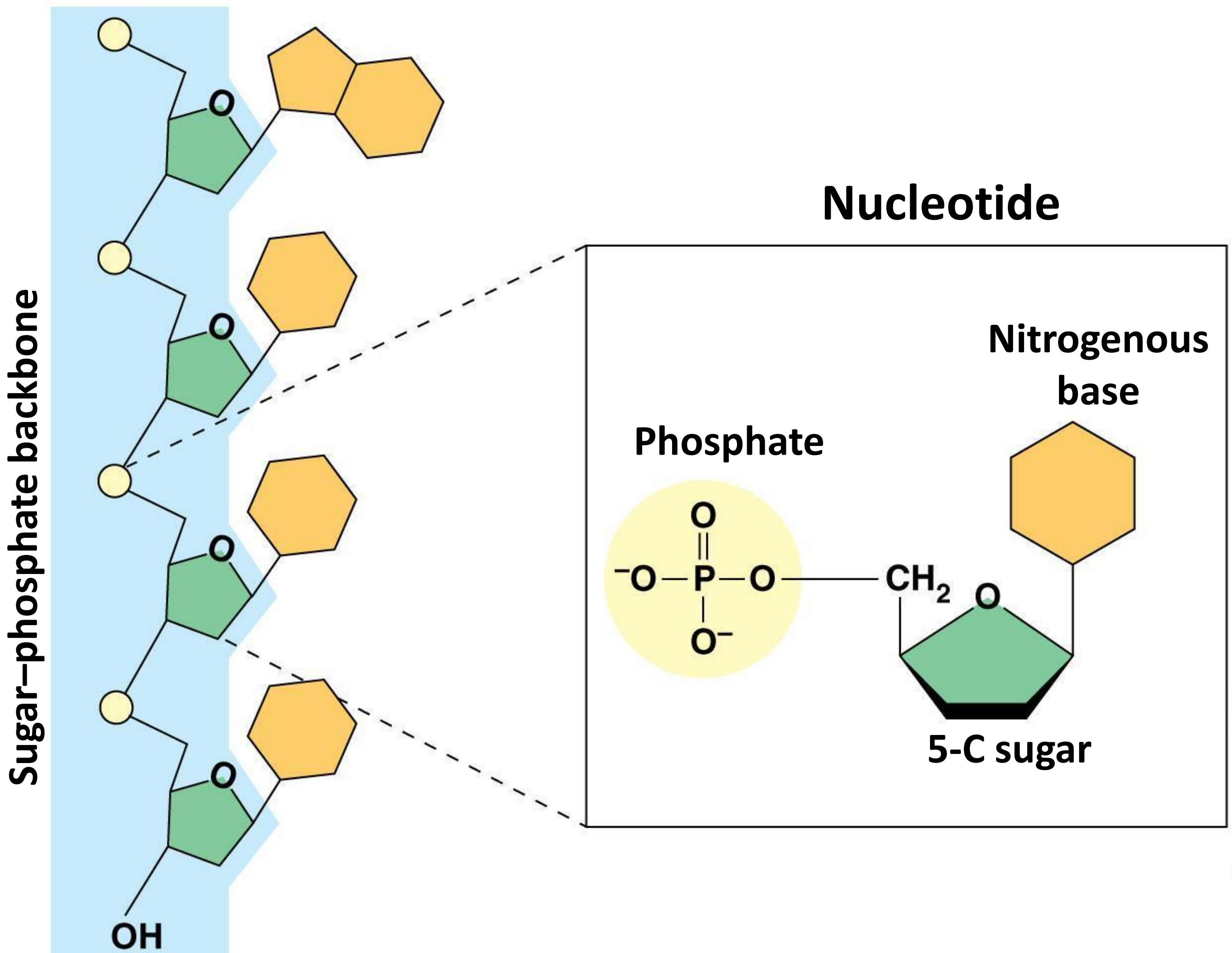
- In DNA the sugar is **deoxyribose** while in RNA it is **ribose**.
- It is the phosphate group that is involved in linking the nucleotides together by a covalent bond in DNA.
- The **backbone** of a polypeptide is a chain of alternating phosphate–sugar–phosphate–sugar molecules, and the nitrogenous bases branch off the side of this backbone.
- A DNA molecule has two polynucleotides spiralling around an imaginary axis, forming a **double helix**.

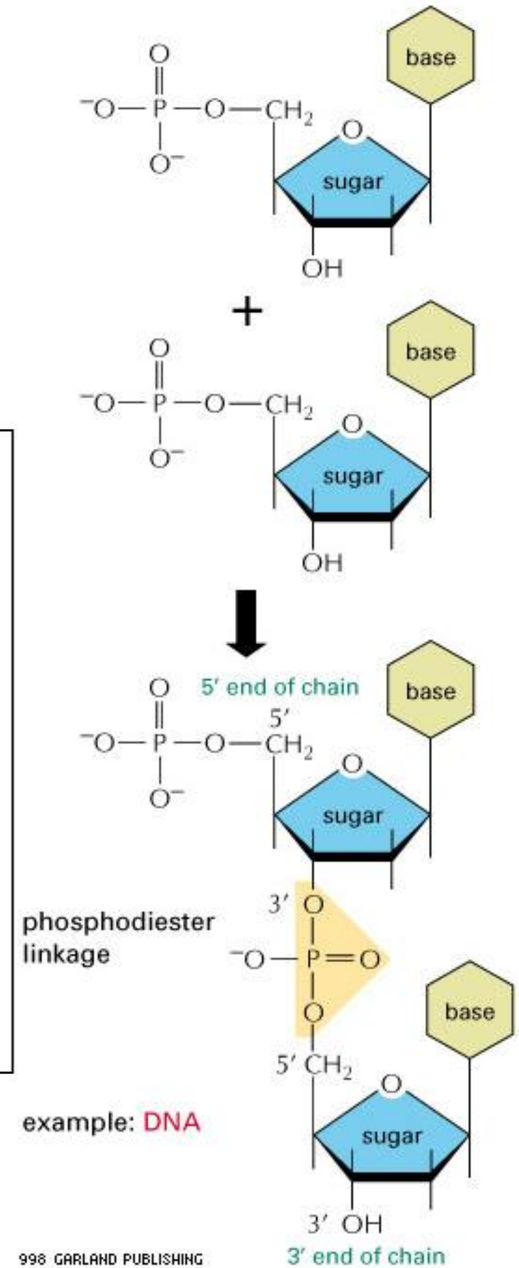
Nucleic Acids

- It is the base part that is responsible for the differences in the nucleotides.
- The bases involve **adenine** (**A**), **cytosine** (**C**), **guanine** (**G**), **thymine** (**T**), and **uracil** (**U**).
- The specific **sequence** of nucleotide bases in DNA forms the molecular basis of the storage of hereditary information.
- The ability of the bases in different nucleic acid molecules to recognise and pair with each other by hydrogen-bonding (**base pairing**) underlies the transmission and expression of hereditary information.

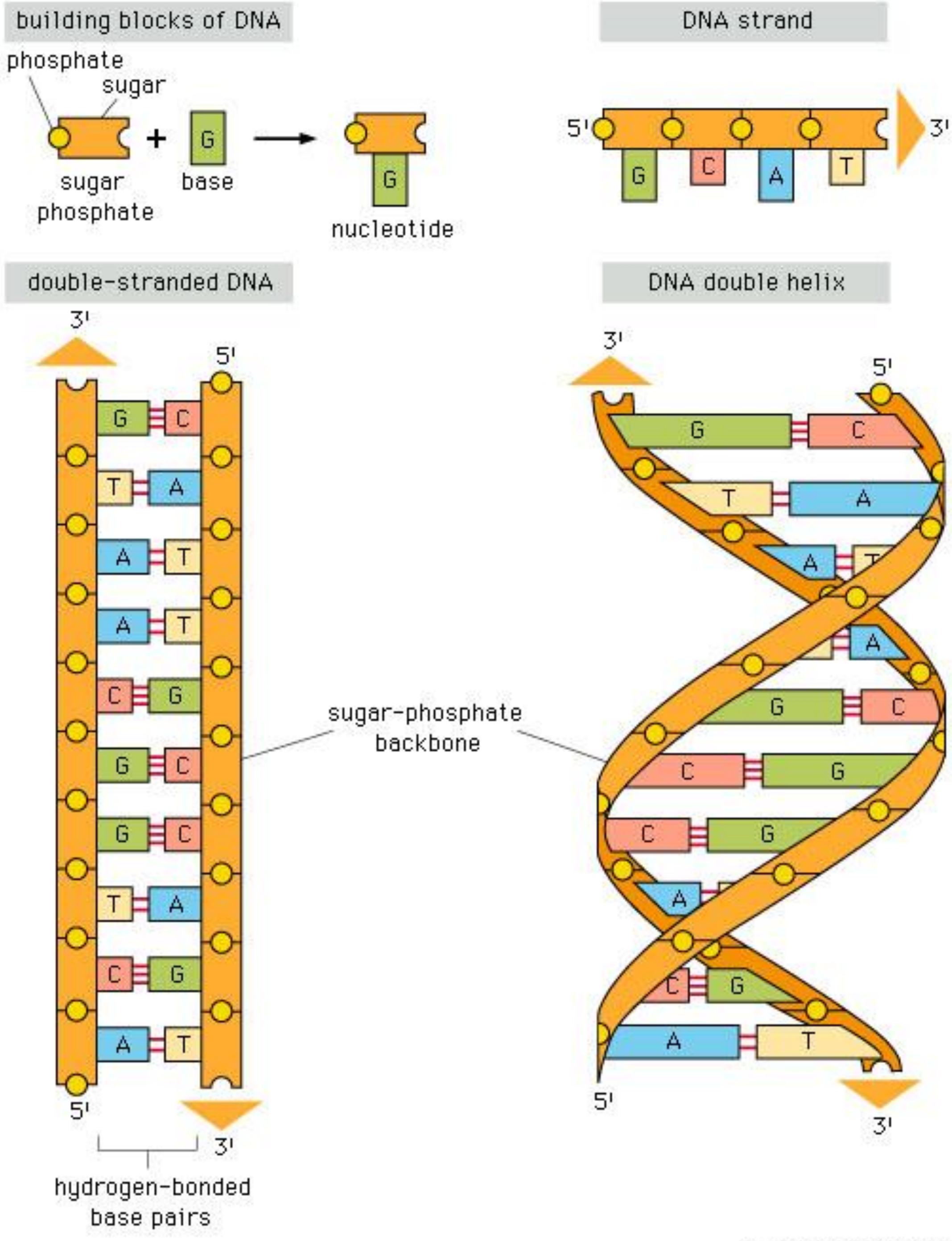
Nucleic Acids

Polypeptide chain

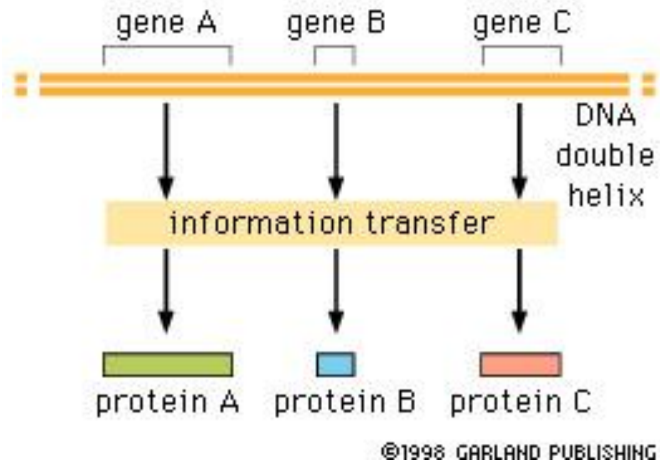


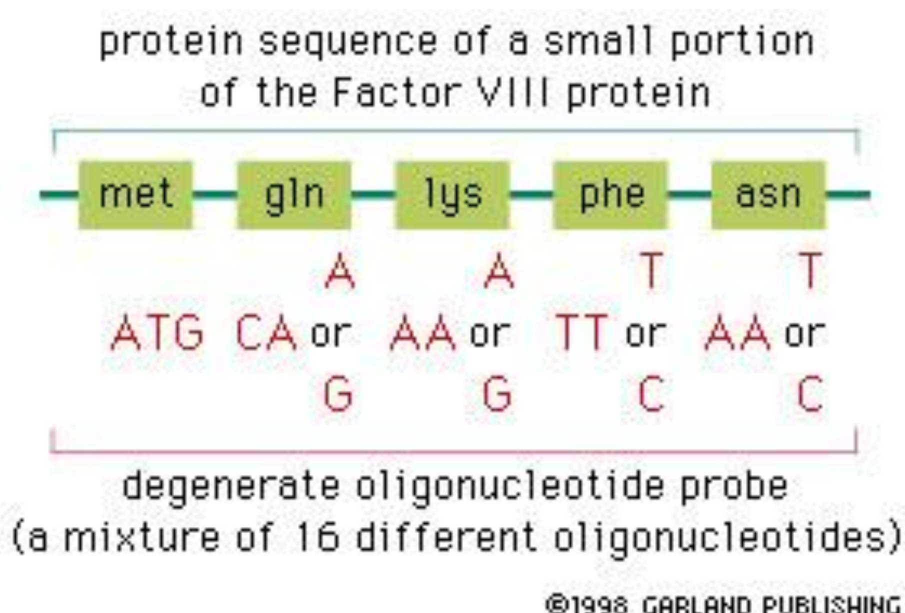


DNA and its building blocks



“Genes” encode proteins



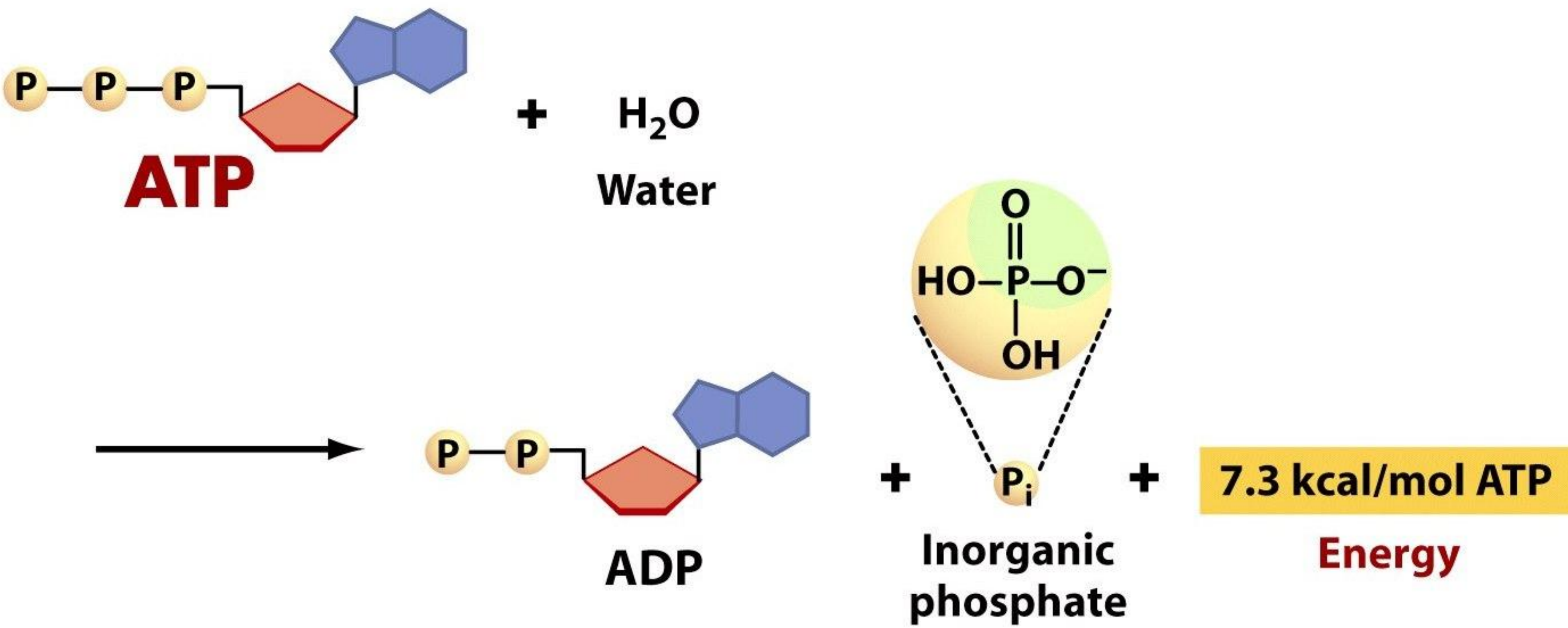


Nucleic Acids

- In addition to serving as subunits of DNA and RNA, nucleotide bases play other critical roles in the life of a cell.

- For example, adenine is a key component of the molecule **adenosine triphosphate** (**ATP**), the energy currency of the cell.

Nucleic Acids



Summary

- Carbon forms the skeleton of biomolecules that can be classified into four major groups: carbohydrates, lipids, proteins, and nucleic acids.
- Within each of the four major groups of biomolecules are subgroups, classified according to structure or functionality.
- The cell is an assembly of all these small and large biomolecules that take part in the reactions necessary for life.
- Carbohydrates consist of sugars and sugar polymers.
- Carbohydrates function as main energy sources for cell metabolism, structural components of cell walls and of other compounds such as nucleic acids, and recognition molecules.

Summary

- Lipids are a broad group of water-insoluble compounds that include triglycerides, phospholipids, steroids, and special-purpose lipids.
- Lipids function as concentrated energy sources for cell metabolism, structural components of cell membranes, and regulatory molecules.
- Proteins are polymers in the cell and represent the end-products of the expression of the cell’s hereditary information.
- Proteins come in a variety of three-dimensional shapes, each made to serve some particular purpose in the cell (such as catalysis, transport, sensing, and defence).
- Nucleic acids, DNA and RNA, are information-containing polymers that store, transmit, and express the cell’s genetic code.

Reading:

pp. 45–65 (Chapter 2)

pp. 106–117 (Chapter 2)

pp. 125–136 (Chapter 3)

*Figures are mainly obtained from Molecular Biology of the Cell, 5th Ed.