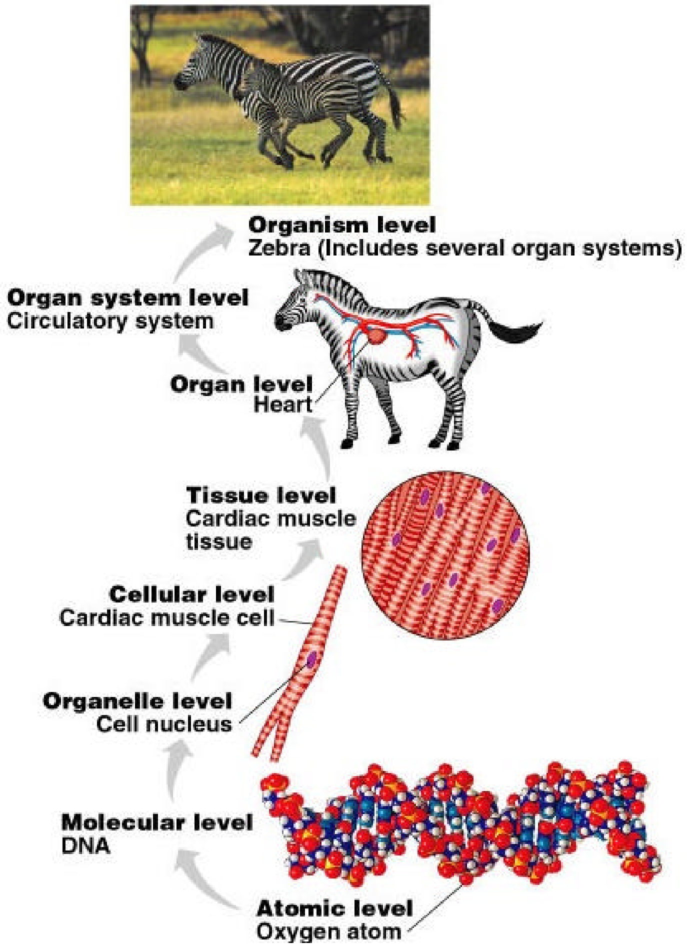
Carbon and Macromolecules

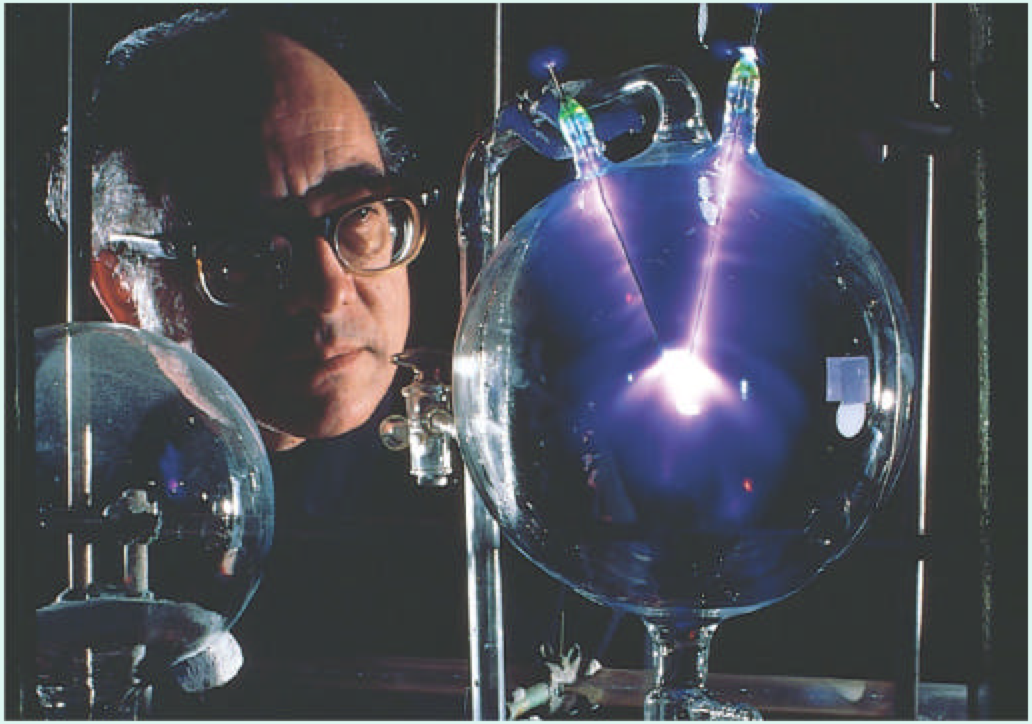
Shared Characteristics of Life

Living organisms are organized in a certain fashion

- An organism is constituted by several organ systems
- Organ systems include several organs
- Organs are made of different tissues
- A tissue is an arrangement of cells
- Cell parts are made of macromolecules
- Macromolecules are atomic arrangements



Carbon in the Beginning



Stanley Miller and his simulations of life in the primordial Earth (1953)

Naturally Occurring Elements in the Human Body

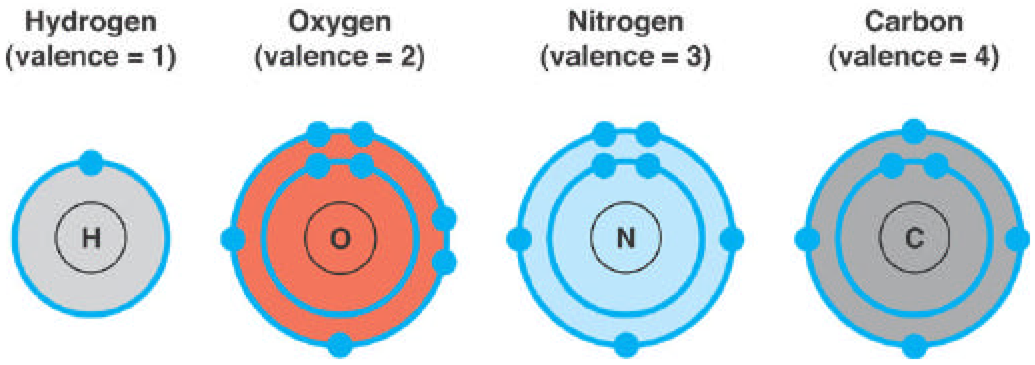
Why these elements?

Table 2.1 Naturally Occurring Elements in the Human Body

Symbol	Element	Atomic Number (See p. 34)	Percentage of Human Body Weight
O	Oxygen	8	65.0
C	Carbon	6	18.5
H	Hydrogen	1	9.5
N	Nitrogen	7	3.3
Ca	Calcium	20	1.5
P	Phosphorus	15	1.0
K	Potassium	19	0.4
S	Sulfur	16	0.3
Na	Sodium	11	0.2
Cl	Chlorine	17	0.2
Mg	Magnesium	12	0.1

Trace elements (less than 0.01%): boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), and zinc (Zn).

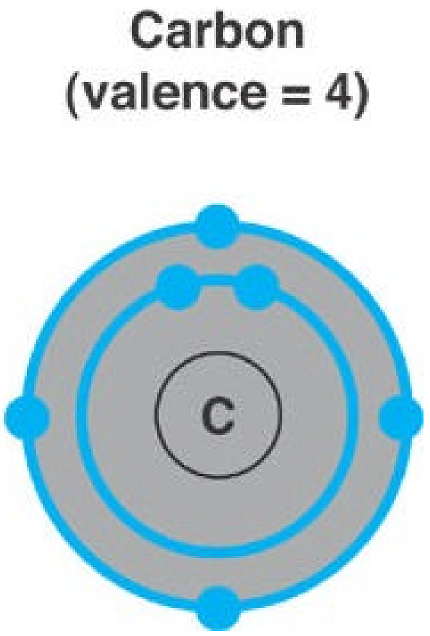
The Main Components of Macromolecules



Carbon Makes Organic Molecules

Why Carbon

- Carbon is the second most abundant element in living organisms
- Carbon can share four electrons, therefore it can bond to four additional atoms
- Carbon establishes covalent bonds (stable, high energy bonds)

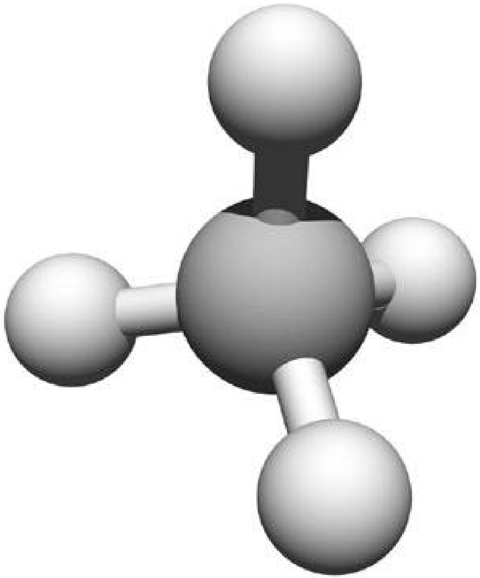


Carbon Makes Organic Molecules

Why Carbon?

- When a carbon atom establishes four single covalent bonds to other atoms, the resulting molecules is tetrahedrical

  What does that mean?



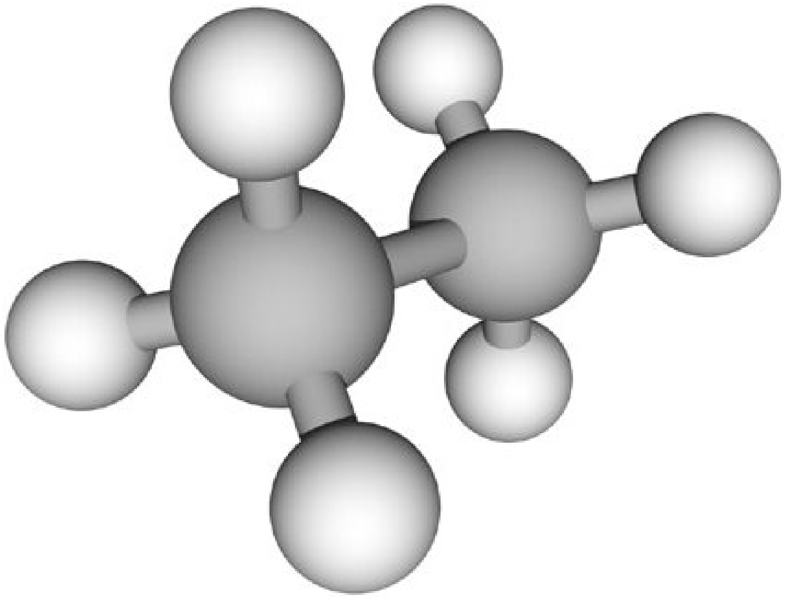
Methane, CH_4

Carbon Makes Organic Molecules

Why Carbon?

- Carbon single covalently bonded to another C atom has the ability to rotate up to 180°

    What does that mean?



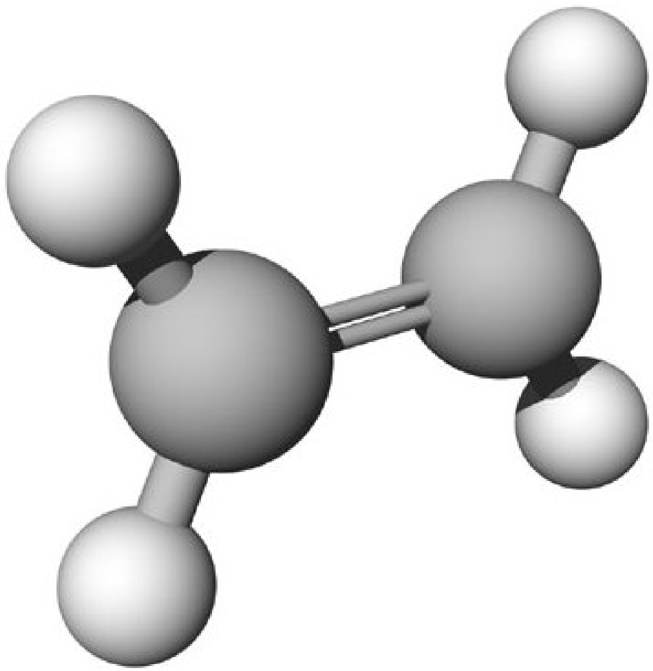
Ethane, C_2H_6

Carbon Makes Organic Molecules

Why Carbon?

- Carbon double covalently bonded with another atom of C (C=C) results in a stable, rigid bond

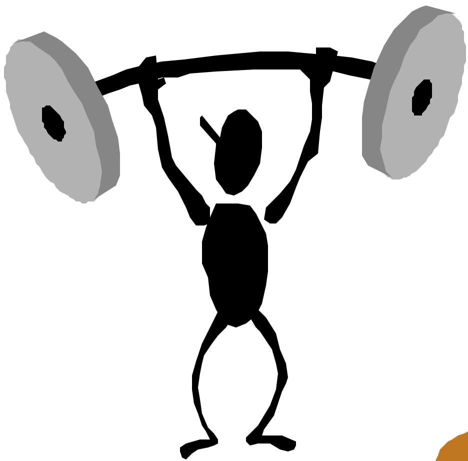
  What does that mean?

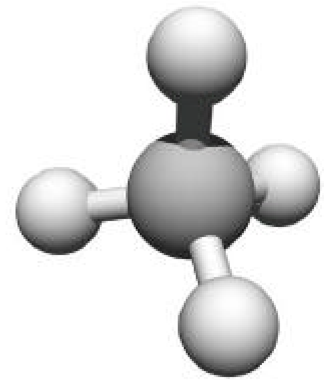


Ethene, C_2H_4

Carbon Makes Organic Molecules

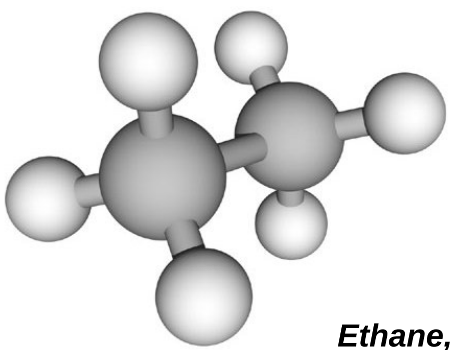
Why Carbon?



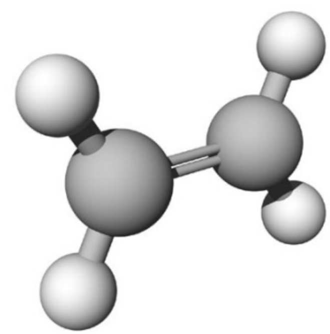


Methane, CH_4

Carbon molecules have strength, flexibility, and great versatility to chemically react with other atoms and molecules

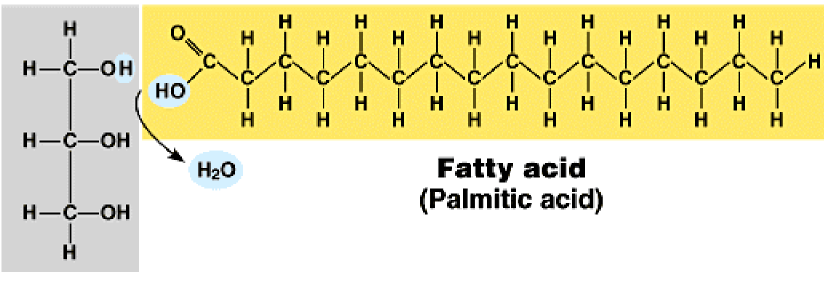


Ethane, C_2H_6

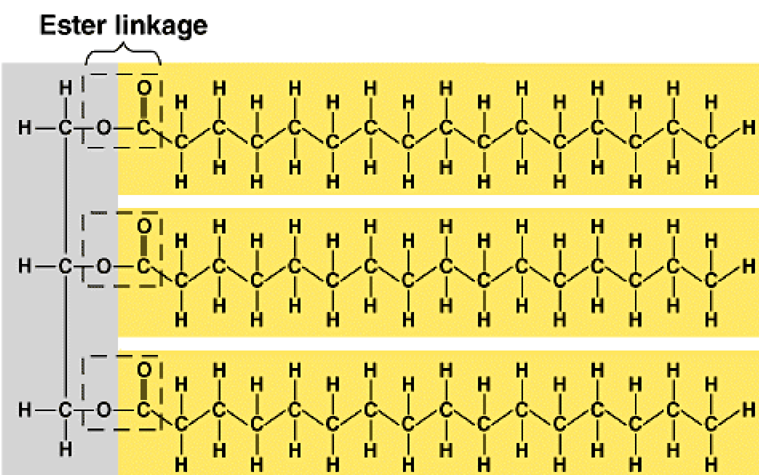


Ethene, C_2H_4

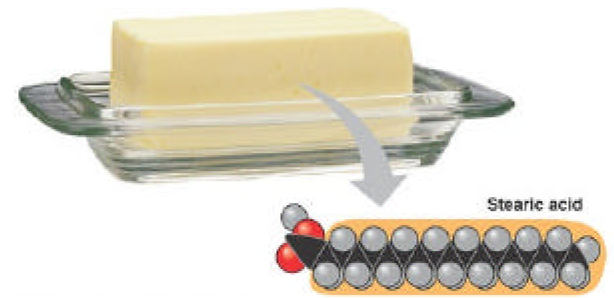
Macromolecules: Hydrocarbon Backbones and Functional Groups



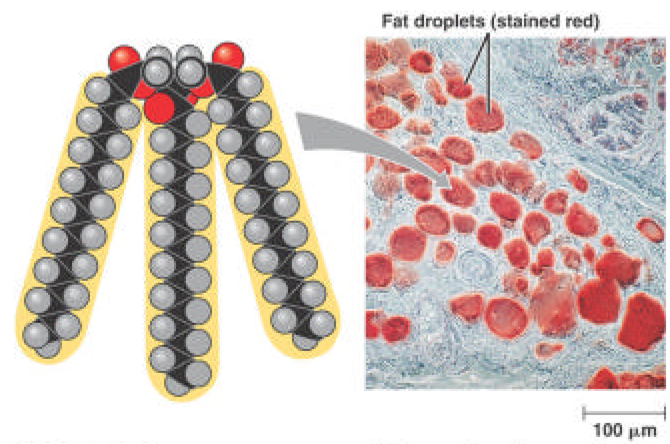
(a) Dehydration synthesis



(b) Fat molecule (triacylglycerol)



(a) Saturated fat and fatty acid



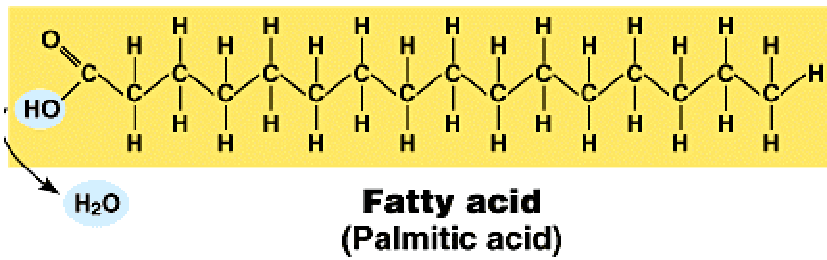
(a) A fat molecule

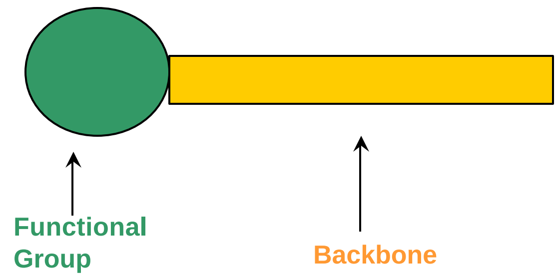
(b) Mammalian adipose cells

Categories of Macromolecules

- **Carbohydrates (sugars):** act as storage and source of energy
- **Lipids (fats):** act as storage of energy; they are components of cell membranes
- **Proteins:** perform multiple cellular functions
- **Nucleic Acids:** hold genetic message and intervene in the processing of genetic information

Macromolecules: Hydrocarbon Backbones and Functional Groups

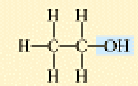
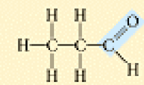
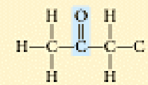
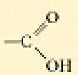
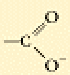
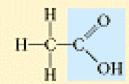
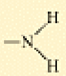
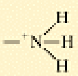
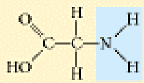
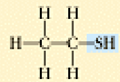
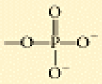
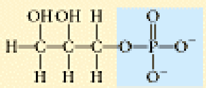




- Macromolecules are constituted by hydrocarbon backbones, which mainly provide structural stability, and by one or several functional groups. Functional groups are involved in many and diverse chemical reactions, establishing bonds with other atoms and molecules

Functional Groups

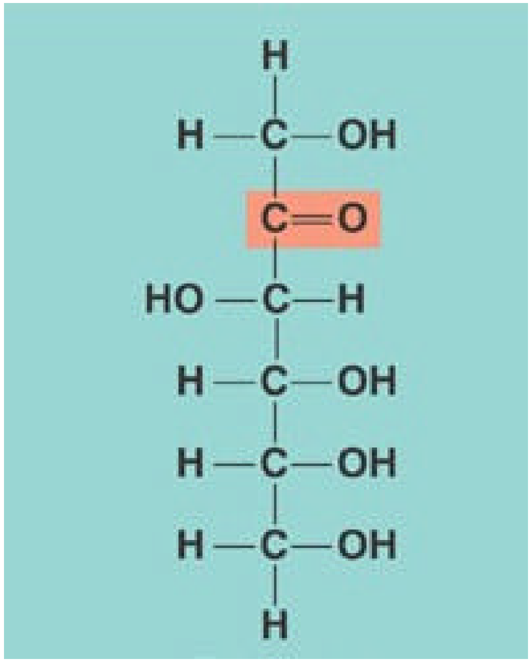
Table 4.1 Functional Groups of Organic Compounds

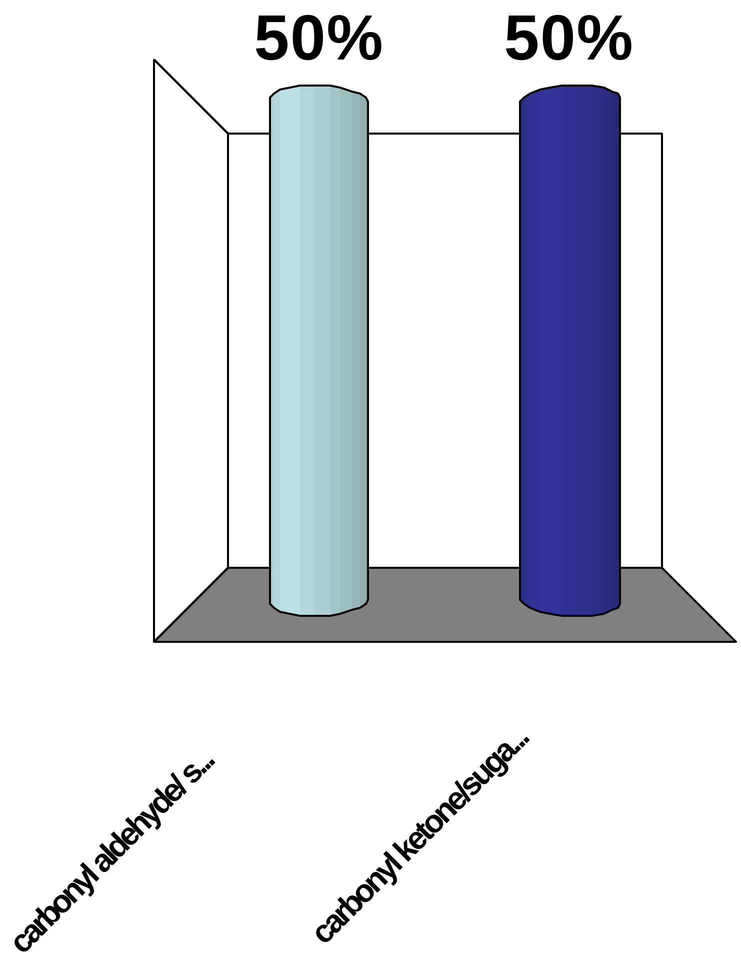
Functional Group	Formula	Name of Compounds	Example
Hydroxyl	—OH	Alcohols	 Ethanol (the drug of alcoholic beverages)
Carbonyl		Aldehydes	 Propanal
		Ketones	 Acetone
Carboxyl	 (non-ionized)  (ionized)	Carboxylic acids	 Acetic acid* (the acid of vinegar)
Amino	 (non-ionized)  (ionized)	Amines	 Glycine* (an amino acid)
Sulfhydryl	—SH	Thiols	 Ethanethiol
Phosphate		Organic phosphates	 Glycerol phosphate

*The ionized forms of the carboxyl and amino groups prevail in cells. However, acetic acid and glycine are represented here in their non-ionized forms.

This functional group is a ____ and therefore the molecule is a ____.

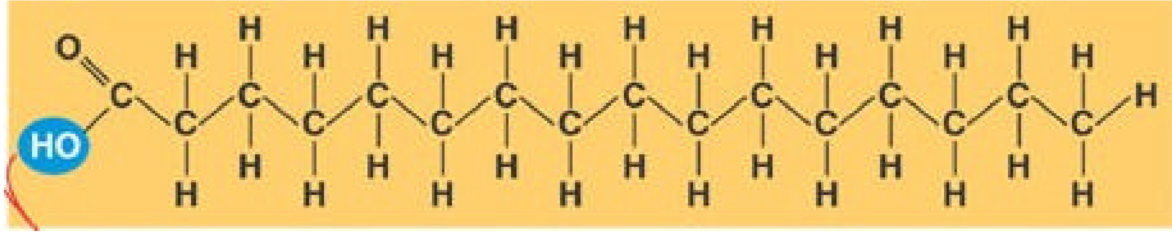
1. carbonyl aldehyde/ sugar (aldehyde)
2. carbonyl ketone/sugar (ketone)

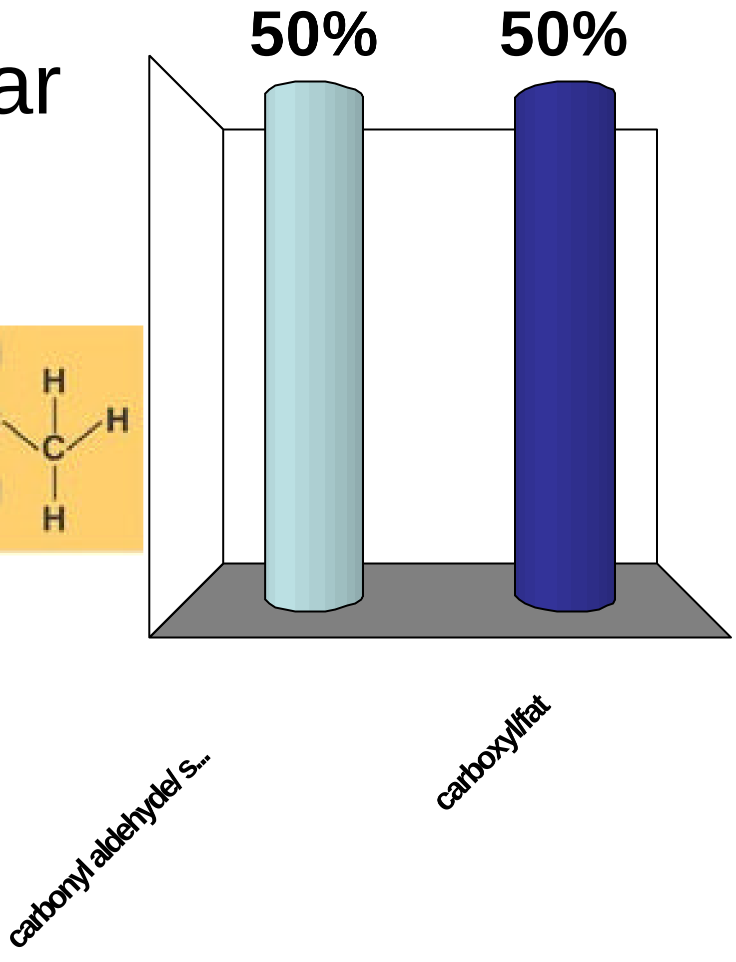




This functional group is a ____ and therefore the molecule is a ___.

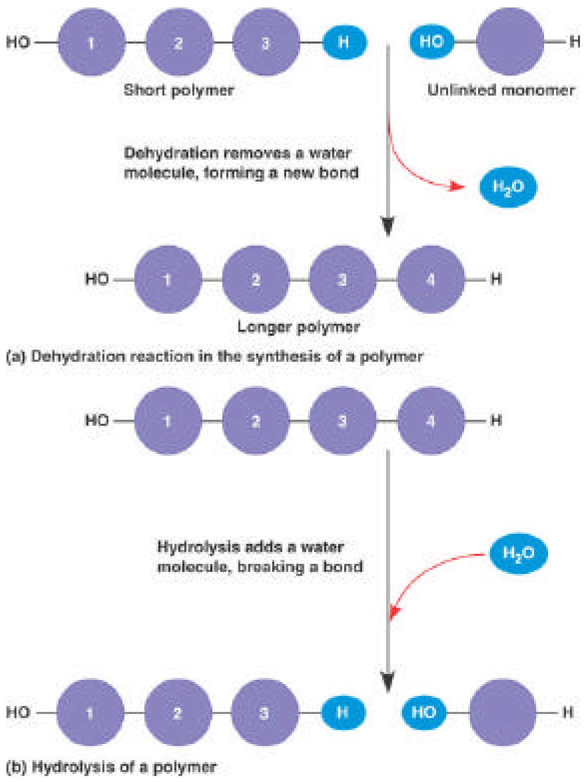
1. carbonyl aldehyde/ sugar
2. carboxyl/fat





Macromolecules: How Are They Built?

- Through *dehydration (or condensation) reactions*, *monomers* are joint together to form *polymers*
- *Hydrolysis reactions* break down polymers into monomers

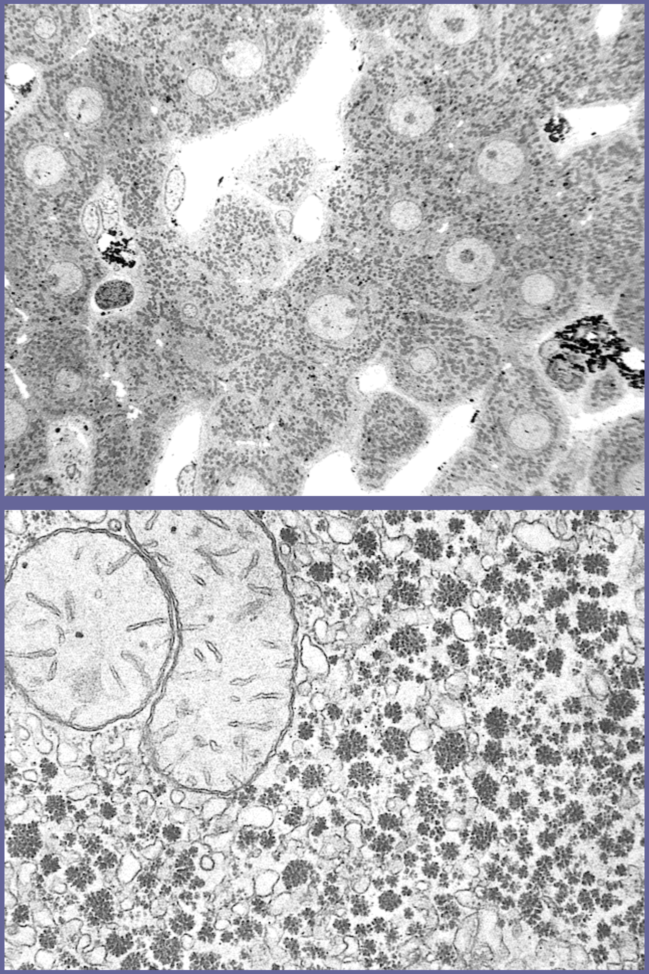


Carbohydrates




Carbohydrates

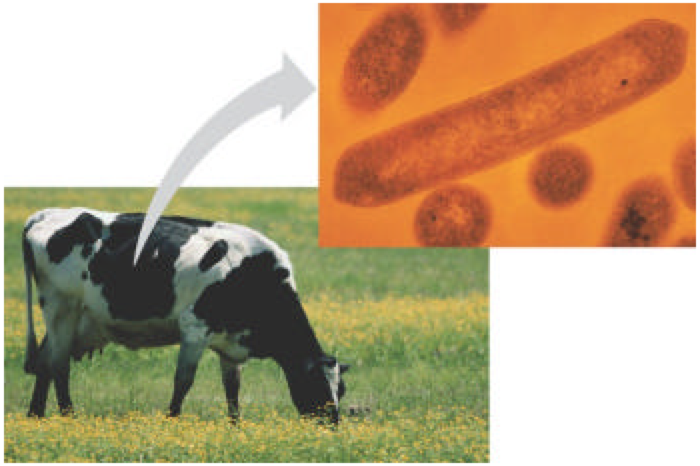
- Carbohydrates are used by cells as the main source of energy. Chemical energy is stored in carbohydrates, which is dispensed when needed
- In carbohydrates the functional group may be a *carbonyl aldehyde* or *carbonyl ketone*



Electron micrographs of glycogen containing liver cells

Carbohydrates

- Carbohydrates also perform structural roles: they make the cell wall of plant cells (cellulose), and the exoskeleton of some animals (chitin)

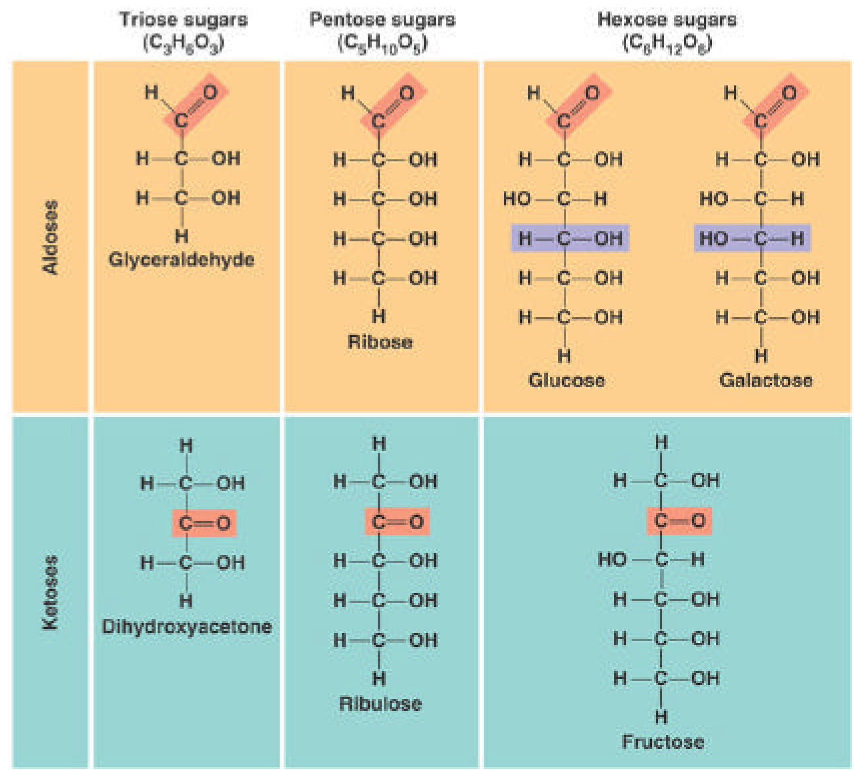


(b) Chitin forms the exoskeleton of arthropods. This cicada is molting, shedding its old exoskeleton and emerging in adult form.

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

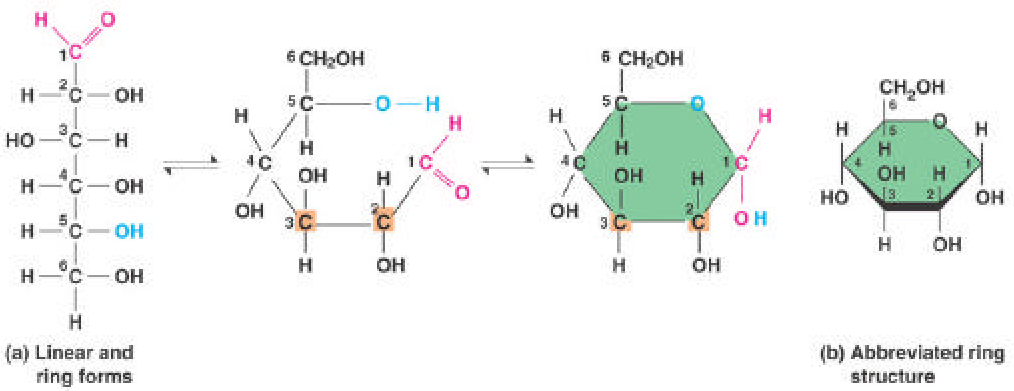
Carbohydrates: Structure Monosaccharides

- Depending on the functional group they harbor, carbohydrates fall into two categories: *aldoses* (carbonyl aldehyde) and *ketoses* (carbonyl ketone)
- Depending on the number of sugar units they have, carbohydrates are *monosaccharides, disaccharides,* or *polysaccharides*
- Monosaccharides are made of <u>one</u> sugar unit



Monosaccharides

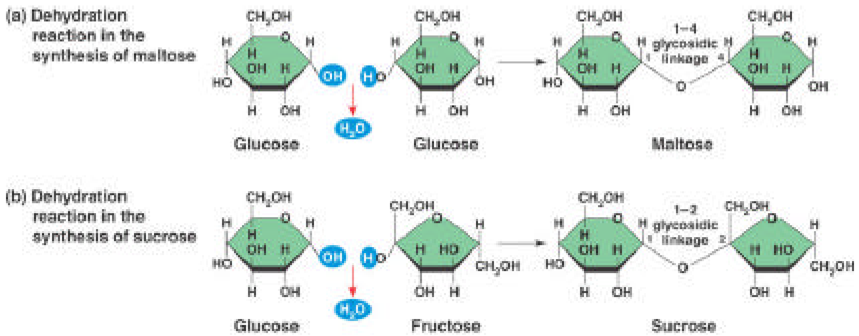
Carbohydrates: Structure
Linear and Ring Forms



- In aqueous solutions, glucose molecules, as well as most other sugars, form rings
- In a ring, each corner represents a carbon

Carbohydrates: Structure Disaccharides

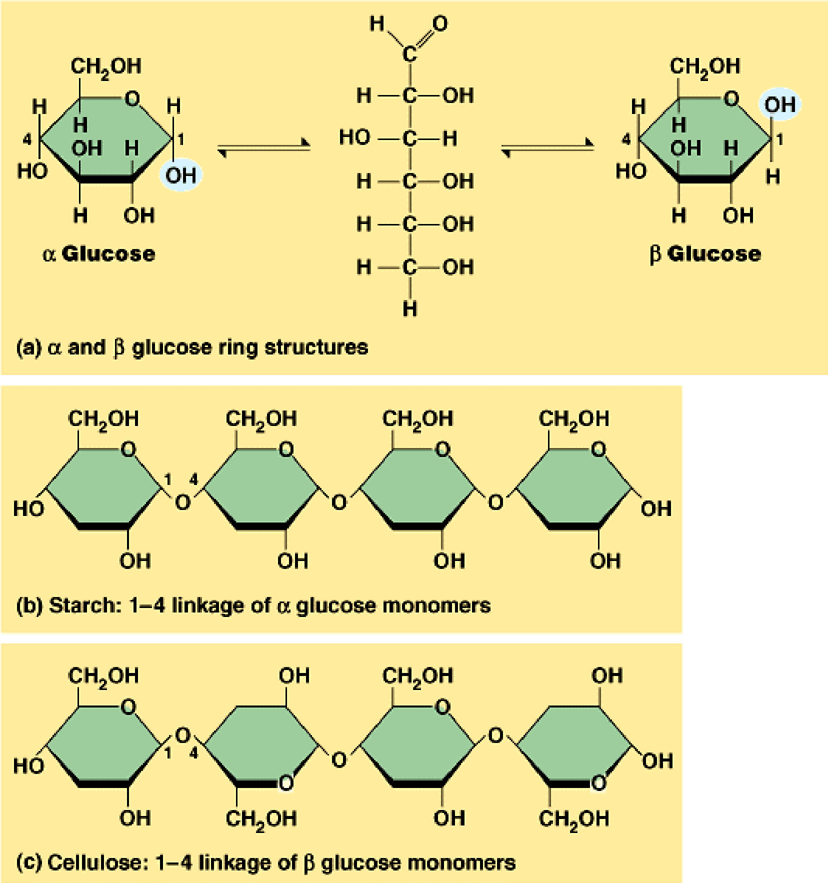
- A disaccharide consists of two monosaccharides joined by a *glycosidic linkage,* a covalent bond formed between two monosaccharides through a dehydration reaction



Lactose

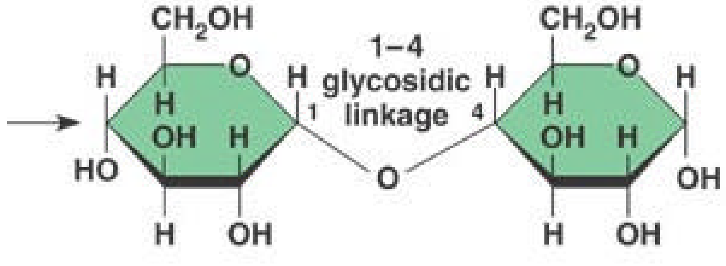
Carbohydrates: Structure Polysaccharides

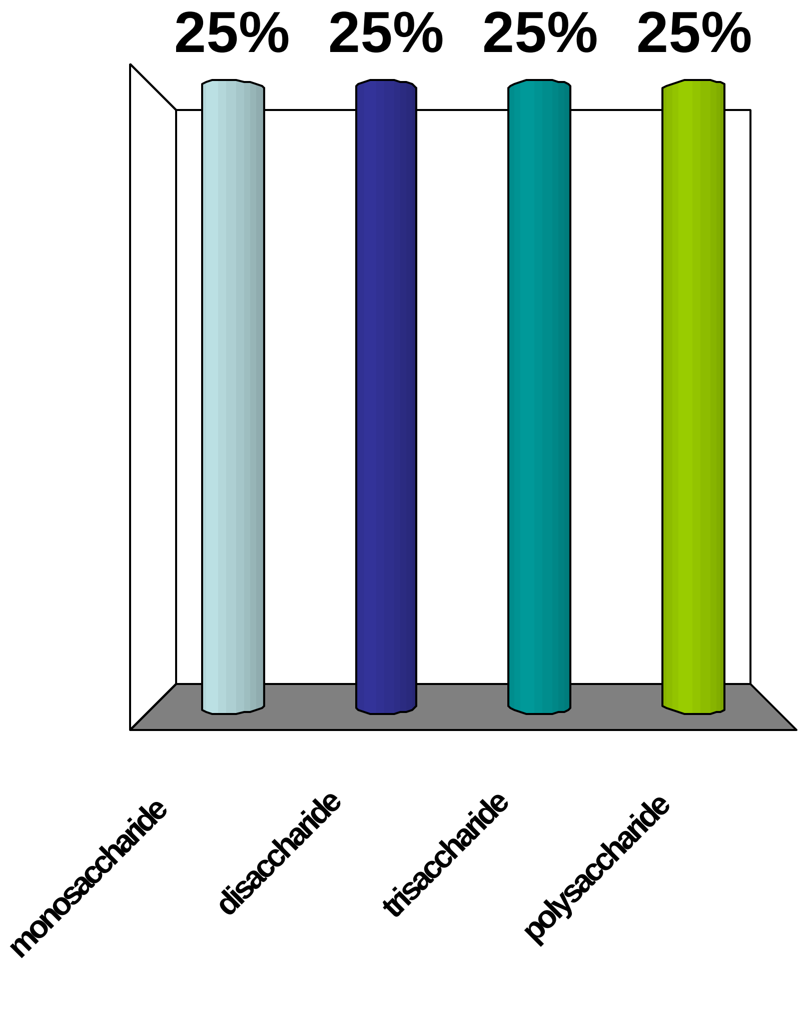
- Large chains of sugar units
- The majority of sugars found in nature exist in the form of polysaccharides



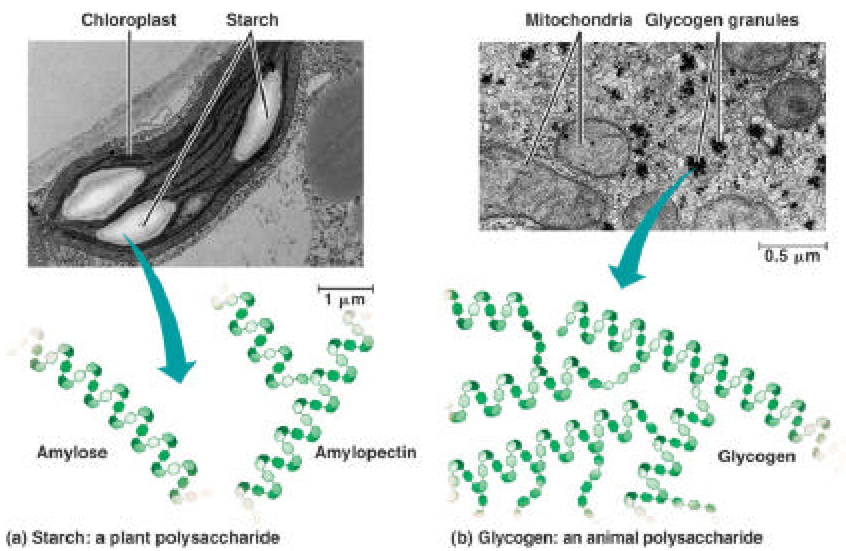
This molecule is a …

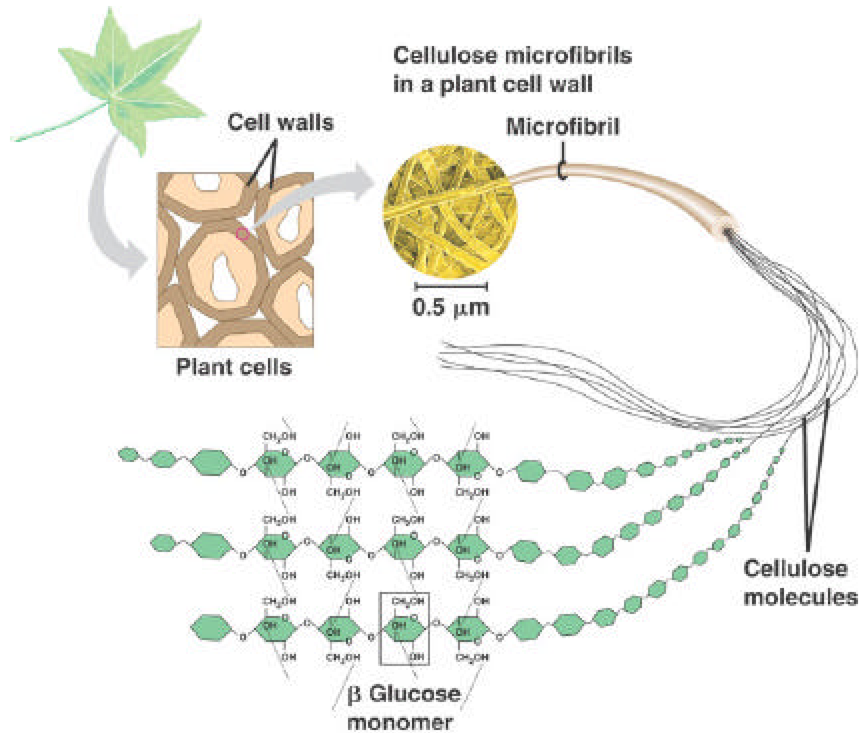
1. monosaccharide
2. disaccharide
3. trisaccharide
4. polysaccharide





Carbohydrates: Structure Polysaccharides

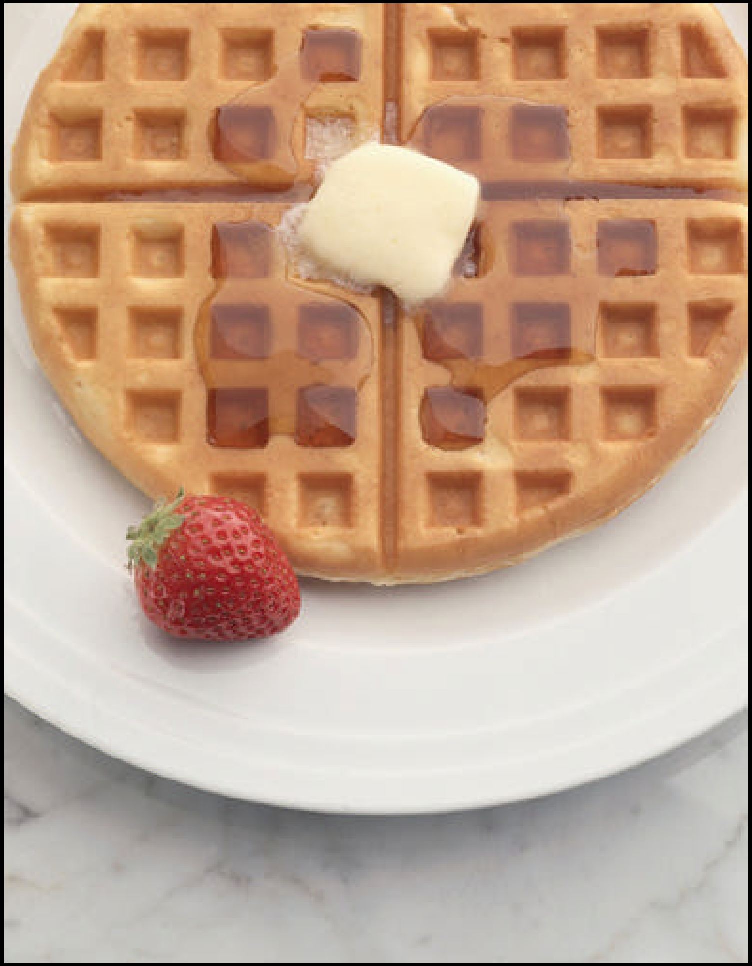




Starch (plants) and glycogen (animals) function as energy storage polysaccharides

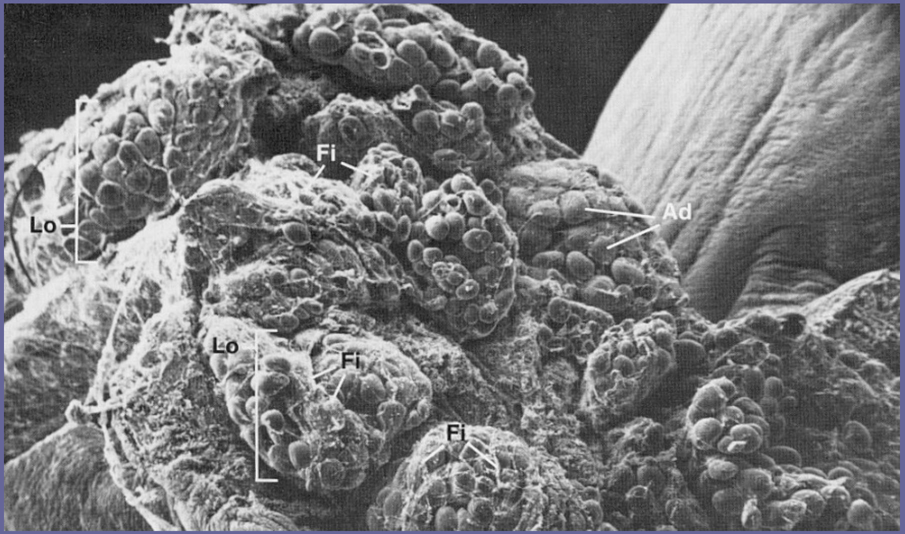
Cellulose (plants) functions as a structural polysaccharide

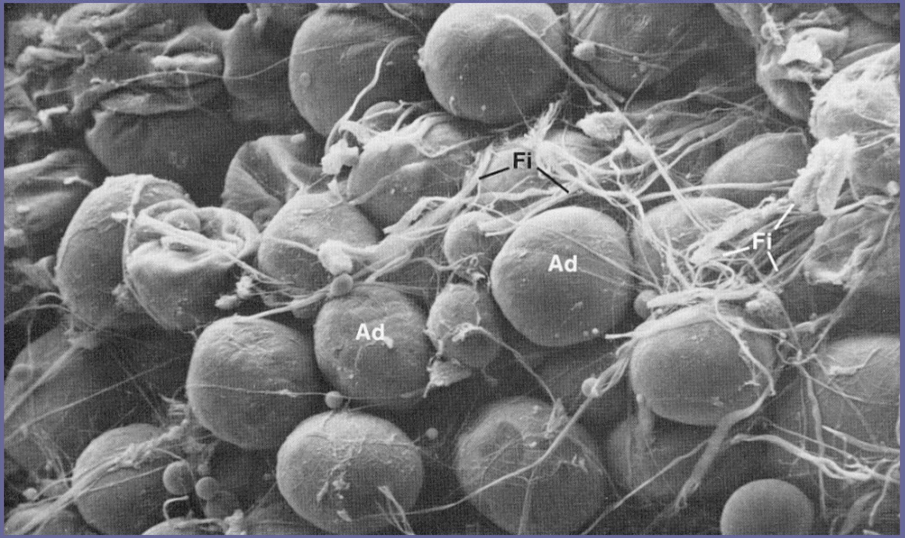
Lipids



Lipids

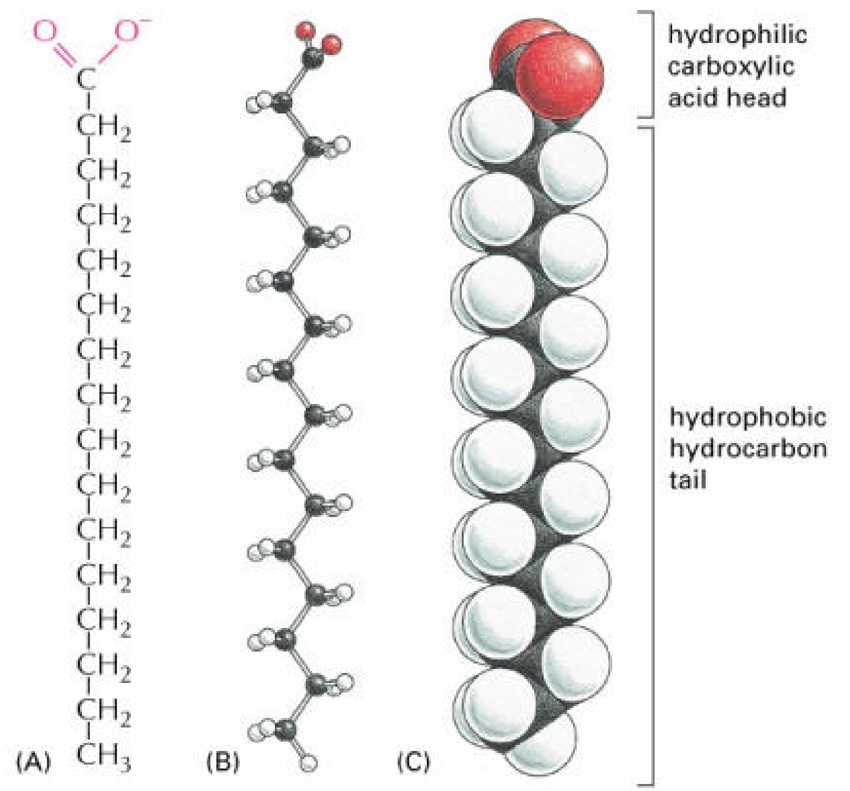
- Lipids are organic molecules insoluble in water. They constitute the main reservoir of stored energy
- Fats also make cell membranes and coatings (i.e. fruit coats)
- The basic structure of fats is a hydrocarbon backbone with a *carboxyl* group attached
- *Fats (fatty acids and triglycerides), phospholipids, and steroids* are the three main categories of lipids



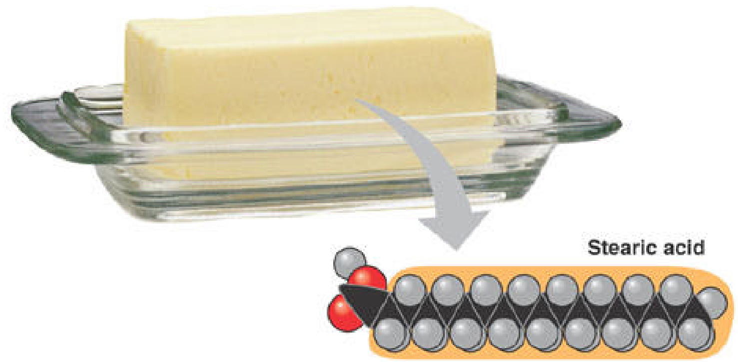


Lipid Structure
Fatty Acids

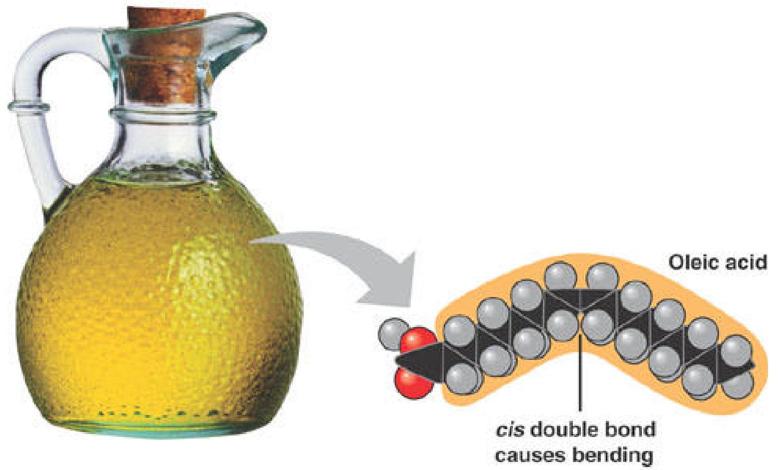
- A fatty acid molecule has two distinct regions: a long, not very reactive, *hydrophobic* hydrocarbon chain, and a carboxylic acid group, extremely reactive and *hydrophilic*
- Molecules such as fatty acids — with two distinct hydrophobic and hydrophilic regions — are termed *amphipathic.*



Lipid Structure
Types of Fatty Acids



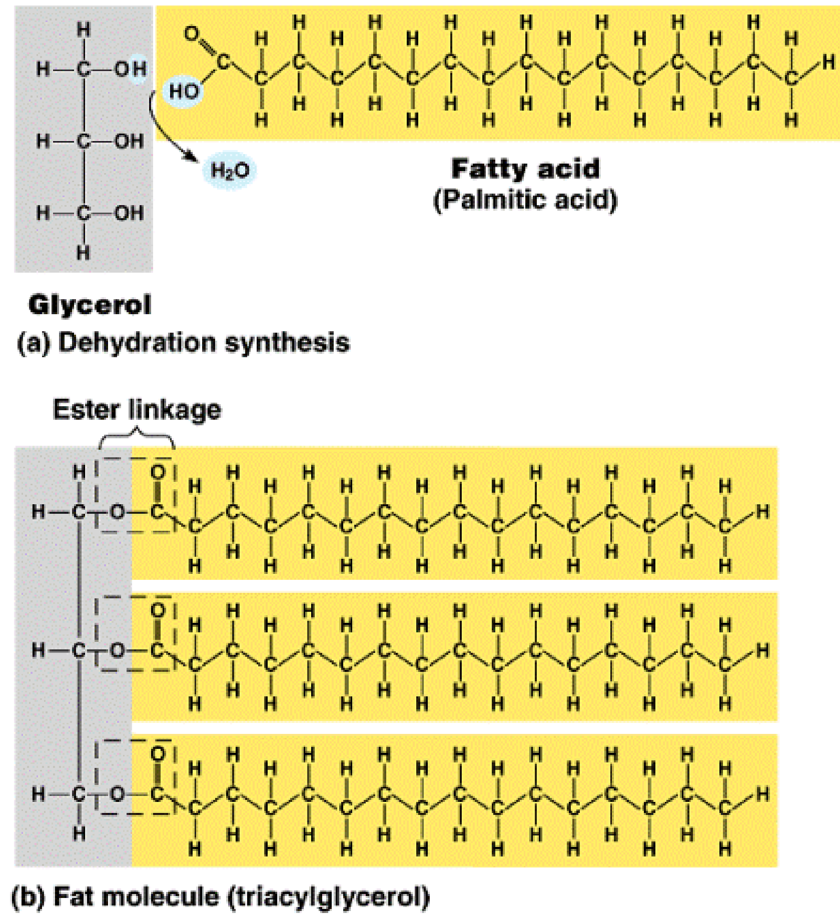
(a) Saturated fat and fatty acid



(b) Unsaturated fat and fatty acid

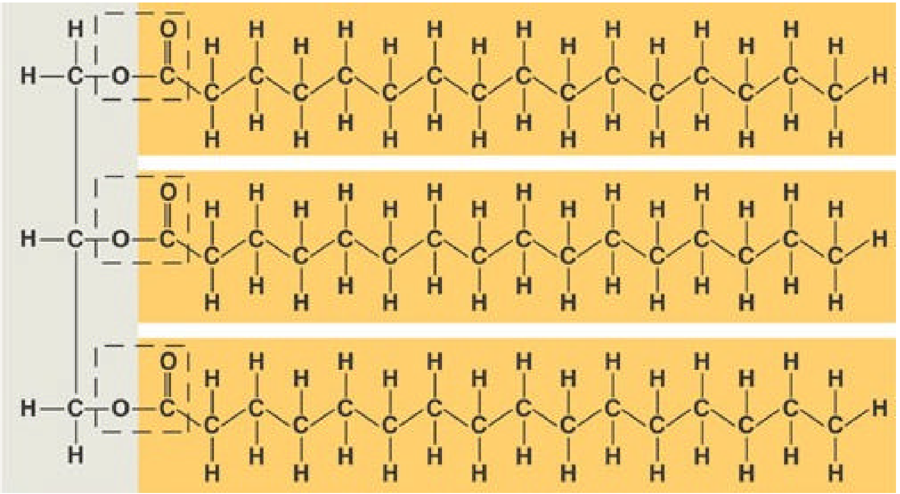
Lipid Structure
Triglycerides

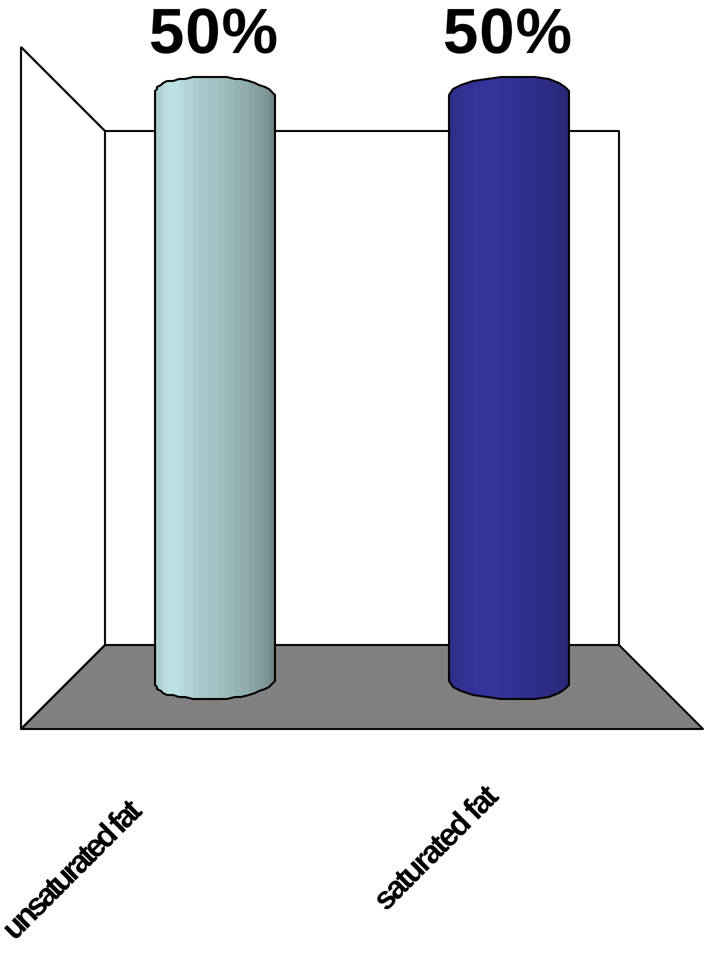
- Fatty acids are very efficient sites of energy storage; they are stored in the cytoplasm of many cells in the form of droplets of *triacylglycerol* molecules — compounds made of three fatty acid chains bonded to a glycerol molecule.
- When a carboxylic acid and an alcohol react, a water molecule is removed, and an ester linkage is formed
- Triglycerides make "the fat" of our bodies. In animals, they are stored as droplets in fat cells or *adipocytes*.



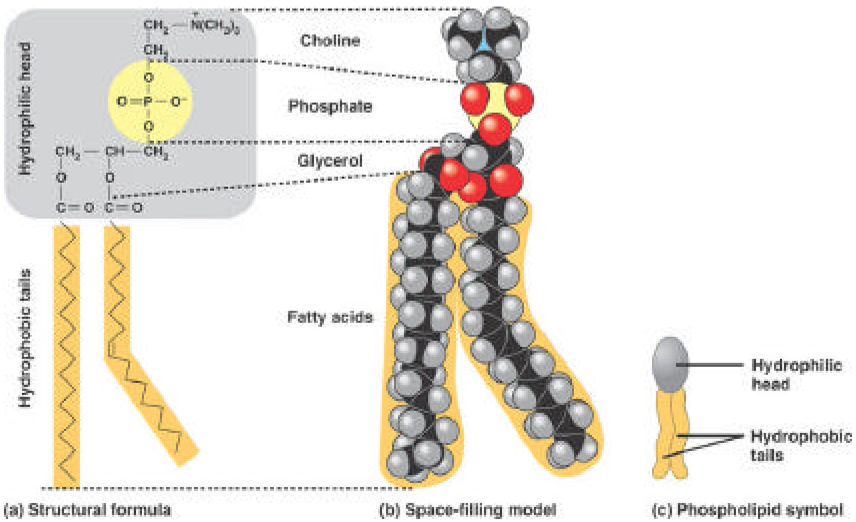
This molecule is a …

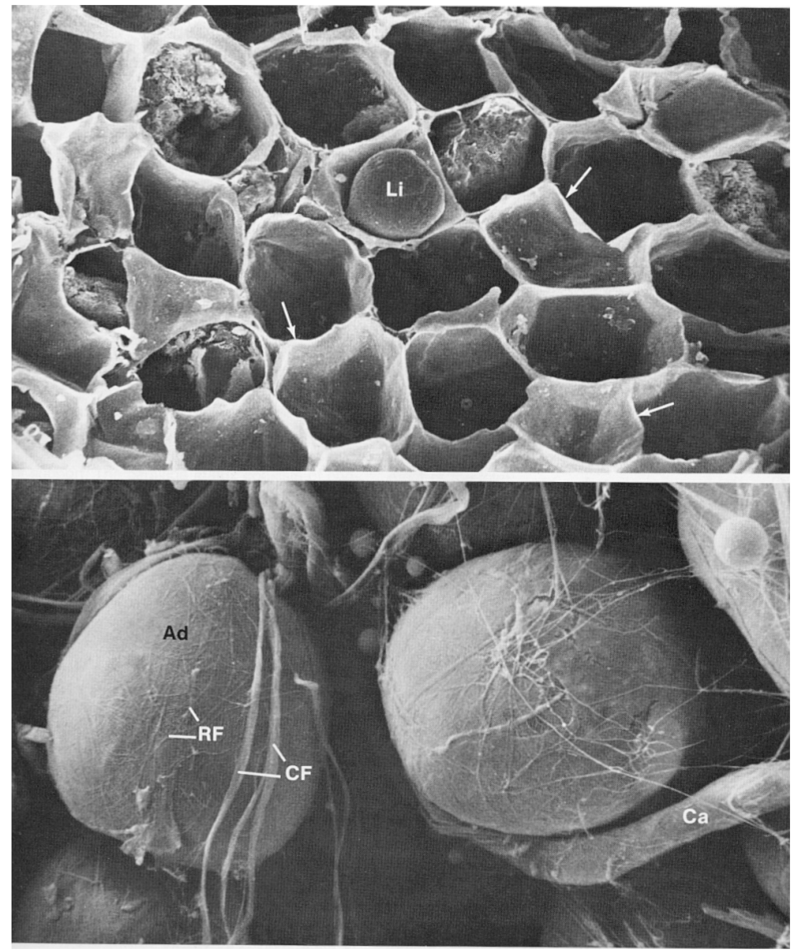
1. unsaturated fat
2. saturated fat





Lipid Structure
Phospholipids



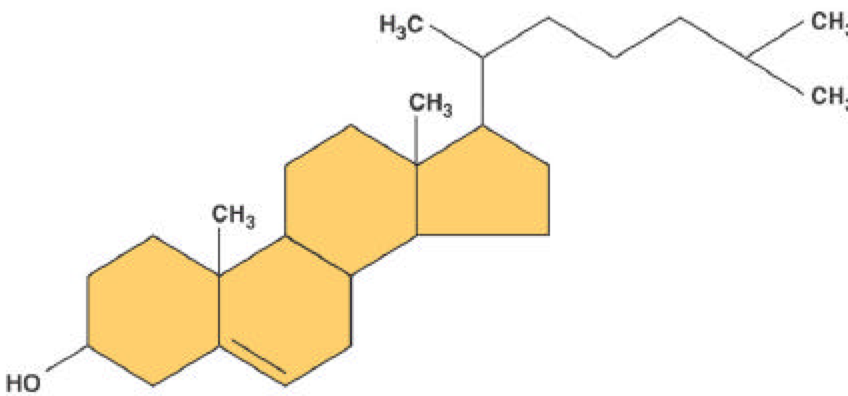


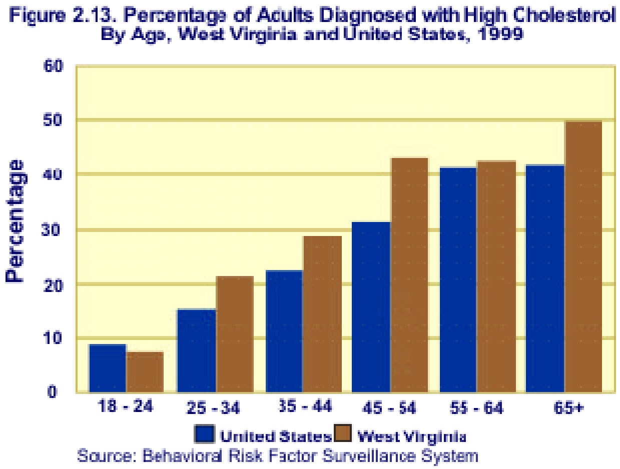
Phospholipids stand as the main components of cell membranes

Adipocytes

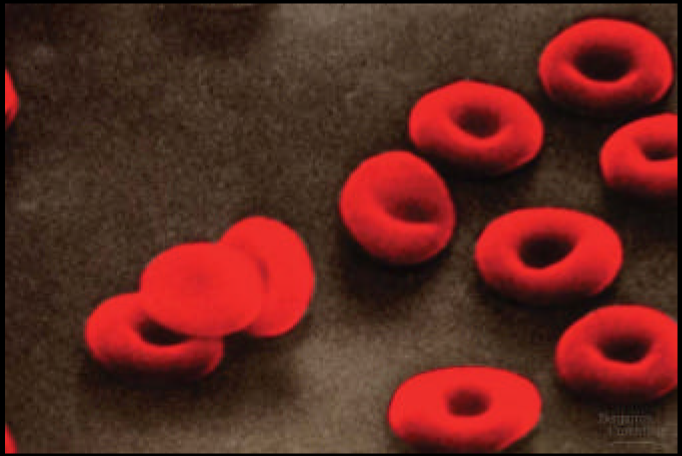
Lipid Structure
Steroids

- Steroids are made by a carbon skeleton consisting of four fused rings
- *Cholesterol* is a common component of animal cell membranes. It is also the precursor of many steroids are synthesized — i.e. hormones like sex hormones of vertebrates



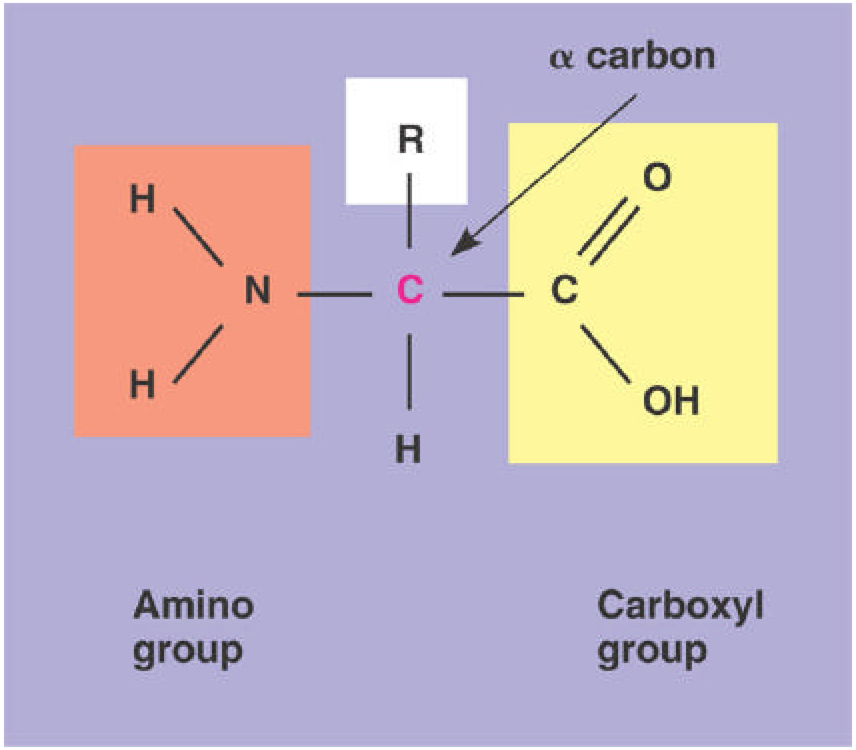


Proteins



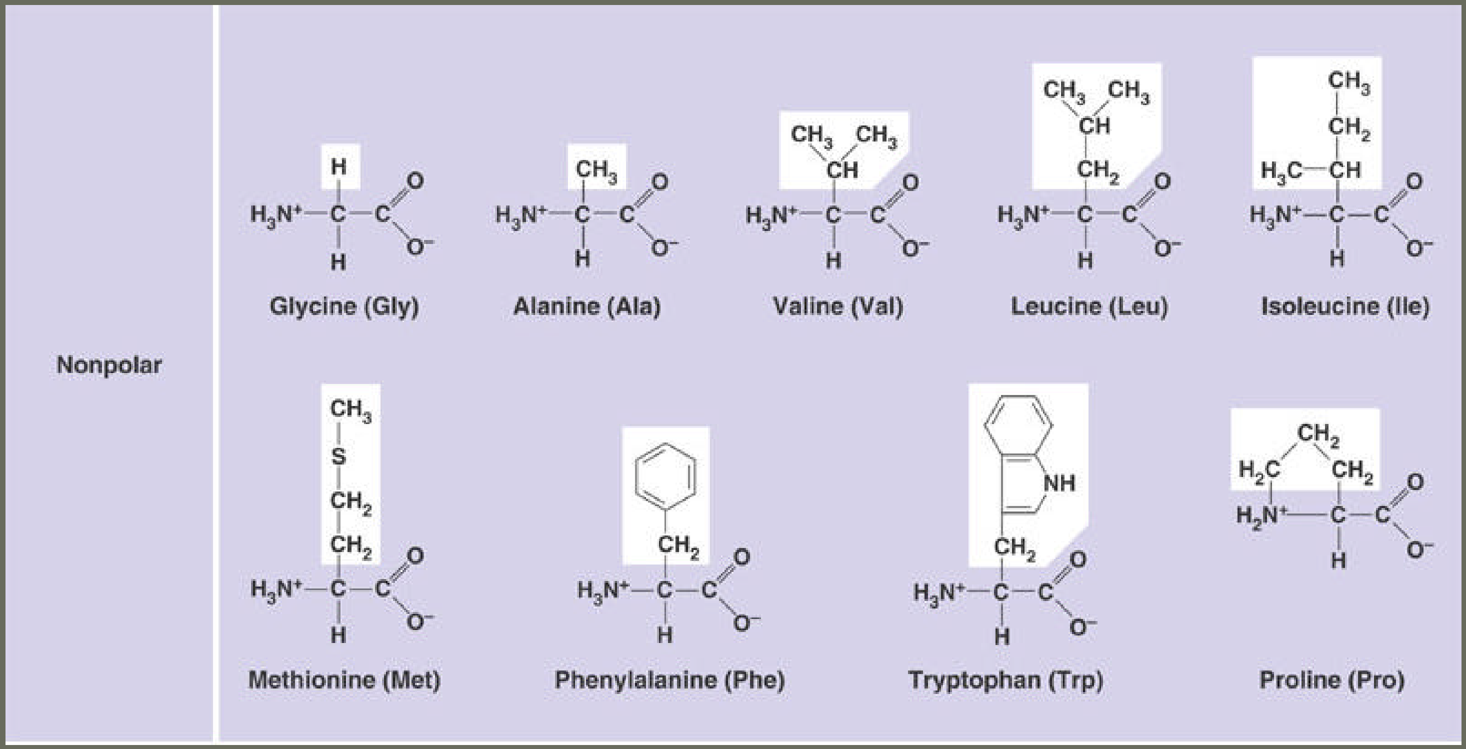
Proteins

- Proteins are present in the cells in large amounts; they may determine cellular size, shape, and function.
- DNA stores in its genes the information to make all the proteins an organism requires for living
- A protein is a stretch of an assortment of 20 different *amino acids (aa)* joined together by *peptide bonds*

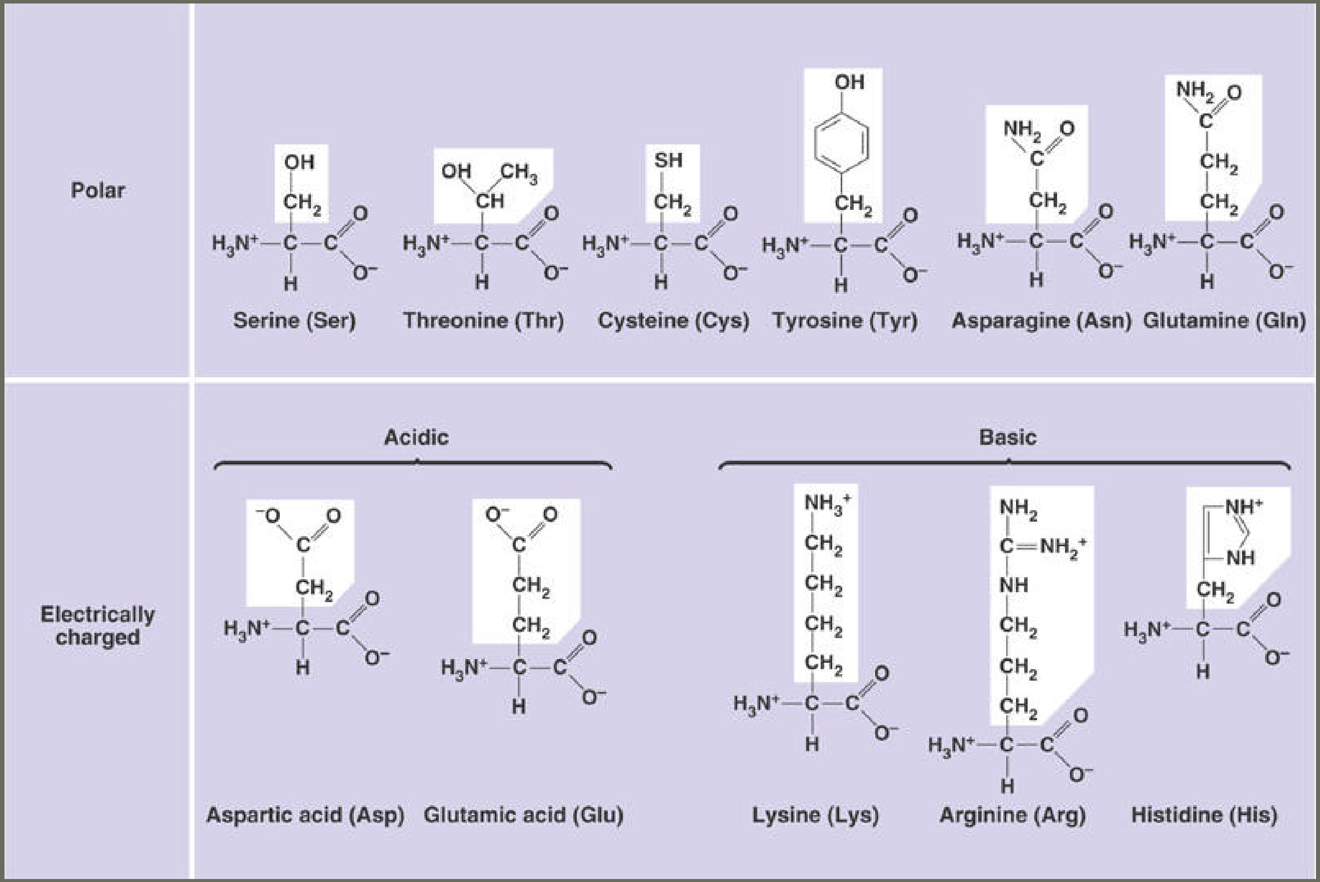


General structure of an amino acid

Proteins
The 20 Amino Acids

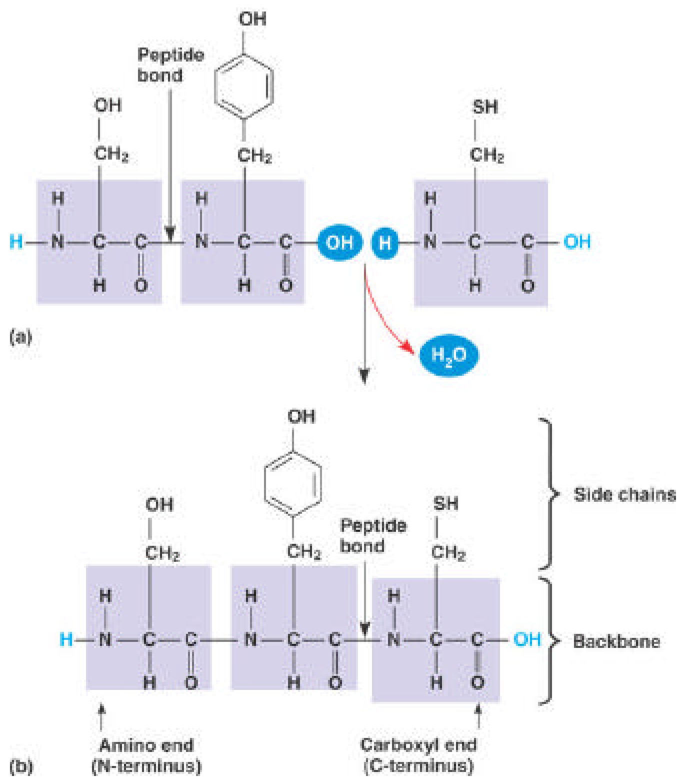


Proteins
The 20 Amino Acids



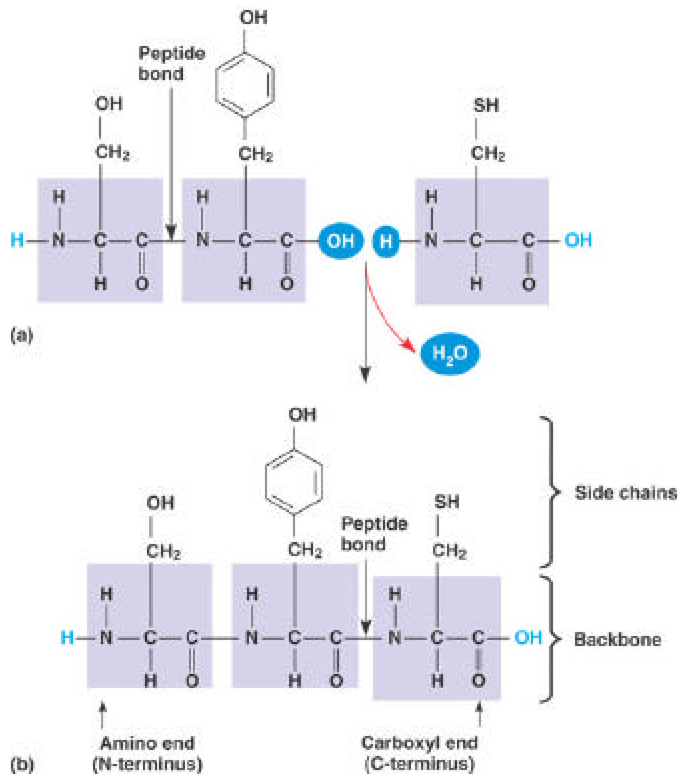
Proteins
How Proteins Are Made

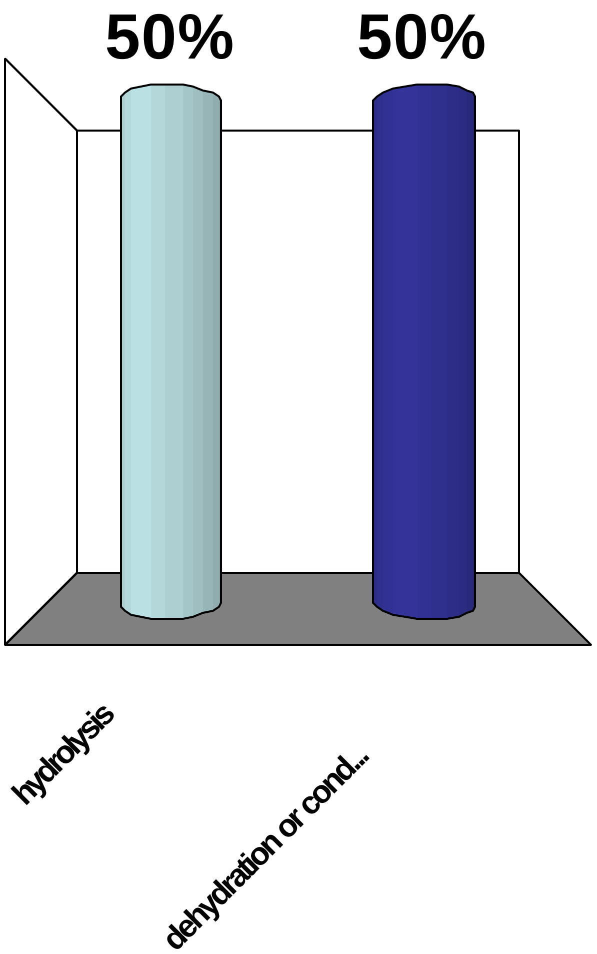
- Amino acids are joined together when a dehydration reaction removes a hydroxyl group from the carboxyl end of one amino acid and a hydrogen from the amino group of another amino acid
- The resulting covalent bond is called a *peptide bond* (C-N)



A ___ reaction is shown below.

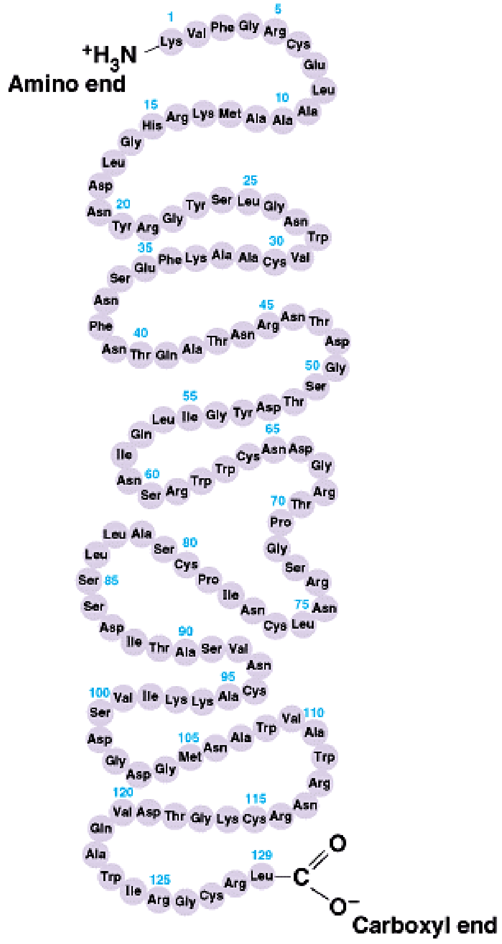
1. hydrolysis
2. dehydration or condensation



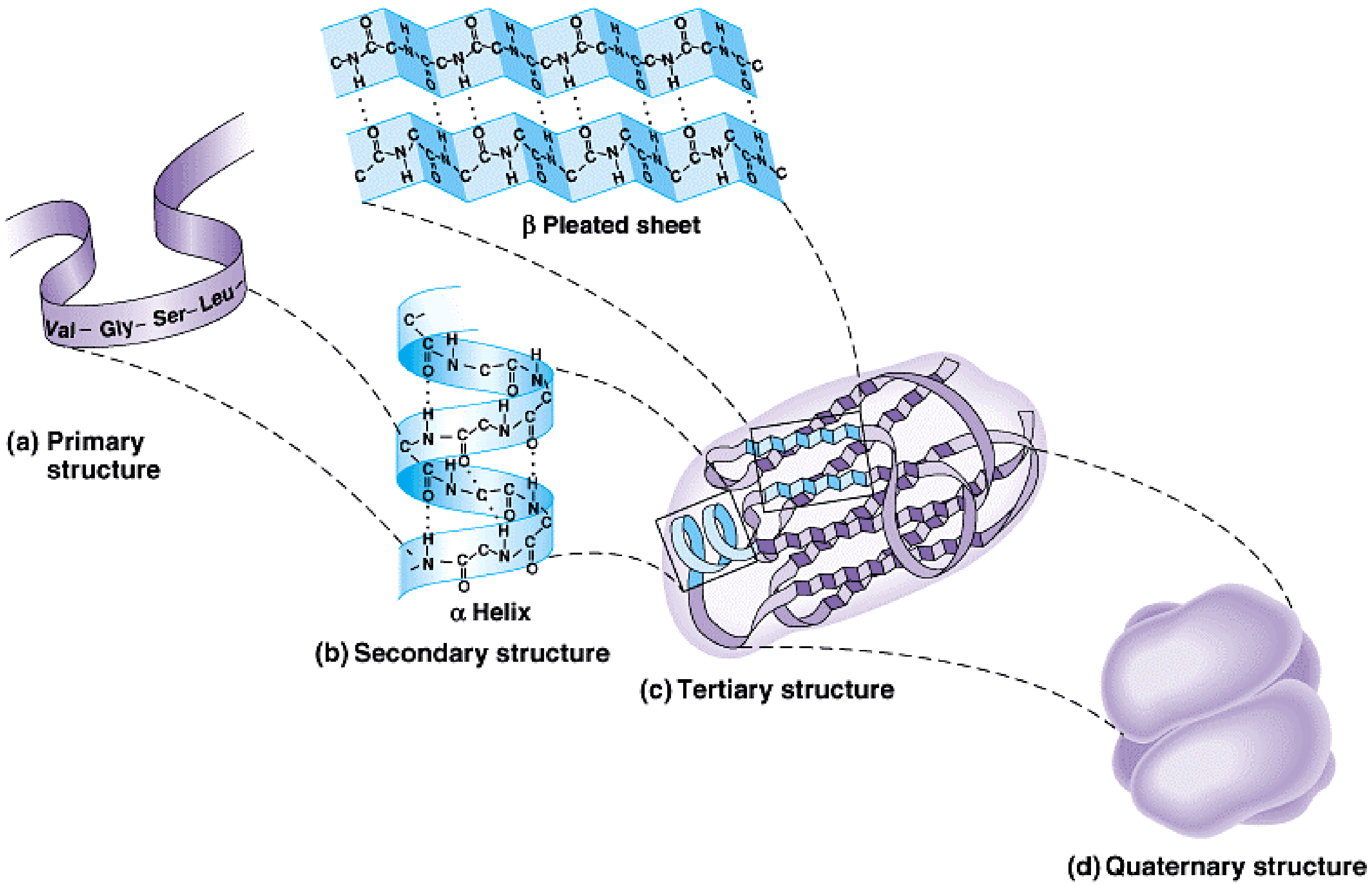


Proteins
How Proteins Are Structured

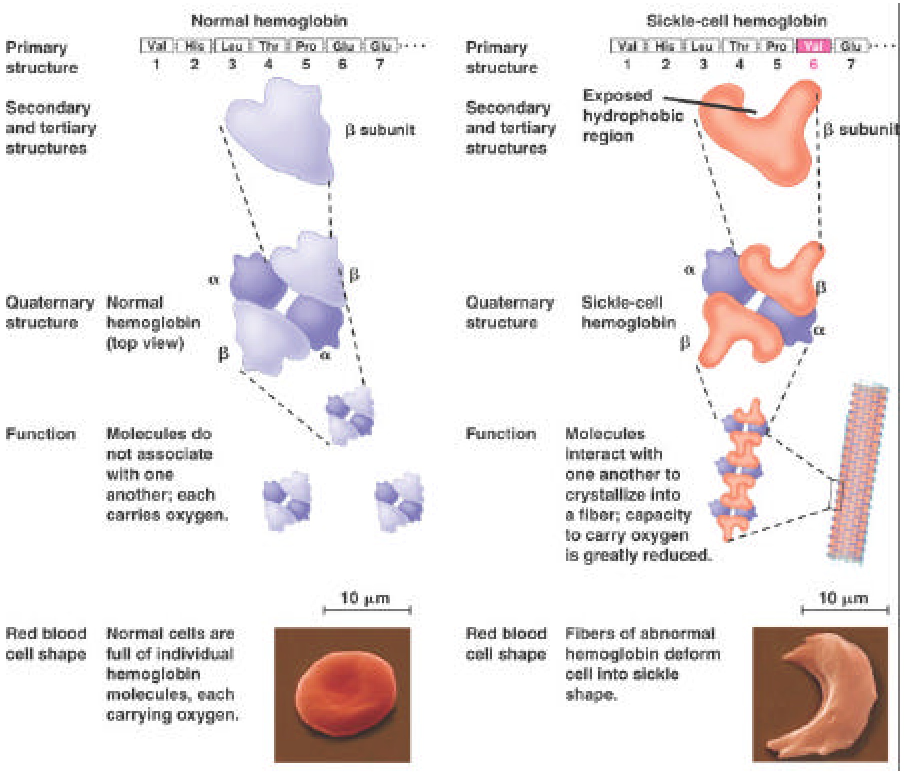
- *Primary structure* of proteins is constituted by its sequence of amino acids
- The first amino acid makes the *amino end,* while the last amino acid of the stretch makes the *carboxyl end*



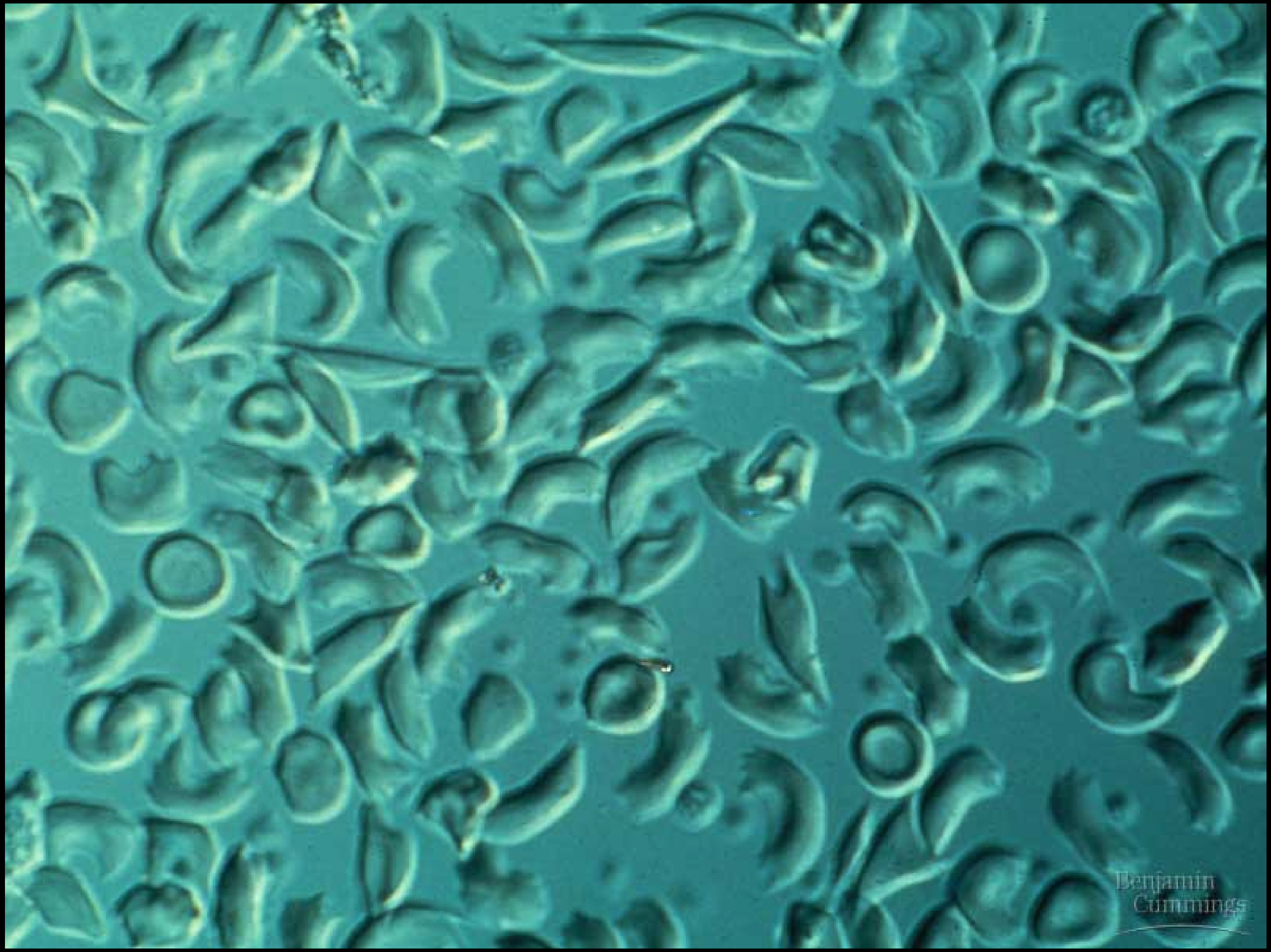
Proteins
How Proteins Are Structured



What Does It Happen When The Primary Structure Is Altered?



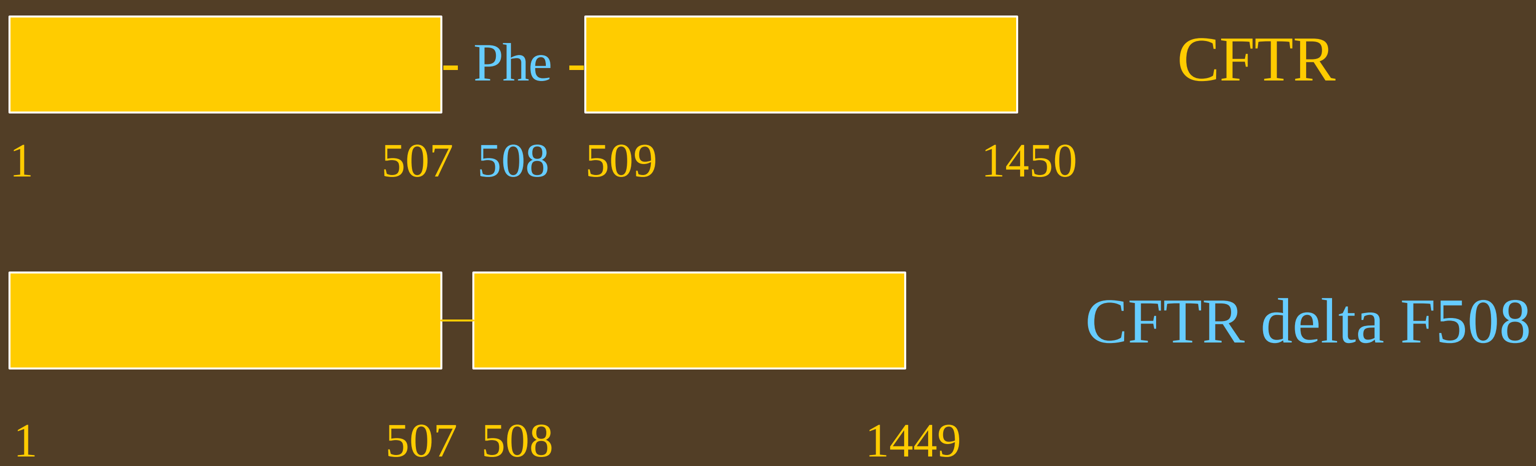
Sickle Red Blood Cells



Cystic Fibrosis Transmembrane Conductance Regulator (CFTR) functions as a channel protein

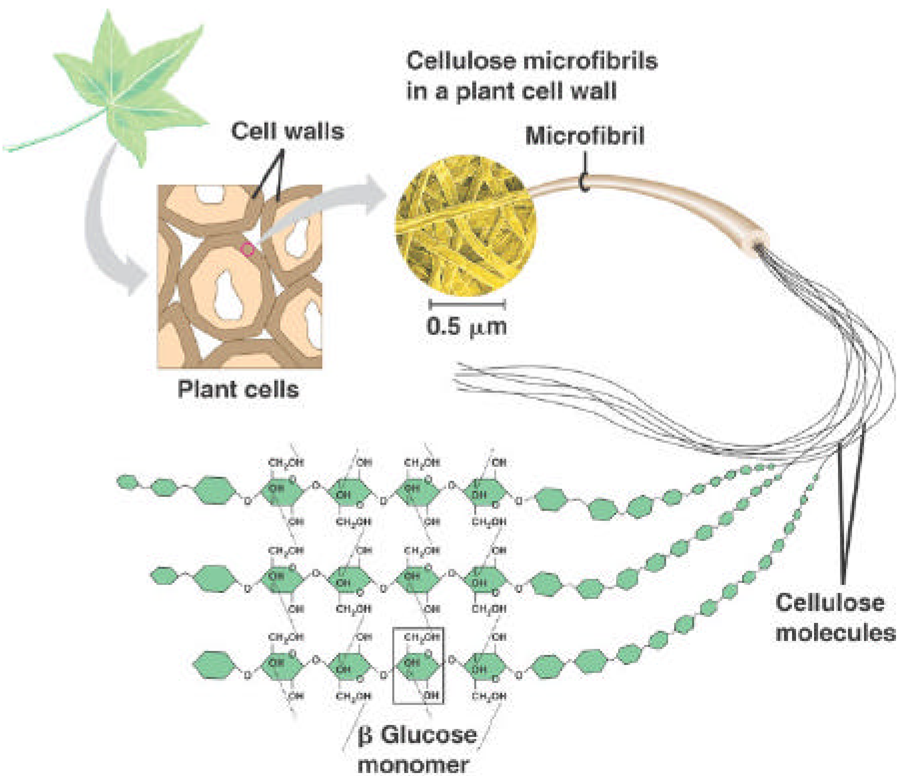
Cystic Fibrosis: a deletion of phenylalanine (Phe) at position 508 in the cystic fibrosis trans-membrane conductance regulator (CFTR) protein produces a functionally defective protein

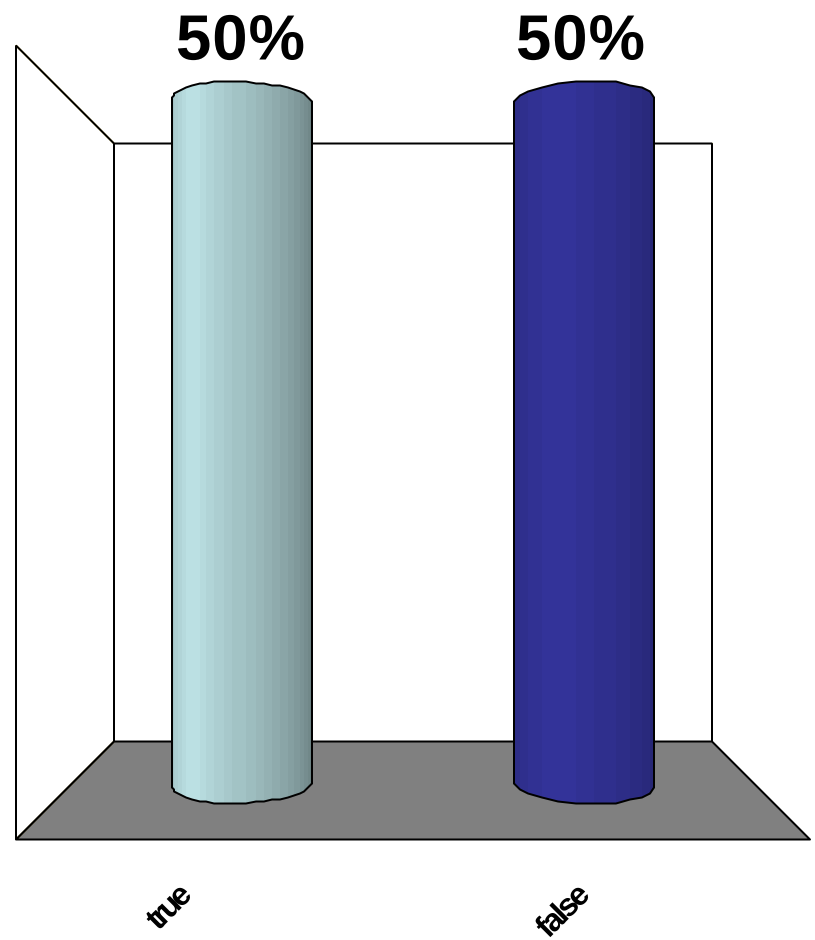
CFTR delta F508, which causes cystic fibrosis.



carbonyl group : polyssacharide : structural support : cellulose

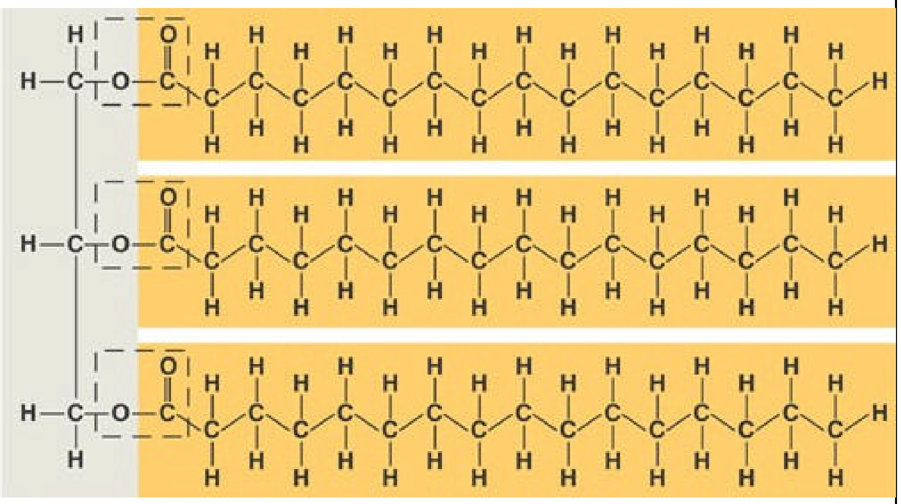
1. true
2. false

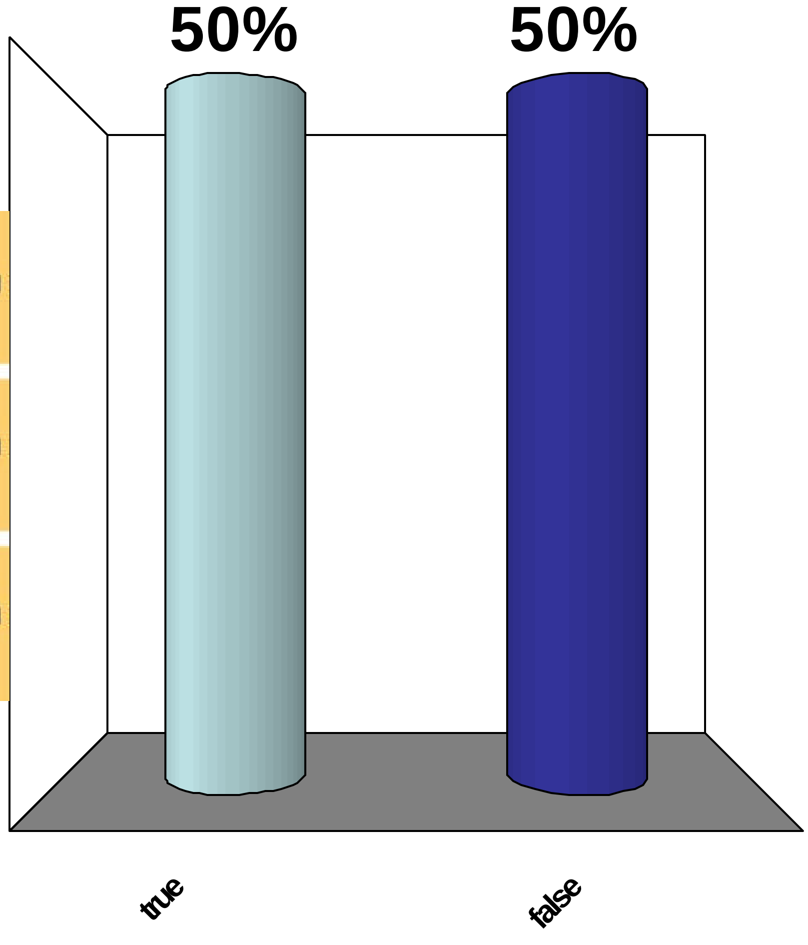




carboxyl group : triglyceride : energy storage : olive oil

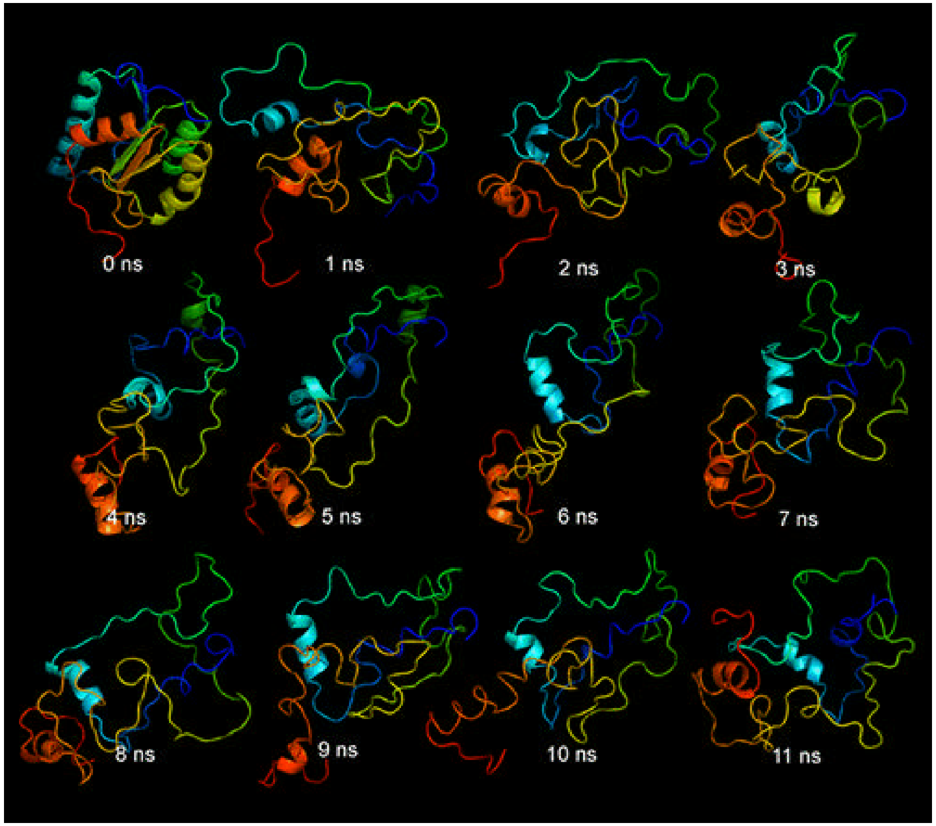
1. true
2. false

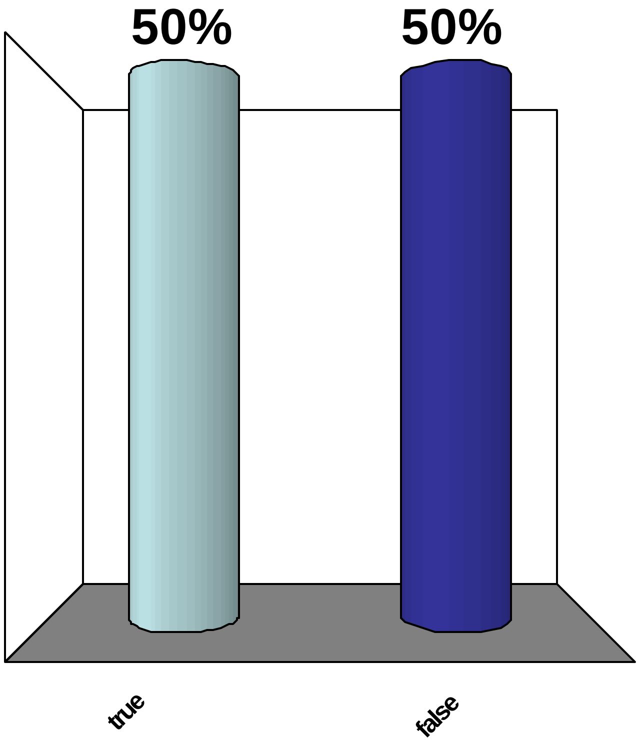




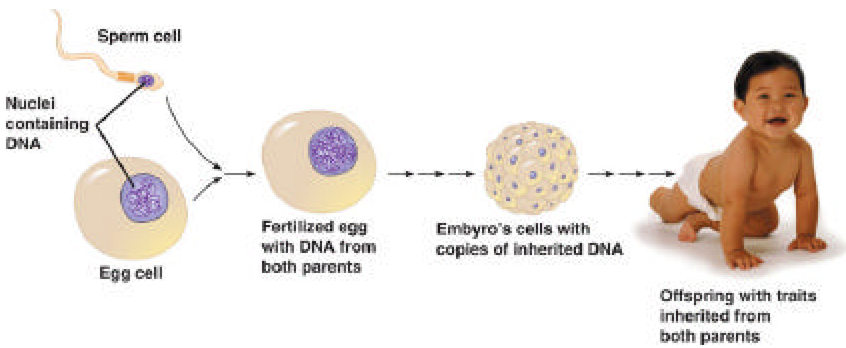
carboxyl group : amino group : R groups : ß-helices

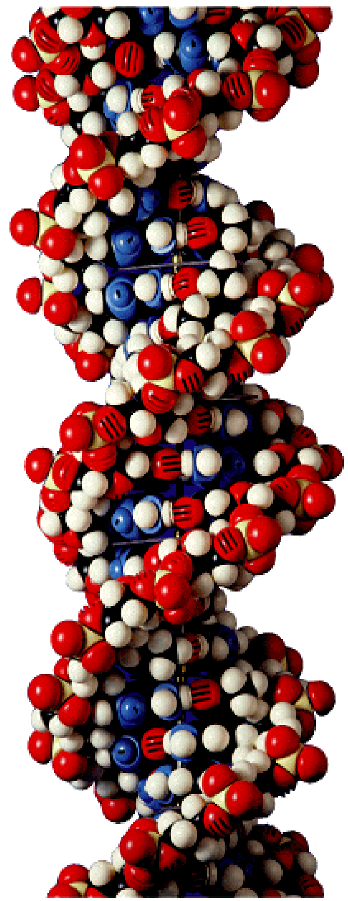
1. true
2. false

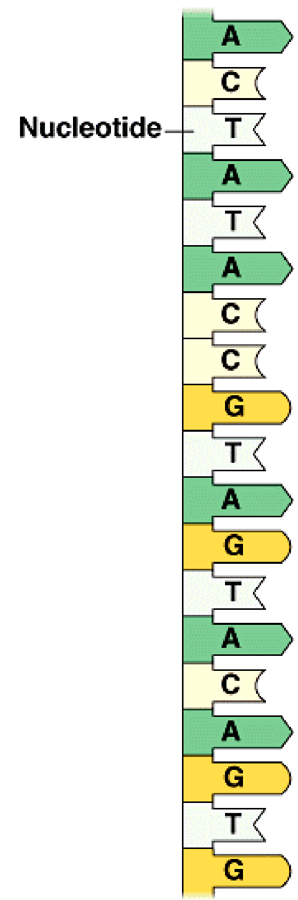




Nucleic Acids




(a) DNA double helix



(b) Single strand of DNA