Chapter 2

Lectures 2,3,4

Organic Compounds

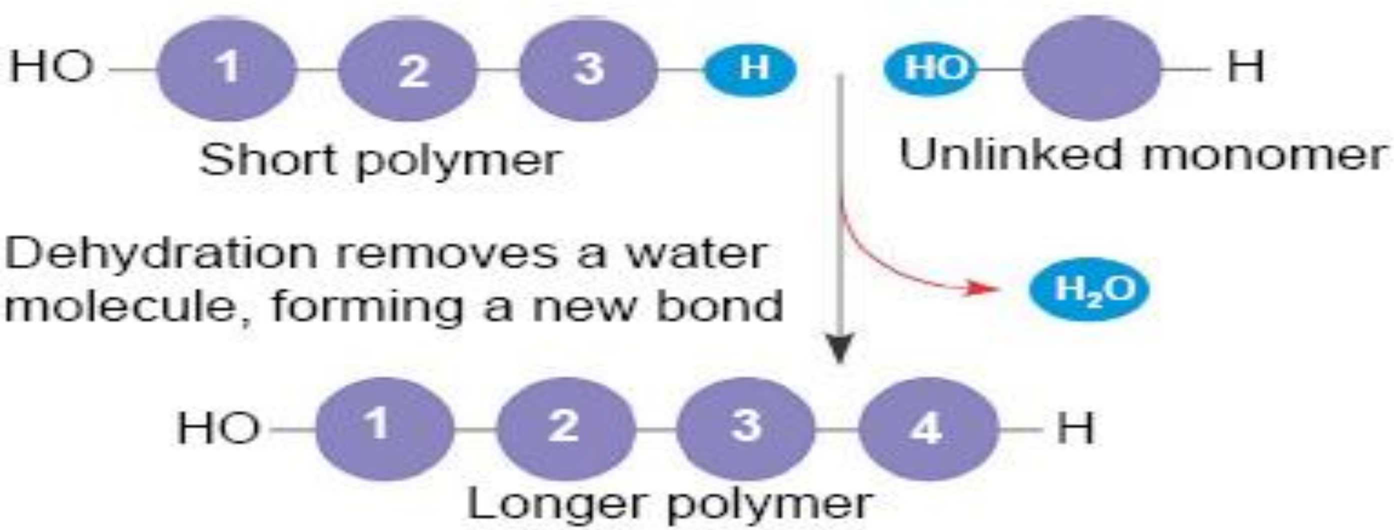
(Biological Molecules)

Organic Compounds

- **Organic compounds contain carbon atoms**
  - With its four valence electrons, a carbon atom can covalently bind with up to four other atoms
    - Leading to an almost infinite set of carbon structures
    - From simple methane (CH_4) to complex ring and chain structures like simple sugars or complex starch molecules
  - Attaching functional groups to the carbon structures helps to increase the solubility and reactivity of organic molecules in water - thus making them useful to biological systems
  - These organic molecules are called Macromolecules
  - Also called polymers
  - Made up of smaller "building blocks" called MONOMERS

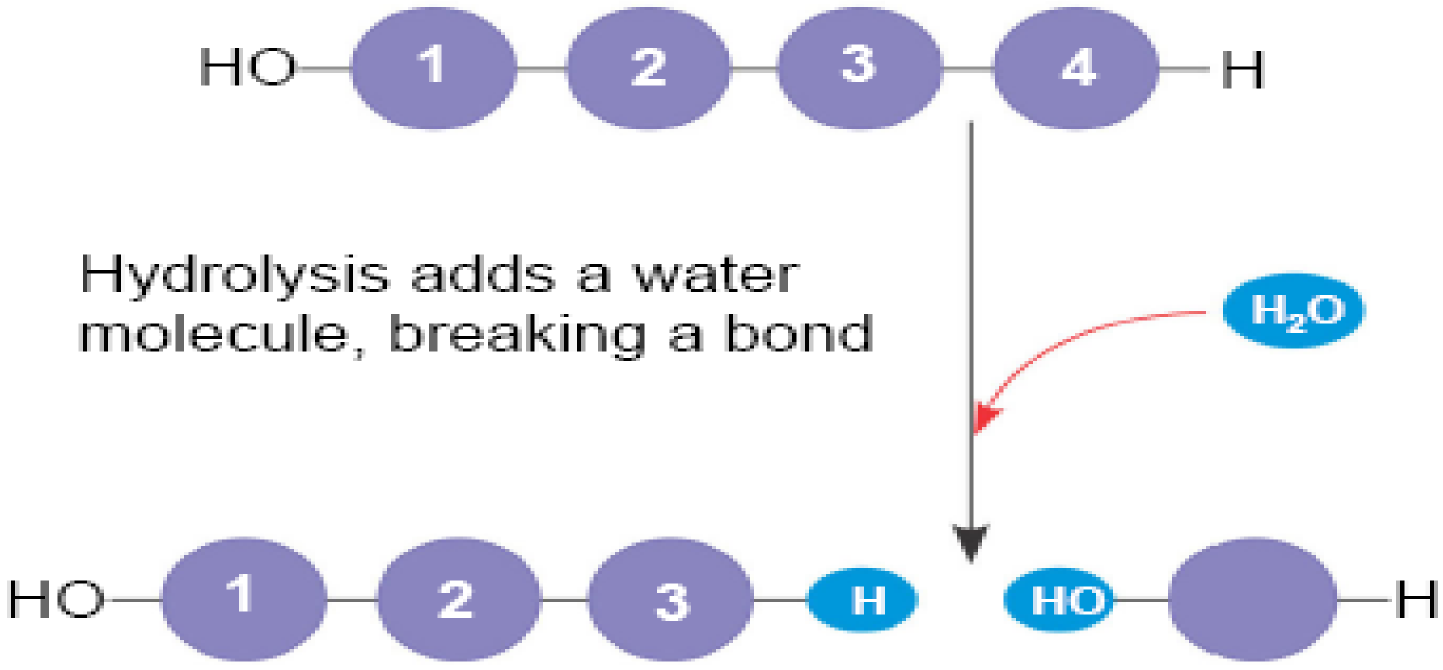
Condensation (Dehydration) reactions

- Monomers form larger molecules by condensation reactions called dehydration reactions



Polymers can disassemble by

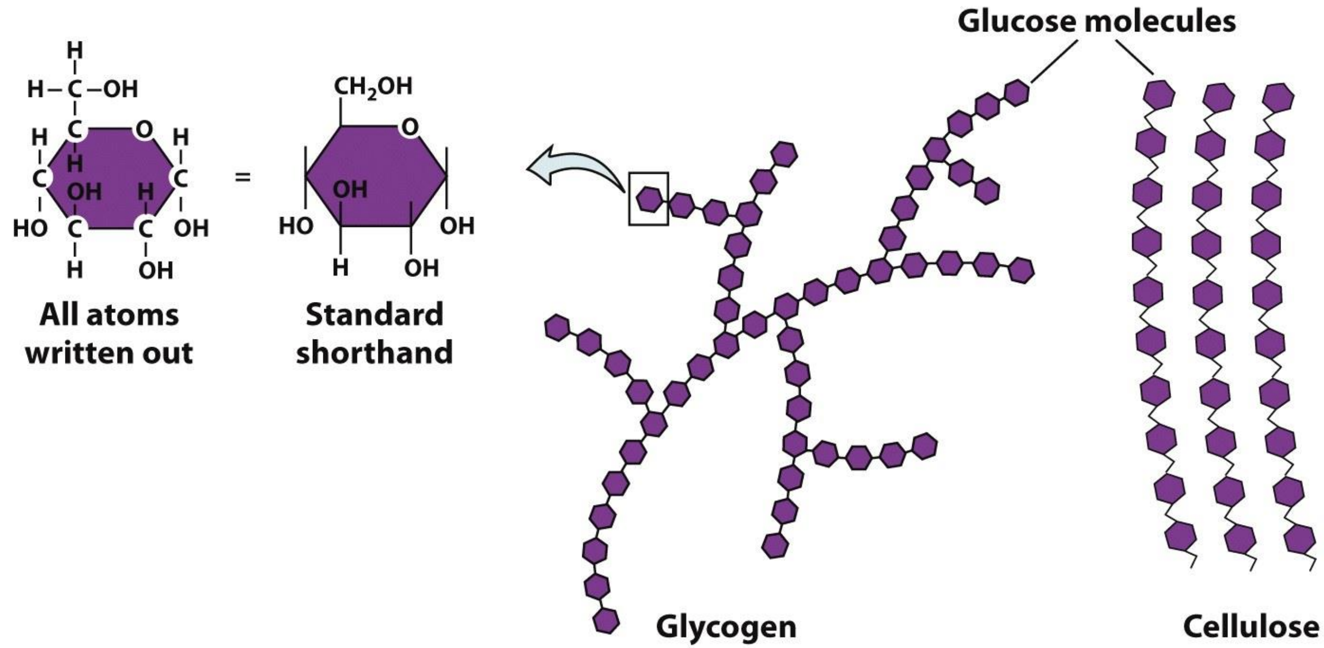
– Hydrolysis



- **Four categories of organic compounds are important to living organisms**
  - Carbohydrates
  - Lipids
  - Proteins
  - Nucleic acids

Carbohydrates

- Carbohydrates are the most abundant organic molecules in organisms
- A carbohydrate is composed of carbon, hydrogen, and oxygen atoms
  - In a ratio of 1:2:1 - for example, $C_6H_{12}O_6$
- Carbohydrates serve as energy source for the human body



Many Carbohydrates are Saccharides (Sugars)

- **Monosaccharides**
  – Single sugar molecules - simple carbohydrates
  – For example, *glucose , fructose , ribose, galactose* etc…
- **Disaccharides**
  – Formed from the binding of *two monosaccharides*
  – For example, *sucrose* (glucose and fructose);
  lactose (glucose and galactose)
  Maltose (glucose + glucose).
  – Are joined by a *glycosidic linkage*

- **Oligosaccharides and Polysaccharides**

- Longer chains (polymers) of monosaccharides (*oligo* = few, and *poly* = many)
- Complex carbohydrates

Glycogen

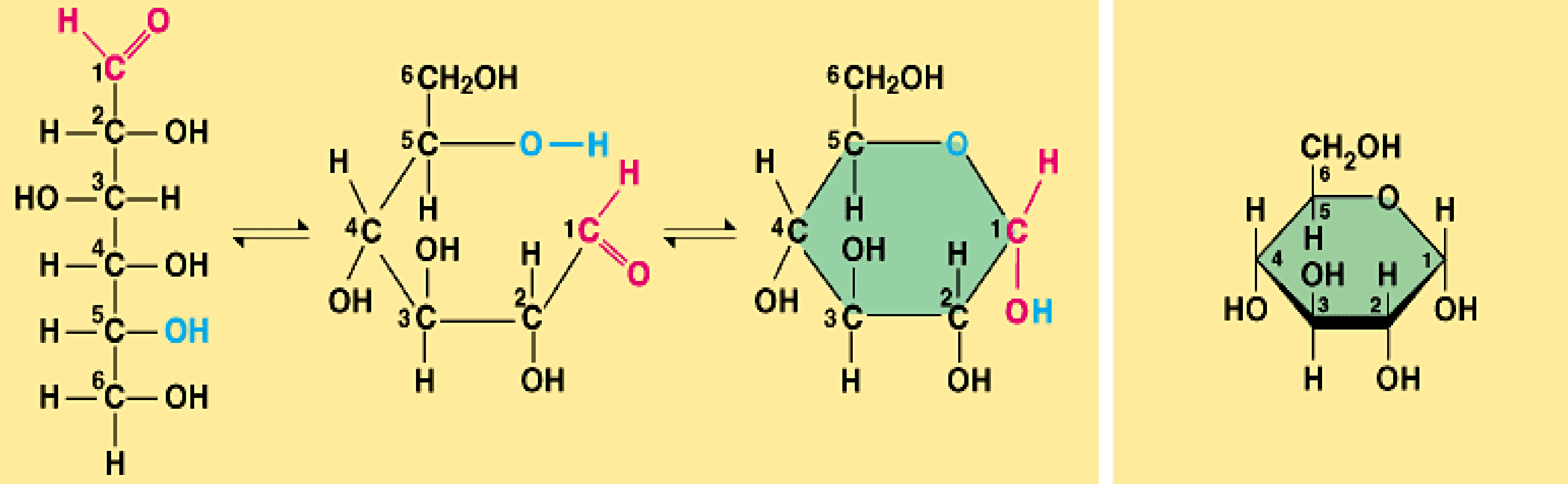
-is a polysaccharide(*energy storage form*) that is stored in muscle and liver tissues
- It consists of long chains of glucose molecules
-stored glucose *in animals*

Starch and cellulose

-- are polysaccharides that are found *in plants*
-They also are long chains of glucose molecules – but are organized differently than glycogen .
- Starch is a major *energy storage* form of glucose *in plants* .
- Cellulose is a *structural polysaccharide in plants* .

In aqueous (watery) solutions, monosaccharides form ring structures

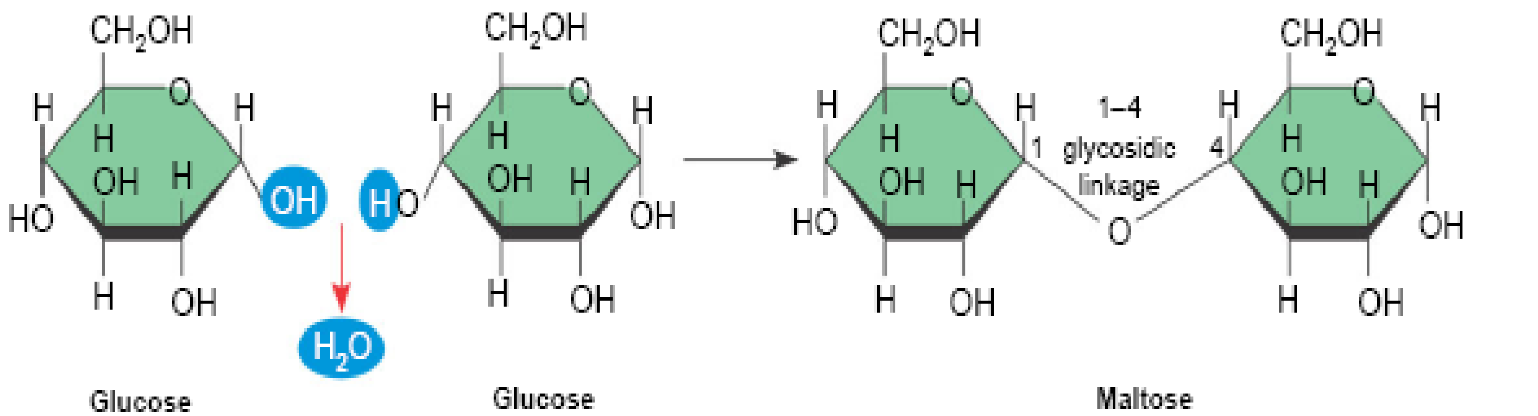
Glucose: Chain and Ring



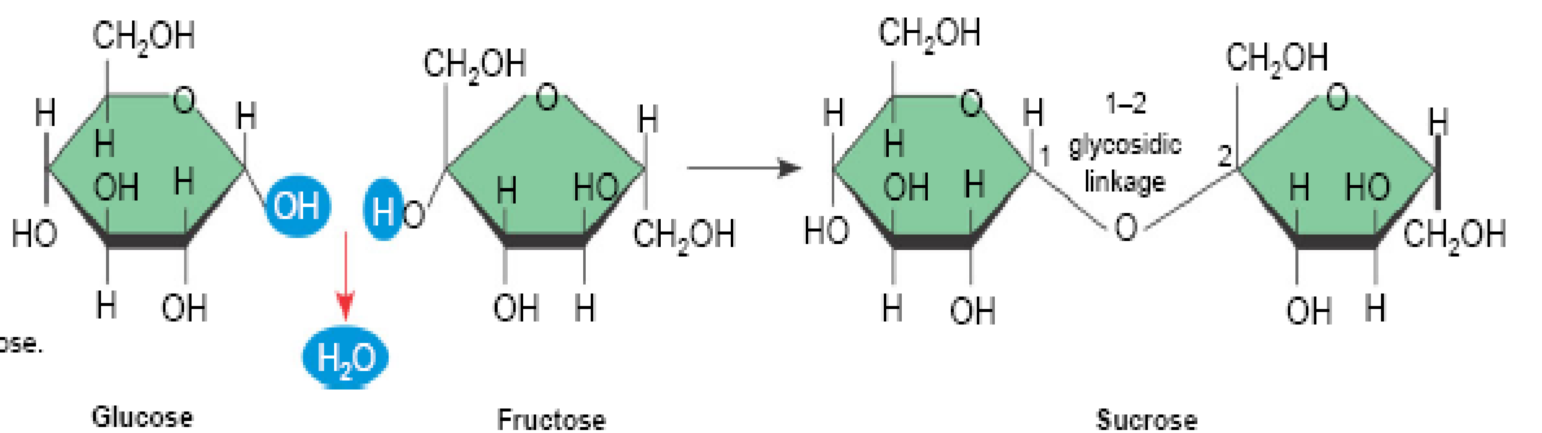
(a) Linear and ring forms

(b) Abbreviated ring structure

- # Examples of disaccharides



(a) Dehydration reaction in the synthesis of maltose. The bonding of two glucose units forms maltose. The glycosidic link joins the number 1 carbon of one glucose to the number 4 carbon of the second glucose. Joining the glucose monomers in a different way would result in a different disaccharide.



(b) Dehydration reaction in the synthesis of sucrose. Sucrose is a disaccharide formed from glucose and fructose. Notice that fructose, though a hexose like glucose, forms a five-sided ring.

Lipids

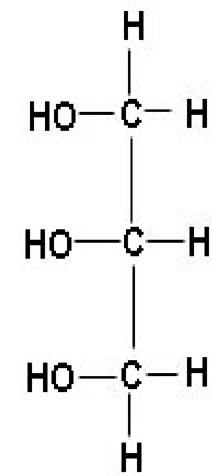
Lipids are Long-Chain Organic Compounds That are Not Soluble in Water

- **Lipids are hydrophobic**
  - Consisting of *fatty acids and glycerol*
  - Lipids are fats, oils, phospholipids, cholesterol ,sterols, and waxes
- **Fatty acids**
  - Energy-storing lipids
  - Long chain of hydrogen and carbon atoms with a carboxyl functional group at one end
  - The carboxyl group can bind to glycerol molecules to build fats
    - Such as *triglycerides* (with *three* fatty acids)
    - And *phospholipids* (with *two* fatty acids)

1. Fats and oils (triglycerides)

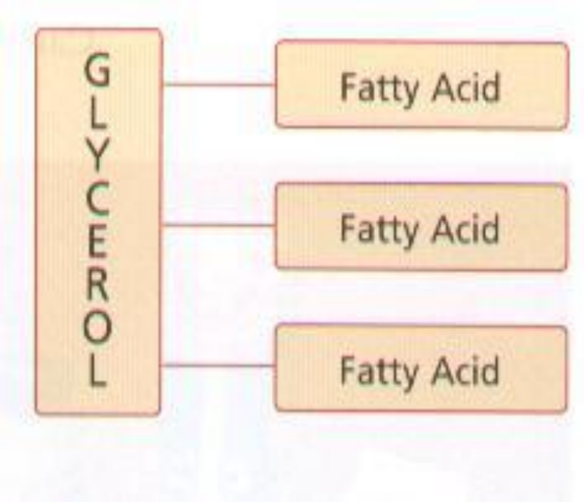
- Composed of Glycerol & 3 fatty acid chains

GLYCEROL

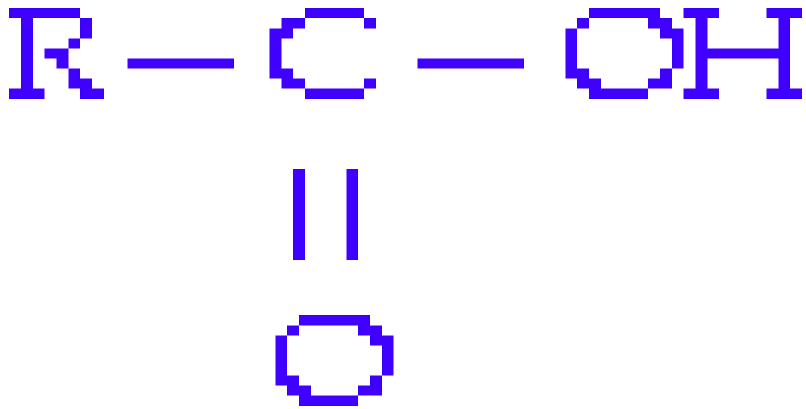


- Glycerol forms a key component and the “backbone” of the fat. Glycerol contains 3 carbons and 3 hydroxyl groups.

- Fat forms when a *glycerol head* connects with *three fatty acid tails*.



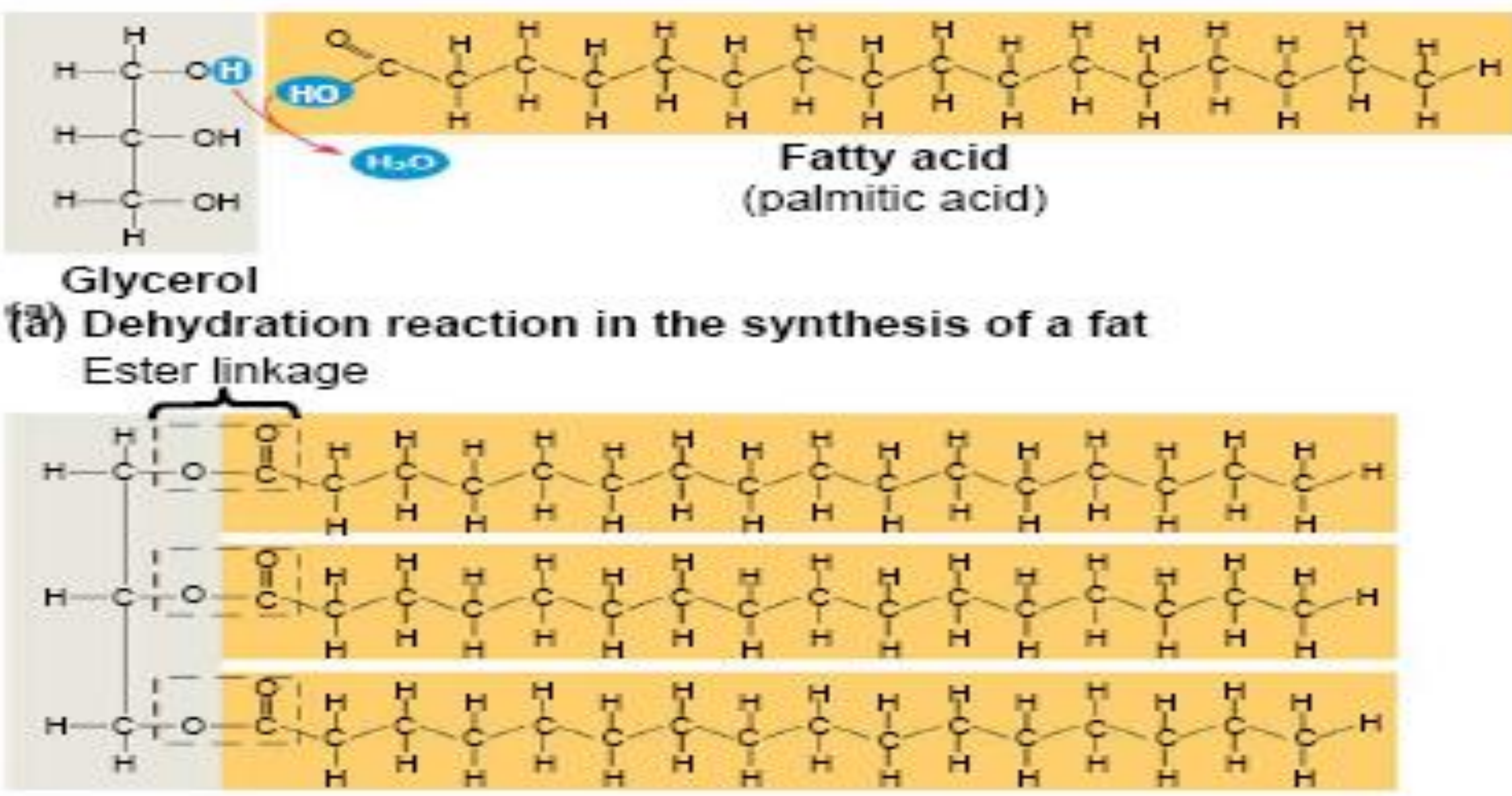
Fatty Acid Structure



- Carboxyl group (COOH) forms the acid.
- R" group is a hydrocarbon chain.

Fats

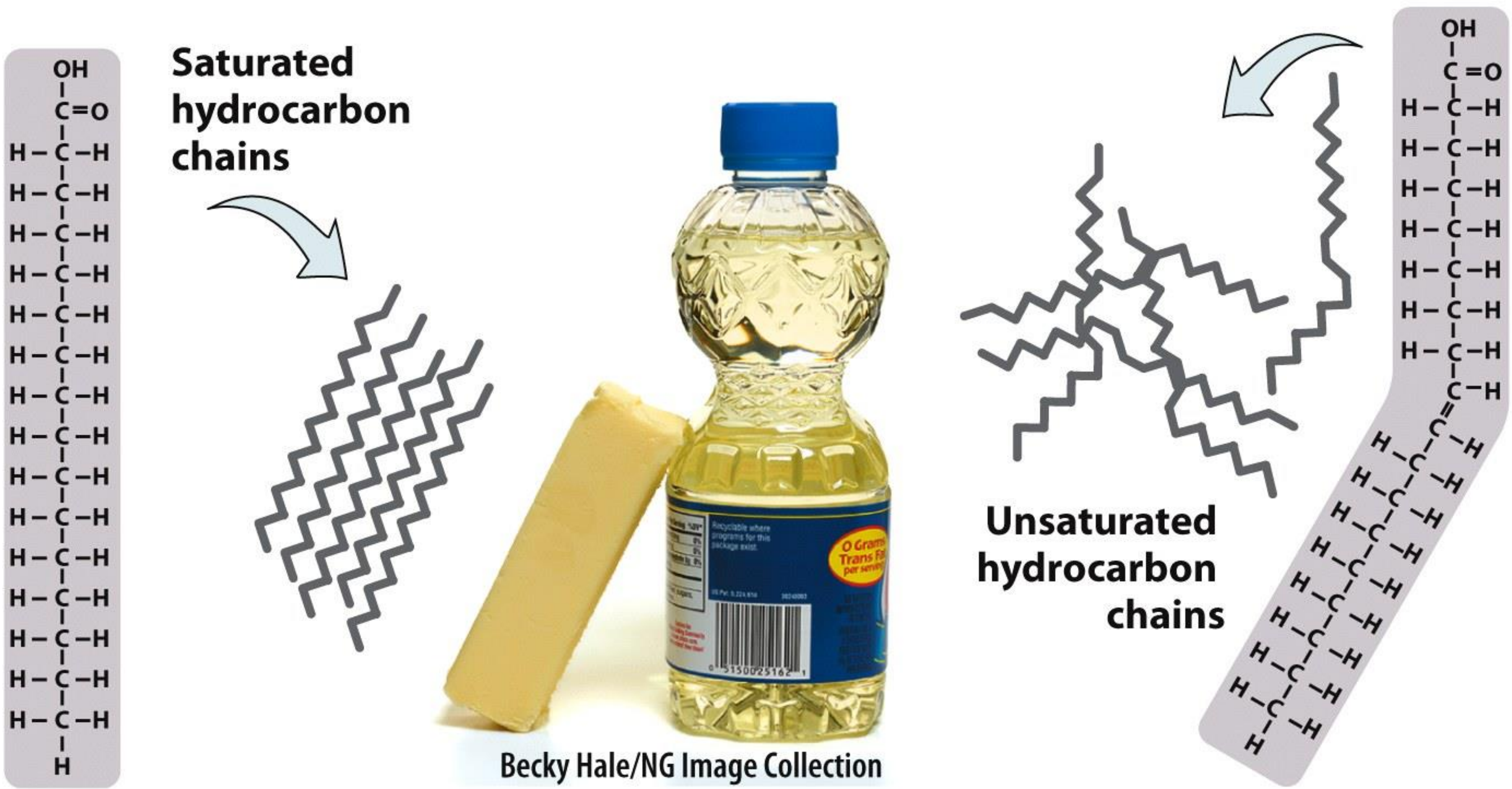
- Dietary fat consists largely of the molecule triglyceride composed of glycerol and three fatty acid chains



Fatty Acids

- **Unsaturated fats have *at least one double bond* between adjacent carbons in their fatty acid chains - and *bend* in shape at each double bond**
  - Monounsaturated (1 double bond); Polyunsaturated (2 or more double bonds)
  - Unsaturated fats tend to be *liquid* at room temperature – i.e., *oils*
- **Saturated fats have *no double bonds* between the carbons in their fatty acid chains - and thus are *straight* in shape**
  - They are completely saturated with hydrogen atoms and cannot hold any more
  - Saturated fats are *solid* to semi-solid at room temperature – i.e., *butter*
  - A diet high in saturated fats may increase the risk of having a stroke or heart attack

Fatty Acids


Saturated hydrocarbon chains
Unsaturated hydrocarbon chains
Becky Hale/NG Image Collection

Fats in Organisms

- Fats with saturated fatty acids are saturated fats
- Most animal fats have a high proportion of saturated fatty acids & exist as solids at room temperature (butter, margarine)

Fats in Organisms

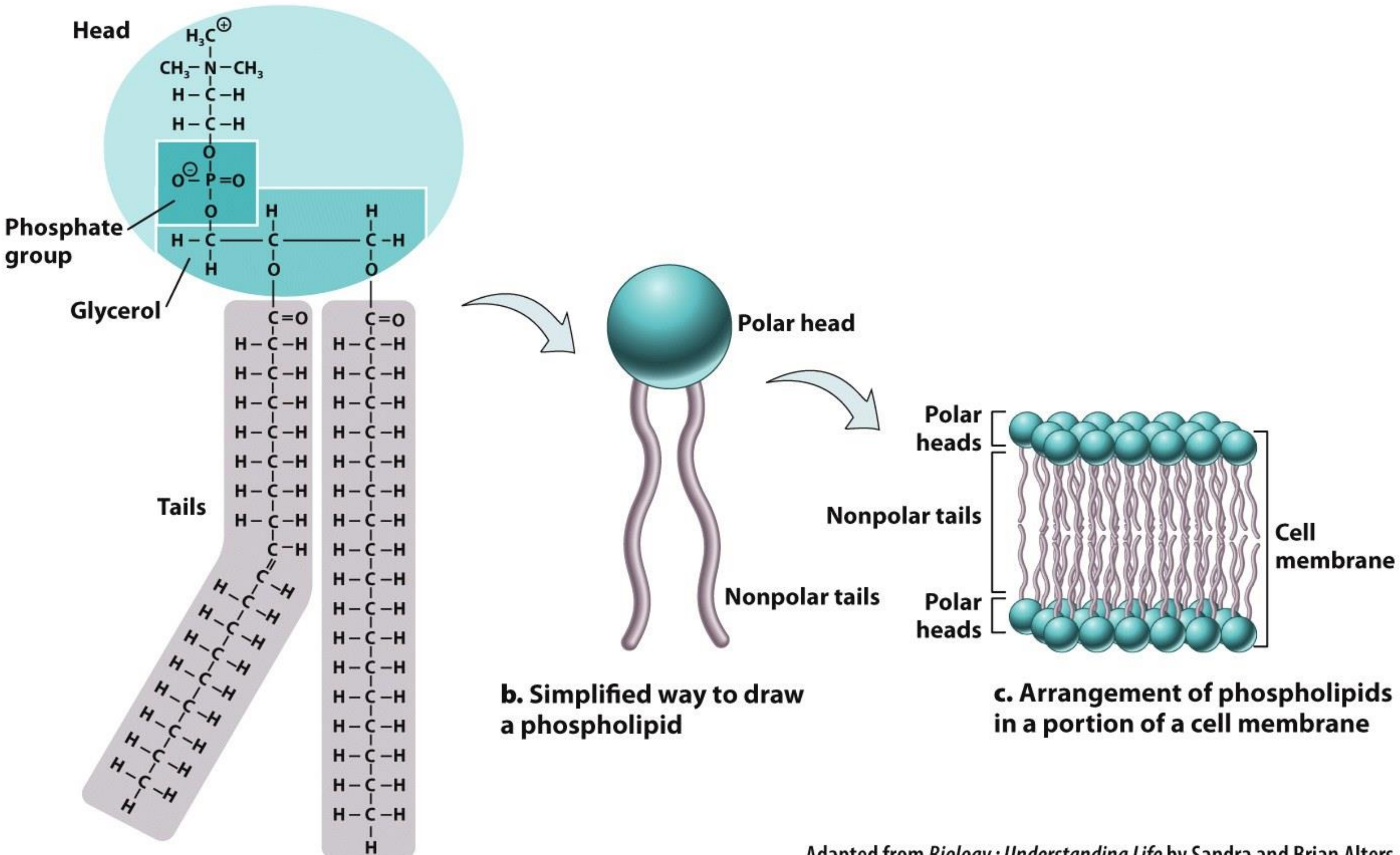
- Fats with unsaturated fatty acids are unsaturated fats
- Most plant oils tend to be low in saturated fatty acids & exist as liquids at room temperature (oils)

Phospholipids

Phospholipids are Both Hydrophilic and Hydrophobic

- Consist of a glycerol molecule, a *polar head (*containing a phosphate group), and *2 non-polar fatty acids tails*
- Their unique structure allows phospholipids to form *bilayers* when placed in water
  - Polar heads face outward – the non-polar fatty acid tails face inward
  - The *cell membrane* is one such bilayer

Phospholipids are Both Hydrophilic and Hydrophobic



a. Chemical structure of a phospholipid

b. Simplified way to draw a phospholipid

c. Arrangement of phospholipids in a portion of a cell membrane

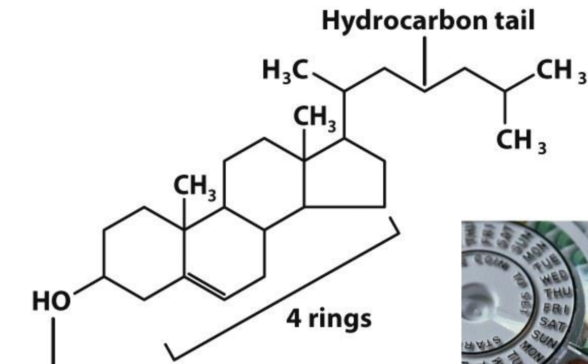
Adapted from *Biology : Understanding Life* by Sandra and Brian Alters, John Wiley&Sons, Inc. Copyright 2006

Steroids

Steroids are Lipids with a Common Four-Ring Structure

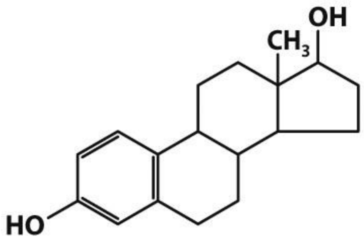
- **Steroids and sterols are important to normal growth and development**
  - Include cholesterol, sex hormones, and metabolism regulators
- ***Cholesterol*** **is an integral part of cell membranes**
  - Allowing for membrane flexibility and growth
- **The** ***sex hormones*** **are steroids that are important to the reproductive systems** -- Estrogen and Testosterone
- ***Anabolic steroids*****, which are related to testosterone, stimulate growth of the muscles**

Steroids and Sterols

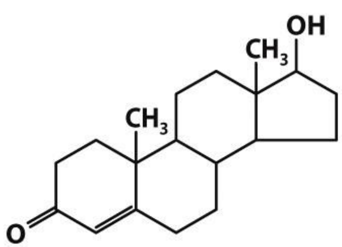


a. **Cholesterol**

Don Farrall/Photodisc/Getty Images

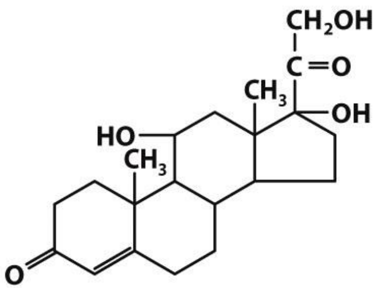


b. **Estradiol (an estrogen or female sex hormone)**



c. **Testosterone (a male sex hormone)**

A.T. Willett/Alamy

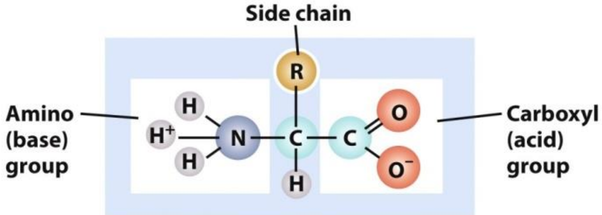


d. **Cortisol**

Proteins

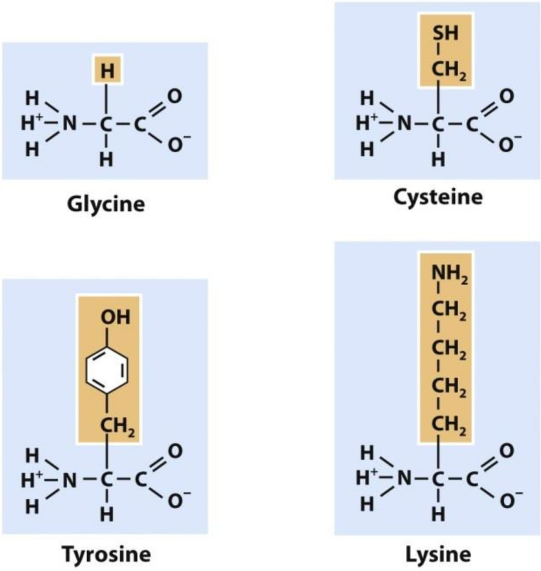
All the different proteins found in the human body are formed from just 20 building blocks called *amino acids*

- Proteins Serve as transport and messenger
- acts as enzymes



An amino acid

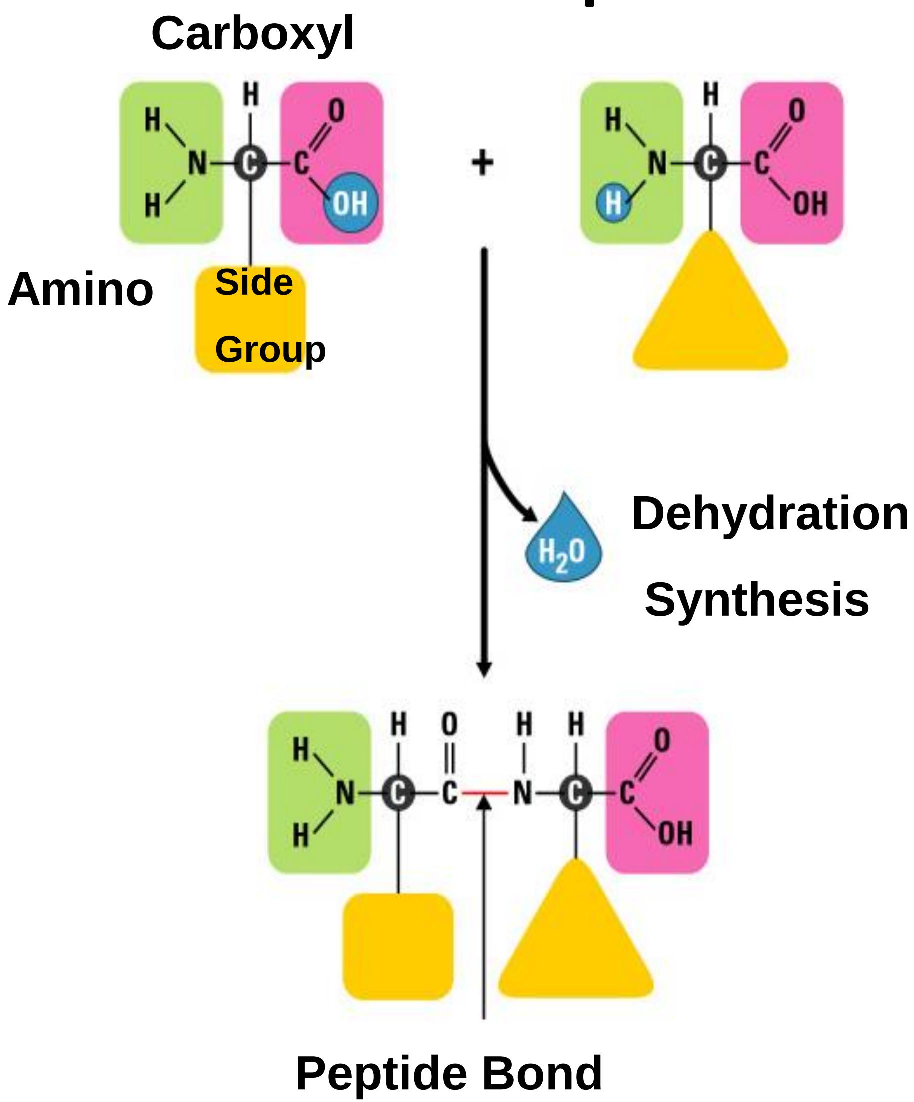
- An amino acid is composed of
  - A central carbon atom with four groups attached to it
    - A hydrogen atom
    - An amino group ($–NH_2$)
    - A carboxyl group (–COOH)
    - A radical group or side chain (R)



Representative amino acids

ALL 20 amino acids have common structure *except for the R group*. The R group determines the activity of the amino acid

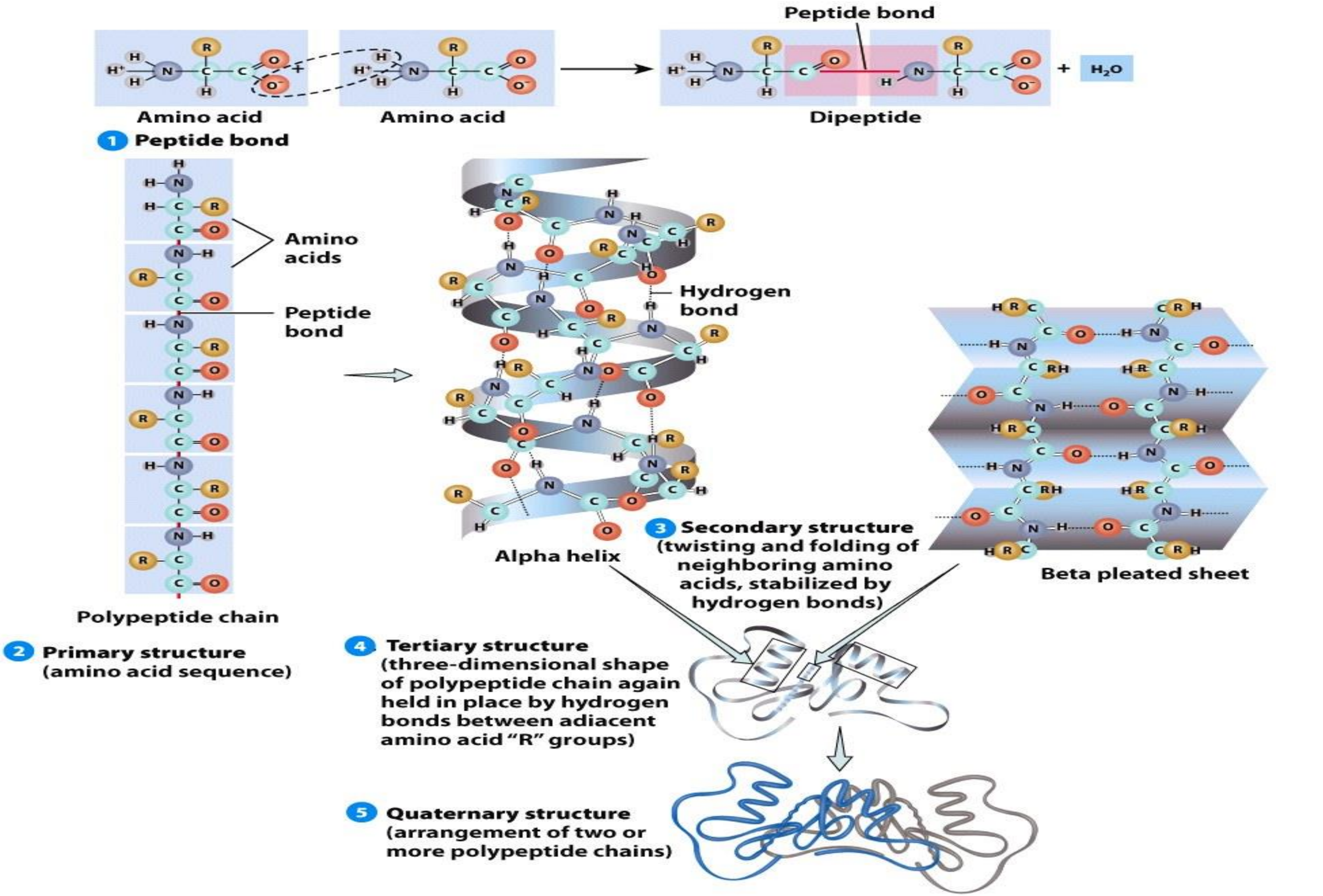
Formation of Peptid bond



Individual Amino Acids Combine to Form Proteins

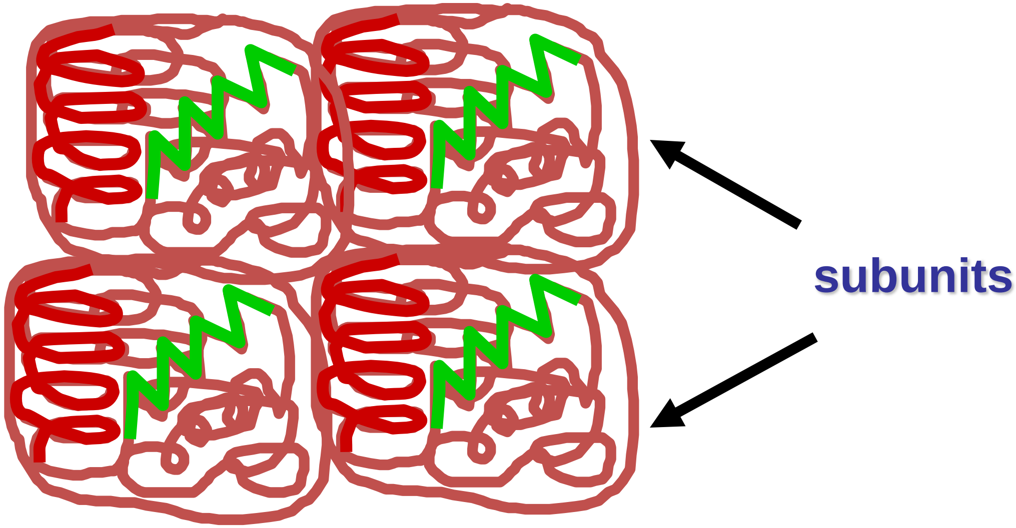
- ***Amino acids are joined by peptide bonds***
  - Peptide bonds form between the *amino group* of one amino acid and the *carboxyl group* of the next amino acid
  - The resulting two amino-acid compound is called a *dipeptide*
- **As more amino acids join the growing chain, it becomes a *polypeptide***
- **Polypeptides are linear sequences (polymers) of amino acids**
  - Polypeptides normally cannot function as proteins
  - Must first develop into a unique three-dimensional shape (conformation)
  - The shape depends on the *specific sequence* of amino acids

VISUALIZING



Quaternary structure

- Aggregation of two or more polypeptide chains(Subunits) that associate to form asingle protein.
- Form in aqueous environment.
- For example ,*haemoglobin* contains four polypeptide chains.



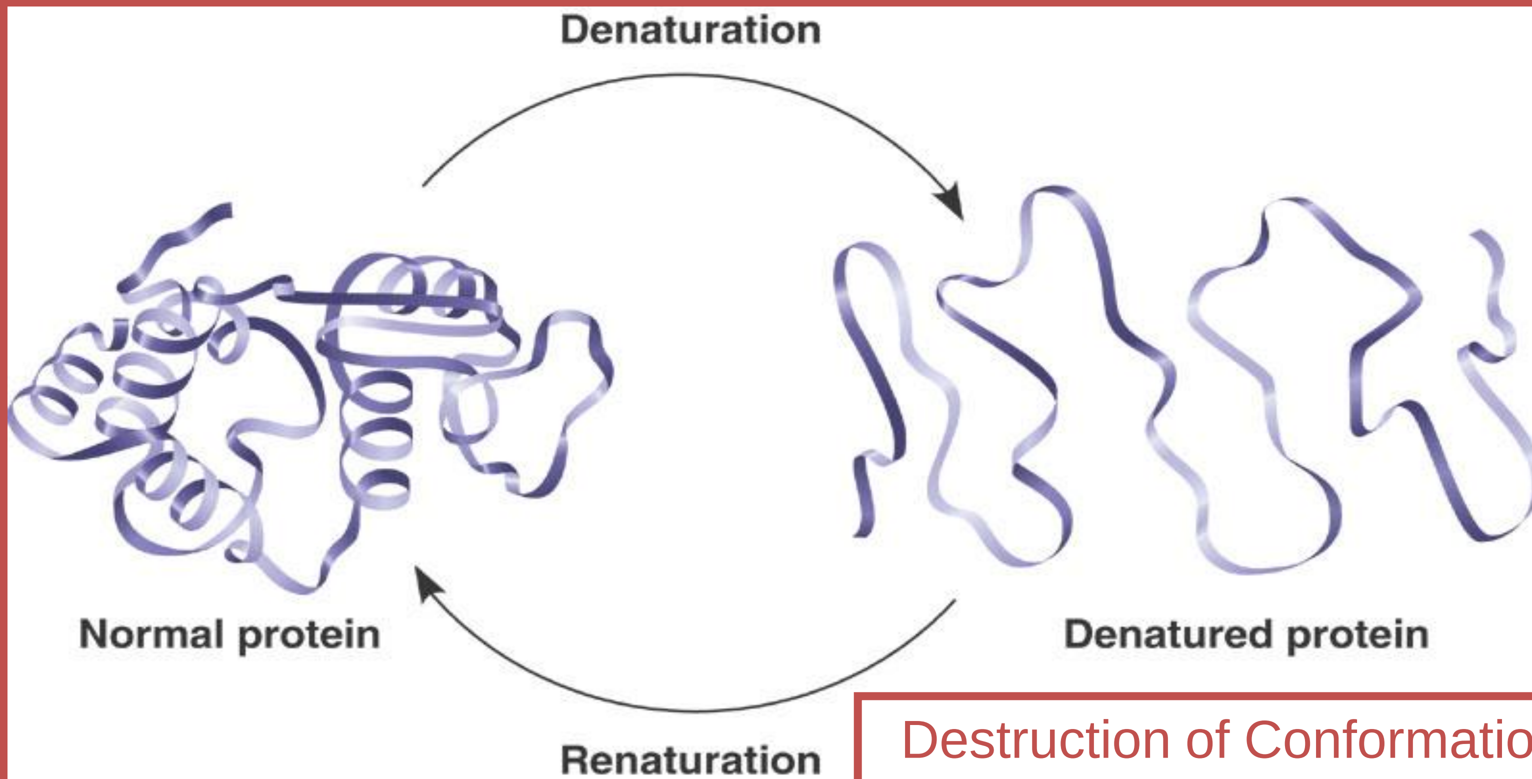
Protein Function Emerges From Its Shape

- **The folding and interacting of adjacent amino acids within a polypeptide determine the final shape of a protein (it's conformation)**
- **The final shape of a protein is either *globular or fibrous***
  - Globular proteins are *round* and usually *water-soluble*
  - Fibrous proteins are *stringy, tough*, and usually *insoluble* in water (provide the framework for supporting cells and tissues)
- **The shape of a protein molecule determines its function, and the final shape is determined by its primary structure (amino acid sequence)**
  - Changing even one amino acid can alter the *folding pattern*, with devastating effects on the protein's function
  - In *sickle cell anemia*, a change in only one amino acid leads to serious consequences

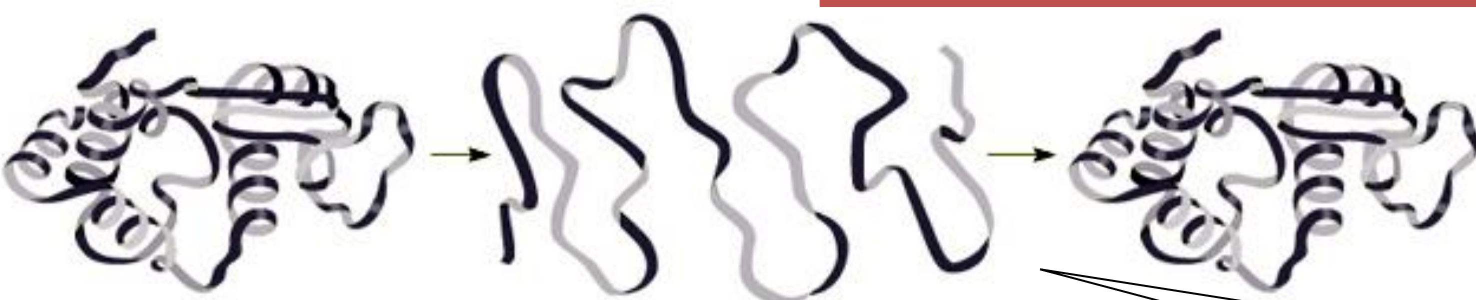
What Determines Protein Structure?

- physical and chemical conditions can affect protein structure.
- Alterations in pH, salt concentration, temperature, or other environmental factors can cause a protein to unravel
- This loss of a protein's native structure is called **denaturation**
- A denatured protein is *biologically inactive*

Protein Denaturation



Destruction of Conformation = Loss of Function



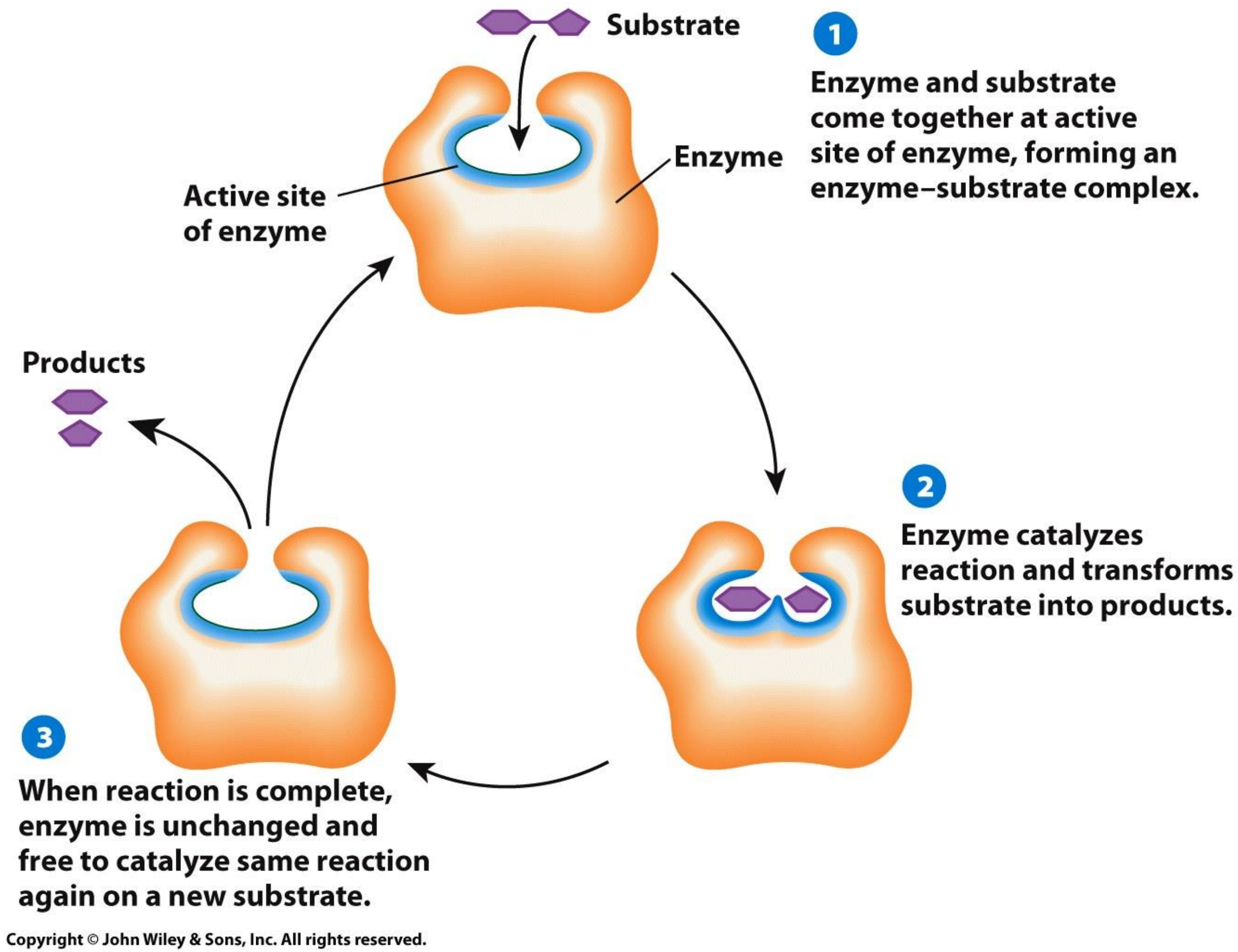
pH, temp, ionic strength, solubility

Some simple proteins can spontaneously renature

Enzymes Serve as Catalysts for Biochemical Reactions

- **Catalysts bring the reactants, or substrates, together, so that they can participate in a chemical reaction *much more quickly***
- **Enzymes facilitate a specific chemical reaction *without being altered* during the chemical reaction**
  - Unlike the substrates which may be altered during the chemical reaction
- **Enzymes *rely on shape* to function properly**
  - The active site of the protein is shaped to bind to one specific substrate
  - After the substrate binds, the enzyme provides an environment for the specific chemical reaction to occur

Enzyme Function



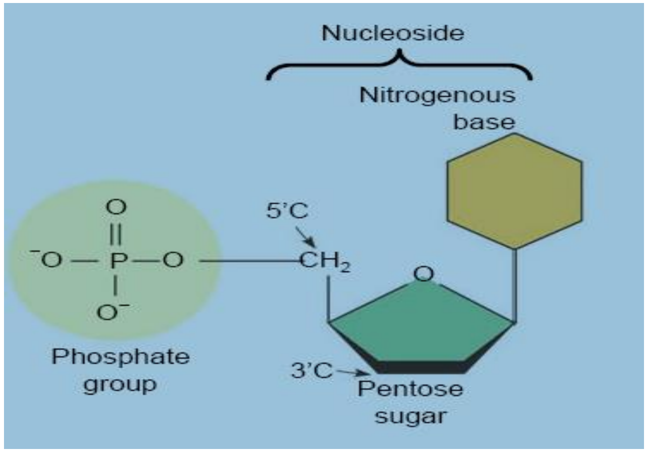
Nucleic Acids

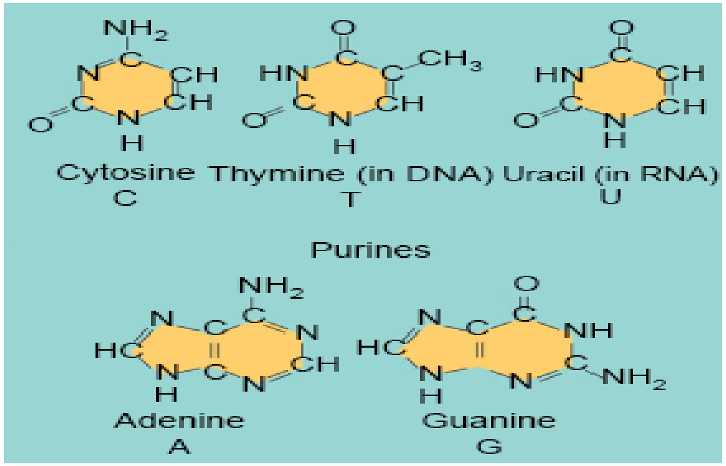
Nucleic Acids Store and Process an Organism's Hereditary Information

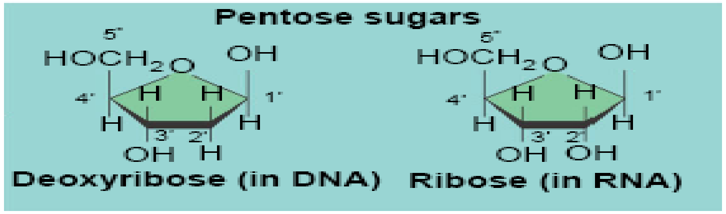
- **There are two types of nucleic acids**
  - Deoxyribonucleic acid (DNA)
  - Ribonucleic acid (RNA)
- **DNA exists in the nucleus of our cells**
  - It contains the hereditary *(genetic) information* of the cell
    - To build proteins
    - To regulate physiological processes
    - To maintain homeostasis
- **RNA acts as *a messenger molecule* both inside and outside the nucleu**
  - RNA serves to regulate cellular metabolism, produce proteins, and govern developmental timing

The Structure of DNA & RNA

- Nucleic acids are composed of units called ***nucleotides***
- The bond is ***phosphodiester*** bond
- Each nucleotide contains a ***base, a sugar,*** and a ***phosphate group***
- sugar is ***deoxyribose*** (DNA) or ***ribose*** (RNA).
- The bases of DNA are adenine, guanine, cytosine, and thymine.
- The bases of RNA are adenine, guanine, cytosine, and uracil







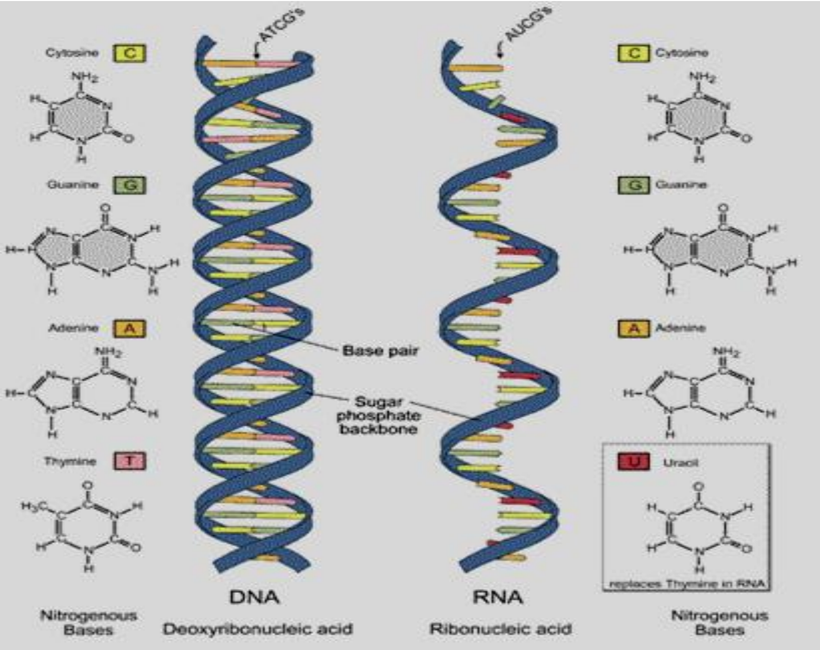
The DNA *double helix*

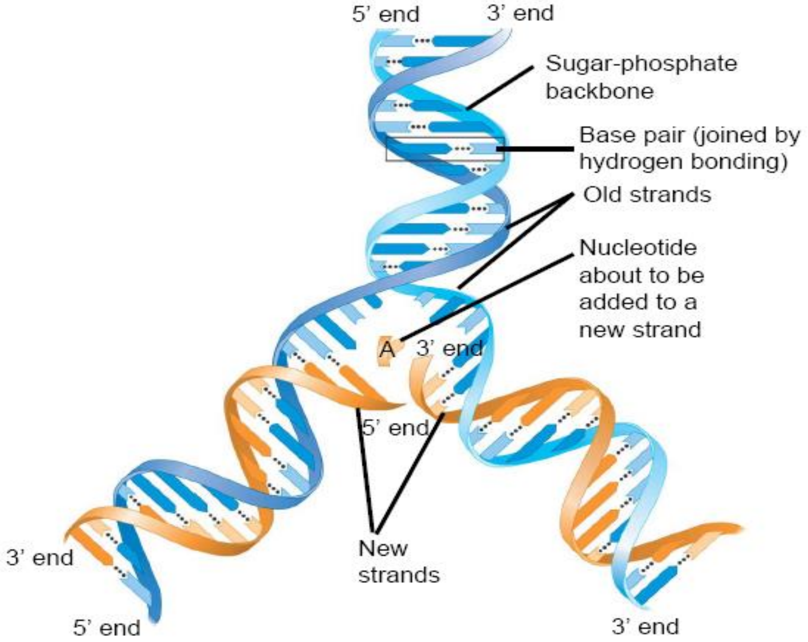
– Consists of two antiparallel nucleotide strands

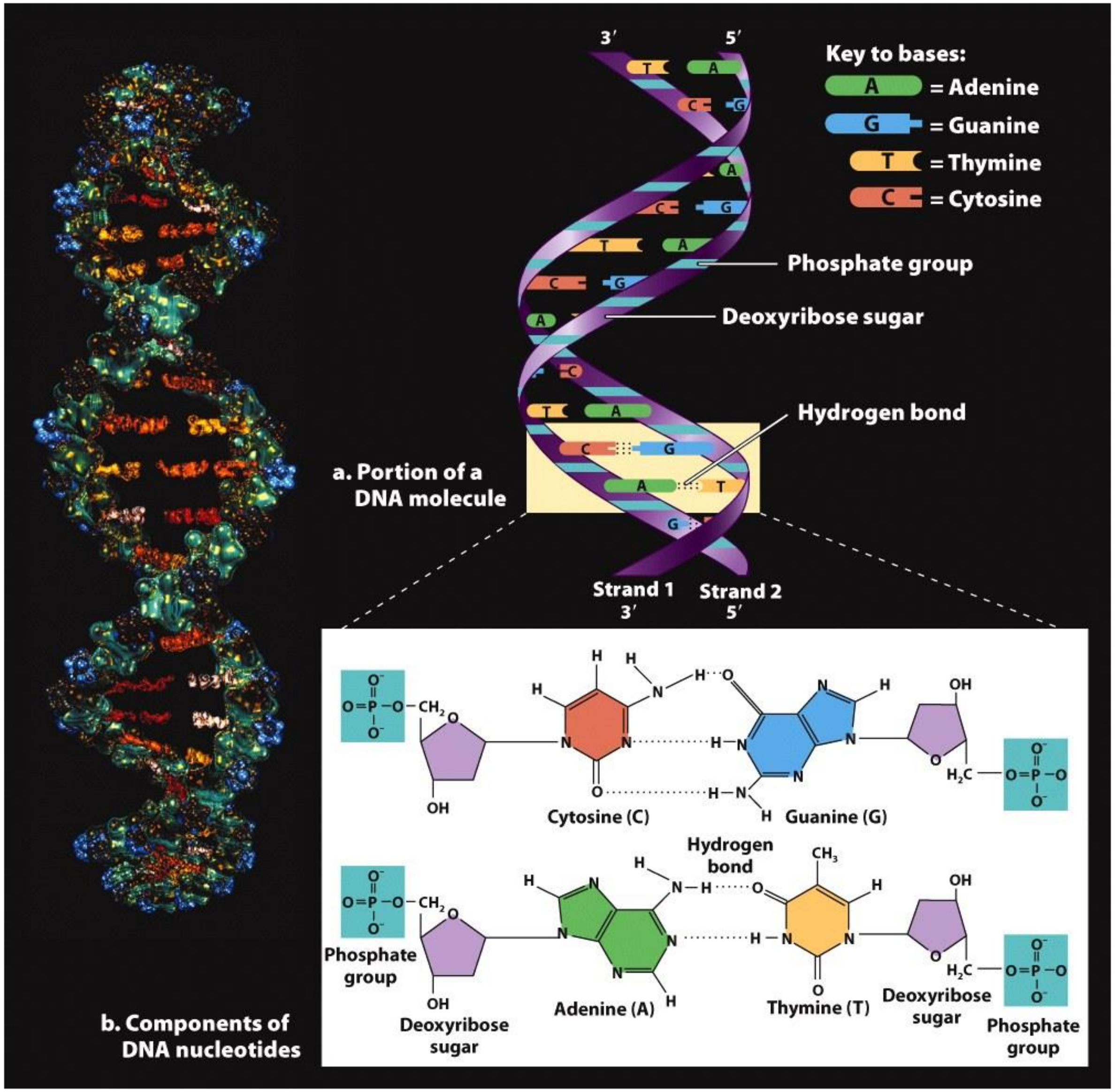
The end of a single strand that has the phosphate group is called the 5’ end. The other end is the 3’ end.

The RNA

- is a *single-stranded* molecule of nucleotides.







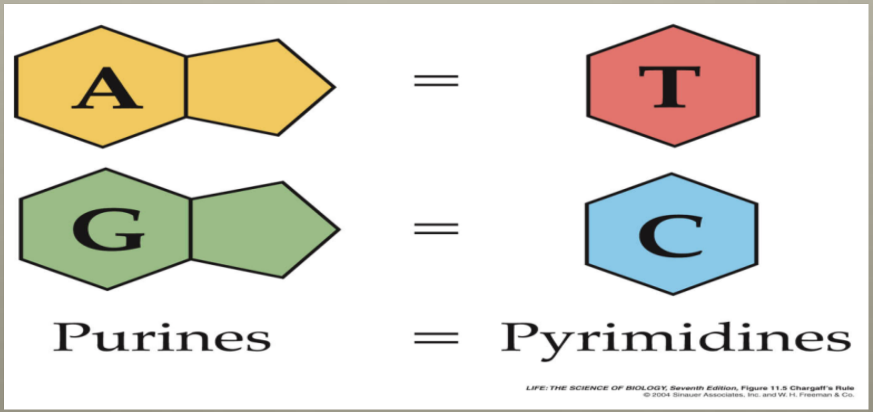
3′
5′
Key to bases:
A = Adenine
G = Guanine
T = Thymine
C = Cytosine
Phosphate group
Deoxyribose sugar
Hydrogen bond
a. Portion of a DNA molecule
Strand 1
3′
Strand 2
5′
Cytosine (C)
Guanine (G)
Hydrogen bond
Adenine (A)
Thymine (T)
Phosphate group
Deoxyribose sugar
b. Components of DNA nucleotides

Complimentary base pairing

- **The nitrogenous bases in DNA**
- **– Form hydrogen bonds in a complementary fashion (A with T only, and C with G only) Chargaff's rule**

A ═ T

G ≡ C

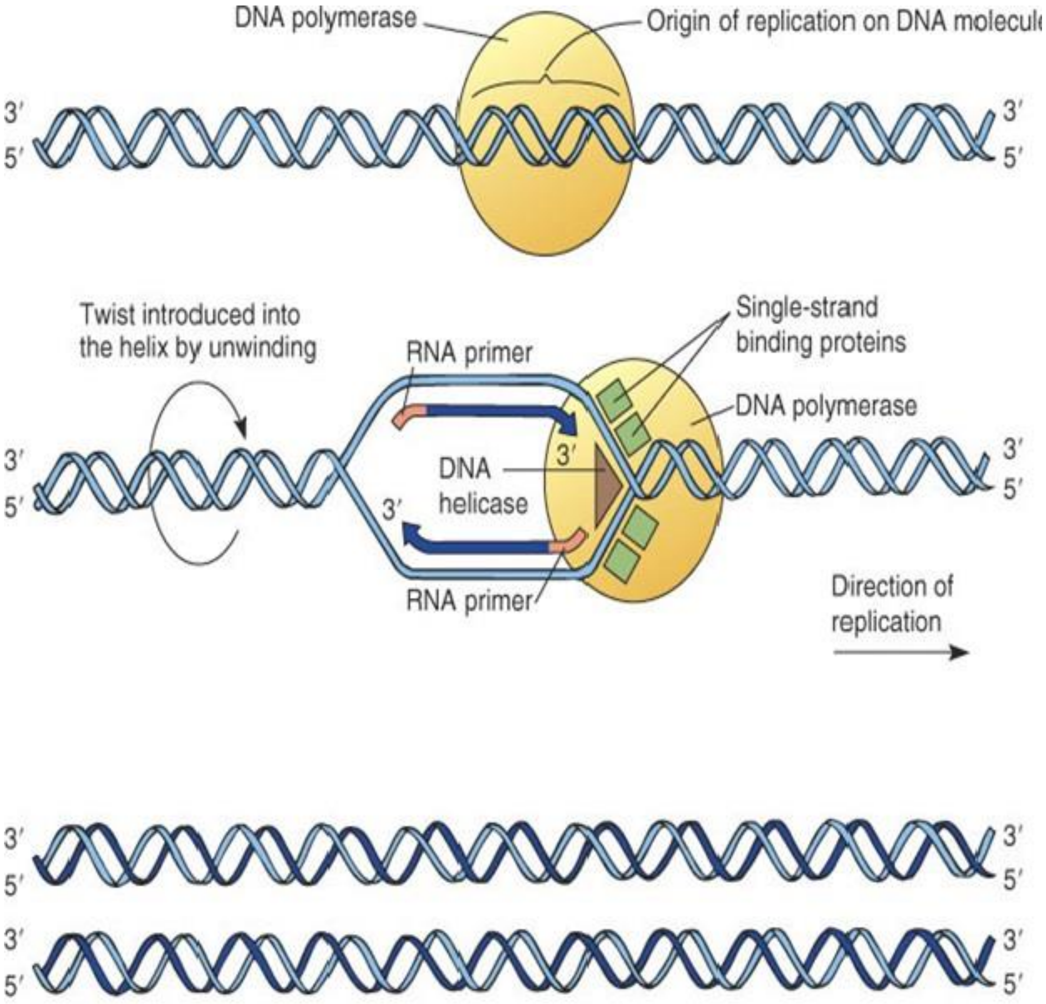


Meselson-Stahl Experiment

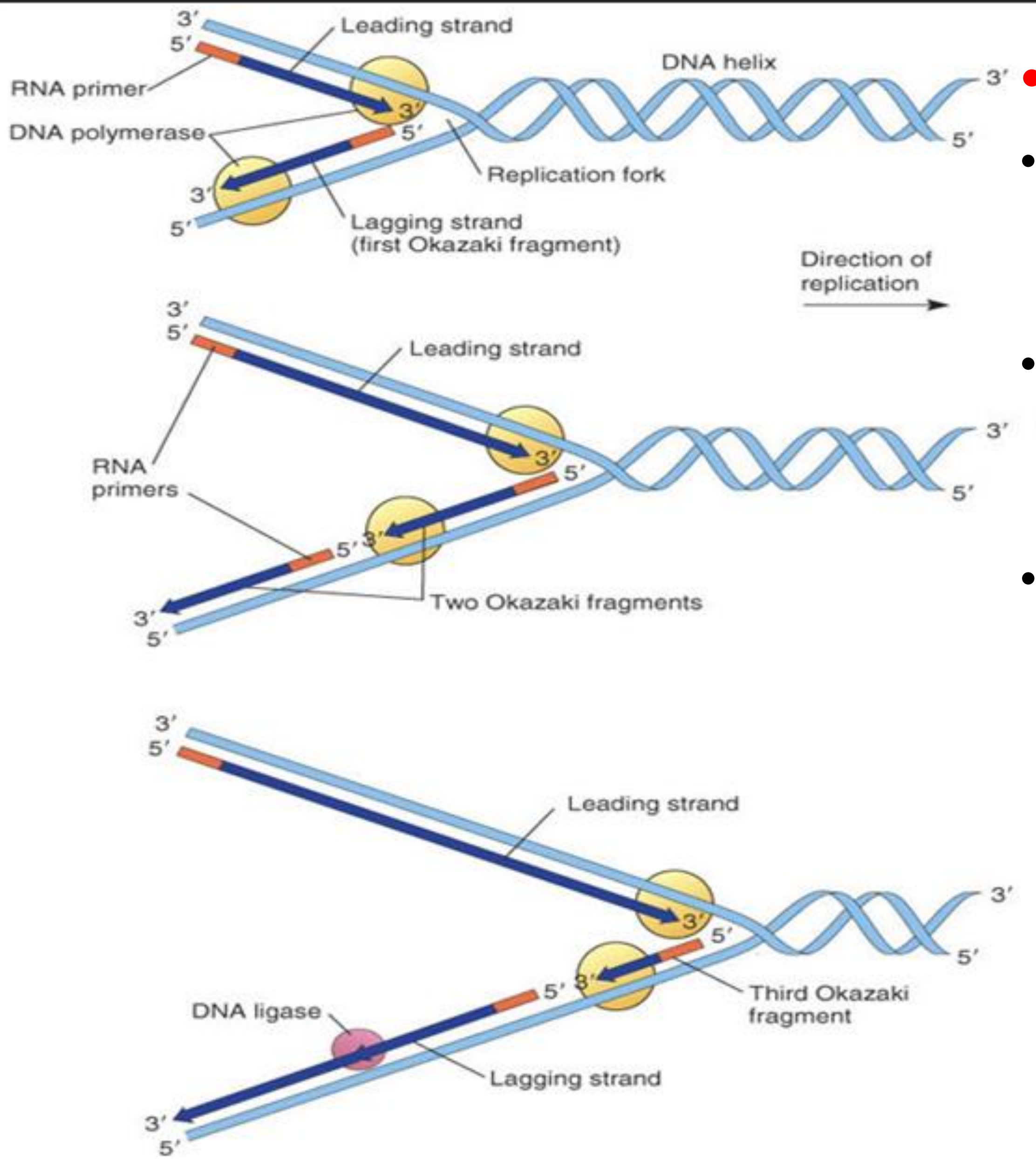
Semiconservative Replication

- Each daughter double helix consists of
  - 1 original strand from parent molecule
  - 1 new complementary strand

Bidirectional Replication



1- strands are separated by “DNA helicase” forming the fork.
“Single strand binding proteins” bind to both DNA strands and prevent the helix from reforming.
2- Elongation of DNA strands requires “RNA primer” which initiates the addition of nucleotides at 3’ end.
3- Finally, two daughter DNA molecules are formed, each containing one old and one newly synthesized strand.
Each double helix is a chromatid of duplicated chromosome.



- **DNA Synthesis**
- Always proceeds in 5′ → 3′ direction

- Leading strand
  - synthesized continuously

- Lagging strand
  - synthesized discontinuously
  - forms short Okazaki fragments
  - "DNA primase" synthesizes RNA primers
  - "DNA ligase" links Okazaki fragments

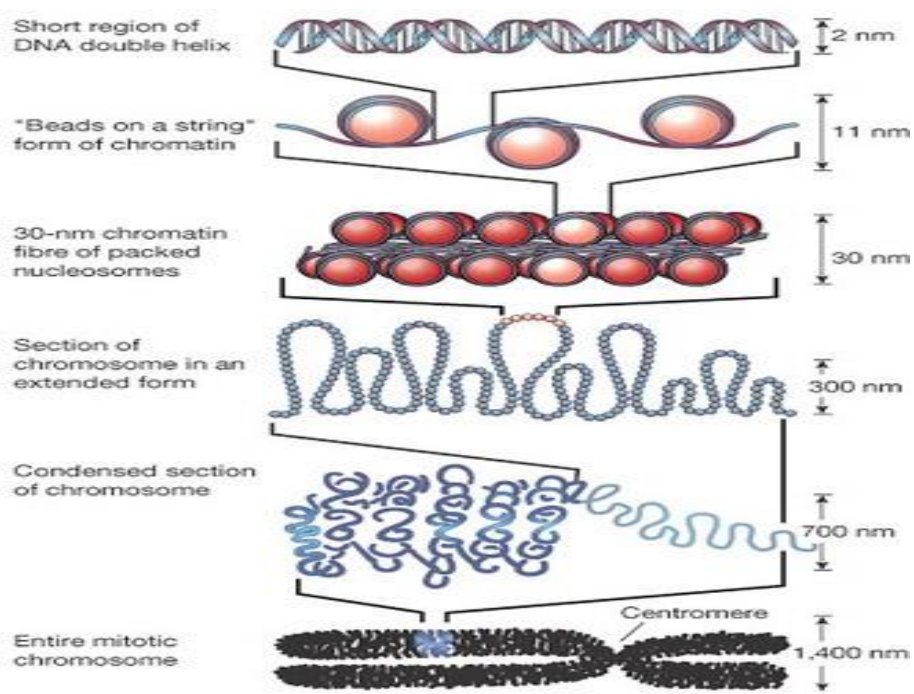
Enzymes Involved in DNA replication

Enzyme	Function
Helicase	separate strands of DNA
DNA Primase	synthesizes a RNA primer
DNA polymerase	add free nucleotides to the 3' end (Make a copy of DNA)
DNA-Ligase	joins the okazaki fragments on lagging strand
Single strand binding (SSB) protein	prevents the helix from re-forming

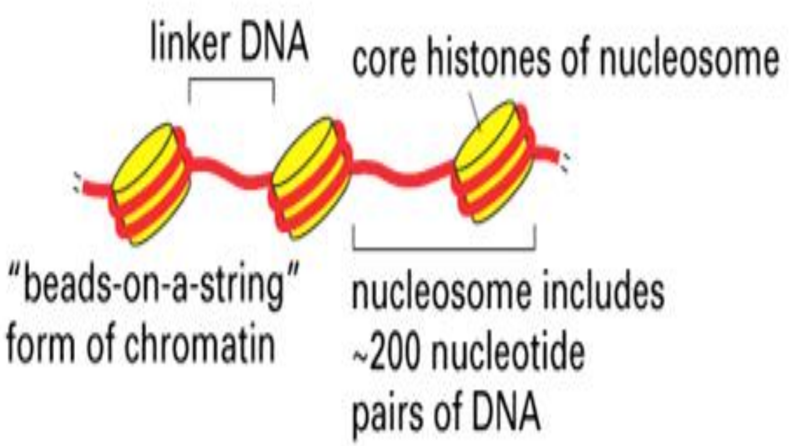
"Packaging" DNA

. 1st level of DNA packaging in eukaryotes is around proteins called *histones*

. Each core histone with its associated DNA is called a *nucleosome* – first level of chromatin packing.



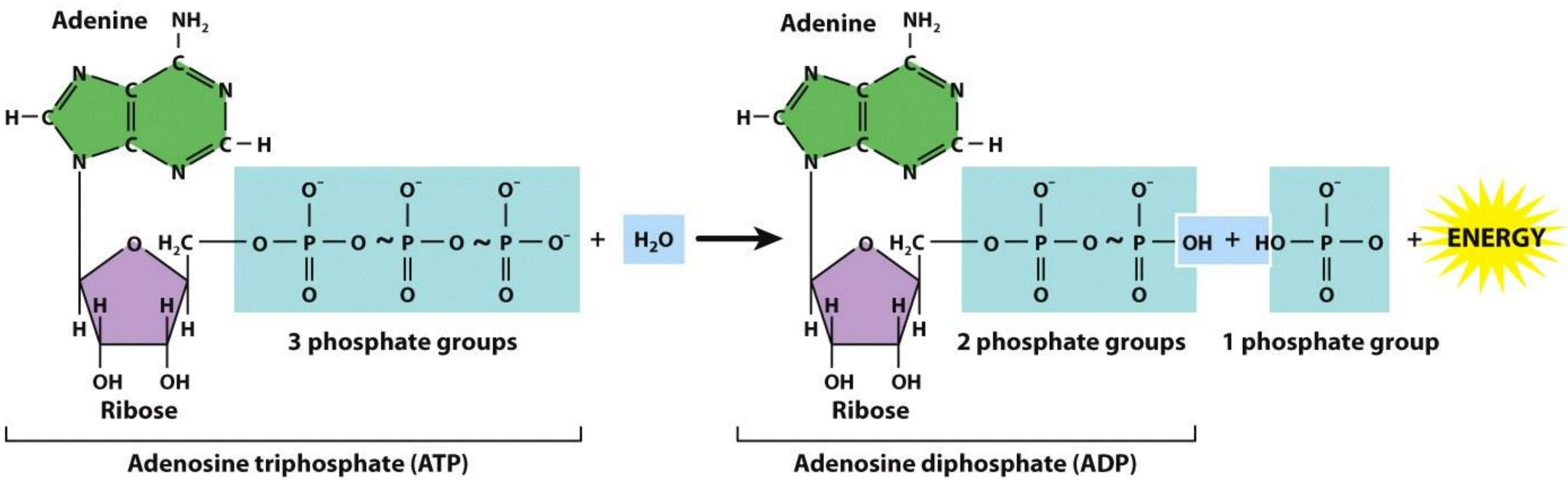
Organization of eukaryotic chromosomes



Life Requires Energy

- **High energy compounds power cellular activity**
- **Most often energy is available in spurts, rather than as a continuous stream all day long**
- **Our energy storage system provides short- and long-term storage**
  - Long-term energy storage includes
    - *Glycogen* in muscles and liver
    - *Triglycerides* packed into specialized storage cells called adipocytes (fat cells)
  - Short-term energy storage uses a high-energy system that is reversible and instantly available
    - The most common storage system is **ATP**, or ***adenosine triphosphate***
    - ATP powers all cellular activity, from forming proteins to contracting muscles

Adenosine Triphosphate



Adenosine triphosphate (ATP) + H_2O = Adenosine diphosphate (ADP) + P_i + Energy