Molecules of Life

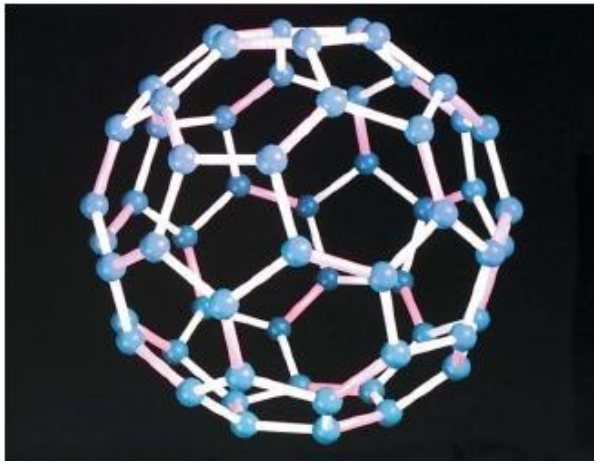
The stuff we're made of

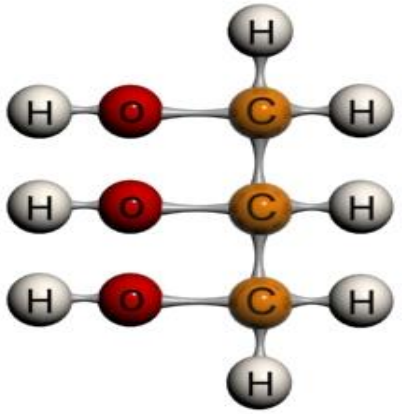
Water

- The human body is mostly water
  - Lean muscle: 75% water
  - Blood: 83% water
  - Body fat: 25% water
  - Bone: 22% water
- All living organisms require water to live

Carbon

- A carbon atom has 4 outer (**valence**) electrons – wants to make 4 bonds to be stable
- Carbon can bond with itself and many other elements
- Because it's so friendly, carbon is present in all life on earth



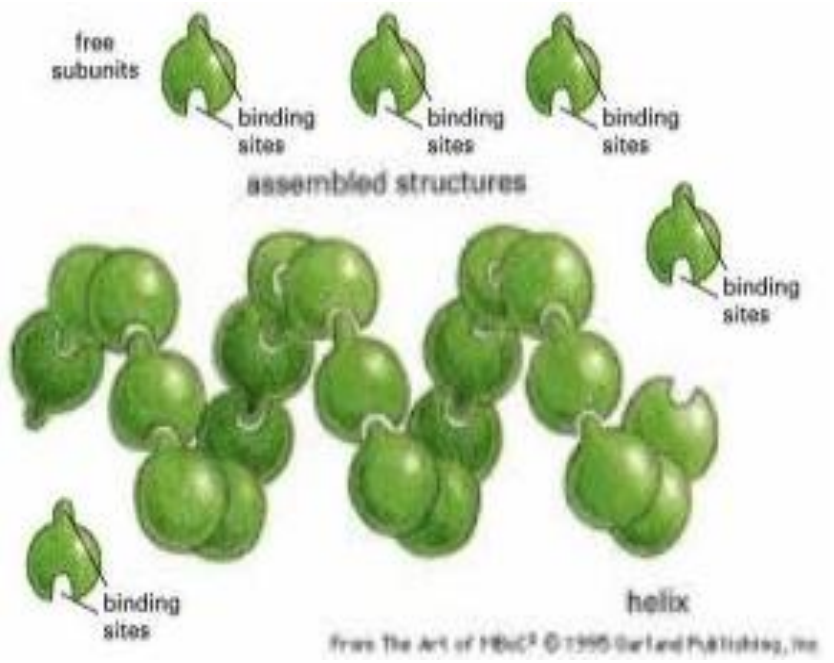


Organic Molecules

- Any molecule containing carbon is called an **organic molecule**

  !! Except CO_2 !!

- Most organic molecules are arranged like chains
  - Each link is a **monomer**
  - A chain is a **polymer**
  - A large molecule made of a long chain or chains is a **macro molecule**

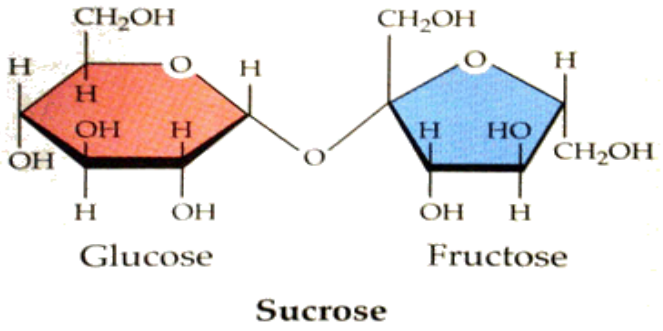


Types of Organic Molecules

- **Carbohydrates**
- **Lipids**
- **Nucleic acids**
- **Proteins**

Carbohydrates

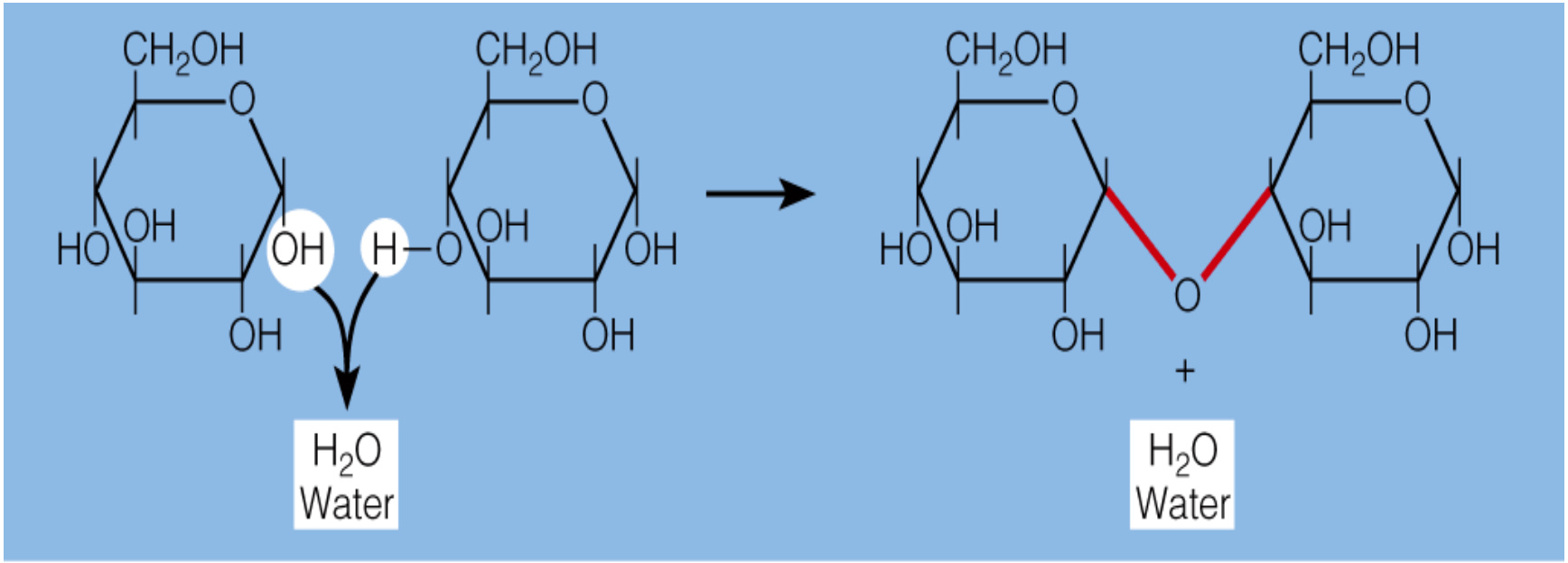
- Molecules used for energy, made of C H O
  - **Monosaccharide:** a simple sugar (glucose, fructose, galactose)
  - **Disaccharide:** two monosaccharides bound together (sucrose aka table sugar)



Sucrose

  - **Oligosaccharide:** 3 to 10 monosaccharides
  - **Polysaccharide:** More than 10 monosaccharides (starch is hundreds of glucose molecules bonded together)

Condensation



Glucose + glucose → Maltose

An OH group from one glucose and an H atom from another glucose combine to create a molecule of H_2O.

The two glucose molecules bond together with a single O atom to form the disaccharide maltose.

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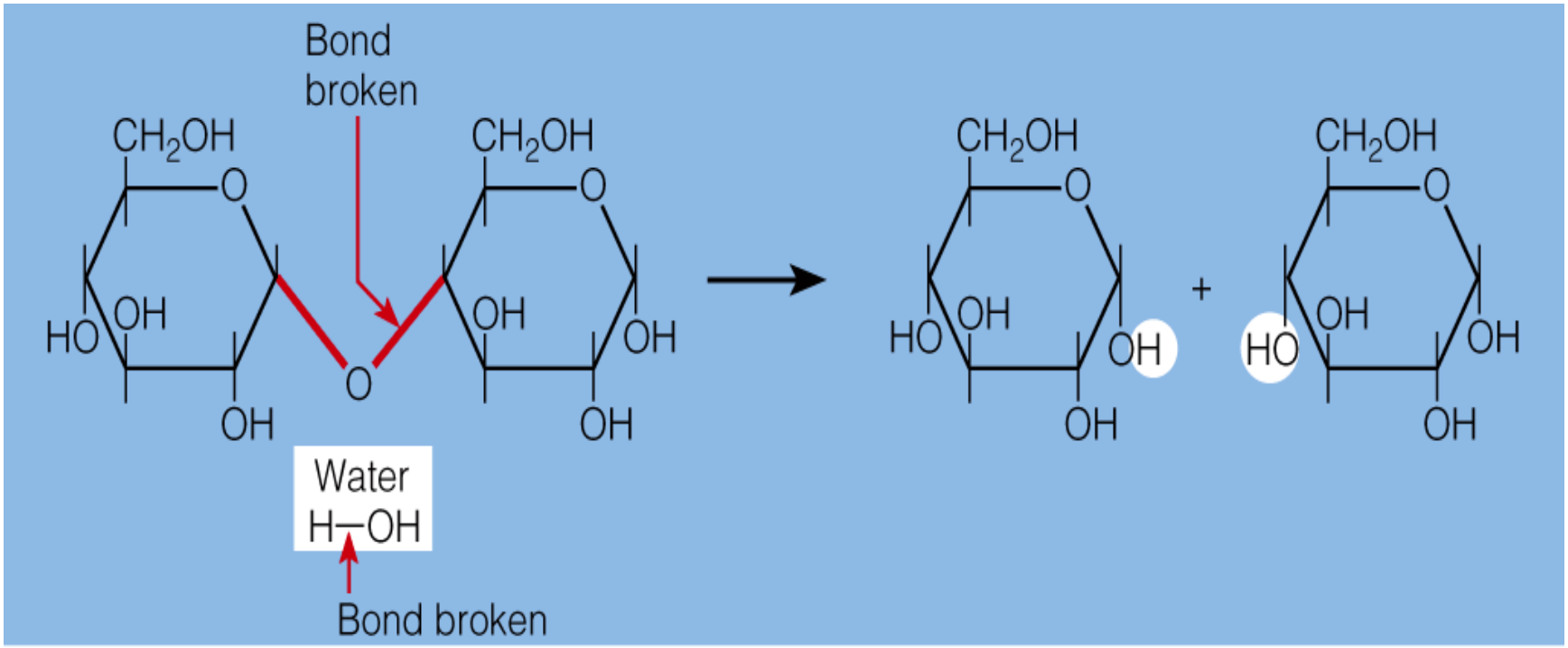
Hydrolysis



Maltose → Glucose + glucose

The disaccharide maltose splits into two glucose molecules with H added to one and OH to the other (from water).

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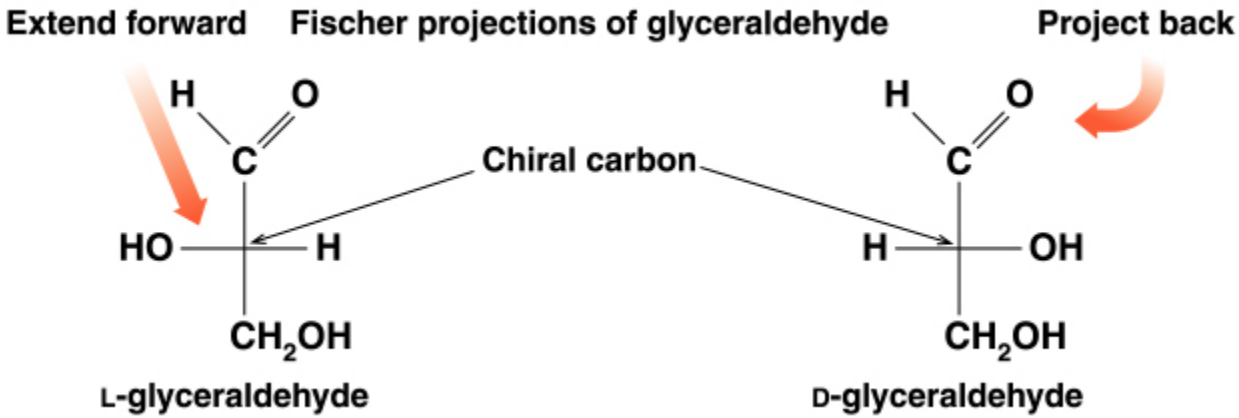
Sugar/Sugar Derivatives	Percent Sweetness
Glucose	75
Fructose (Sweetest Sugar)	175 (Highest)
Galactose	30
Sucrose	100
Lactose	20
Maltose	30
Xylitol	250

Non-Carbohydrate Synthetic Sweetners	Percent Sweetness
Saccharin	45,000 times
Aspartame (Asp-Phe)	18,000 times
Thaumatin and Monellin	10,000 times
Cyclamate	1000 times

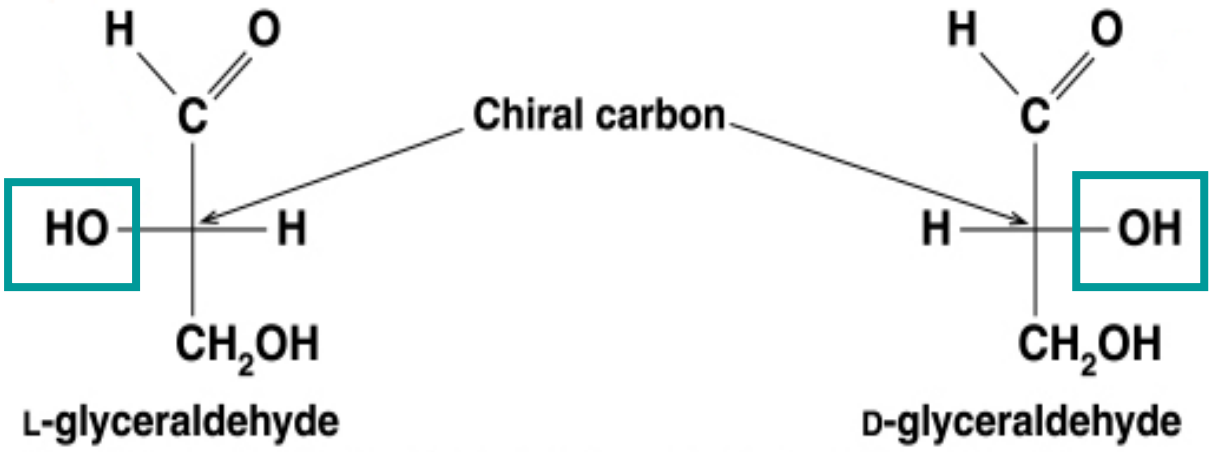
Fischer Projections

- Used to represent carbohydrates (chiral carbons)
- Places the most oxidized group at the top (C1)
- Uses horizontal lines for bonds that come forward
- Uses vertical lines for bonds that go back



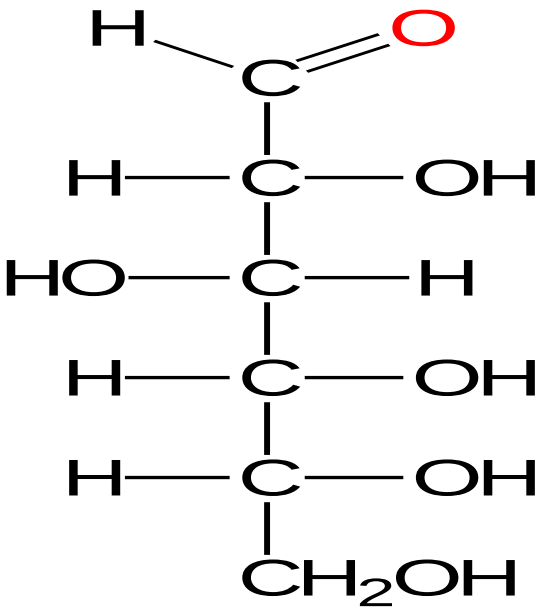
D and L Notations

- By convention, the letter L is assigned to the structure with the —OH on the left
- The letter D is assigned to the structure with —OH on the right



Aldose

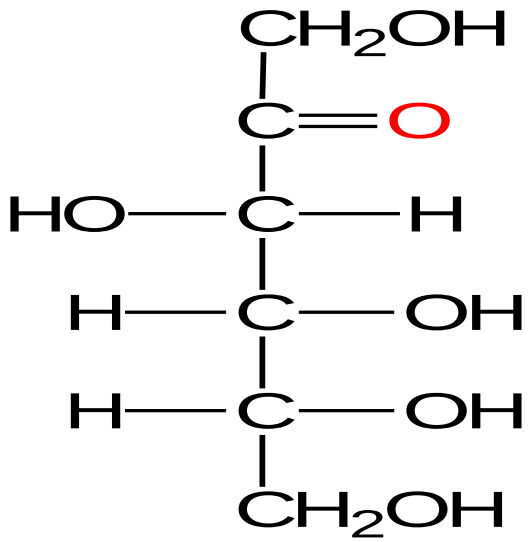
(e.g., Glucose) have an aldehyde group at one end.



D-glucose

Ketose

(e.g., Fructose) have a ketone group, usually at C2.



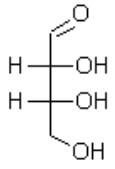
D-fructose

Monosaccharides Sub Classification

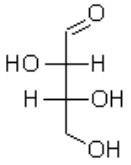
- Monosaccharides are sub classified based on:
  - Functional Group
  - Number of Carbon atoms.

Number of Carbon Atoms	Aldoses (Aldehyde-CHO)	Ketoses (Ketone -C=O)
3 Triose	Aldo Triose Glyceraldehyde	Keto Triose Di HydroxyAcetone
4 Tetrose	Aldo Tetrose Erythrose	Keto Tetrulose Erythrulose
5 Pentose	Aldo Pentose Ribose, Xylose, Arabinose	Keto Pentulose Ribulose, Xylulose
6 Hexose	Aldo Hexose Glucose, Galactose, Mannose	Keto Hexose Fructose
7 Heptose	Aldo Heptose SedoHeptose	Keto Heptulose SedoHeptulose

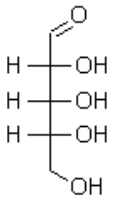
Aldose



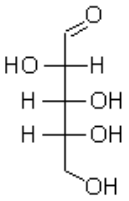
D-Erythrose



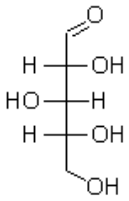
D-Threose



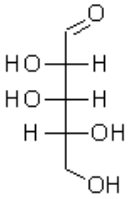
D-Ribose



D-Arabinose

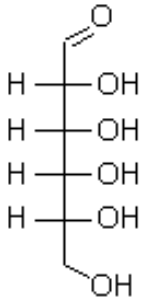


D-Xylose

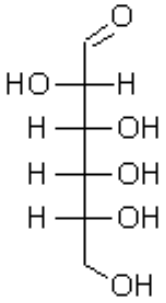


D-Lyxose

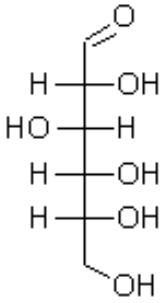
Royal **Arabian** **Xylophonists** **Lyricize**



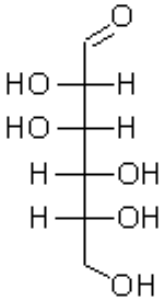
D-Allose



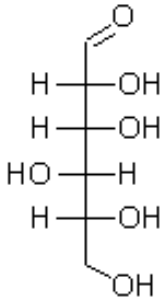
D-Altrose



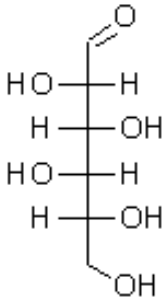
D-Glucose



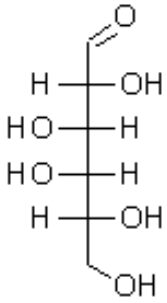
D-Mannose



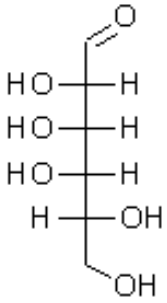
D-Gulose



D-Idose



D-Galactose



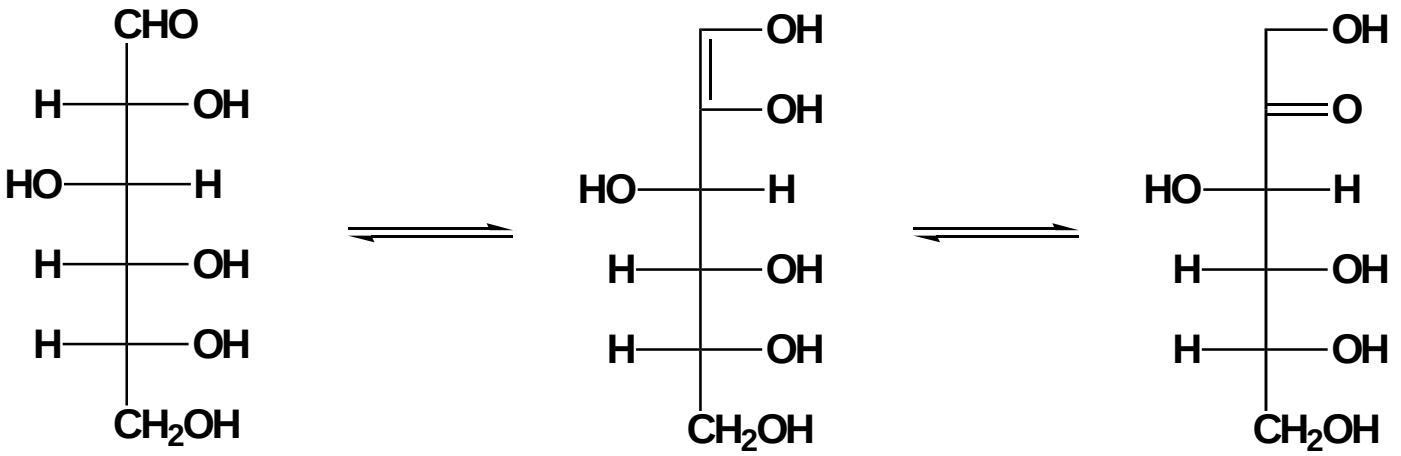
D-Talose

All **Altruists** **Gladly** **Make** **Gum** **In** **Gallon** **Tanks**

Ketone Sugars

Ketones are not easy to oxidize except for ketoses

Enediol reaction -- All monosaccharides are reducing sugars



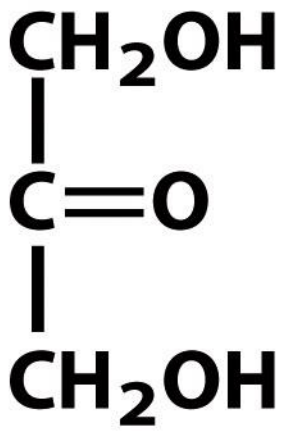
Aldose

cis-enediol intermediate

Ketose

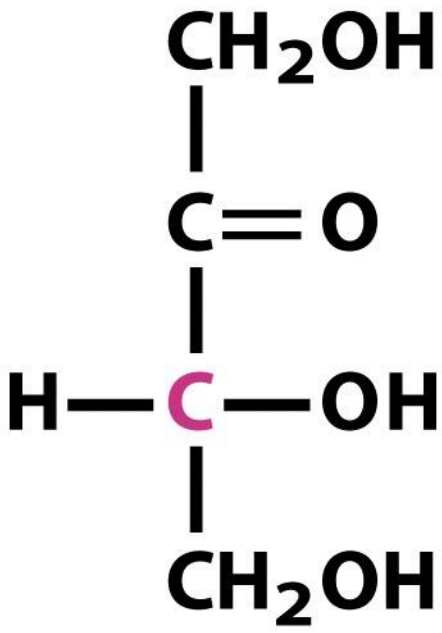
D-Ketoses

Three carbons



Dihydroxyacetone

Four carbons



D-Erythrulose

Figure 7-3b part 1
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D-Ketoses

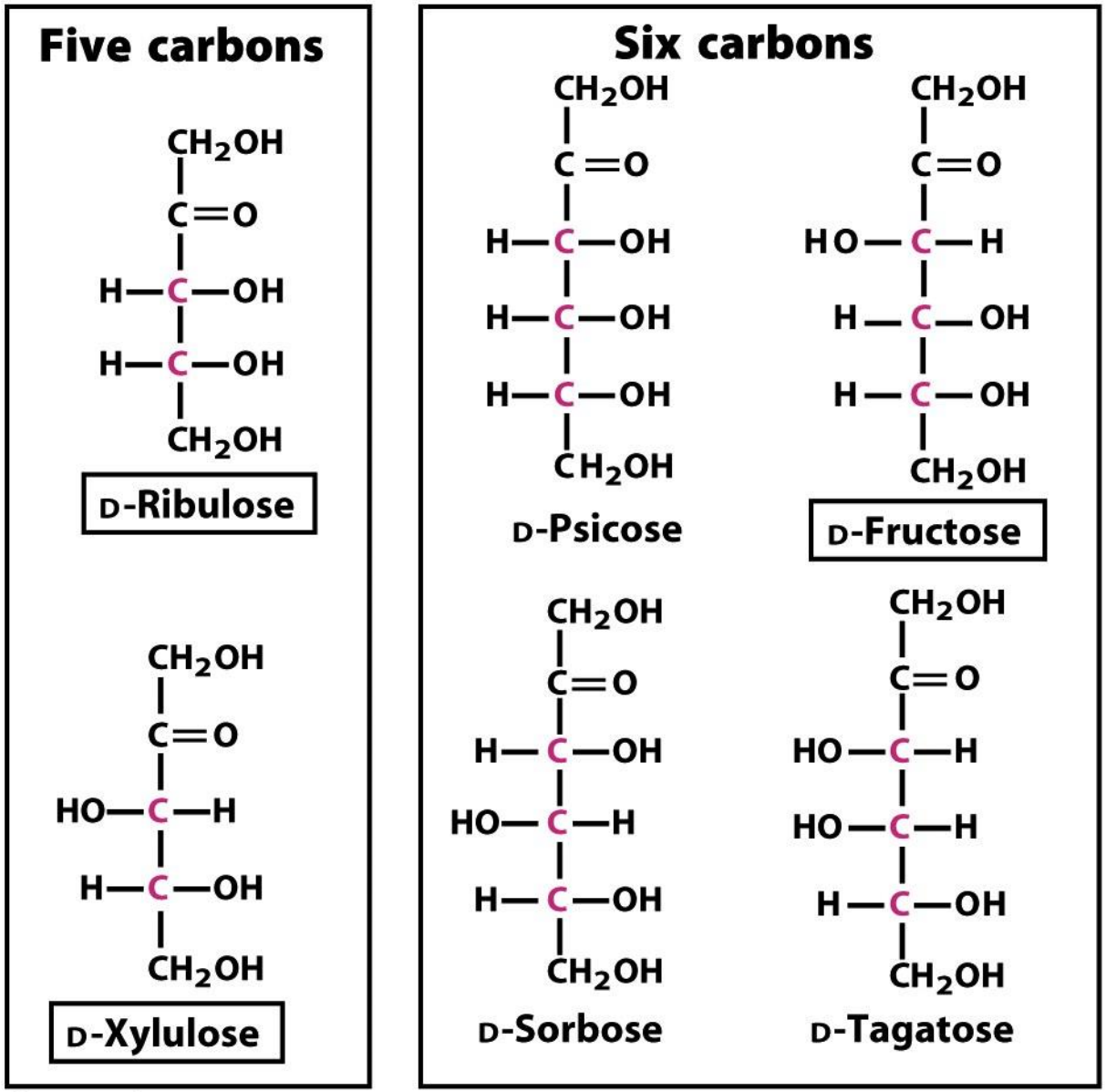

Figure 7-3b part 2

Lehninger Principles of Biochemistry, Fifth Edition

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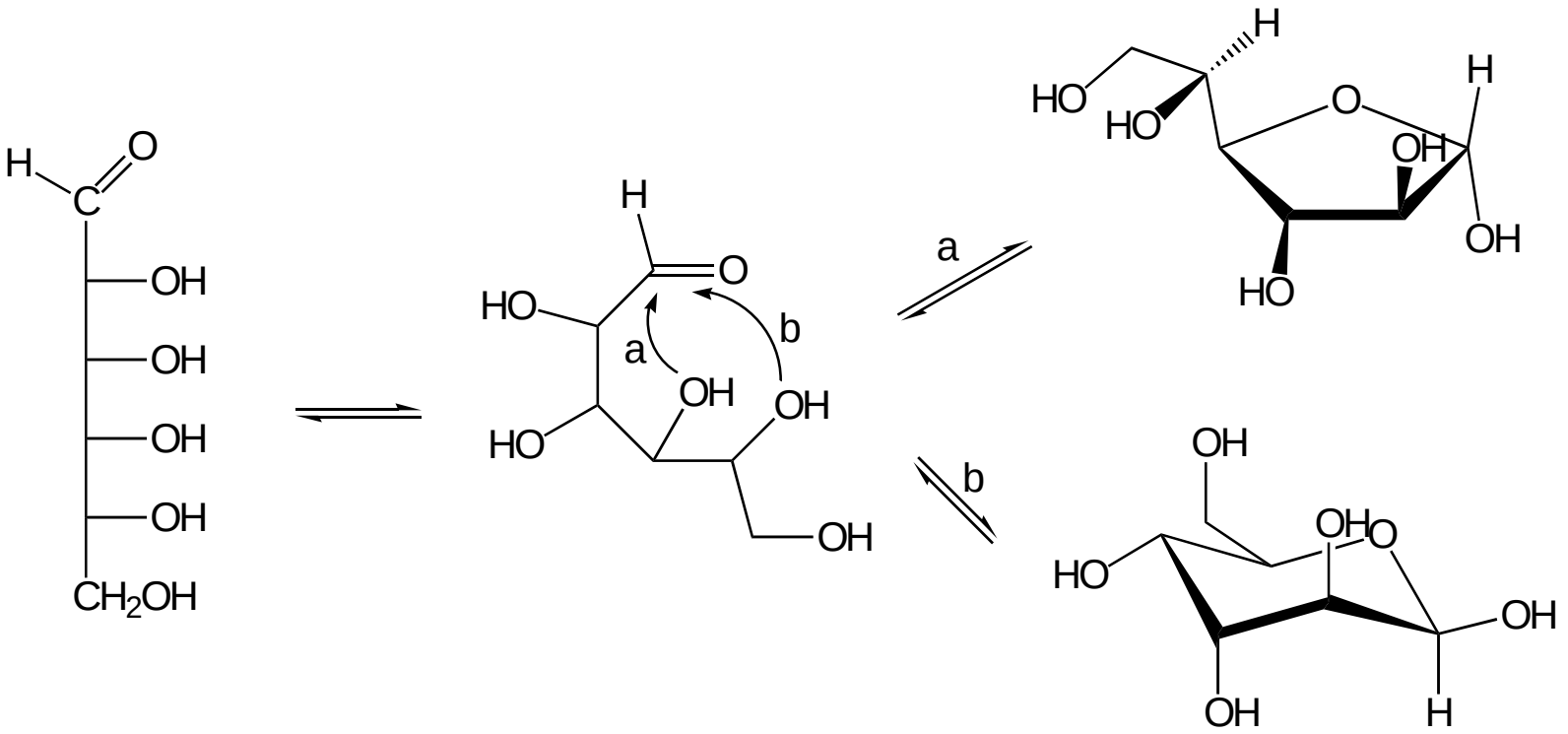
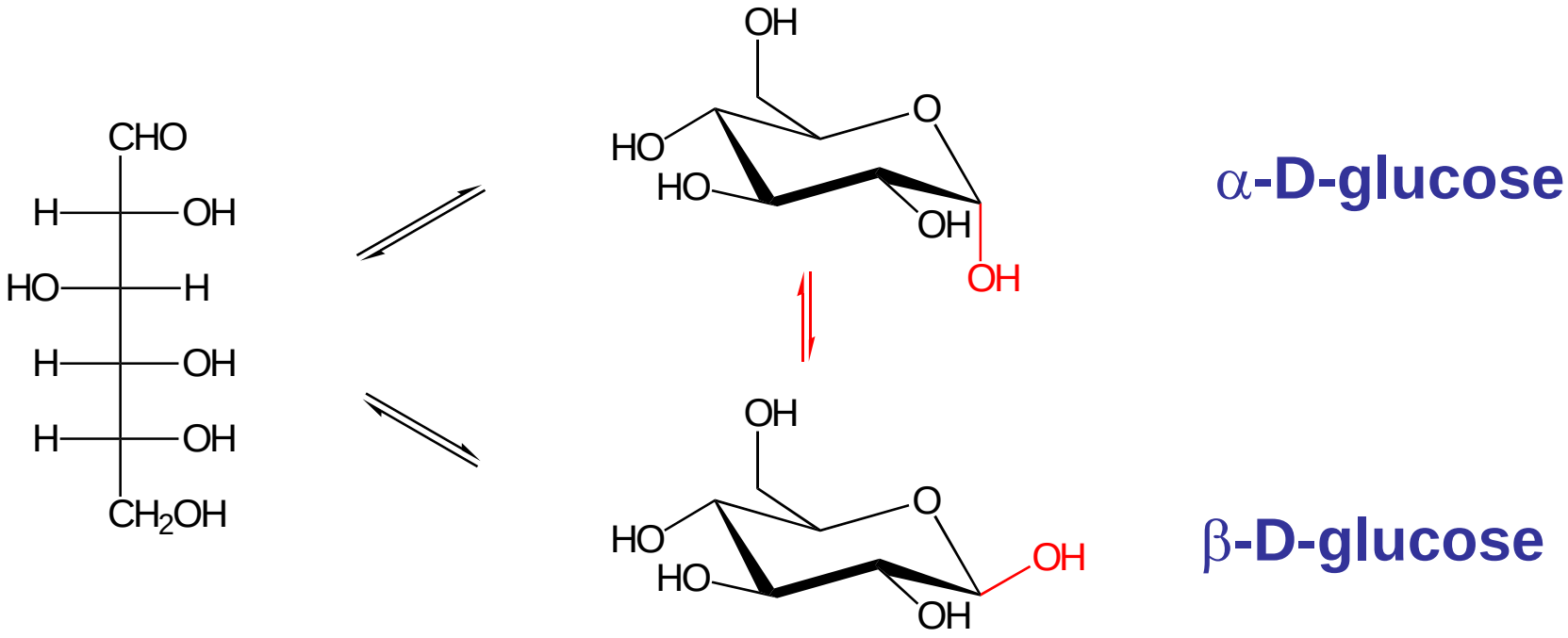
Intramolecular Cyclization

Chain can bend and rotate



Cyclization of D-glucose



Reducing Sugar

- Sugar structure **possessing free or potential (reactive)** aldehyde or ketone group is termed as **reducing sugar.**
- Reducing sugars **show reducing property** efficiently in alkaline medium and **reduces certain metallic ions** as- Cu^{++};Bi^{++};Fe^{+++}
- **Reducing Sugars** answer following **tests positive**
- Benedict's Test
- Fehling's test
- Nylander's Test
- Form Osazones.
- Reducing Shows Mutarotation (Change in Optical activity)

Benedict's Test

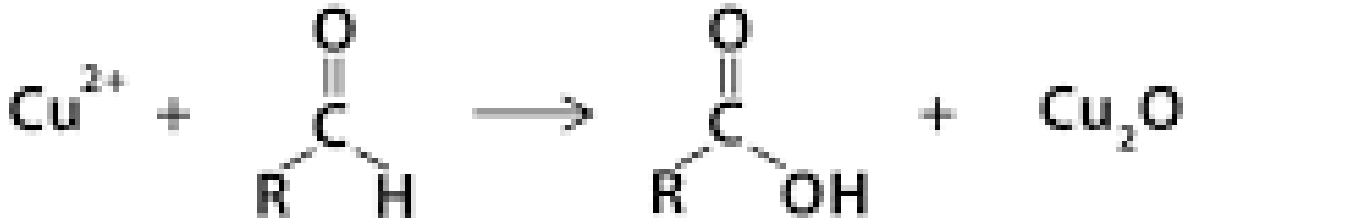
A. Preparation of Benedict's Reagent

$CuSO_4.5H_2O$ + Na_2CO_3 + $Na_3C_6H_5O_7$

Copper sulfate pentahydrate | Sodium carbonate | Sodium citrate

→ **Benedict's Reagent**

B. Benedict' Test Reaction



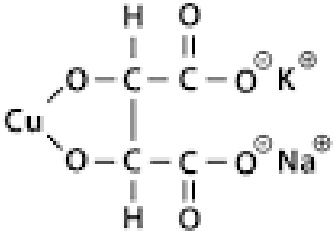
Cupric ions | Aldehyde | Carboxylic acid | Cuprous oxide (brick-red precipitate)

ChemistryLearner.com

Fehling's Solution

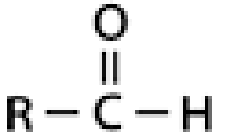
$CuSO_4.5H_2O$ + $2NaOH$ + $KNaC_4H_4O_6.4H_2O$ → (Δ)

Cupric sulfate | Sodium hydroxide | Potassium sodium tartrate (Rochelle salt)

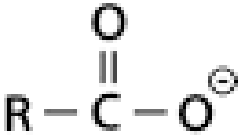


Fehling's solution + Na_2SO_4 (Sodium sulfate) + $11H_2O$ (Water)

Fehling's Test Reaction



Aldehyde + $2Cu^{2\oplus}$ (Cupric (Copper (II))) + $5OH^{\ominus}$ (Hydroxide) →



Carboxylate + $Cu_2O\downarrow$ (Cuprous oxide (Copper (I)) (Red precipitate)) + $3H_2O$ (Water)

Nylander's Test

$$NH_4OH + AgNO_3 \longrightarrow NH_4NO_3 + Ag(OH)$$

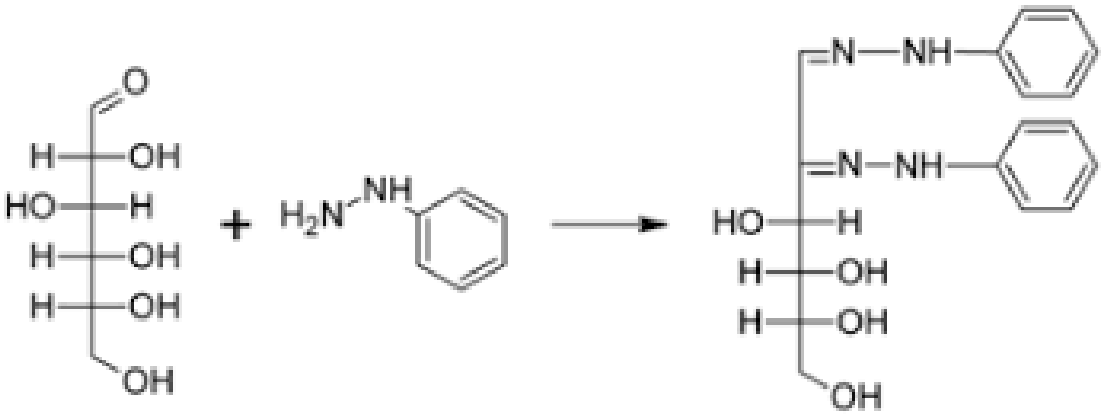
$$2Ag(OH) \longrightarrow Ag_2O + H_2O$$

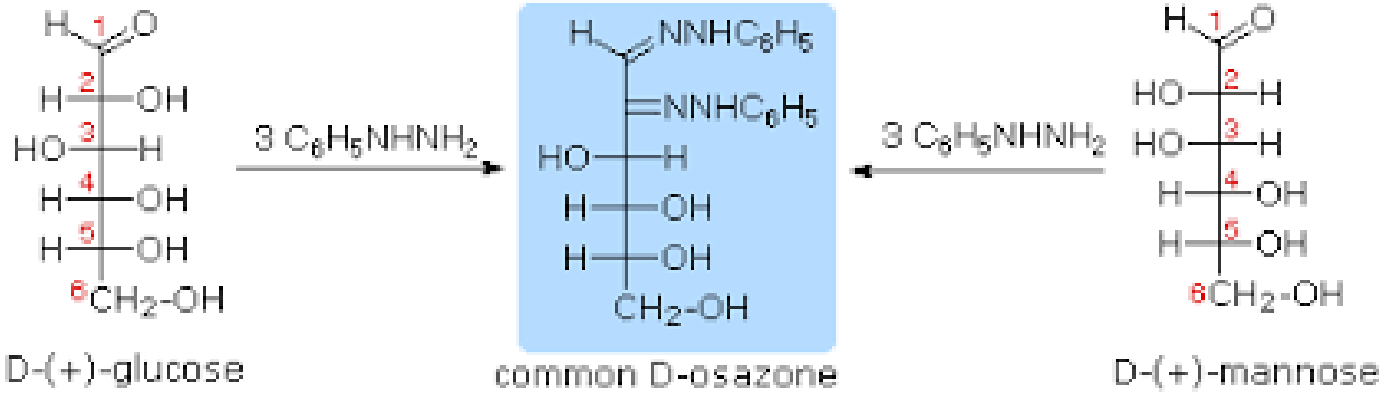
$$\begin{array}{l} CH_2OH \\ | \\ (CHOH)_4 + Ag_2O \\ | \\ CHO \end{array} \longrightarrow \begin{array}{l} CH_2OH \\ | \\ (CHOH)_4 + 2Ag \\ | \\ COOH \end{array}$$

Glucose

Silver mirror

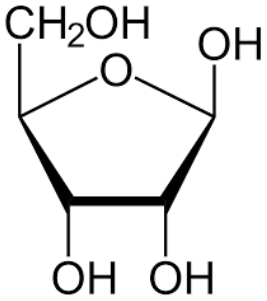
Osazone formation



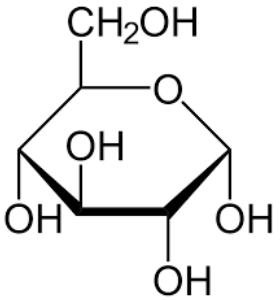


Examples Of Reducing Sugars

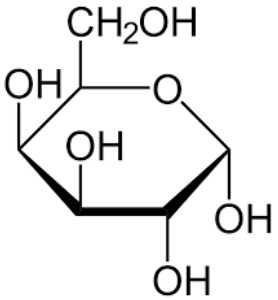
- All Monosaccharides are reducing sugars.
- Monosaccharides are strong reducing agents.
- Monosaccharides–



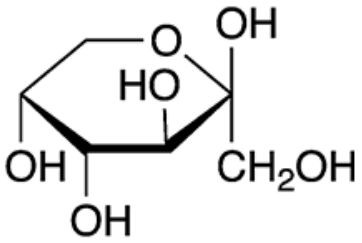
Ribose



Glucose

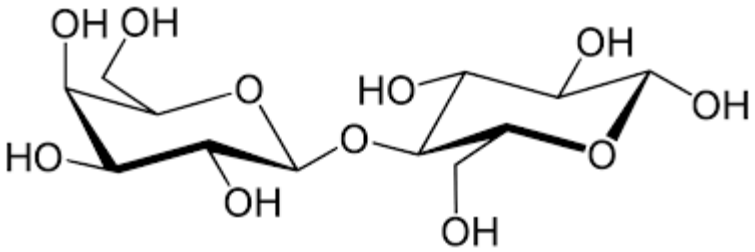


Galactose

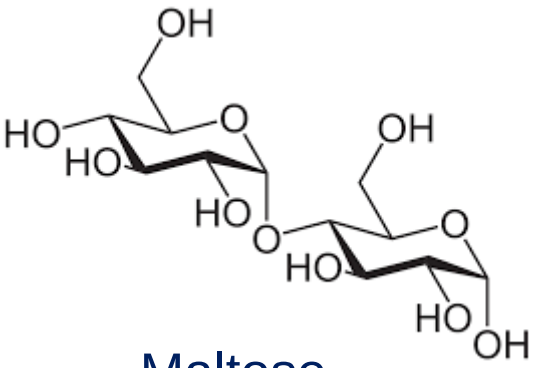


Fructose.

- Disaccharides are weak reducing agents.
- Reducing Disaccharides-



Lactose



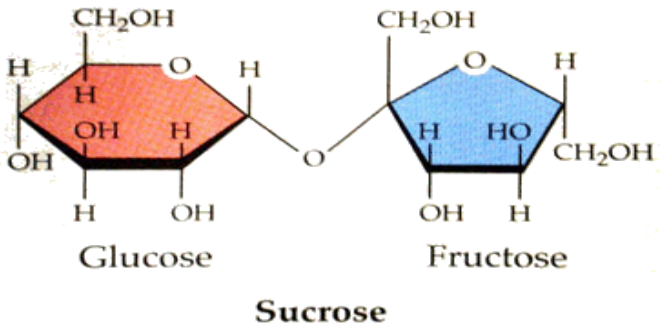
Maltose.

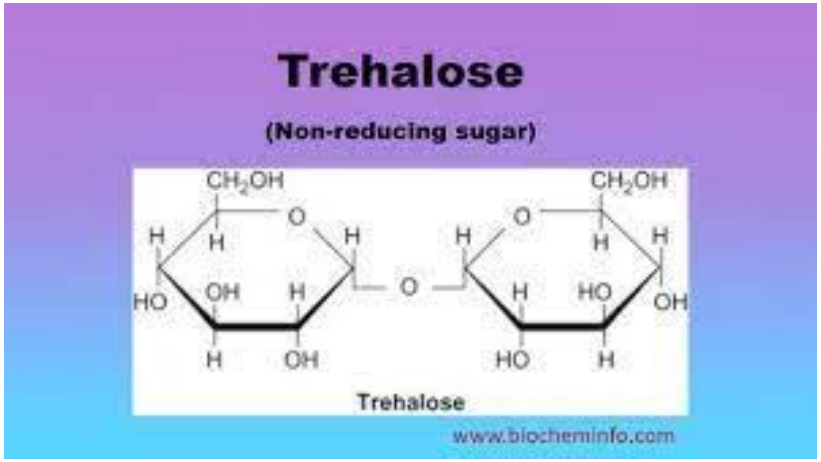
Non-Reducing Sugars

- Sugar structure **not possessing free or potential aldehyde or ketone** group in its structure is termed as non reducing sugar.
- Non reducing sugar **does not show reducing property** and do not reduce metallic ions.
- Non reducing sugars give following reducing tests negative.
- Benedict’s Test
- Fehling’s test
- Nylander’s Test
- Do not form Osazones
- Non-Reducing sugars do not exhibit Mutarotation (Change in Optical activity)

Examples of Non reducing Sugars

- Non reducing Disaccharides.





Sucrose

(Biomedically Important)

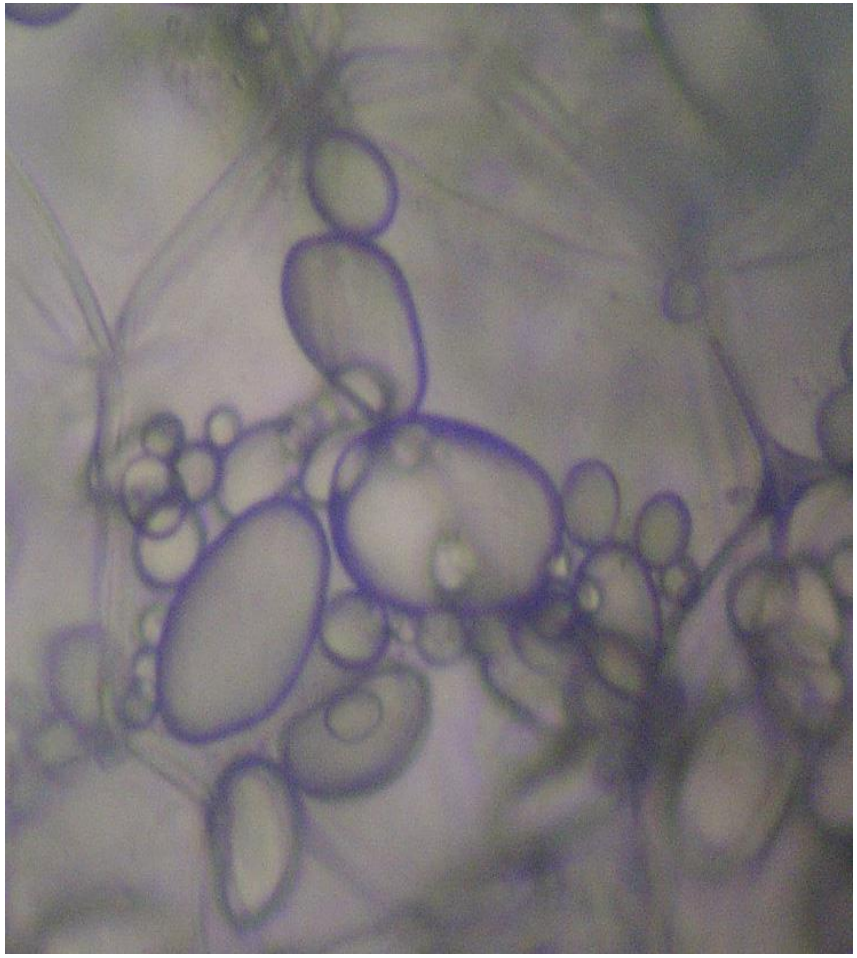
Trehalose

(Glu-Glu linked with α(1-1) glycosidic bond)

- Polysaccharides/Complex Carbohydrates are Non reducing.

Carbohydrates

Glycogen stored in liver cells (red)



Starch compartments in potato cells

Cellulose in plant cell walls (outer blue layer)

Lipids

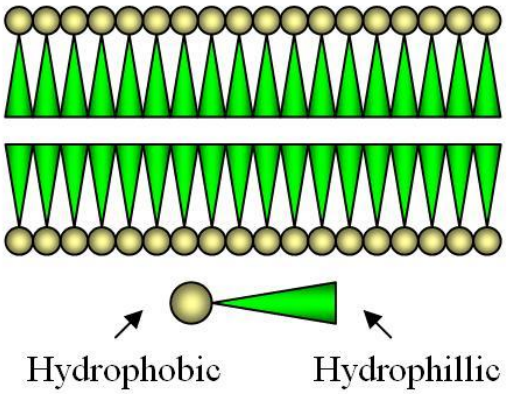
- Fatty compounds made of C H O, don't interact with water **(hydrophobic)**
  - Cell membranes are composed two lipid layers, which keep water from crossing
- Lipids are polymers made up of fatty acid monomers
  - Fatty acids have oily "tails" and polar "heads"

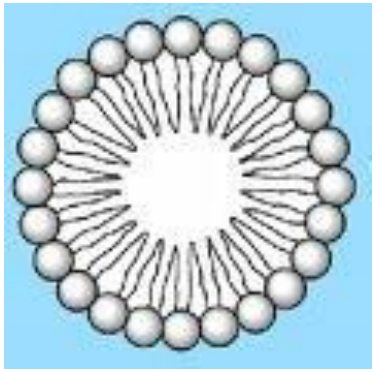
Polar
(Yay water!)

Non polar
(Boo water!)

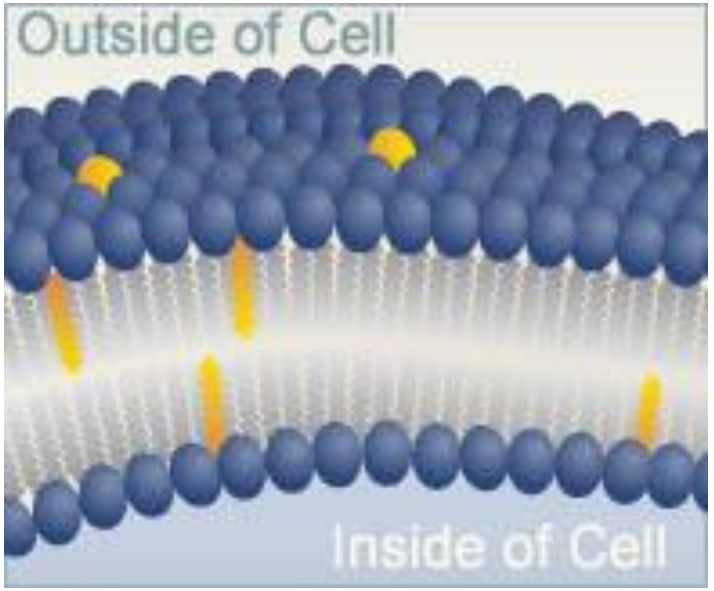
Lipid Layers

- Lipids in water will arrange themselves to hide their hydrophobic tails



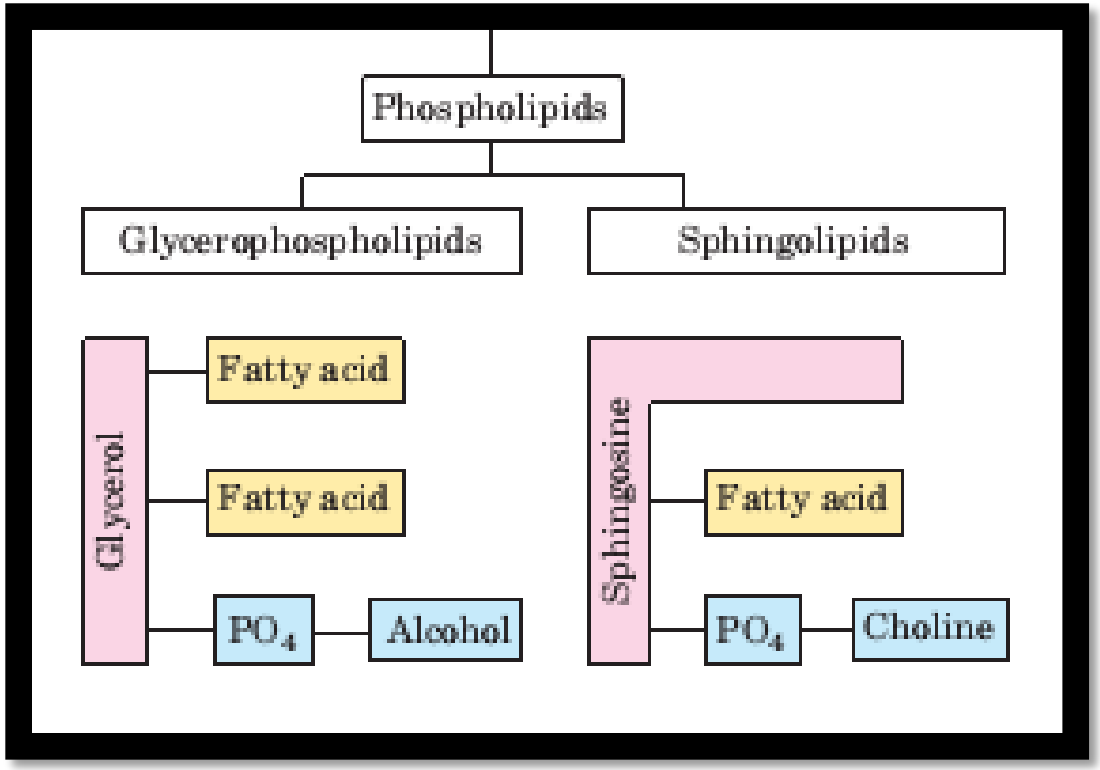


- Cell membranes are composed of a phospholipid bi-layer



PHOSPHOLIPIDS

Phospholipids may be classified on the basis of the type of alcohol present



A. Glycerophospholipids

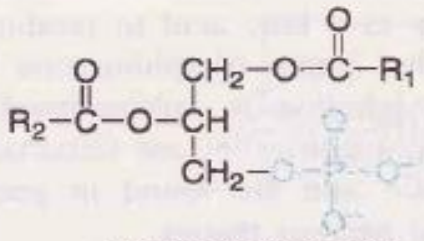
ALCOHOL IS GLYCEROL

- ✓ Phosphatidylcholine
- ✓ Phosphatidyl ethanolamine
- ✓ Phosphatidyl serine
- ✓ Phosphatidyl inositol
- ✓ Plasmalogens
- ✓ Cardiolipins

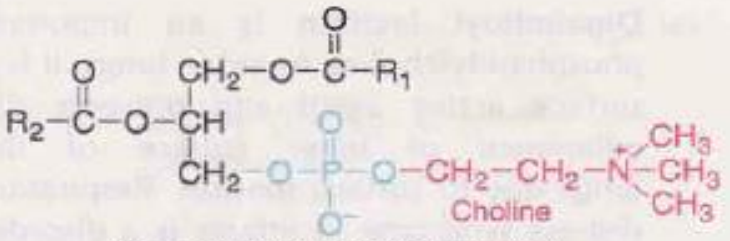
B. Spingophospholipids

ALCOHOL IS SPINGOSINE

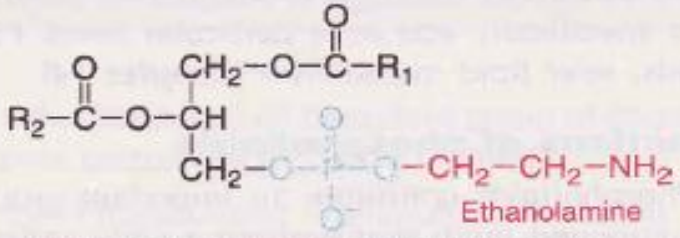
- ✓ Spingomyelins



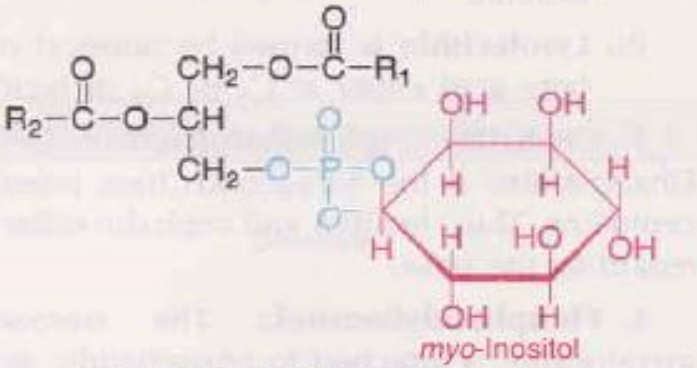
(1) **Phosphatidic acid**



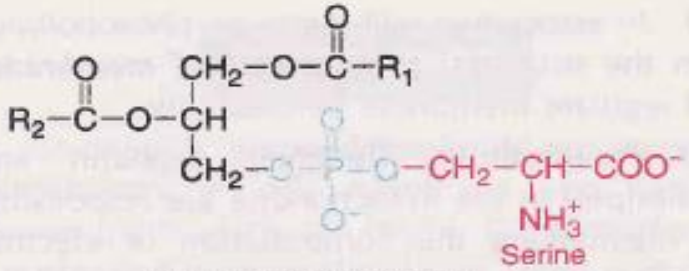
(2) **Lecithin** (phosphatidylcholine)



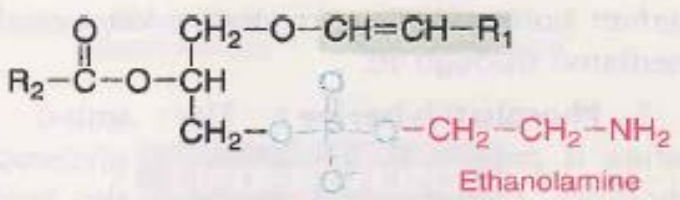
(3) **Cephalin** (phosphatidylethanolamine)



(4) **Phosphatidylinositol**

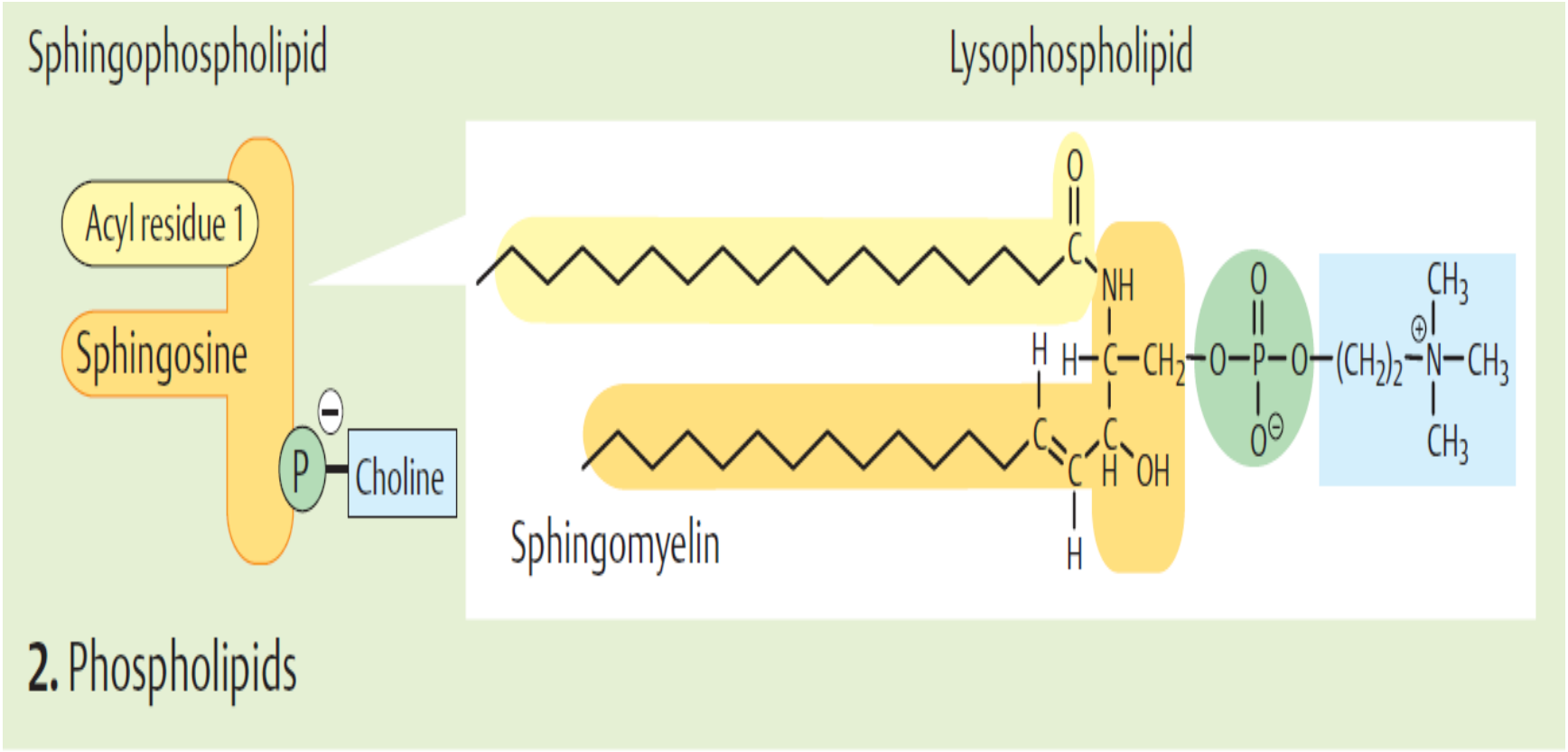


(5) **Phosphatidylserine**



(6) **Plasmalogen** (phosphatidalethanolamine)

SPHINGOPHOSPHOLIPID



Functions of phospholipids

- In association with proteins phospholipids form the structural components of membranes and regulate membrane permeability.

- Phospholipids participate in the absorption of fat from the intestine.

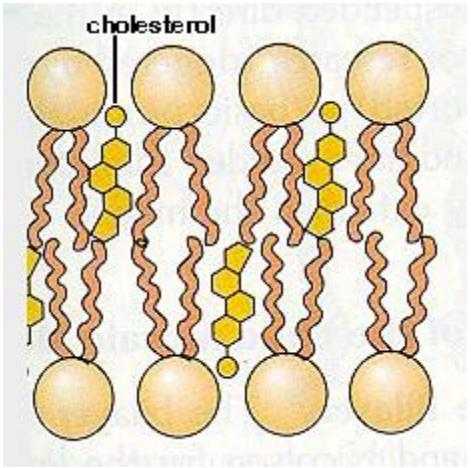
- Essential for the synthesis of different lipoproteins, and thus participate in the transport of lipids.

- Accumulation of fat in liver (fatty liver) can be prevented by phospholipids, hence they are regarded as lipotropic factors.

- Arachidonic acid, an unsaturated fatty acid liberated from phospholipids, serves as a precursor for the synthesis of eicosanoids (prostaglandins, prostacyclins, thromboxanes etc.).

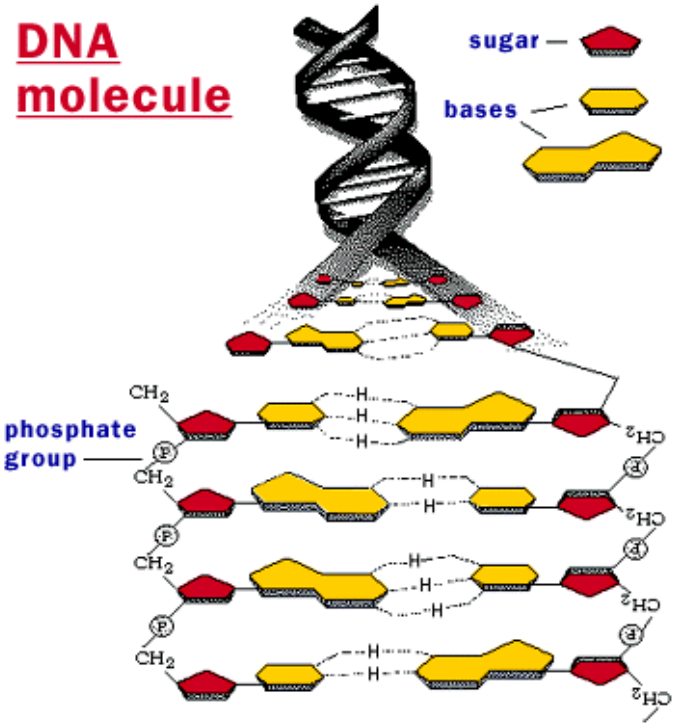
Other Lipids

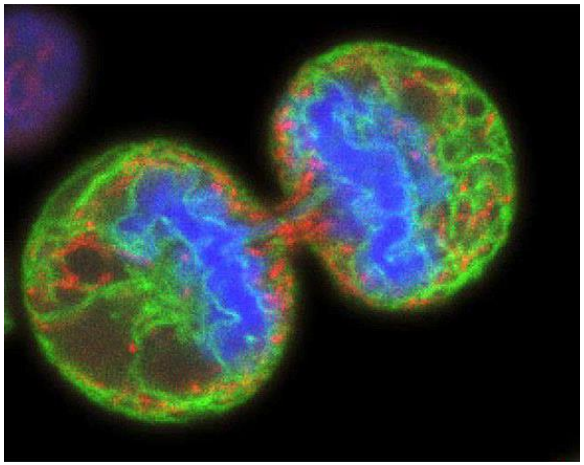
- Waxes
- Oils
- Steroids



Nucleic Acids

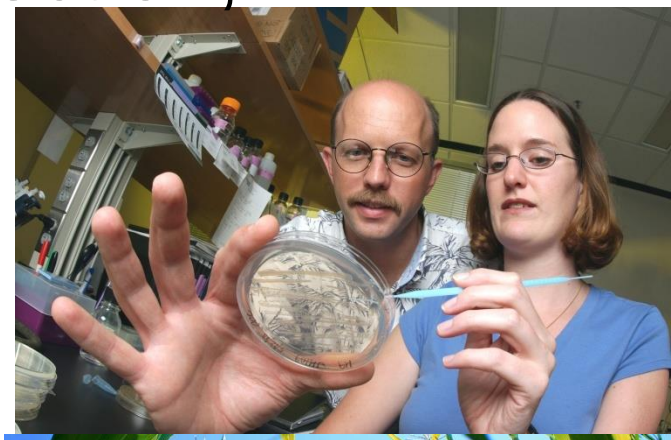
- The genetic material in any cell
  - Deoxyribonucleic acid (DNA) and Ribonucleic acid (RNA)
  - Polymer chains composed of a combination of 5 different monomers

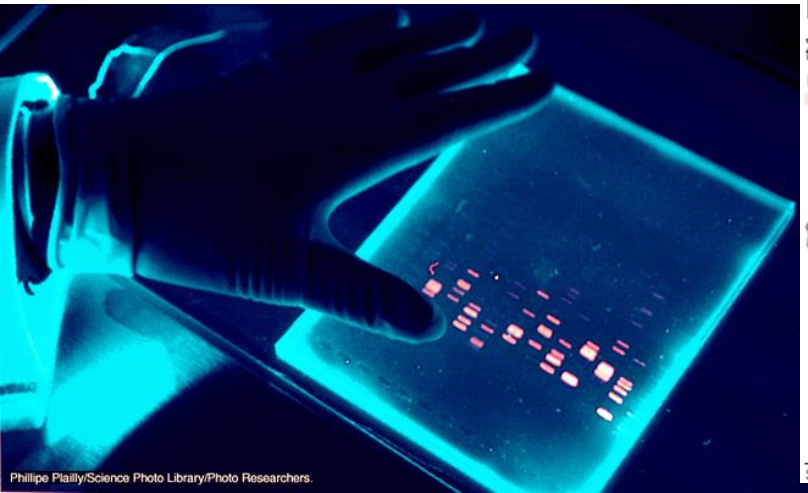




Why is the Study of DNA Important?

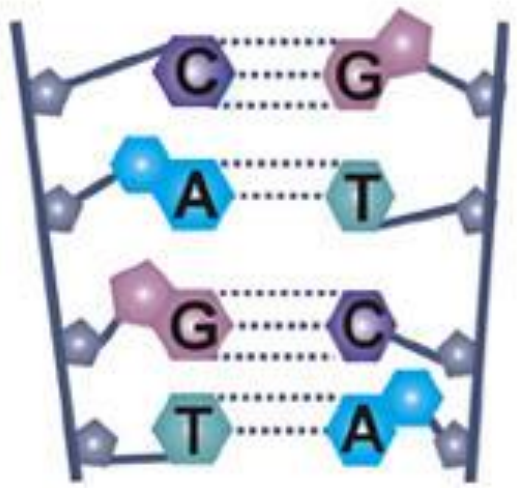
- It's essential to all life on earth
- Medical Benefits—disease detection, treatment, prevention
- Development of Crops
- Forensics





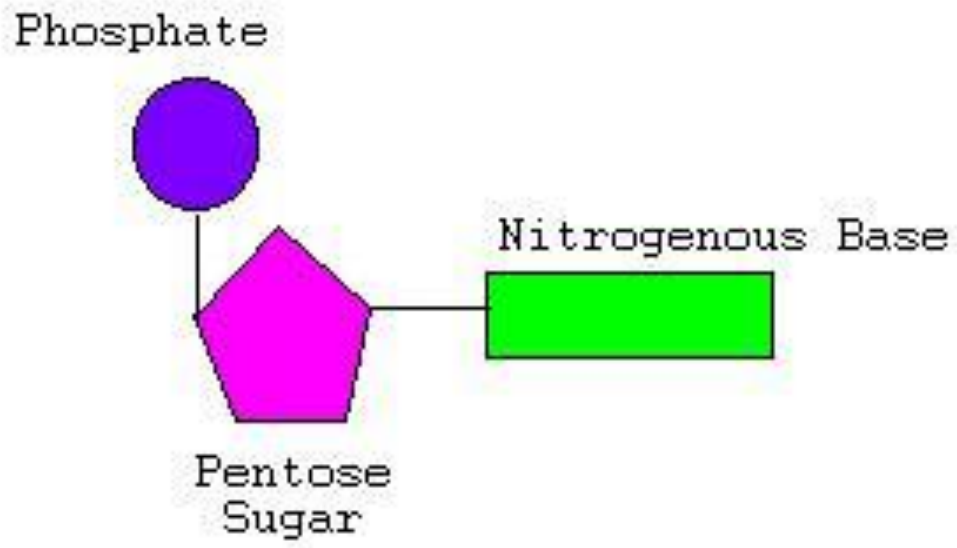
DNA Structure

- DNA is a polymer (composed of repeating subunits called nucleotides)
- 2 long strands
  - Each a chain of nucleotides



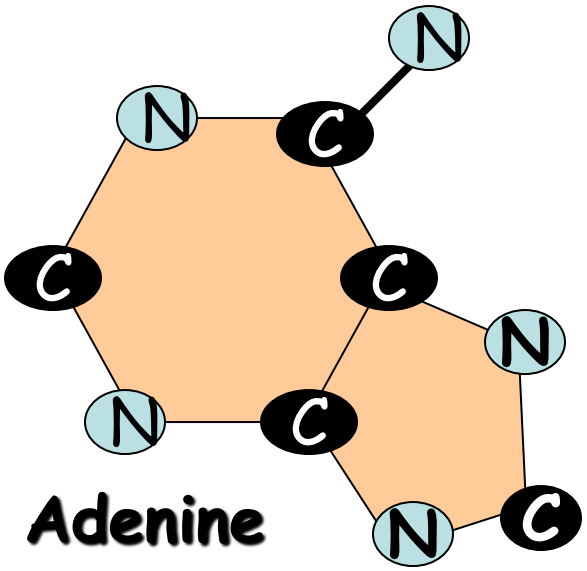
Nucleotides

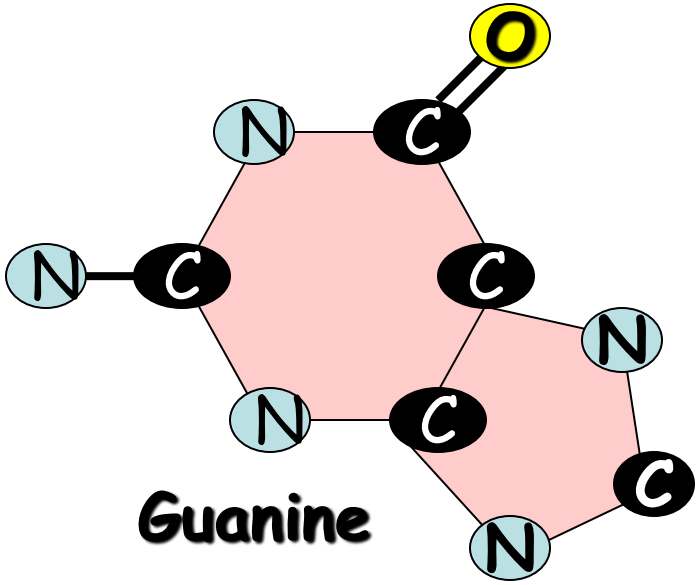
- Consists of…
  - Phosphate
  - Carbon sugar (deoxyribose)
  - Nitrogen base



Adenine and Guanine are PURINES

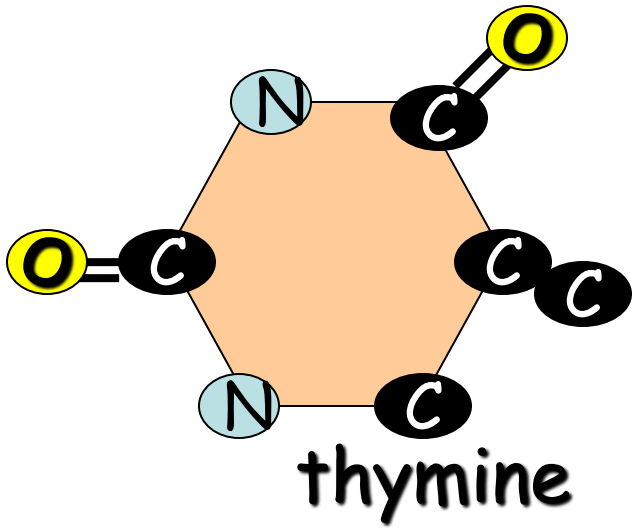
- Adenine and guanine each have two rings of carbon and nitrogen atoms.



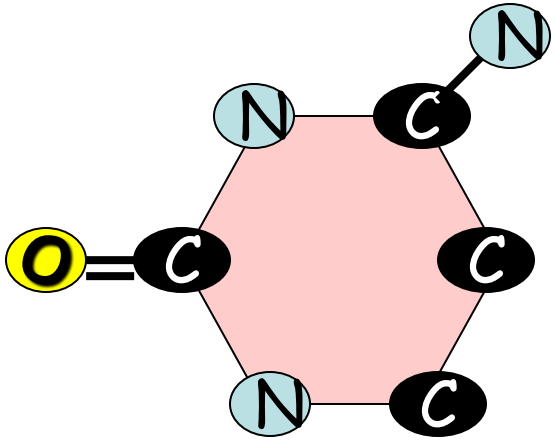


Thymine and Cytosine are PYRIDAMINES

- Thymine and cytosine each have one ring of carbon and nitrogen atoms.



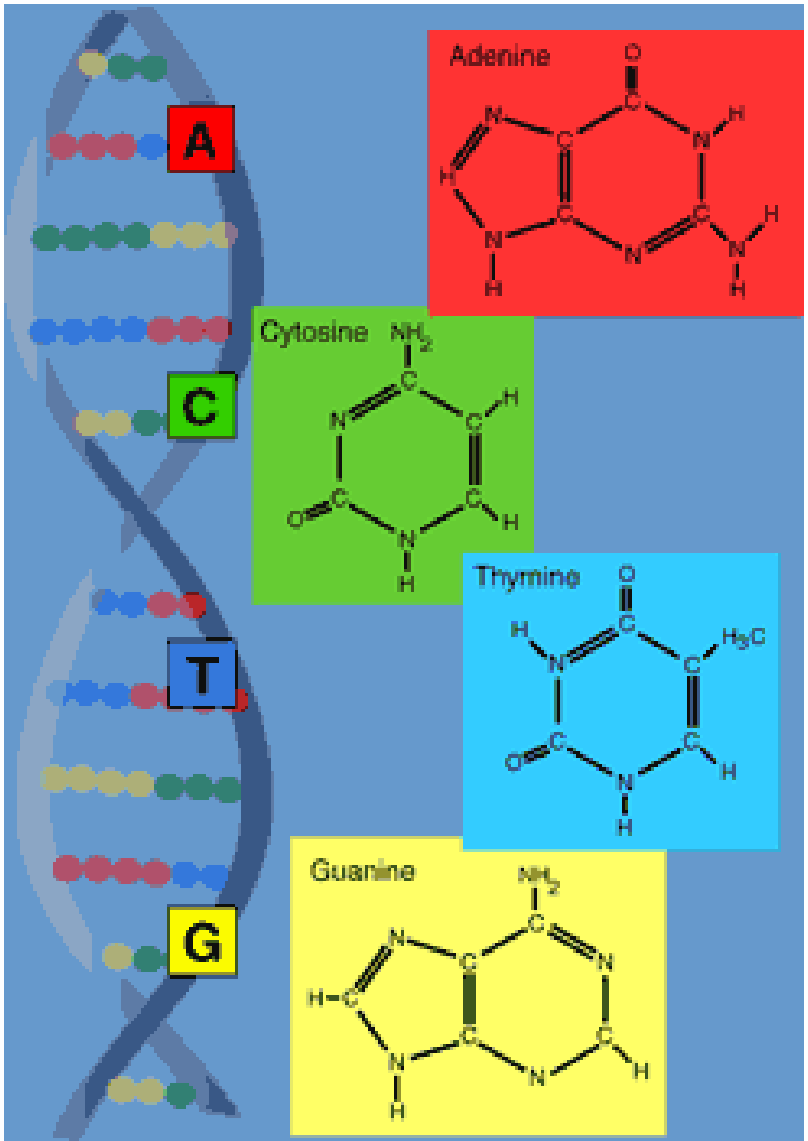
thymine



cytosine

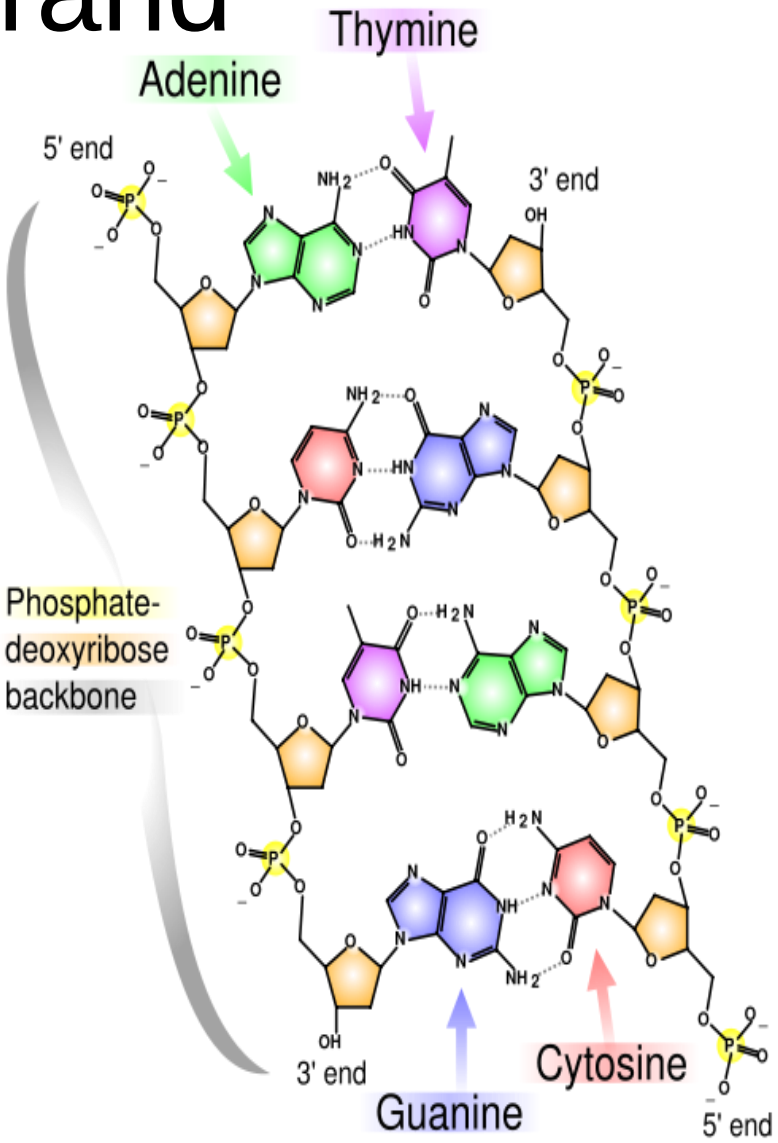
Types of Nitrogenous Bases

- A = adenine
- T = thymine
- C = cytosine
- G = guanine



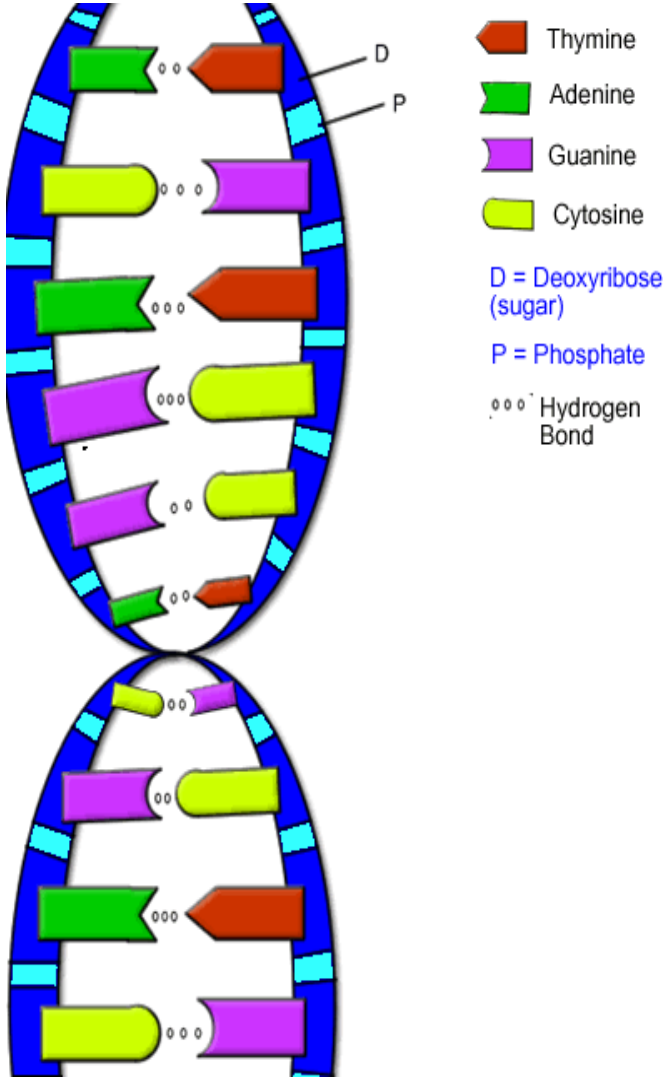
DNA Strand

- Each nucleotide bonds to the next one to form a strand.
  - The two strands twist around a central axis to form a double helix.
  - Sides of the ladder alternate phosphate and sugar (deoxyribose)
  - Rungs are held together by Hydrogen bonds



Base Pair Rule

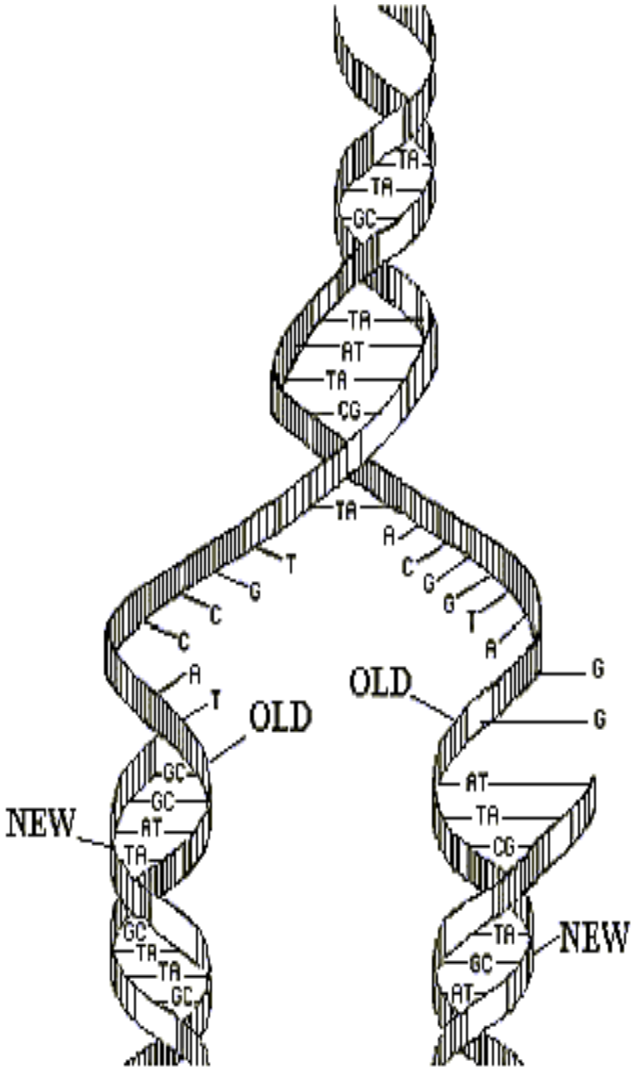
- Adenine can bond only with Thymine
  - A-T or T-A (2 H bonds)
- Cytosine can bond only with Guanine
  - C-G or G-C (3 H bonds)
- This is called the **BASE PAIR RULE**



Nitrogenous Bases

- Those 4 bases (ATCG) have endless combinations
  - Just like the letters of the alphabet can combine to make an infinite number of words.
- The two strands are said to be complimentary
  - That means that if you have GAATAC on one side you will have _ _ _ _ _ _ on the other.

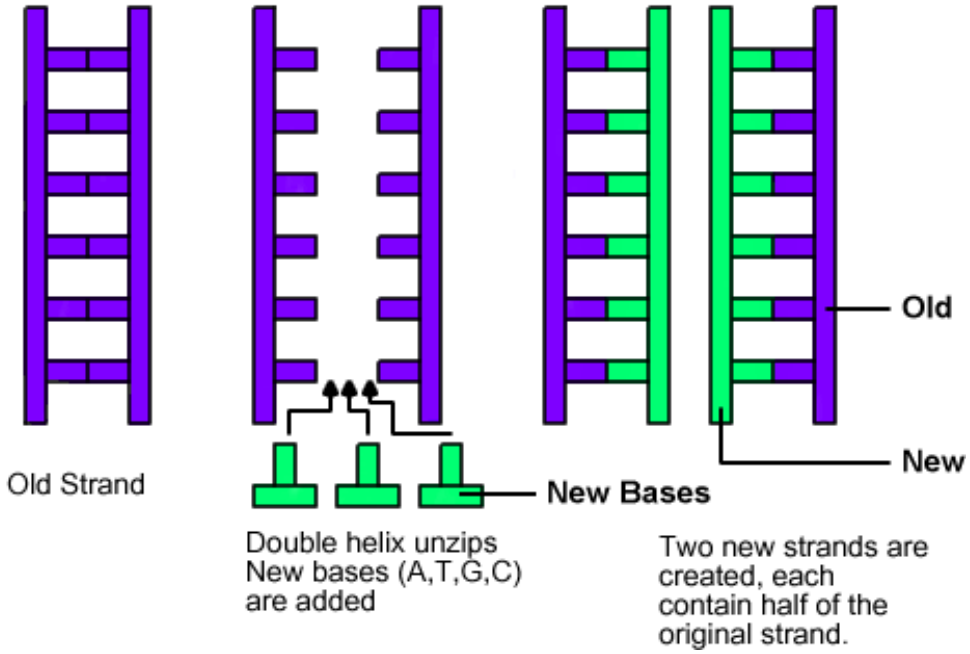
Replication



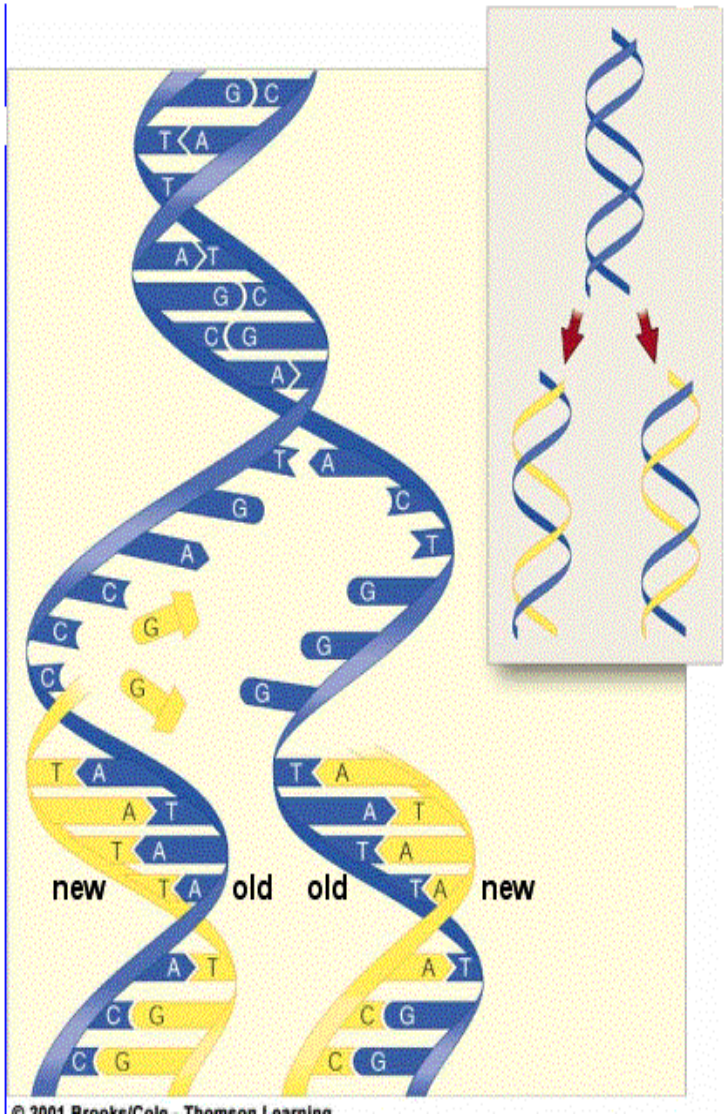
- The process by which DNA makes a copy of itself
- Why does DNA need to copy?
  - Cells divide for an organism to grow or reproduce
  - Every new cell needs a copy of DNA
- In DNA replication enzymes work to unwind and separate the double helix and add complimentary nucleotides to the exposed strands

Replication

- DNA replication is semi-conservative.
  - When it makes a copy, one half of the old strand is ALWAYS kept in the new strand
  - This helps reduce the number of copy errors.



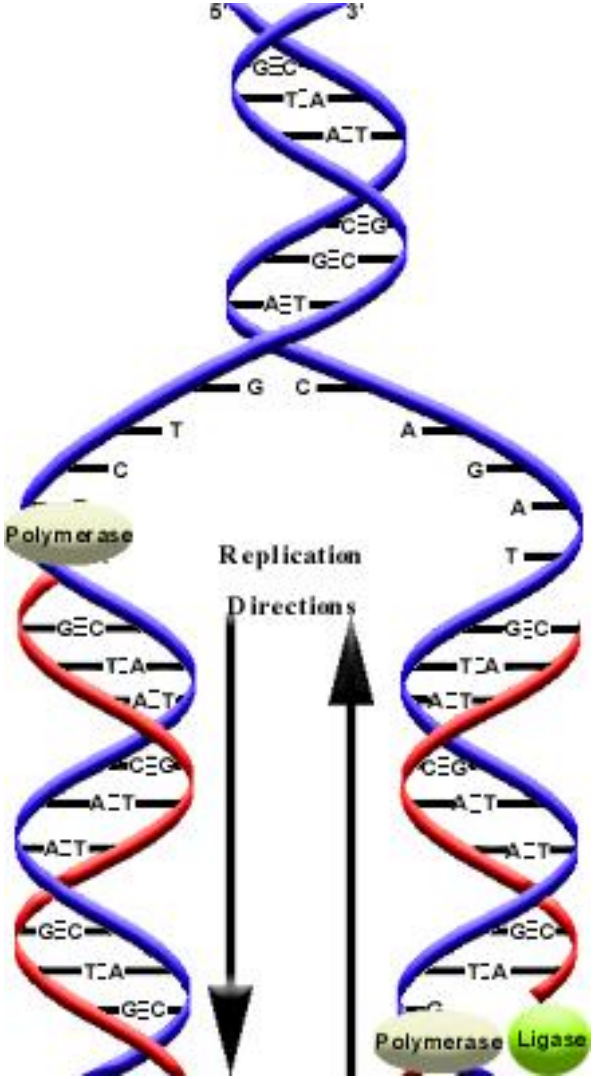
DNA Replication



- DNA helicases—break H-bonds linking bases
- DNA polymerases—move along each of the strands, adding nucleotides, according to base pairing rules.

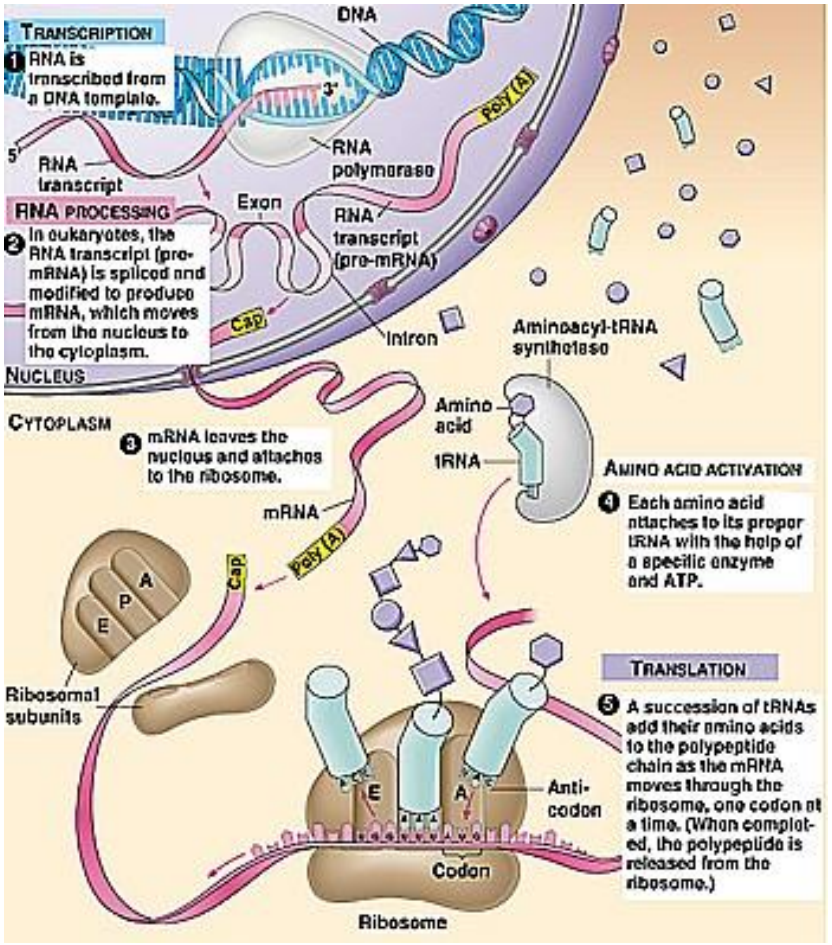
DNA Replication

- The result is two exact copies of the original DNA
- Each new double helix is composed of one original DNA strand and one new strand.
  - Semi-conservative



Translation

- DNA is in the nucleus
  - To make proteins, DNA must get its instructions to the ribosomes who make proteins.
  - To transport its instructions, it uses Messenger RNA (mRNA)



RNA

- Ribonucleic Acid
  - Consists only of one strand of nucleotides
  - Has ribose (a 5C sugar) NOT deoxyribose
  - Has uracil (U) as a nitrogenous base NOT thymine

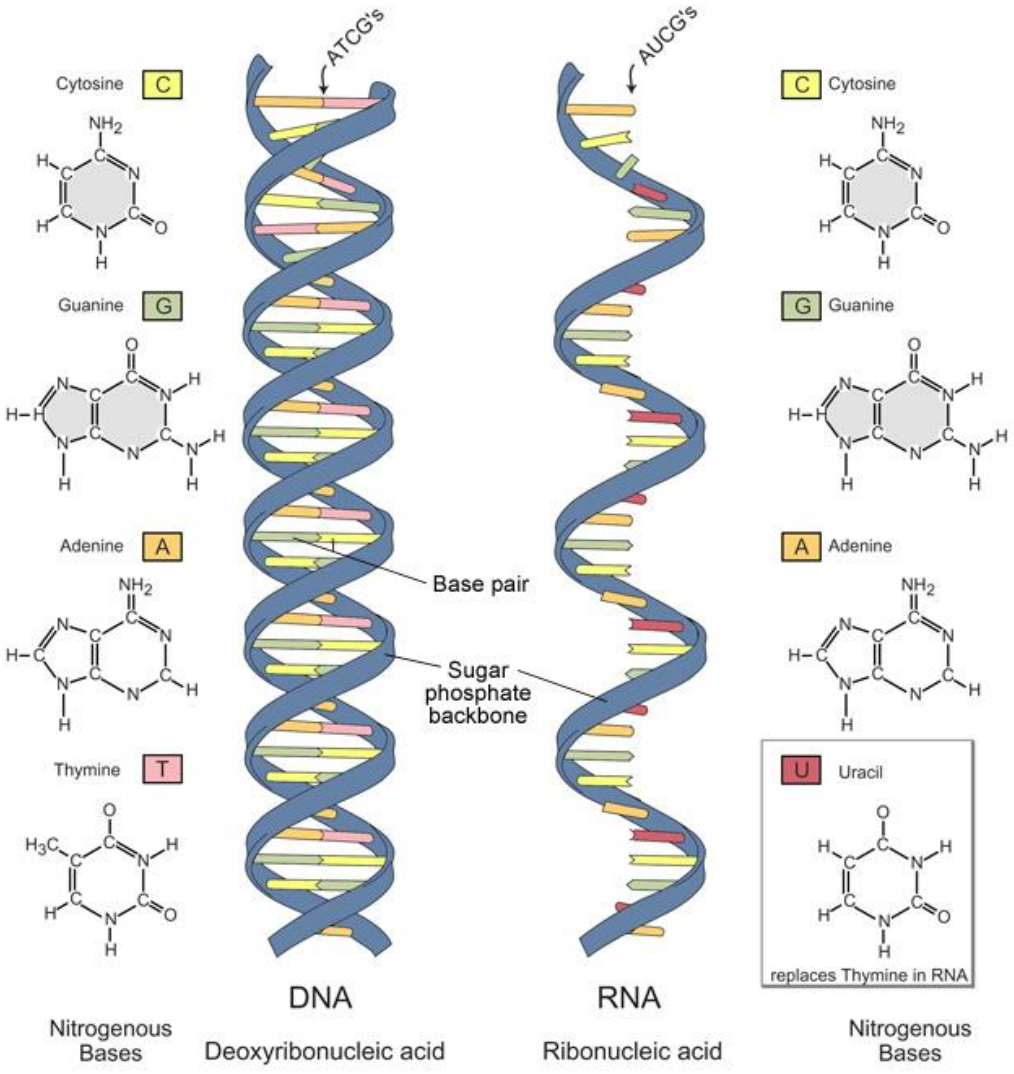
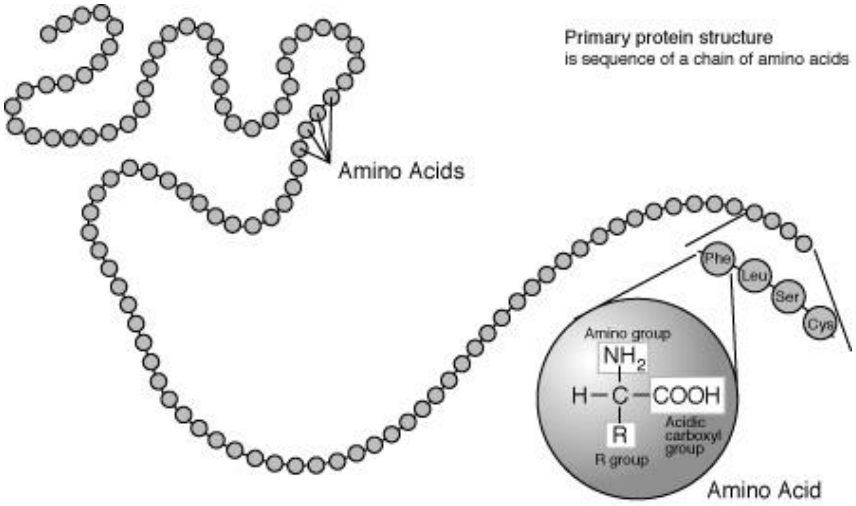


Image adapted from: National Human Genome Research Institute.

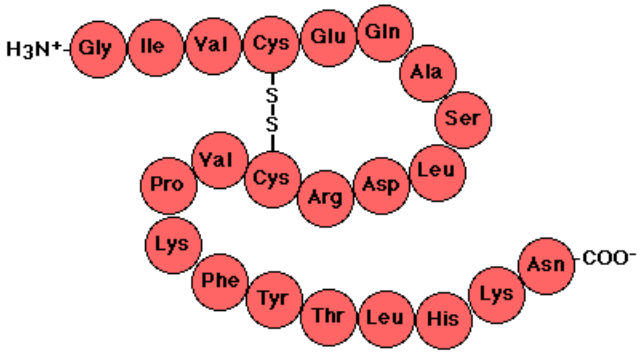
Proteins

- Structural building blocks of cells in all tissues (not just muscle!)
- Polymers composed of 300 – 100k+ monomers
- Monomers are called **amino acid**
- There are 20 amino acids, many of which must come from your diet

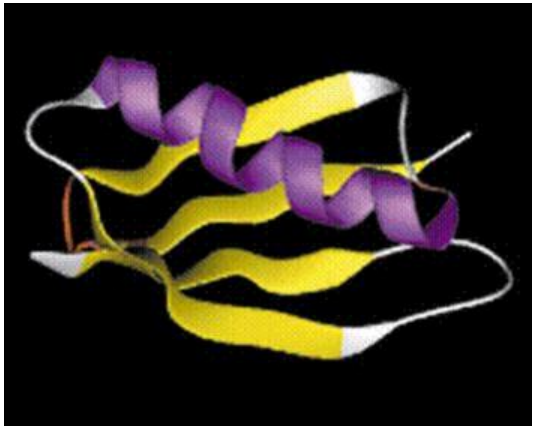


Protein Structure

- **Primary structure** – the order of amino acids making up the polymer string

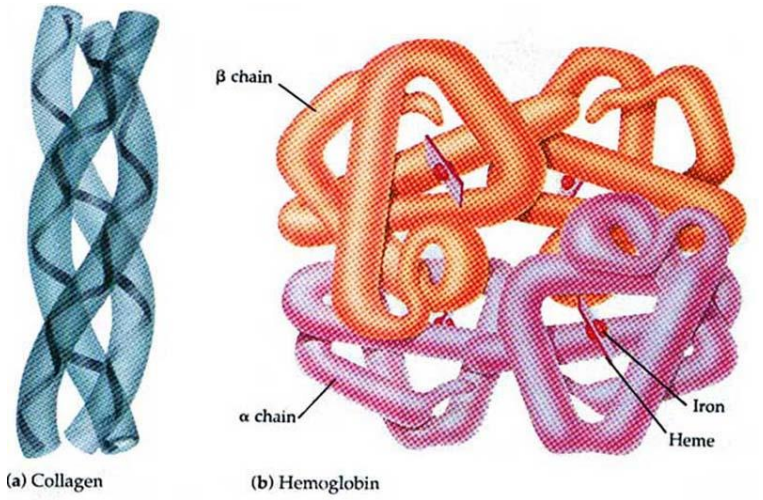


- **Secondary structure** – helixes and sheets of the polymer string folding on itself

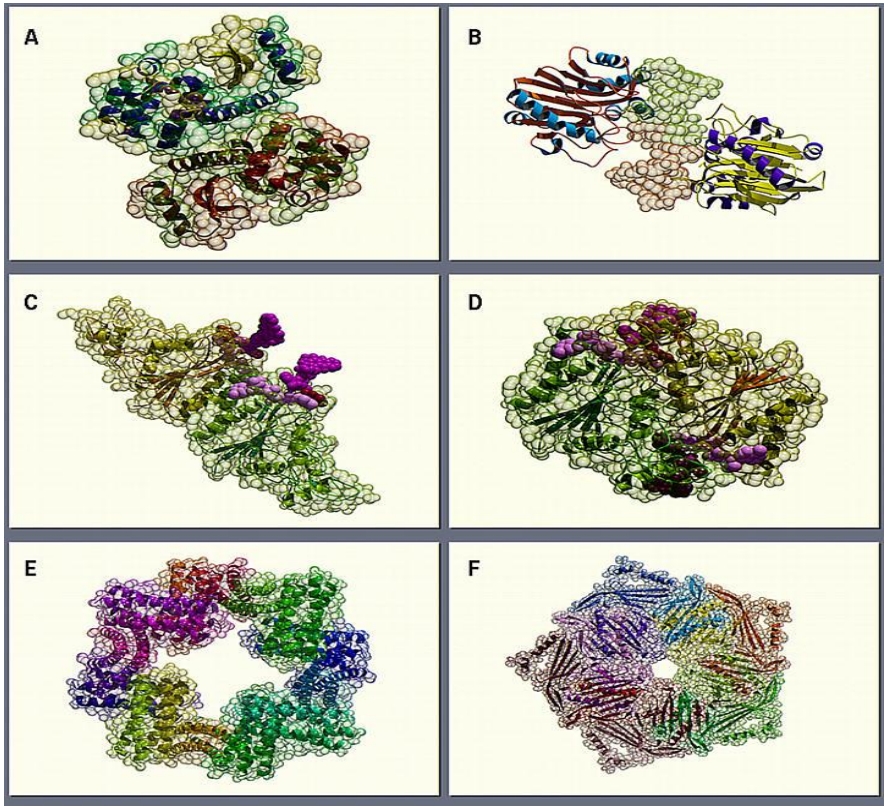


Protein Structure

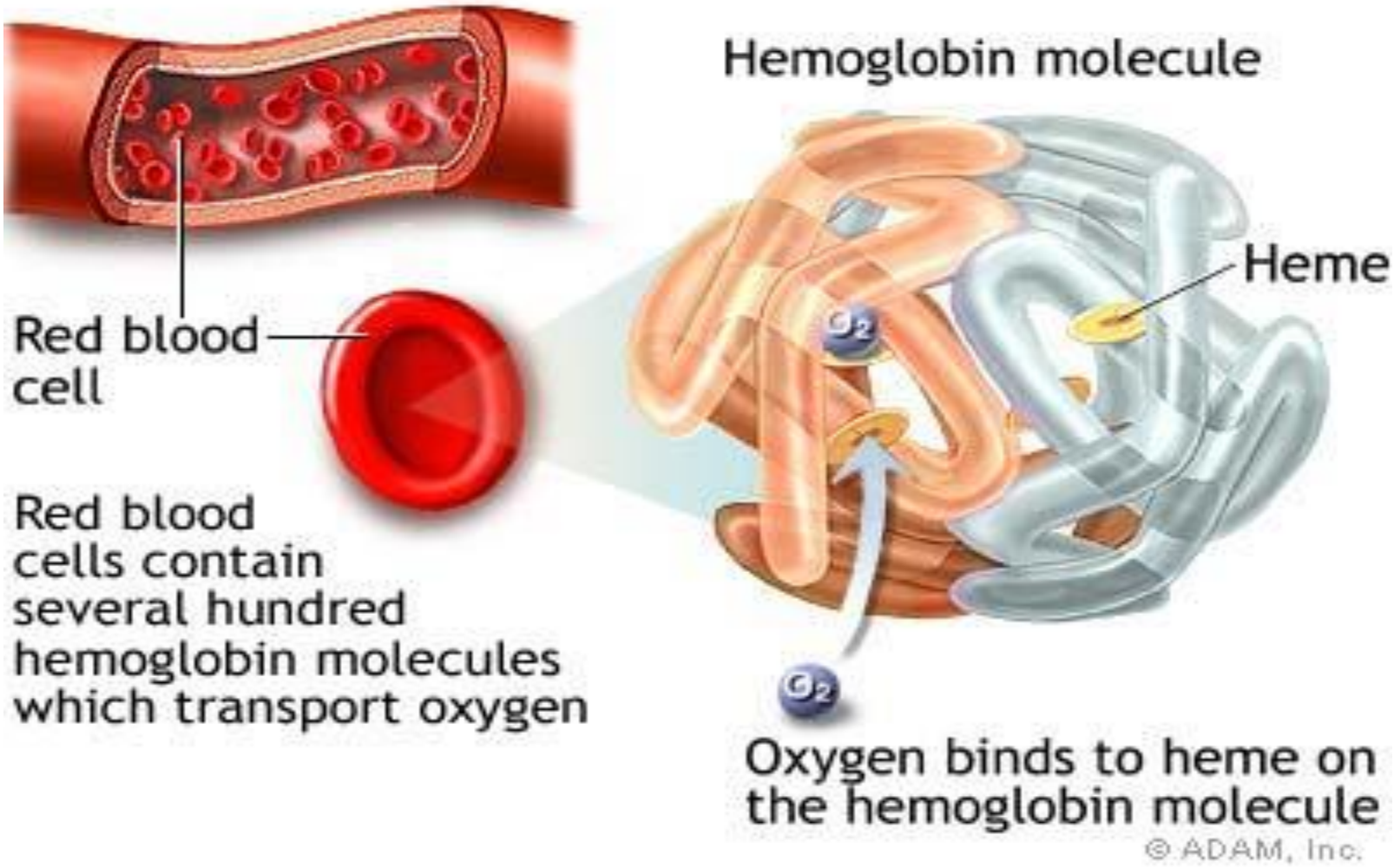
- **Tertiary structure** – globs of sheets and helixes folding around each other



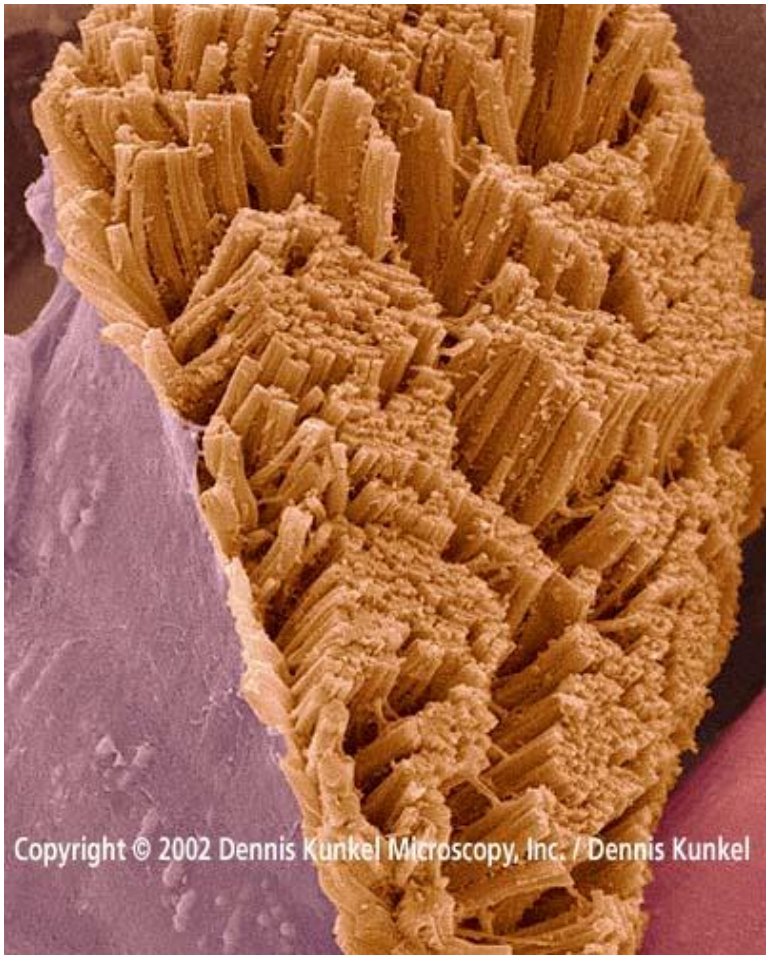
- **Quaternary Structure** – individual proteins bound to each other to form a multi-protein unit with is own unique function



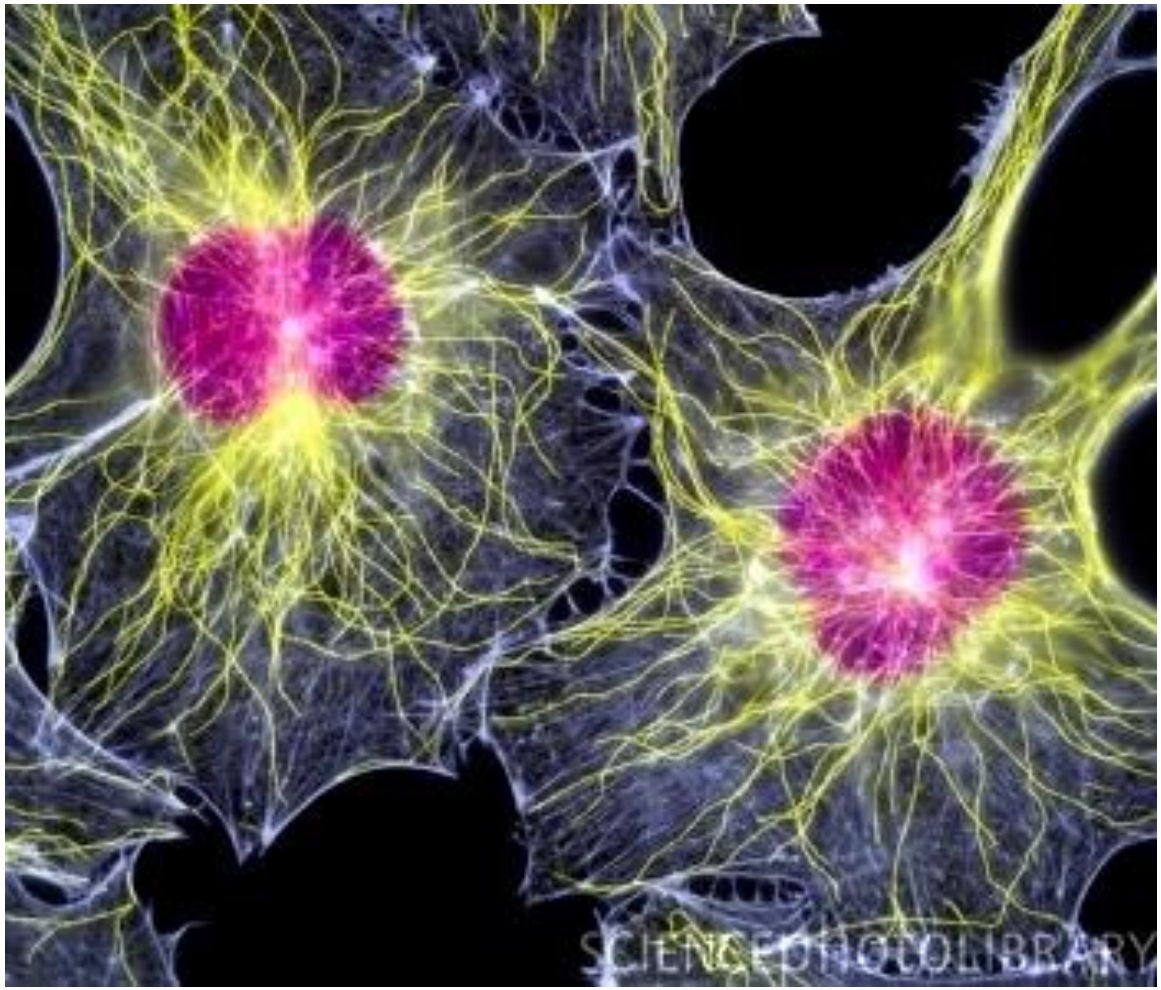
Hemoglobin carries oxygen in the blood



Actin fibers in skeletal muscle cells



Proteins make up the cell cytoskeleton



Enzymes to copy and repair DNA