Collin College

BIOL 2401

Anatomy &Physiology I
Chapter 2

Acids and Bases

- Acids release H^+ and are therefore proton donors

  $$\mathbf{HCl \rightarrow H^+ + Cl^-}$$

- Bases release OH^- (or are proton acceptors)

  $$\mathbf{NaOH \rightarrow Na^+ + OH^-}$$

- Strong acids and strong bases dissociate to completion
- Weak acids and bases are in equilibrium between dissociated and un-dissociated parts.
- In such instances, the reaction is an equilibrium between weak acids and weak bases

  $$\textbf{Acetic acid} \longleftrightarrow \textbf{Acetate}^- + \mathbf{H^+}$$

  (weak acid) ***(weak base)***

Acid-Base Concentration (pH)

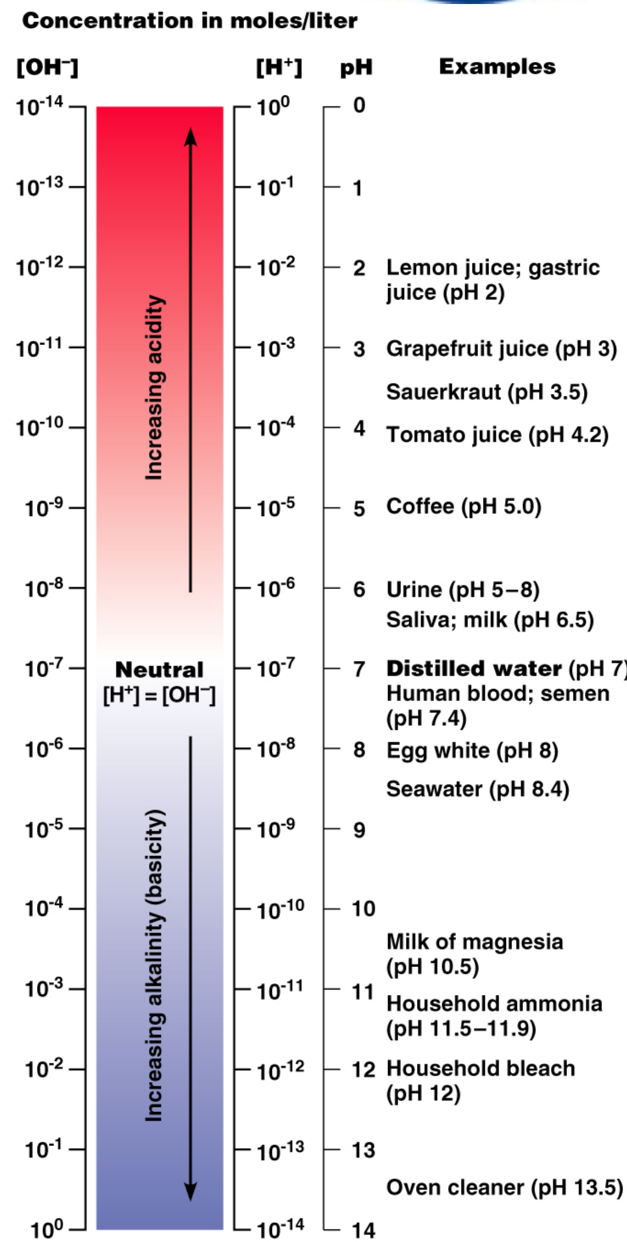
pH = - log [H$^+$]

where [H$^+$] is the concentration of free protons in solution, expressed in Molar concentration

[H$^+$] = 10^{-pH}

- **Acidic**: pH 0–6.99
- **Basic**: pH 7.01–14
- Chemical Neutral: pH 7.00

pH is thus an index for protons that are unbound and freely available to react.



Acid-Base Concentration (pH)

A quick reminder of the definition of logarithmic values

The log is the exponent associated with a base 10 value.

log 1 = log 10^0 = 0

log 10 = log 10^1 = 1

log 100 = log 10^2 = 2

log 1000 = log 10^3 = 3

log 0.1 = log 1/10 = log 10^{-1} = -1

log 0.01 = log 1/100 = log 10^{-2} = -2

log 0.001 = log 1/1000 = log 10^{-3} = -3

The implication of logarithmic values is that a unit change is actually a 10-fold change !

Acid-Base Concentration (pH)

$pH = -\log [H^+]$ where $[H^+]$ is in Molar

$[H^+] = 10^{-pH}$

The implication of logarithmic values is that a unit change is actually a 10-fold change !

A solution with pH 7 has

$[H^+] = 10^{-pH} = 10^{-7}$ Molar concentration (0.0000001 M or 100 nM)

A solution with pH 4 has

$[H^+] = 10^{-pH} = 10^{-4}$ Molar concentration (0.0001 M or 100,000 nM)

Difference between pH 7 and pH 4 is that pH 4 is **1000 x** more acidic !!

Physiological pH

- In Chemical terms , pH 7.0 is neutral.
- In physiological terms, ‘happy’ average blood has a pH between **7.35 - 7.45**

Therefore, physiological neutrality refers to a blood pH of ~ 7.4

Blood pH below 7.35 is called an acidotic condition (acidosis)

Blood pH above 7.45 is referred to as an alkalotic condition (alkalosis)

The changes our body can tolerate in free floating protons is very limited

pH = 7.4 $[H^+] = 10^{-pH} = 10^{-7.4}$ Molar concentration (0.00000004 M) (or 40 nM)
pH = 7.0 $[H^+] = 10^{-pH} = 10^{-7}$ Molar concentration (0.0000001 M) (or 100 nM)

That difference of 60 nM can be quite dangerous in human bodies.

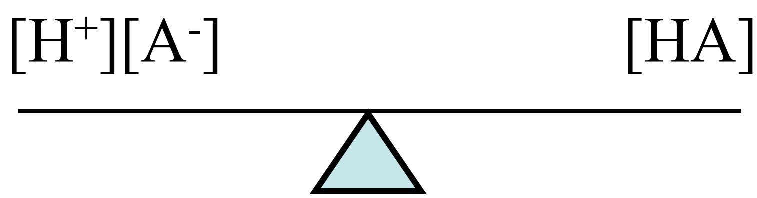
Buffers

- To prevent major changes in pH, the body has many Buffers. These are Systems that resist abrupt and large swings in the pH of (body) fluids. Usually is a combination of a weak acid and a weak base via chemical reaction.

$$\mathbf{H^{+} + A^{-} \rightleftharpoons HA \qquad (HA = weak\ acid\ ;\ A^{-} = weak\ base)}$$

The reactions proceed quite fast back and forth until an equilibrium is reached. Such chemical reactions are called equilibrium reactions.

1)

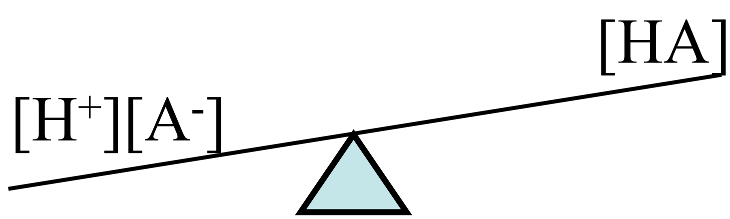


In equilibrium

Buffers

$H^+ + A^- \rightleftharpoons HA$ **(HA = weak acid ; A^- = weak base)**

If the equilibrium is disturbed, the chemical reaction will respond by re-establishing that equilibrium. For example, the diagram below shows us this system is out of equilibrium. From a chemical standpoint, how would we get back to equilibrium ?



Out of equilibrium

In this case, as it relates to pH, we are out of equilibrium because too much acid (excess of $\mathbf{H^+}$) is present. The reaction will proceed to the right, making more [HA] and reducing **H^+ and A^- in the process.**

Buffers

Example : The Carbonic acid-bicarbonate system (a very important chemical system in our body)

- A reaction between water and carbon dioxide, producing carbonic acid
- Carbonic acid dissociates into bicarbonate ions and protons
- The chemical equilibrium between CO_2, H_2O, carbonic acid and bicarbonate resists pH changes in the blood

$$H_2O + CO_2 \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

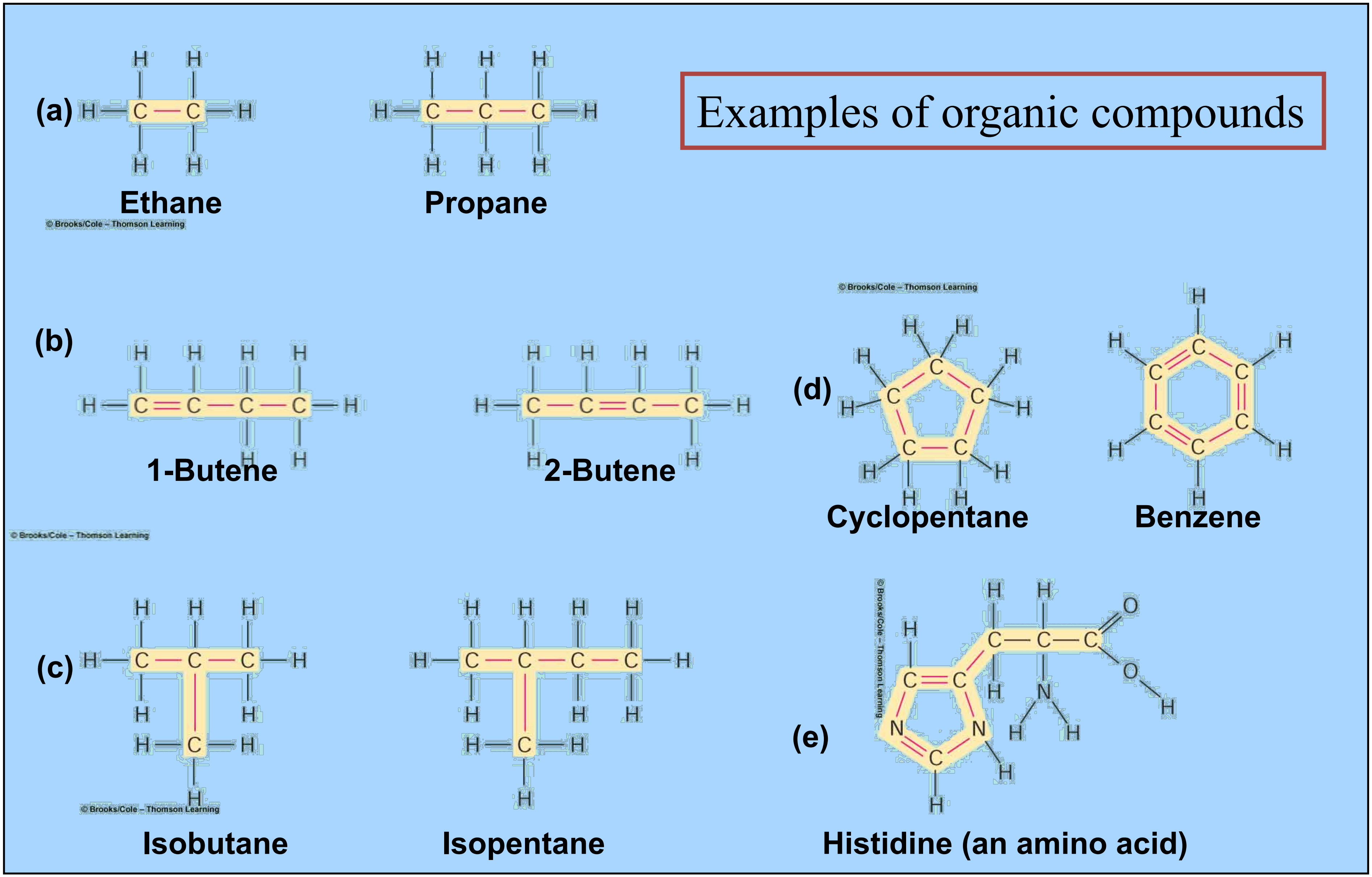
The presence of too much CO_2 (or not enough protons) will result in production of H^+ and HCO_3^- (bicarbonate) (the reaction will be pushed to the right) !

The presence of too many protons (or not enough CO_2) will result in production of CO_2 (the reaction will be pushed to the left) !

Basic Biochemistry

- Organic compounds
  - Contain carbon, hydrogen, and other atoms such as oxygen, nitrogen, phosphate. All atoms are covalently bonded, and can range from small to often large molecules
  - Due to the fact that carbon can create 4 covalent bonds, it allows for the making of an enormous variety of very complex molecules.
- Inorganic compounds
  - Do not contain carbon
    - Water
    - Salts (dissociate easy into anions and cations - they are electrolytes and conduct electrical currents)
    - Many acids and bases

Examples of organic compounds



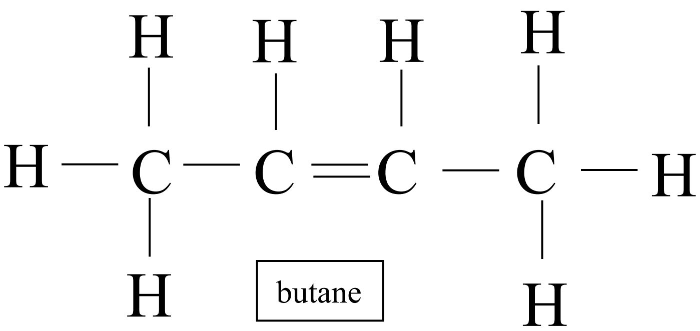
Untold chemistry rules

Sometimes chemical structures are written with the assumption that the reader knows chemistry rules.

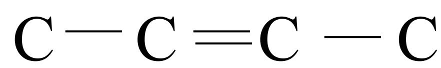
Thus, hydrogen always makes one, oxygen two and carbon makes four covalent bonds.

Structures may be drawn without ‘spelling’ out the carbon or hydrogens. The assumption is that the reader knows where they are located by looking at the covalent bonds.

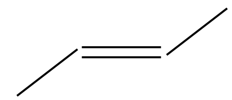
Examples of Untold chemistry rules



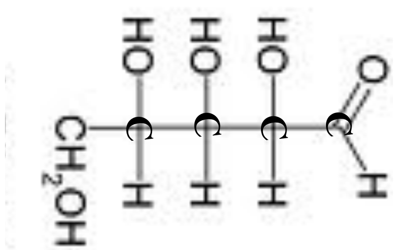
becomes



or



L-ribose



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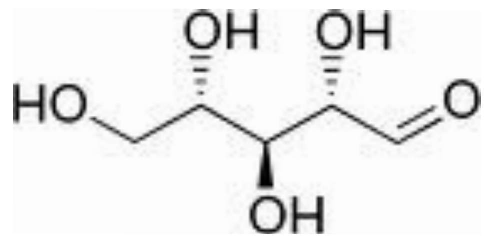

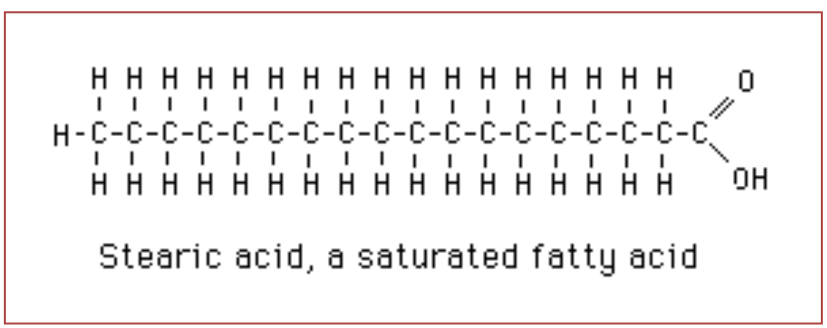

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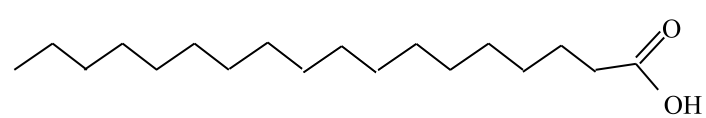
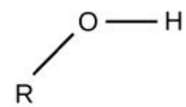
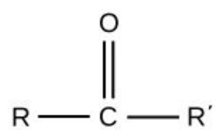
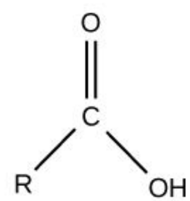
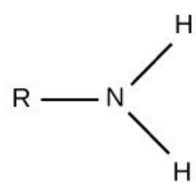
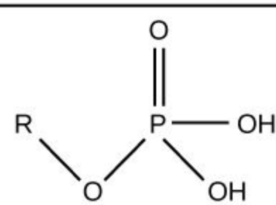


Functional Groups

- Functional groups are a particular set of atoms that provide function and reactivity to molecules
- Many reactions occur between functional groups of different molecules
- The concept of being hydrophilic or hydrophobic can be deduced by the kind of functional groups are present
- Molecules with only C and H atoms are called **hydrocarbons** : they have no functional groups, and no charges (cannot interact with water – always hydrophobic)

Functional Groups

Functional Group	Structure	Properties
Hydroxyl		Polar
Methyl	$R-CH_3$	Nonpolar
Carbonyl		Polar
Carboxyl		Charged, ionizes to release H^+. Since carboxyl groups can release H^+ ions into solution, they are considered acidic.
Amino		Charged, accepts H^+ to form NH_3^+. Since amino groups can remove H^+ from solution, they are considered basic.
Phosphate		Charged, ionizes to release H^+. Since phosphate groups can release H^+ ions into solution, they are considered acidic.

Functional Groups

- What makes a molecules hydrophilic ?
- The more charges a molecule has, the better it can interact with polar water molecules – it will easily dissolve in water (hydrophilic)
- The less (or absence of) charges, the harder it becomes to interact with water (hydrophobic)
- Many functional groups exists in a reversible protonated-deprotonated state, creating charged groups and increasing the water solubility.
- The methyl group (- CH_3) is the only hydrophobic group

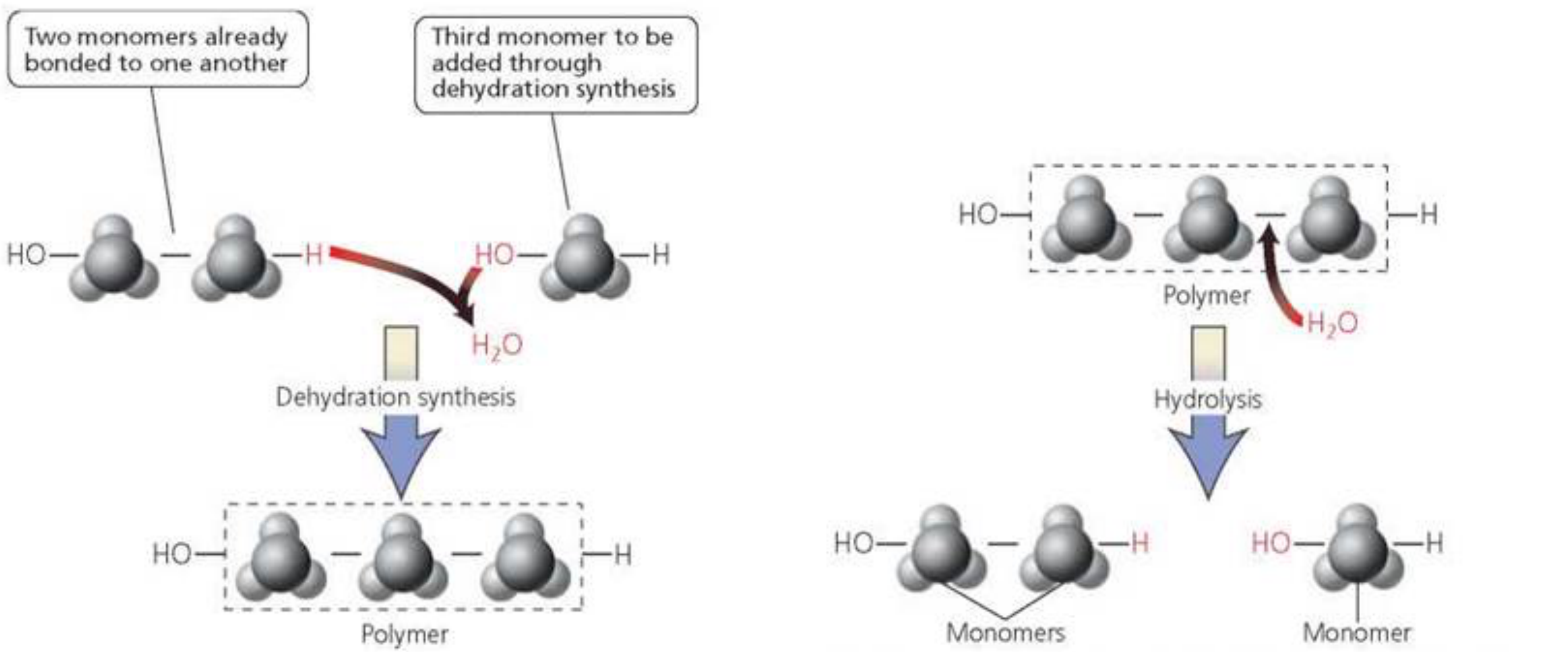
Functional Groups

- R = rest of the molecule
- $\mathrm{R-OH} \rightleftharpoons \mathrm{R-O^{-} + H^{+}}$ Hydroxyl Group (-OH)
- $\mathrm{R-C(=O)-OH} \rightleftharpoons \mathrm{R-C(=O)-O^{-} + H^{+}}$ Carboxyl Group (-COOH)
- $\mathrm{R-N(H)-H + H^{+}} \rightleftharpoons \mathrm{R-N^{+}(H)(H)-H}$ Amino Group (- NH_2)
- $\mathrm{R-O-P(=O)(OH)-OH} \rightleftharpoons \mathrm{R-O-P(=O)(O^{-})-O^{-} + 2H^{+}}$ Phosphate Group ($-H_2PO_4$)

The Biological Important Organic Compounds

- Molecules unique to living systems contain carbon and hence are organic compounds
- They include 4 major classes :
  - **Carbohydrates** - **Proteins** - **Lipids** - **Nucleic Acids**
- Each class is characterized by having specific building blocks from which the larger molecules are created
  - Synthesis of larger molecules from the building blocks (monomers) occurs via dehydration synthesis reactions (also called condensation reaction) between their functional groups
  - Breakdown of larger molecules into monomers occurs via hydrolysis reactions.

The Biological Important Organic Compounds



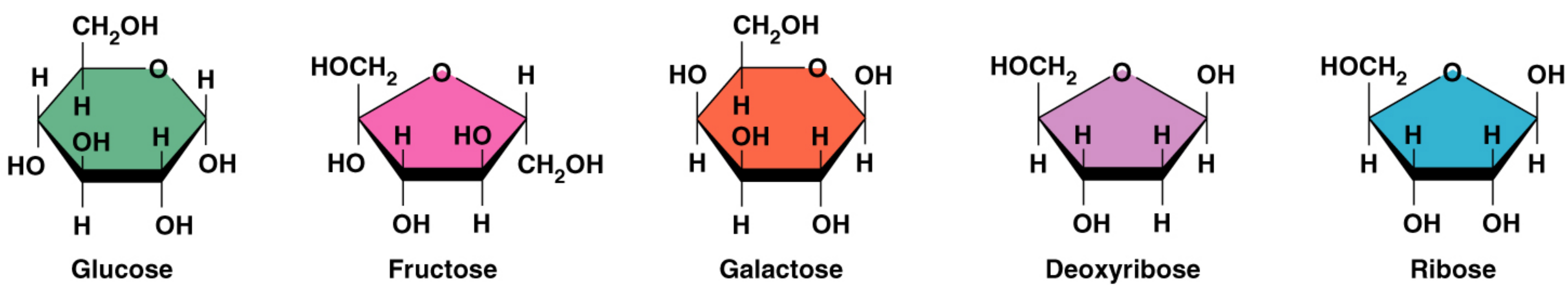
(a) Polymers are formed by dehydration synthesis, in which a water molecule is removed and two monomers are joined.

(b) Polymers are broken down by hydrolysis, in which the addition of a water molecule disrupts the bonds between two monomers.

Always keep in mind that the making and breaking of bonds in biological systems require specific enzymes (one for dehydration synthesis, another one for hydrolysis).

Carbohydrates

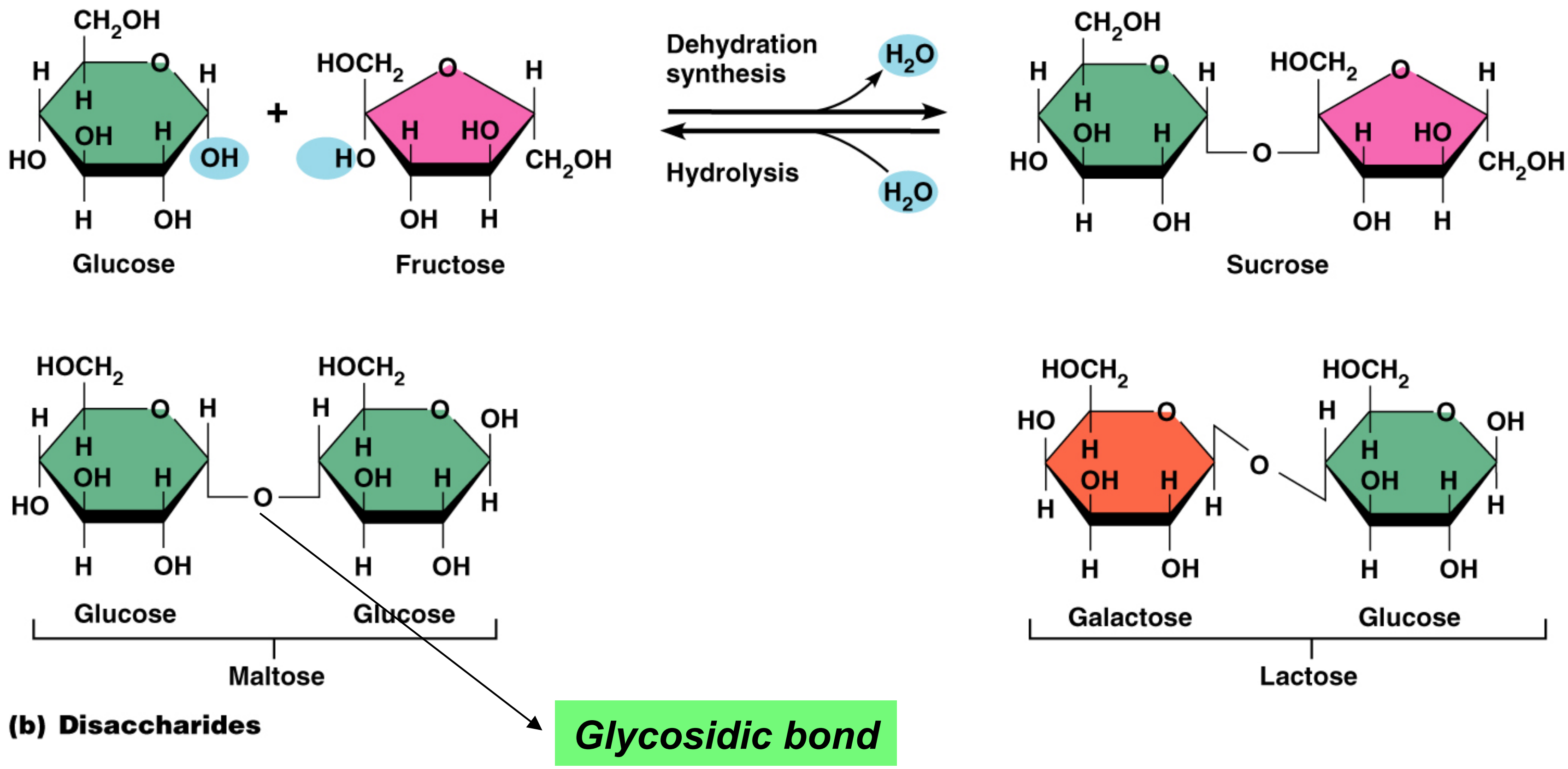
- Contain carbon, hydrogen, and oxygen
- Their major function is to supply a source of cellular food
- Building blocks (monomers) are the simple sugars or mono-saccharides
- Mono-saccharides can usually be written as "carbons with water" ⟶ $C_n(H_2O)_n$
- Example: Glucose = $C_6H_{12}O_6 = C_6(H_2O)_6$



(a) Monosaccharides

Carbohydrates

- Disaccharides or double sugars are combinations between 2 monosaccharides via dehydration synthesis: the covalent bond between two sugars is called a **glycosidic** bond



(b) Disaccharides

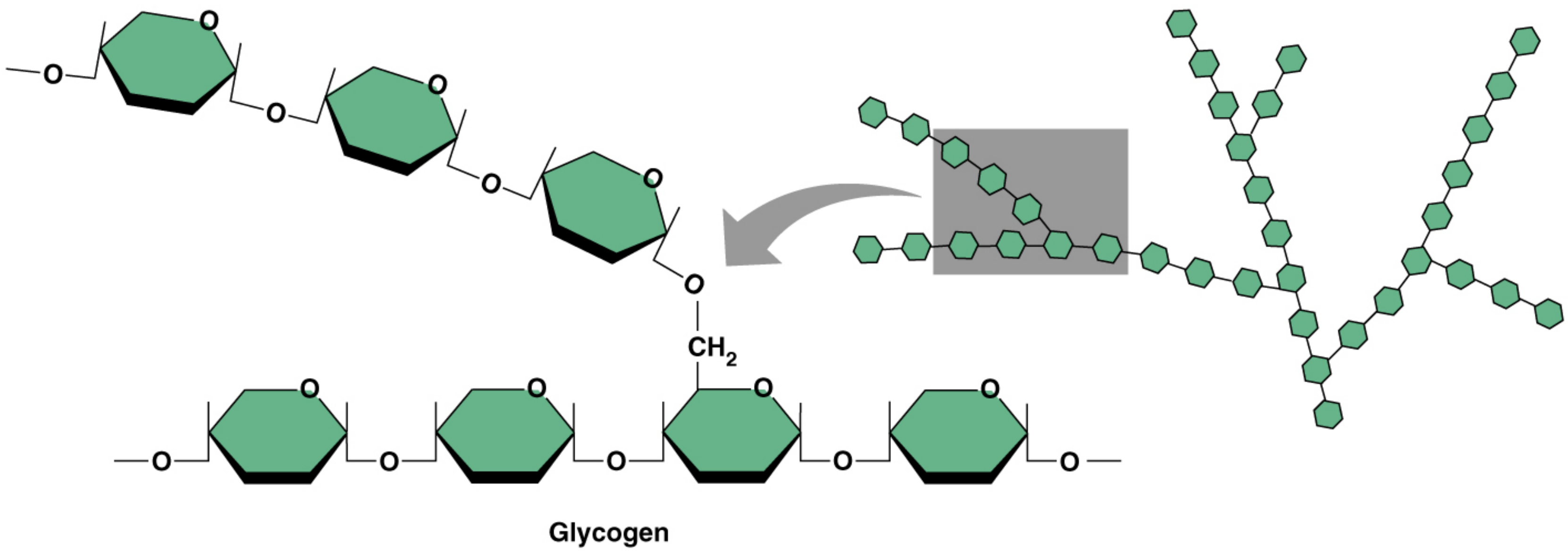
Carbohydrates

- Notice the many –OH functional groups of carbohydrates. This allows them to carry charges and make bonds. Sugars are very hydrophillic (you knew that…)
- Enzymes that break these glycosidic bonds are found in the lining of the small intestine.
  - Sucrase – Maltase – Lactase
- Only simple sugars can be taken up by the intestinal transporters

- Lactose Intolerance : due to absence of lactase
- Congenital sucrase-isomaltase : people with this condition cannot break down the sugars sucrose and maltose.
- Both conditions result in indigestion/cramping/bloating/diarrhea

Carbohydrates

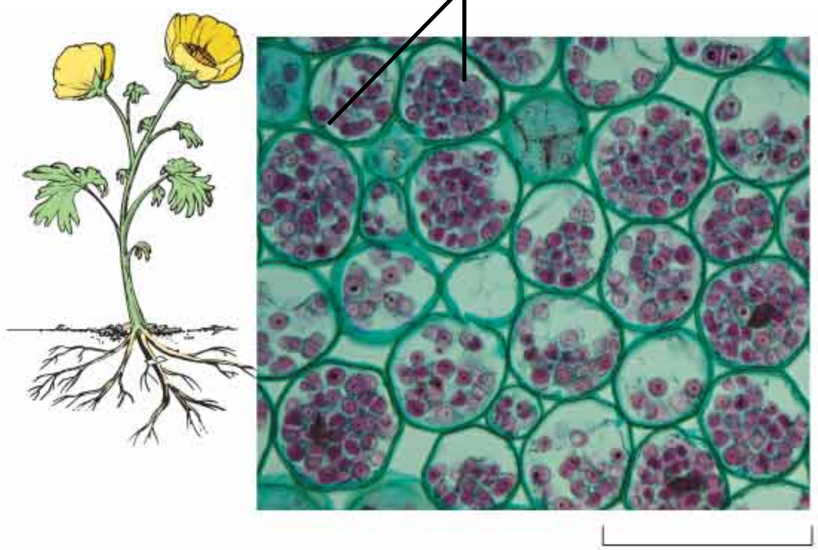
- Poly-saccharides are polymers of simple sugars
- Typical examples are starch (plants) and glycogen (animals). Both are large polymers of glucose units.

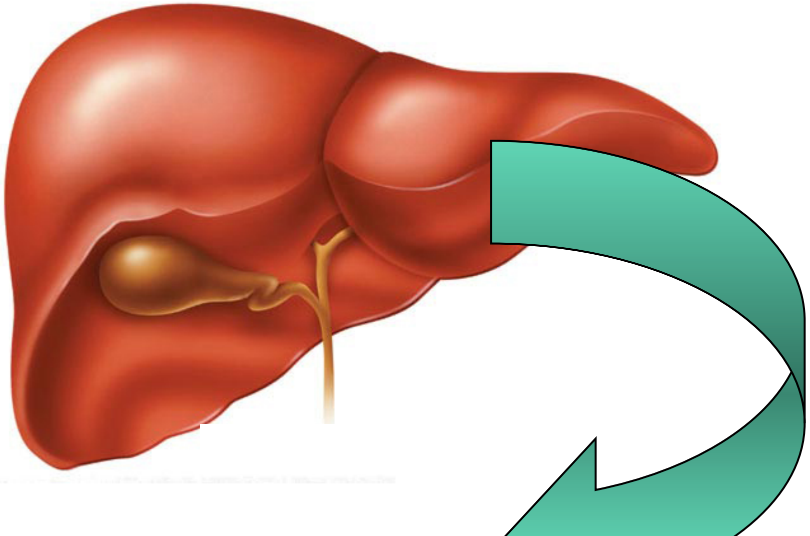


(c) Portion of a polysaccharide molecule (glycogen)

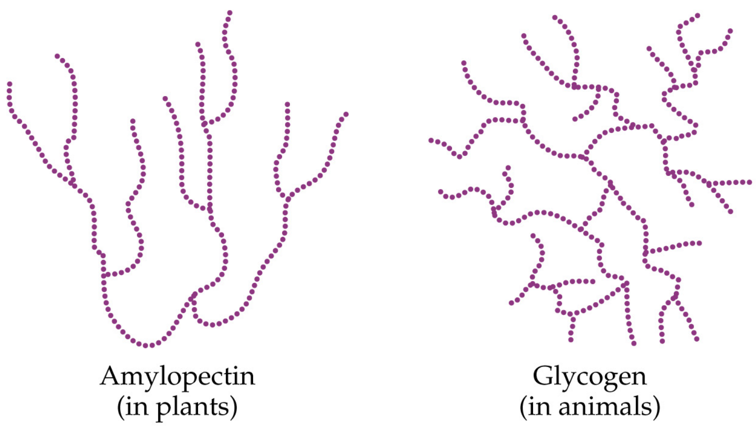
Carbohydrates

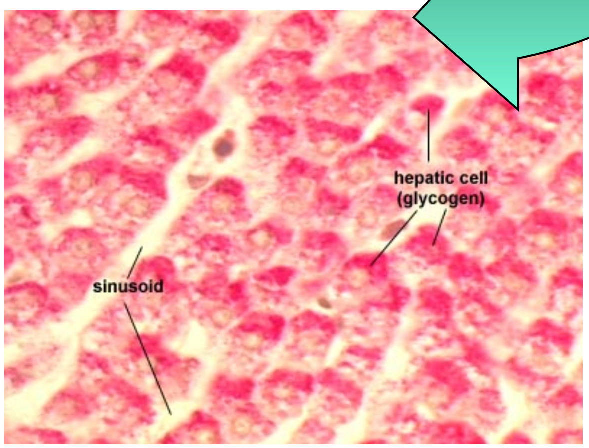
Amyloplasts containing starch





Comparison of branching in amylopectin and glycogen





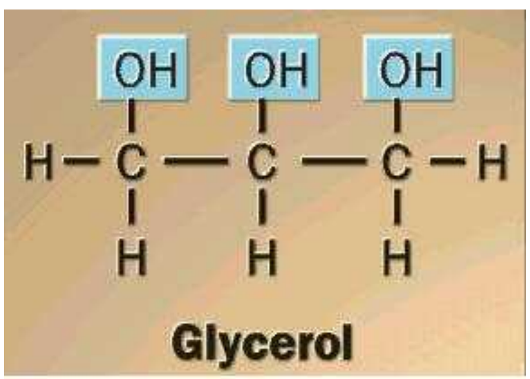
Hepatic cells containing glycogen

Lipids

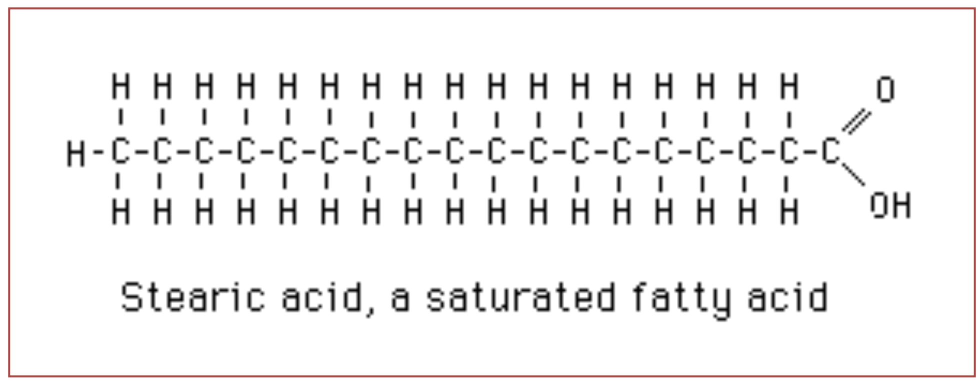
- Consist mainly of carbon and hydrogen with few functional groups
- A chain of only hydrogen and carbons is called a hydrocarbon chain and is extremely hydrophobic.
- The functional groups on a lipid are usually the only parts that have some hydrophillic properties
- Examples of Lipids:
  - Neutral fats or triglycerides
  - Phospholipids
  - Steroids
  - Eicosanoids

Neutral Fats (Triglycerides)

- Most abundant lipid in living organisms- used as a form of energy reserve
- Also known as tri-acylglycerols since they are made from 3 fatty acids and one glycerol molecule

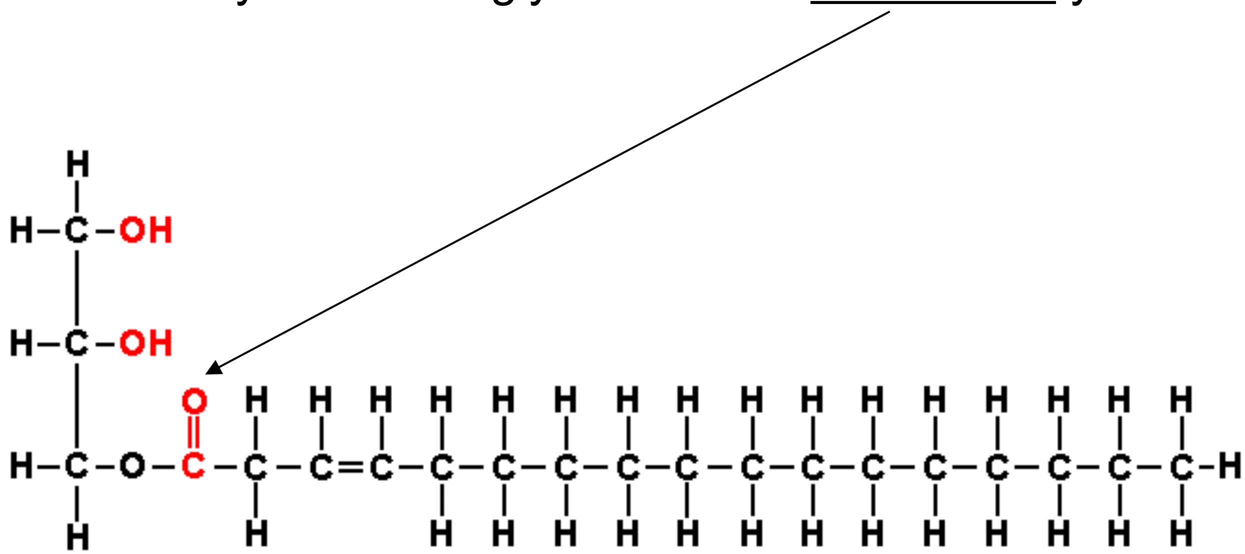


3 carbon alcohol that contains 3 -OH groups



A fatty acid is an unbranched hydrocarbon chain with a carboxyl group at one end ; notice the many carbons and hydrogens, making it very hydrophobic !

Addition of one fatty acids to a glycerol via an **ester bond** yields a Mono acyl glycerol

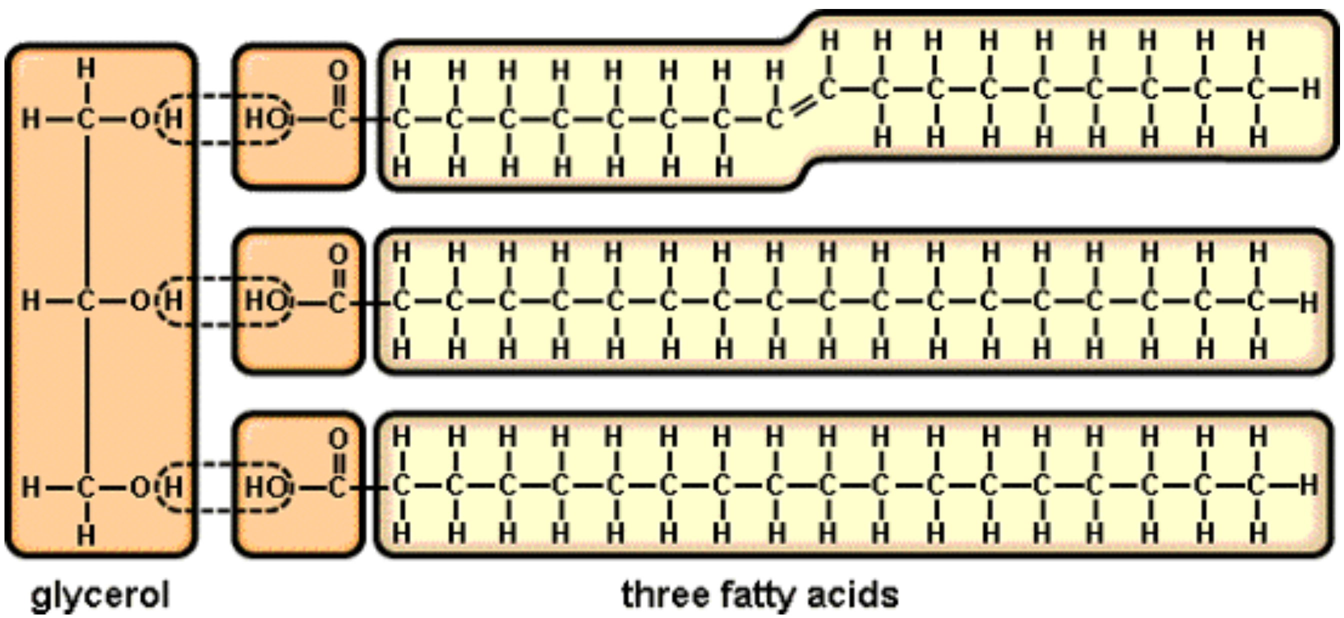


Addition of a second fatty acids to this Mono acyl glycerol yields Di-Acylglycerol

Notice that glycerol has 3 –OH groups. Thus, glycerol by itself is hydrophillic. But once it starts making bonds with fatty acids, they become occupied and can't interact with water anymore.

Addition of a third fatty acids to this Di acyl glycerol yields Tri-Acylglycerol

also known as a tri-glyceride



Notice how many covalent bonds there are in each fatty acid compared to glucose ! Thus a triglyceride provides about 9 times more energy than glucose.

Fatty acids come in different forms and most have even number of carbons such as 14 carbons, 16, 18 , 20 carbons.

Oleic acid, for example, is the most abundant fatty acids and has 18 carbons

Fatty acids are also found in a saturated and unsaturated form

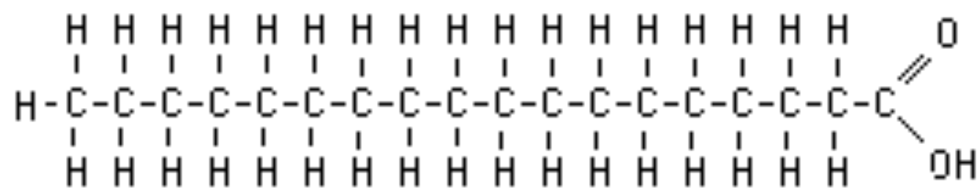
Saturated fatty acids

- Contain the maximum possible hydrogen atoms
- This means that every carbon except for the carboxyl group, is ‘saturated’ with hydrogen
- This thus also means that there are no double bonds between carbon atoms

Unsaturated fatty acids

- Contain one or more double bonds between the carbon atoms

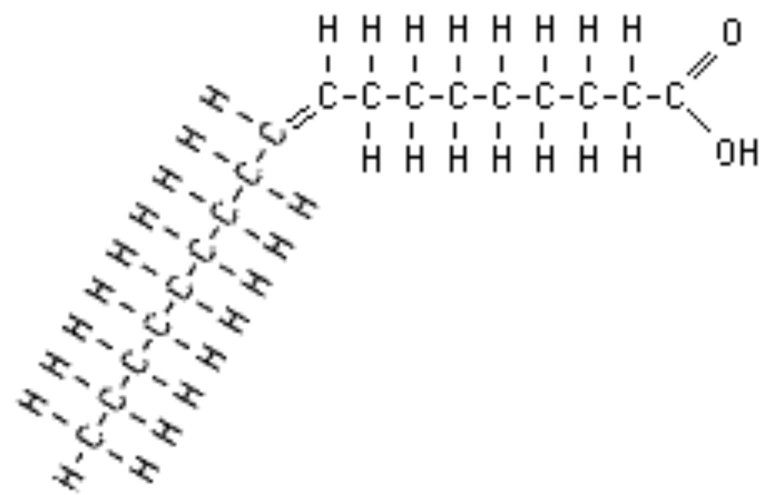
Properties of Saturated fatty acids


Stearic acid, a saturated fatty acid

- Tend to be solid at room temperature because the fatty acids form linear structures in the fats
- Animal fats, lards, solid vegetable shortenings (butters…) are examples of this.

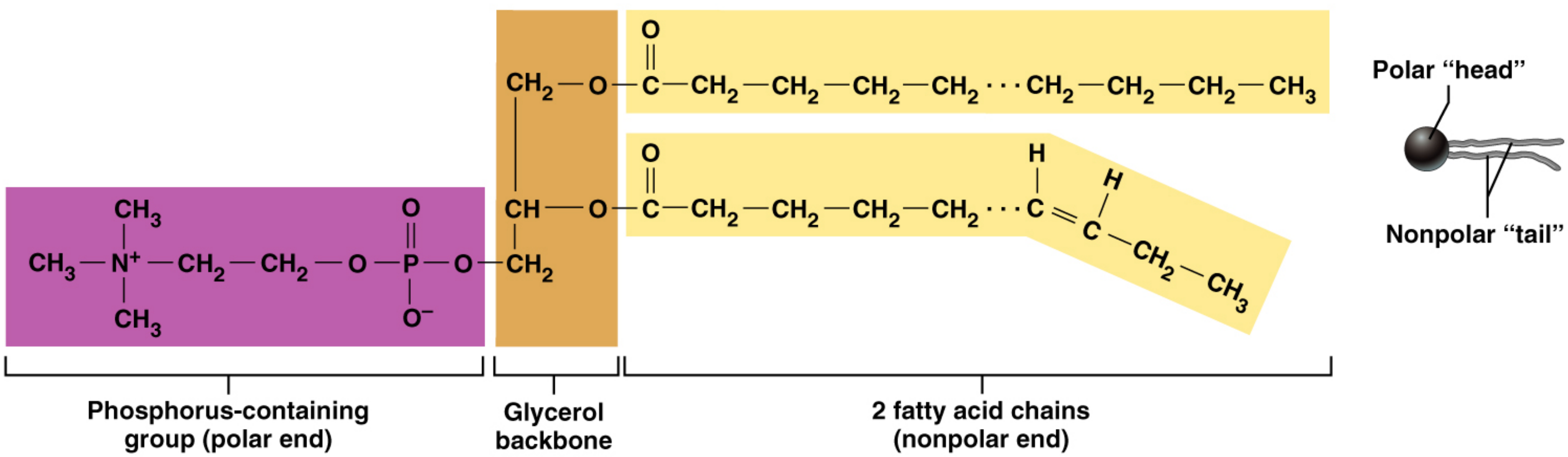
Properties of Un-Saturated fatty acids

- They can be mono unsaturated or poly unsaturated
- Because the double bonds create kinks, these fats tend to be liquid at room temperature


Oleic acid, a monounsaturated fatty acid. Note that the double bond is *cis*; this is the common natural configuration.

Other Lipids

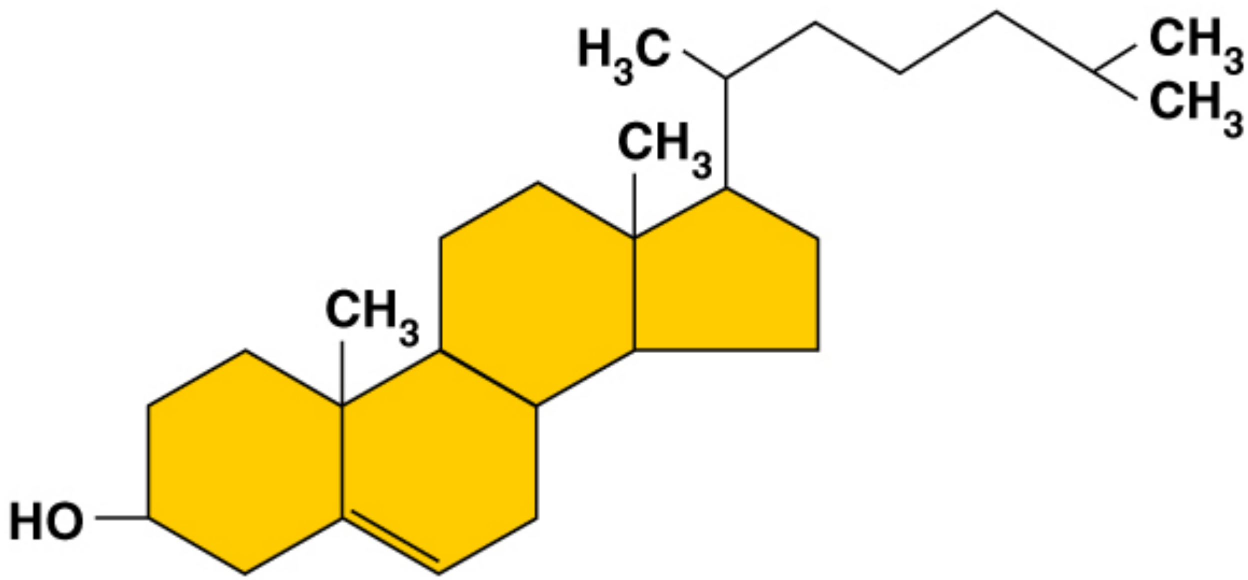
- Phospholipids – modified triglycerides with two fatty acid groups and a phosphorus group
- The fatty acids provide a hydrophobic character while the charged phosphorous group provides a hydrophilic aspect.



(b) Phospholipid molecule (phosphatidylcholine)

Other Lipids

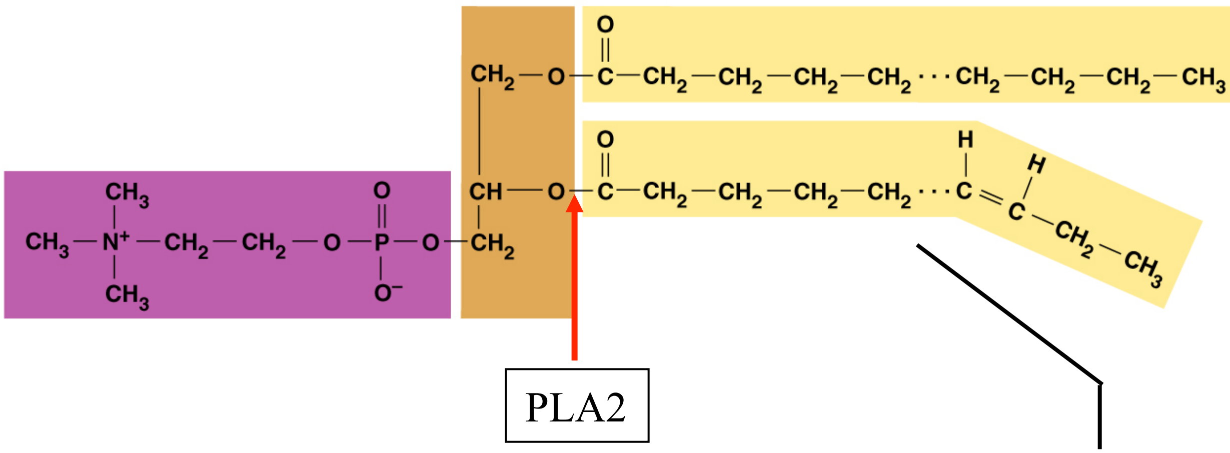
- **Steroids** – flat molecules with four interlocking hydrocarbon rings (derived from cholesterol)



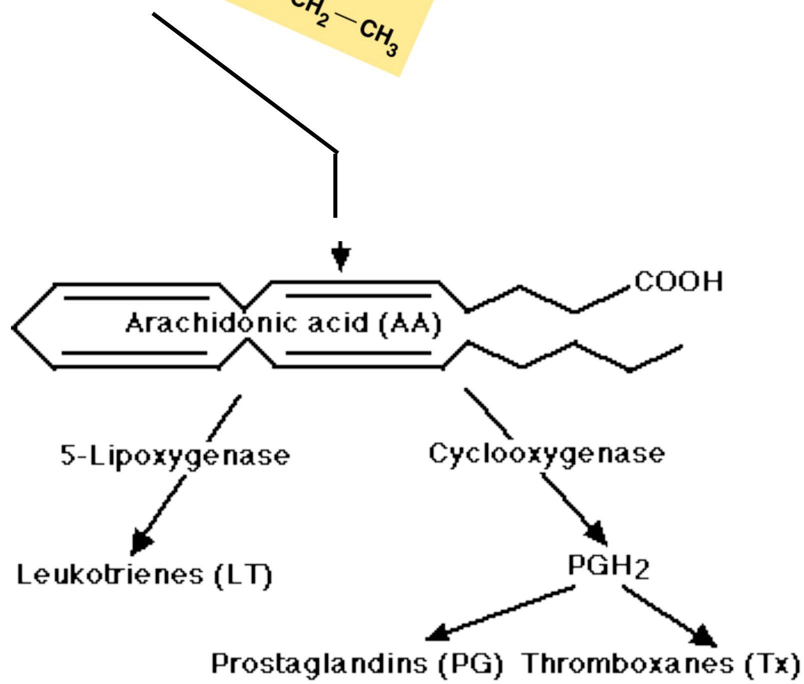
(c) Cholesterol

Eicosanoids : compounds derived from the 20-carbon poly-unsaturated fatty acid Arachidonic Acid.

Arachidonic acid results from the action of Phospholipase A2 on specific cell membrane phospholipds !



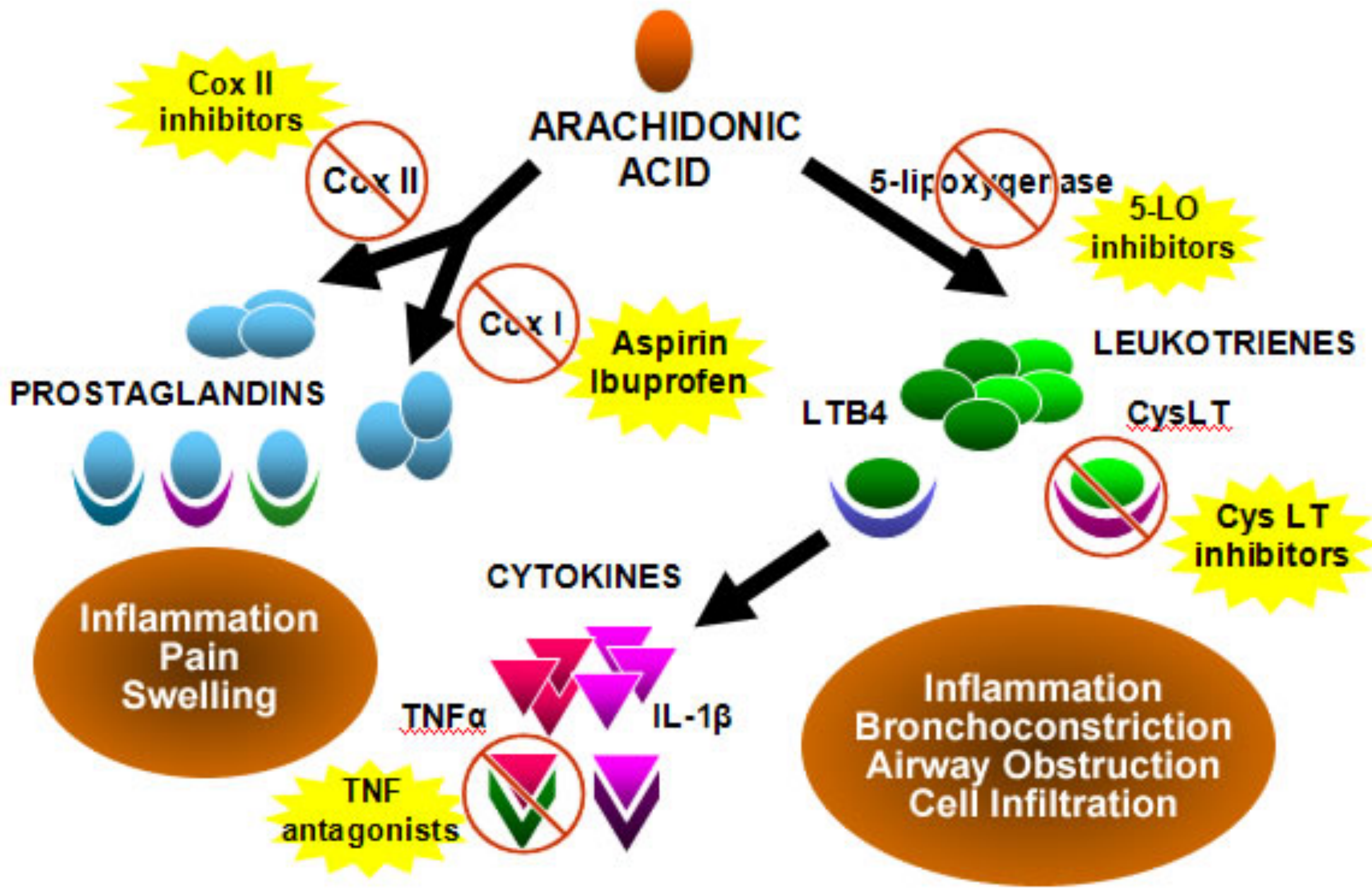
Action of other enzymes on AA yields the eicosanoids. Typical examples are Leukotrines, Prostaglandins and Thromboxanes.



Eicosanoids

- Eicosanoids have various roles in inflammation, fever, regulation of blood pressure, blood clotting, immune system modulation, control of reproductive processes and tissue growth, and regulation of the sleep/wake cycle.
- Non-steroidal anti-inflammatory drugs (NSAIDs), such as aspirin and derivatives of ibuprofen, inhibit Cyclooxygenase activity and formation of prostaglandins involved in fever, pain and inflammation. They inhibit blood clotting by blocking thromboxane formation in blood platelets.
- Ibuprofen and related compounds act by blocking the hydrophobic channel by which arachidonate enters the Cyclooxygenase active site.
- Corticosteroids are anti-inflammatory because they prevent inducible Phospholipase A2 expression, reducing arachidonate release.

Arachidonic acid is metabolized to produce inflammatory mediators. Many current anti-inflammatory and pain medicines inhibit some portion of the arachidonic acid pathways.

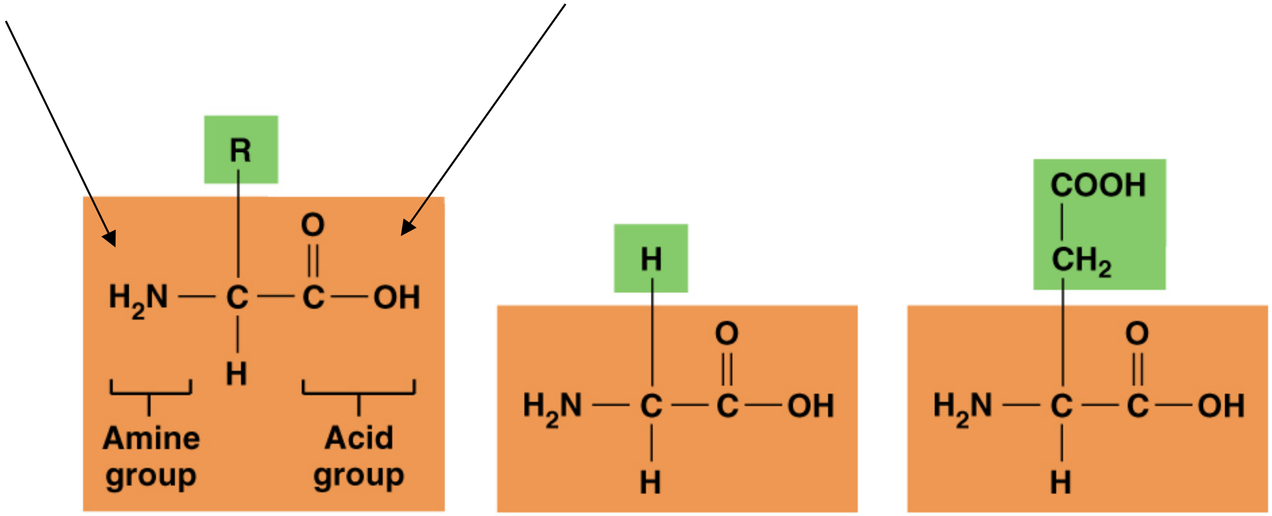


Representative Lipids Found in the Body

- Neutral fats – found in subcutaneous tissue and around organs
- Phospholipids – chief component of cell membranes
- Steroids – cholesterol, bile salts, vitamin D, sex hormones, and adrenal cortical hormones
- Fat-soluble vitamins – vitamins A, E, and K
- Eicosanoids – prostaglandins, leukotrienes, and thromboxanes
- Lipoproteins – transport fatty acids and cholesterol in the bloodstream

Amino Acids and Proteins

- Amino acids are the building blocks of proteins.
- Amino acids are characterized by having an amino group (- NH_2) and a carboxyl group (- COOH)



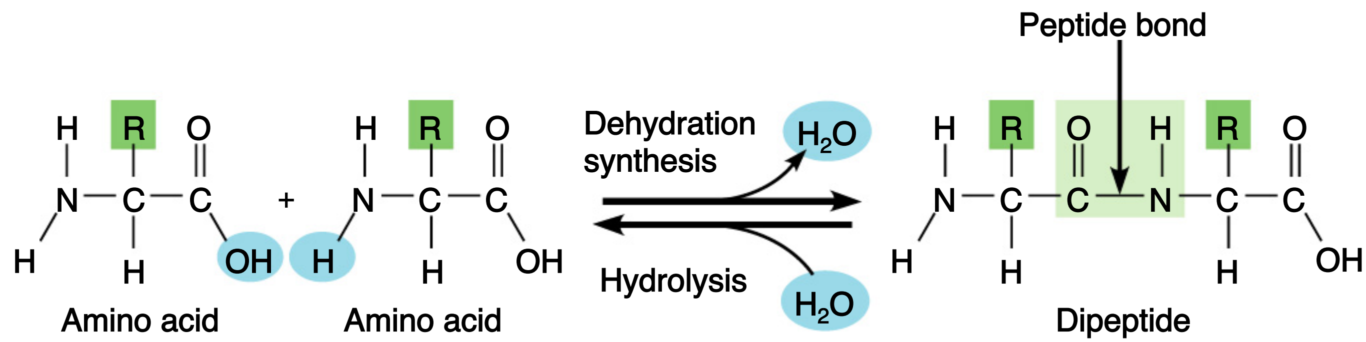
(a) Generalized structure of all amino acids

(b) Glycine (the simplest amino acid)

(c) Aspartic acid (an acidic amino acid)

Proteins

- Proteins are macromolecules composed of combinations of 20 types of amino acids bound together with peptide bonds



- Di-peptide = Linking two amino acids together
- Tri-peptide = Linking two amino acids together
- Oligo-peptide = 4 to 10 amino acids linked together
- Polypeptide = > 10 amino acids linked together
- Proteins = > 50 amino acids linked together

Proteins

- When amino acids are strung together, the amino acids start interacting with each other according to their hydrophilic, hydrophobic and/or ionic properties.
- Such interactions are necessary and result in the typical 2 and 3 dimensional configurations of a protein, referred to as the structural levels of organization.

Structural Levels of Proteins

- **Primary** – is the linear sequence of how the amino acids are strung together

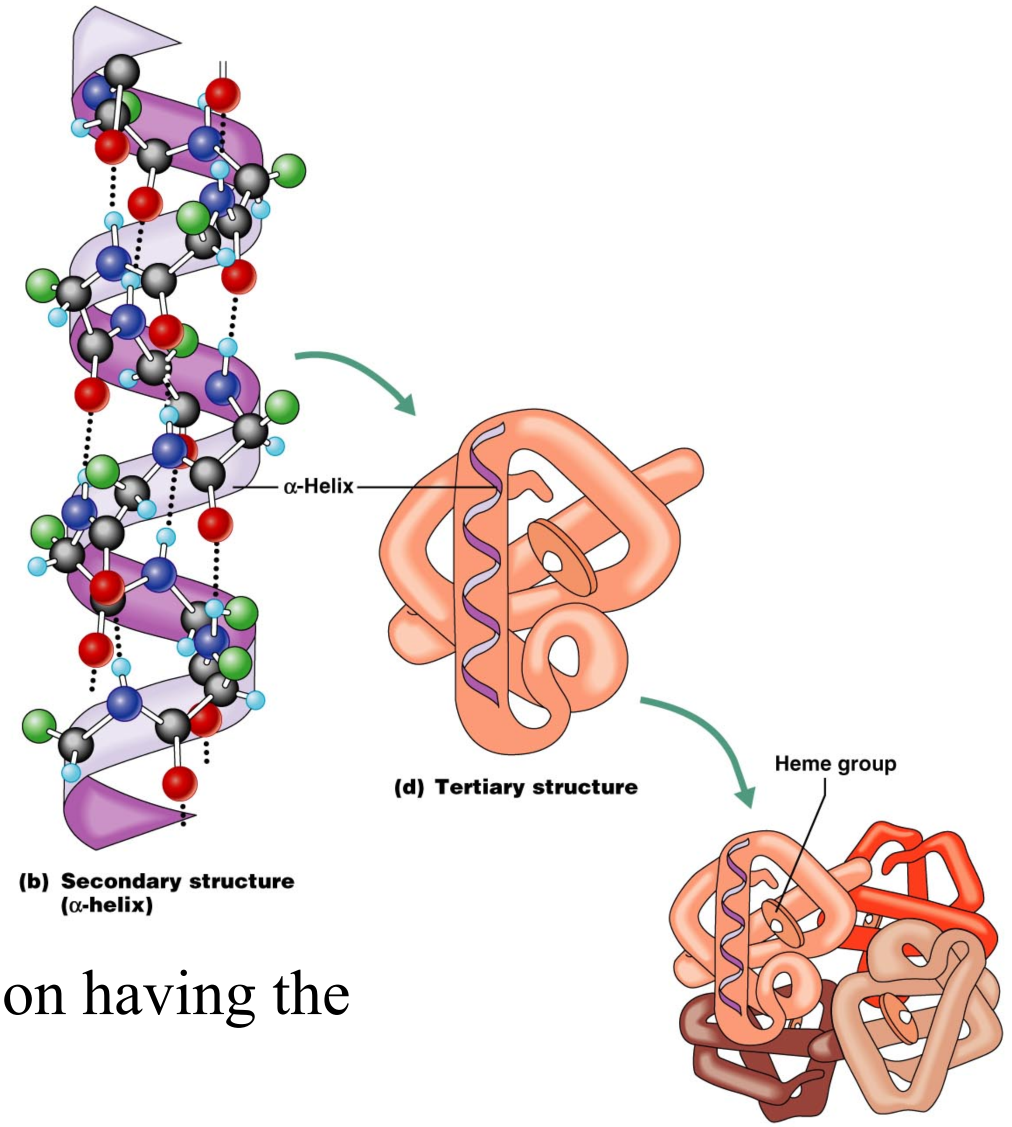
  This primary sequence is what determines the functionality of a protein. It can be viewed like an alphabet that conveys information

  A wrongly inserted amino acids may completely destroy the function of a protein and are often encountered in genetic diseases.

  For example : Grab the cat….. Grab the hat ….. Grab the can …. Grab she cat….

Structural Levels of Proteins

- Secondary – alpha helices or beta pleated sheets
- Tertiary – superimposed folding of secondary structures resulting in a 3 dimensional structure
- Quaternary – two or more polypeptide chains linked together in a specific manner to create a functional protein



(b) Secondary structure (α-helix)

(d) Tertiary structure

(e) Quaternary structure (hemoglobin molecule)

All these structures depend on having the proper primary structure !

Fibrous and Globular Proteins

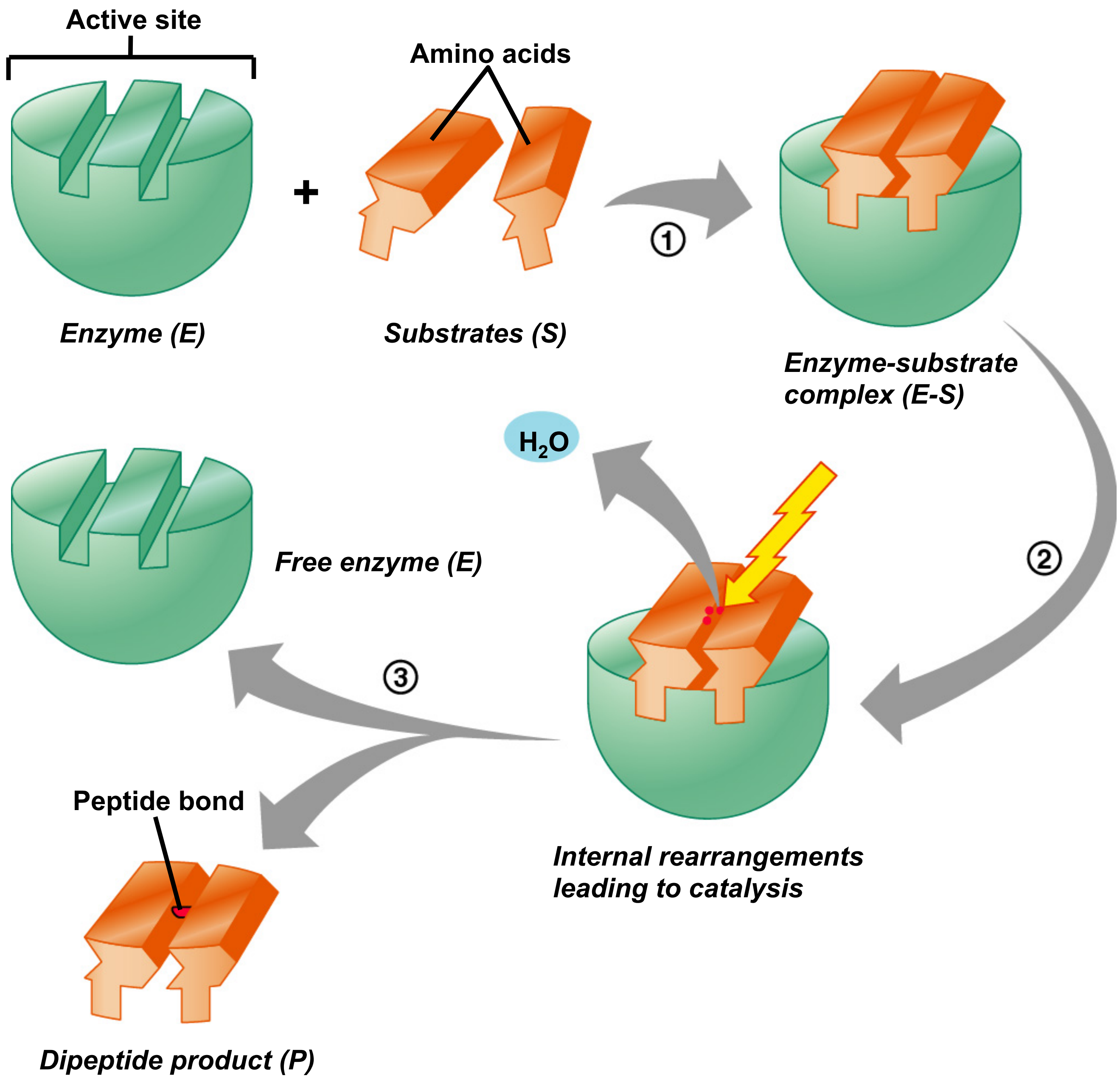
- Fibrous proteins
  - Extended and strand-like proteins
  - Examples: keratin, elastin, collagen, and certain contractile fibers
- Globular proteins
  - Compact, spherical proteins with tertiary and quaternary structures
  - Examples: antibodies, hormones, and enzymes
  - Destruction of the tertiary structure most often results in loss of function such as occurs during denaturation (due to pH, temperature or ionic influences)

Major Classes of Proteins and Their Functions

Protein Class	Functions and Examples
Enzymes	Catalyze specific chemical reactions
Structural proteins	Strengthen and protect cells and tissues e.g., collagen strengthens animal tissues)
Storage proteins	Store nutrients; particularly abundant in eggs (e.g., ovalbumin in egg white) and seeds (e.g., zein in corn kernels)
Transport proteins	Transport specific stubstances between cells (e.g., hemoglobin transports oxygen in red blood cells; move specific substances (e.g., ions, glucose, amino acids) across cell membranes
Regulatory proteins	Some are protein hormones (e.g., insulin); some control the expression of specific genes
Motile proteins	Participate in cellular movements (e.g., actin and myosin are essential for muscle contraction)
Protective proteins	Defend against foreign invaders (e.g., antibodies play a role in the immune system)

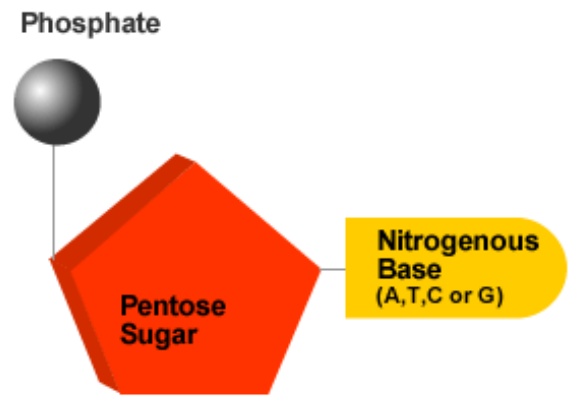
Mechanism of Enzyme Action

- Life is possible due to the presence of enzymes
- Frequently named for the type of reaction they catalyze or the substrate they use
- Enzyme names usually end in -ase
  - Examples : ATPase , Catechol Oxidase
- Enzyme binds with substrate at the active site
- Product is formed at a lower activation energy
- Product is released and enzyme comes out of the reaction unchanged and can be used over again


Active site
Amino acids
Enzyme (E)
Substrates (S)
1
Enzyme-substrate complex (E-S)
H_2O
2
Free enzyme (E)
3
Peptide bond
Internal rearrangements leading to catalysis
Dipeptide product (P)

Nucleic Acids

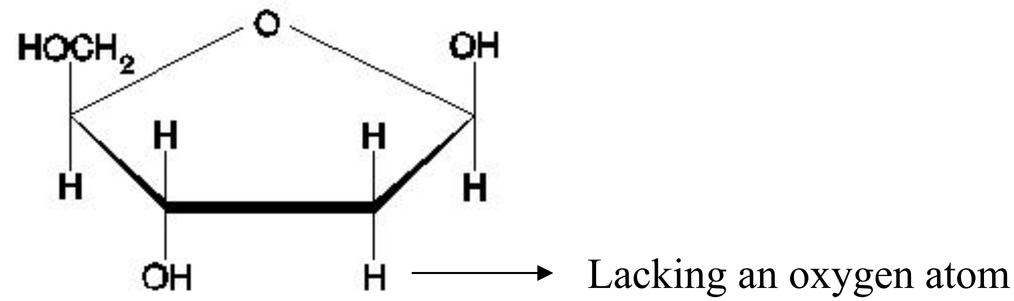
- Composed of carbon, oxygen, hydrogen, nitrogen, and phosphorus
- Their structural unit is **the nucleotide**,
  It is composed of a
  - **Nitrogen-containing base**,
  - **Pentose sugar**, and
  - a **phosphate group**



- Five nitrogen bases contribute to nucleotide structure – adenine (A), guanine (G), cytosine (C), thymine (T), and uracil (U)
- Two major classes –
  - DNA (deoxyribose nucleic acid)
  - RNA (ribose nucleic acid)

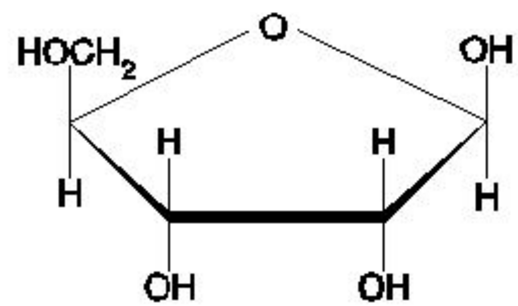
Two types of sugars in Nucleic Acids

Deoxyribose is the sugar used in DNA



Deoxyribose

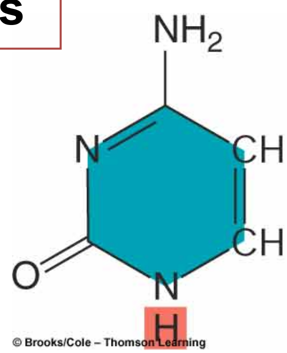
Ribose is the sugar used in RNA



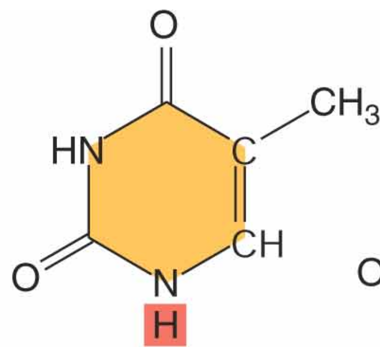
Ribose

Two Classes of Nitrogenous Bases

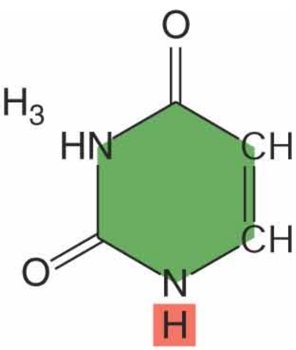
Pyrimidines



Cytosine (C)

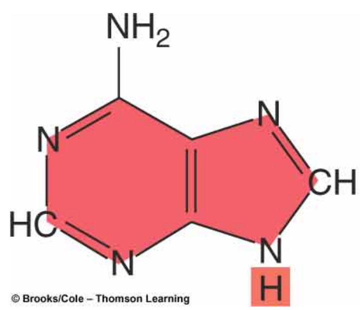


Thymine (T)

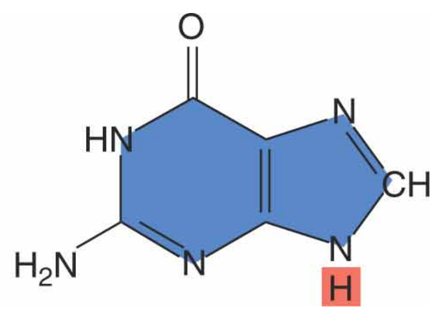


Uracil (U)

Purines



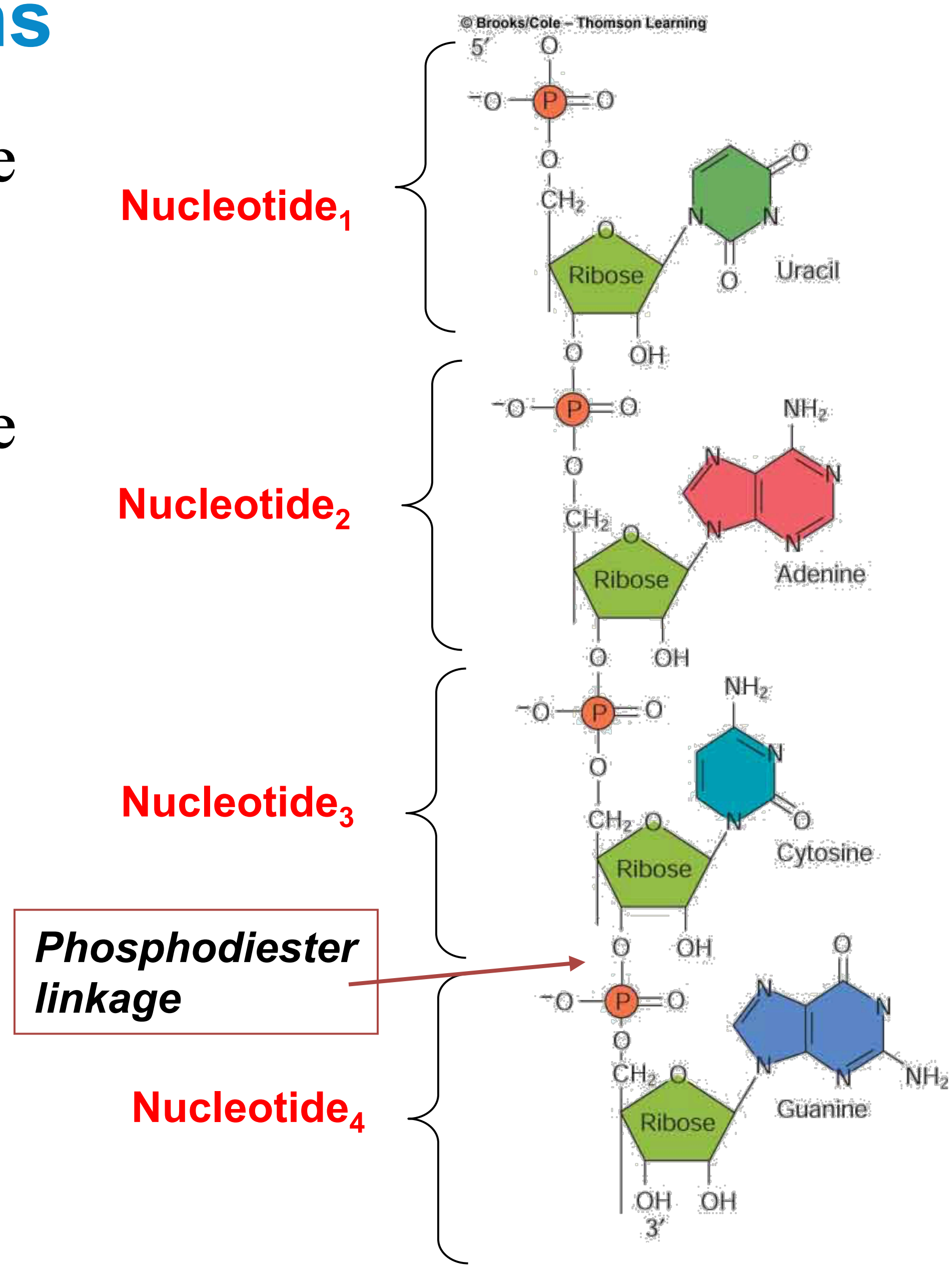
Adenine (A)



Guanine (G)

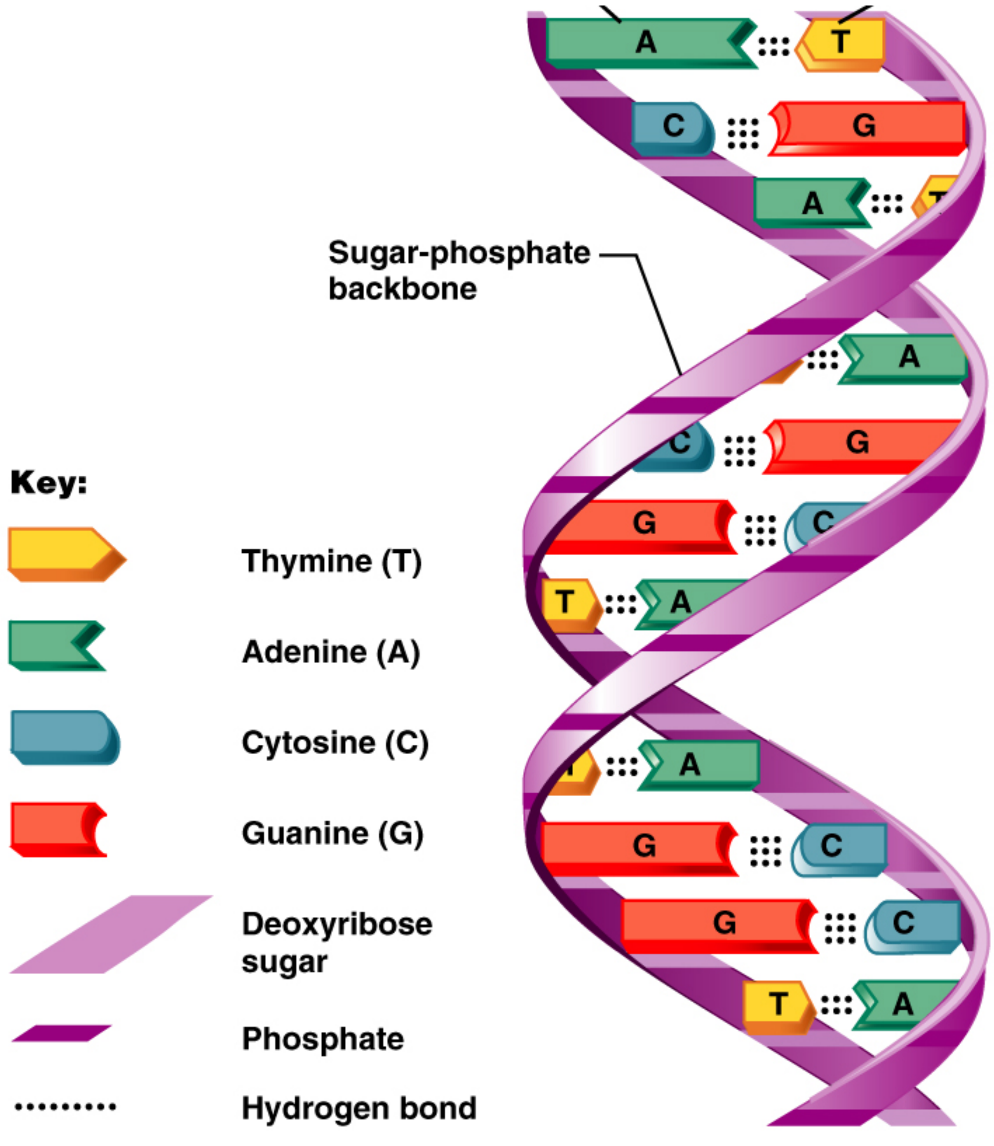
Nucleotide chains

- Nucleotide chains are the backbone of both DNA and RNA
- Nucleotide chains are polymers of nucleotides linked together by phosphodiester bonds.



Structure of DNA

- Found only in the nucleus and contains the genetic information (the genes)
- DNA is made from 2 nucleotide chains,
- Chains held together by hydrogen bonds between specific base pairs and provide the typical double helix structure
- T always pairs up with A
- C always pairs up with G.



(b)

Ribonucleic Acid (RNA)

- Single-stranded nucleotide chain found in both the nucleus and the cytoplasm of a cell
- The other difference with DNA is that RNA uses the nitrogenous base uracil instead of thymine
- Three varieties of RNA exist: messenger RNA, transfer RNA, and ribosomal RNA

Differences between DNA and RNA

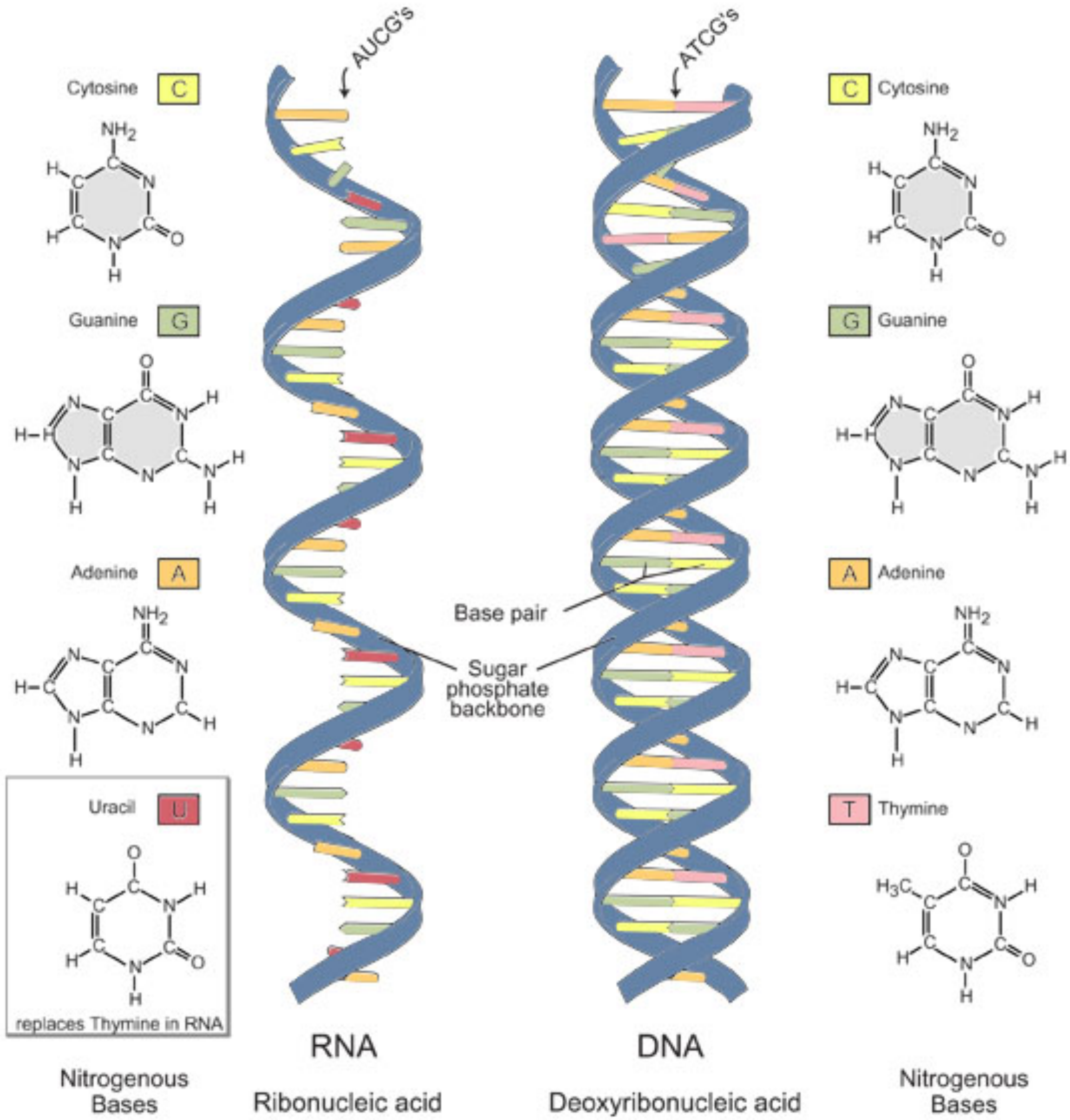
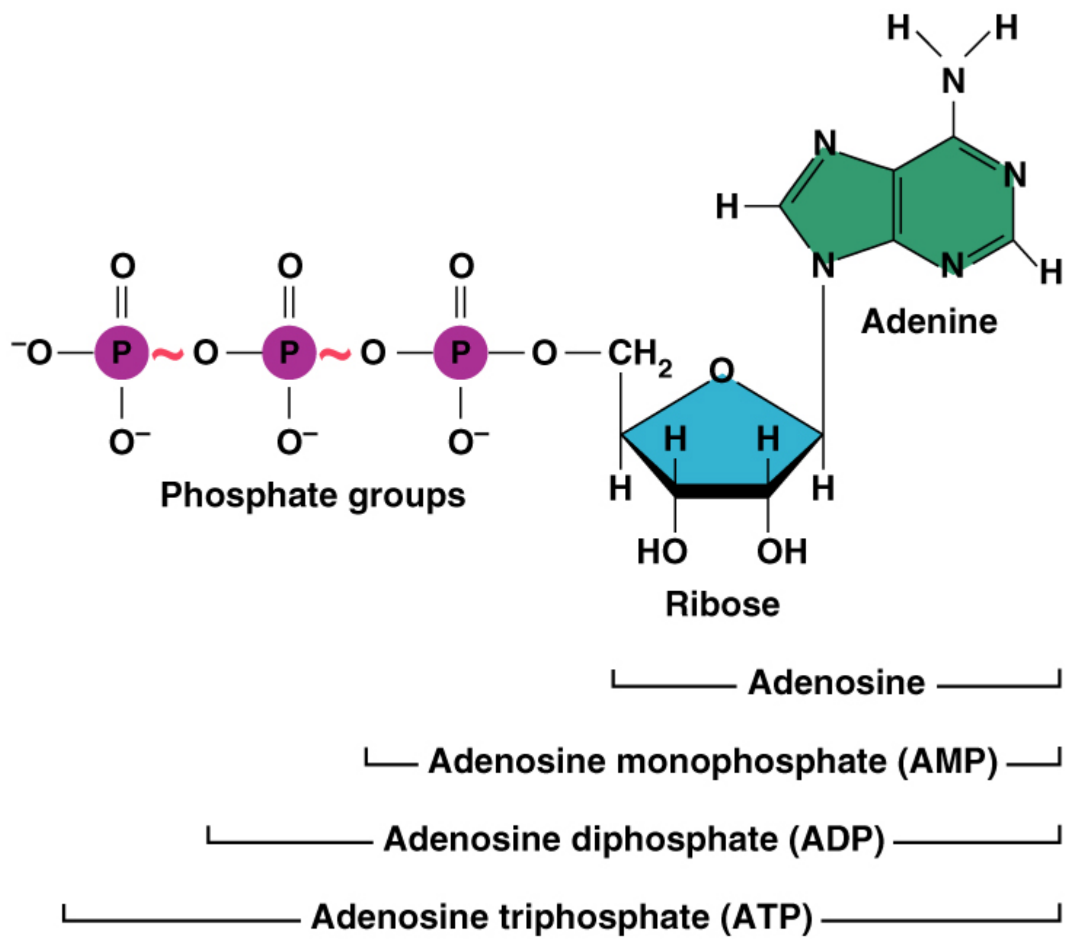


Image adapted from: National Human Genome Research Institute. Talking Glossary of Genetic Terms. Available at: www.genome.gov/ Pages/Hyperion//DIR/VIP/Glossary/Illustration/rna.shtml.

Adenosine Triphosphate (ATP)

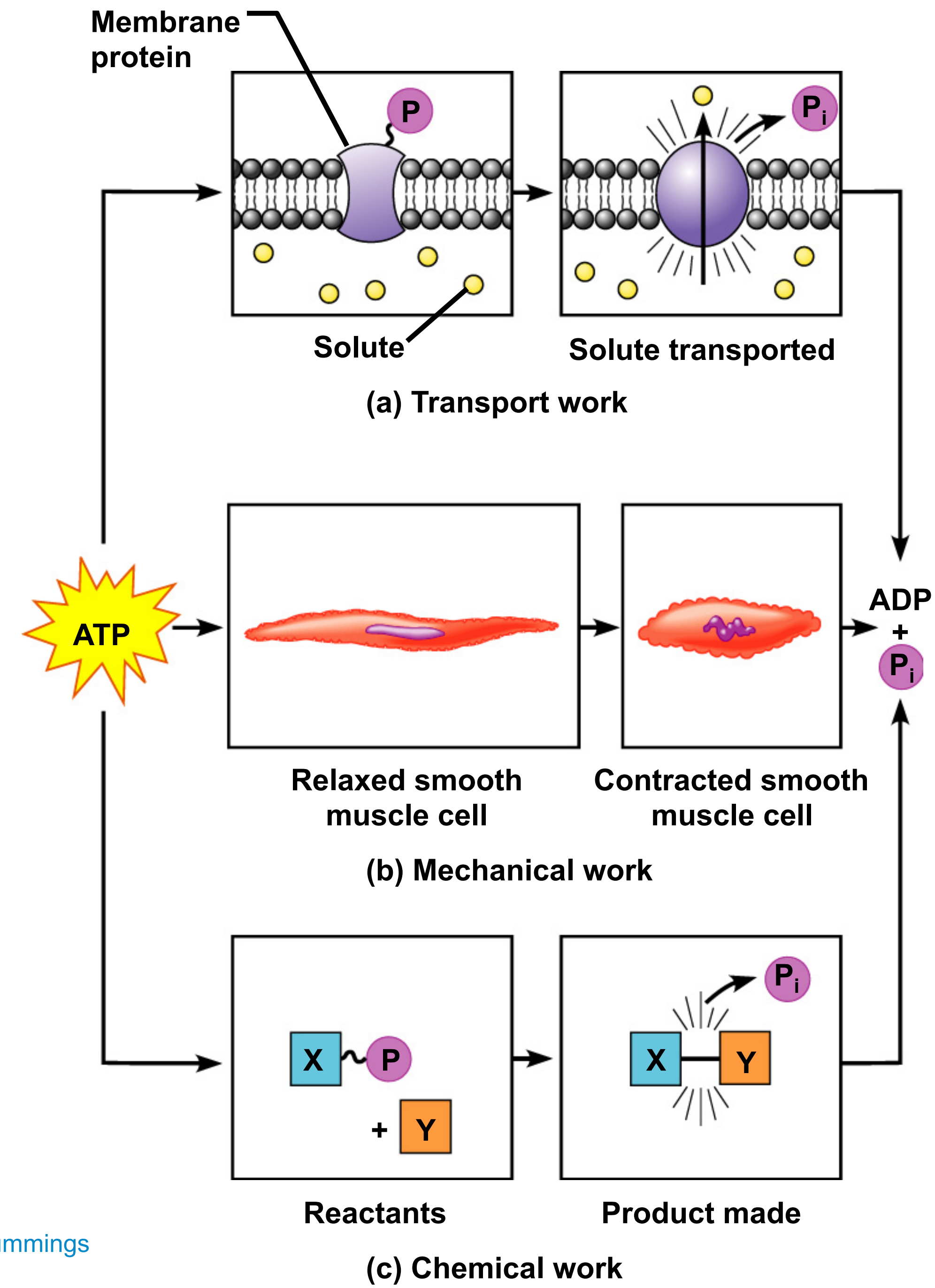
- Source of immediately usable energy for the cell
- Single Adenine-containing RNA nucleotide with three phosphate groups



ATP

- Hydrolysis of ATP yields energy (catalyzed by specific enzymes)
- ATP + H_20 ⟶

  ADP + P_i + Energy
- Since a cell uses up all it's ATP in ~ 5 seconds, ATP it needs to make new ATP almost continuously !
- What organelle is responsible for cellular ATP production ?



Metabolism and Energy Supply

- The food we eat has energy locked up in the covalent bonds
- However, this energy needs to be released by oxidative reactions just like fire and oxygen release the energy in wood or paper (both carbohydrate sources).

$$\text{Wood} + O_2 \longrightarrow CO_2 + H_20 + \text{Heat}$$

$$\text{Glucose} + O_2 \longrightarrow CO_2 + H_20 + \text{ATP}$$

The big difference is that in burning wood, all the energy is released as heat …… fleeting energy

In your body, the energy is harvested at discrete steps in a molecular form, to be used later for all forms of energy requiring steps.