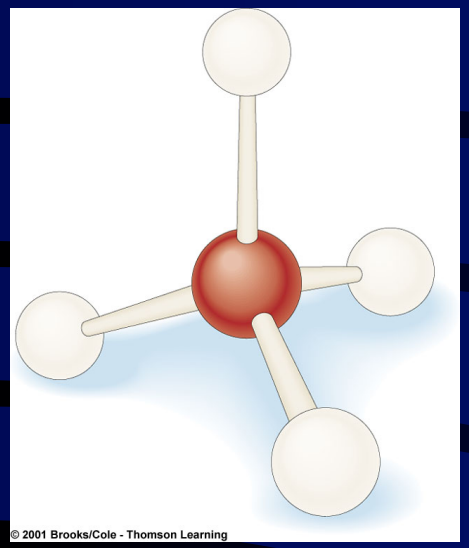
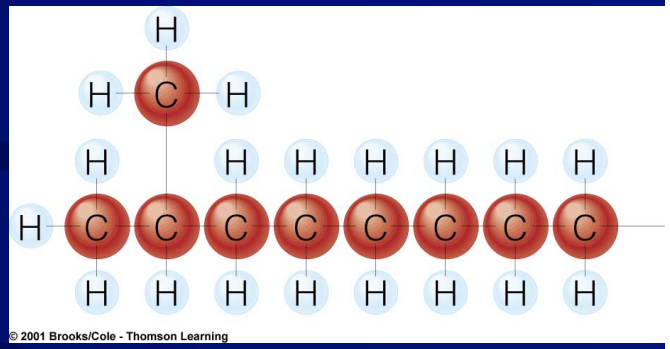
Carbon Compounds In Living Organisms



Honors Biology

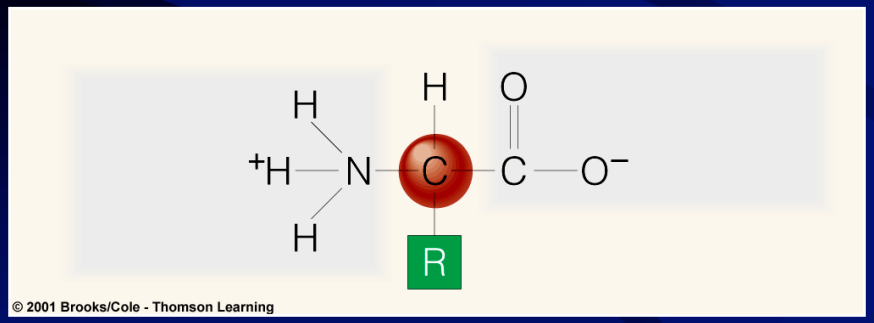
Chapter 3



Revised by:

R. LeBlanc, MS

8/'08



The Two Main Divisions of Chemistry

1. ***Organic Chemistry*** - The study of the chemical reactions involving the element carbon.

Examples: formation of proteins, fats, carbohydrates, nucleic acids, coal, oil, natural gas.

- 2. ***Inorganic Chemistry*** - The chemical reactions and properties of all the elements in the periodic table and their compounds, with the exception of the element carbon.

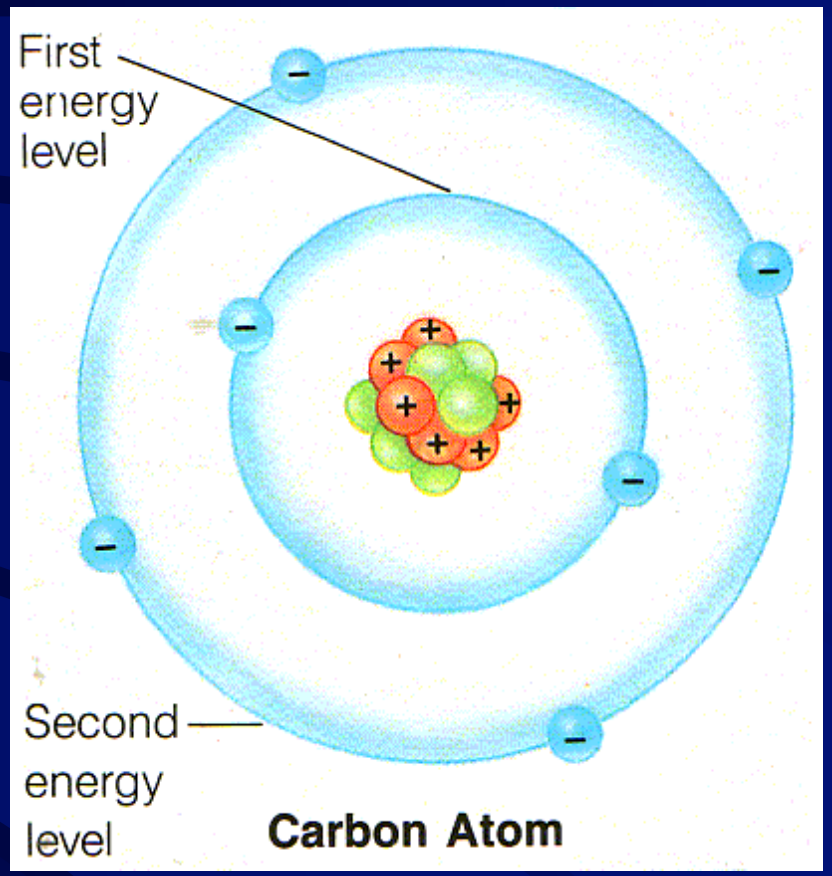
Examples: formation of salts and oxides

Why is the carbon atom so reactive?

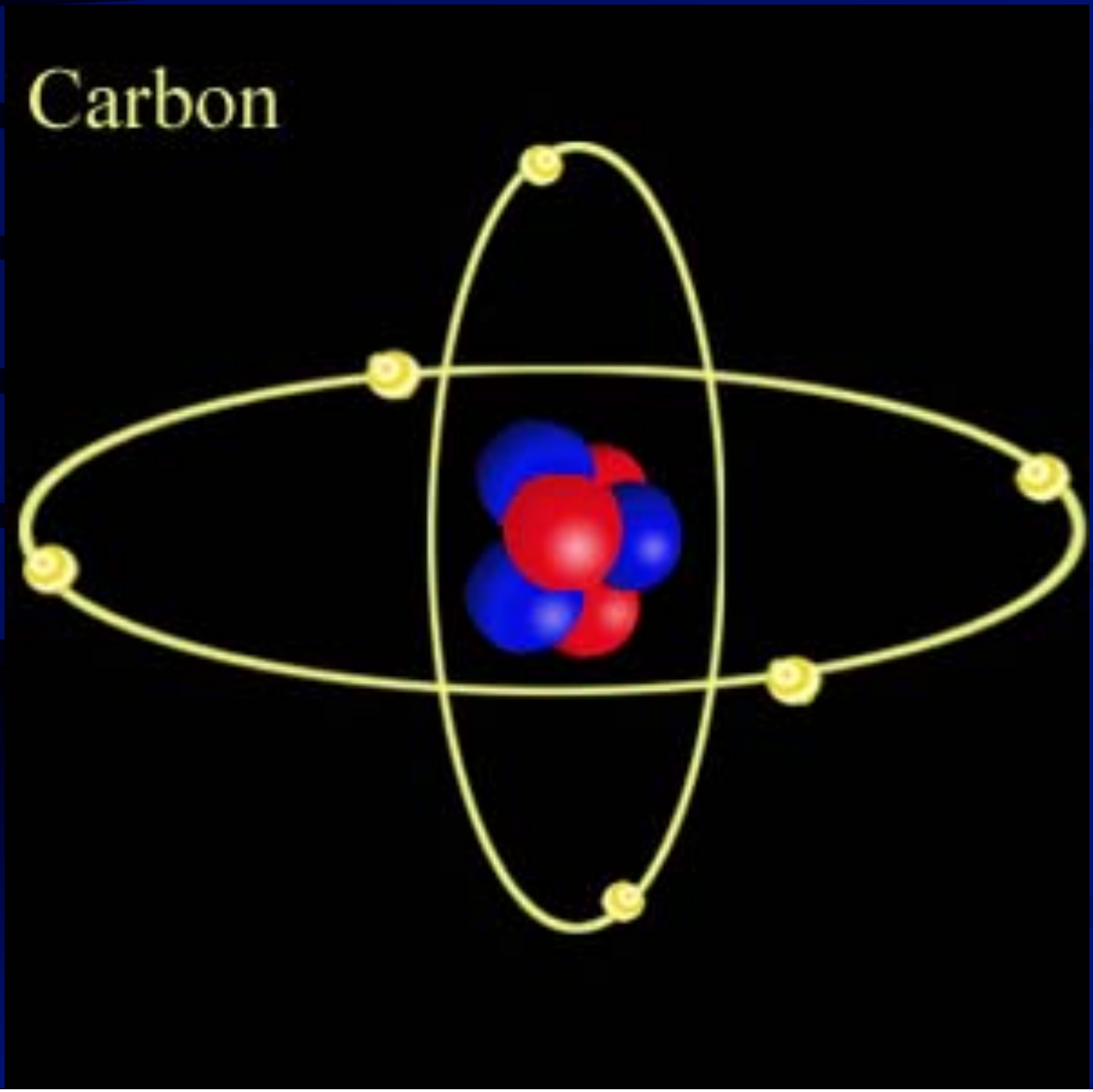
- Carbon has an atomic number of 6…..
  - ***6-protons***
  - ***6-neutrons***
  - ***6-electrons***
  - 2 electrons in the first energy level and 4 in the outer energy level.
  - Thus, ***it can bond with up to 4 other atoms!***
- Carbon can bond with itself into ***long chains*** or into ***rings***.
- ***Hydrocarbons*** are carbon atoms bonded with only hydrogen.
- Carbons can form ***single***, ***double*** or ***triple*** bonds with other atoms.

Atomic Structure of Carbon

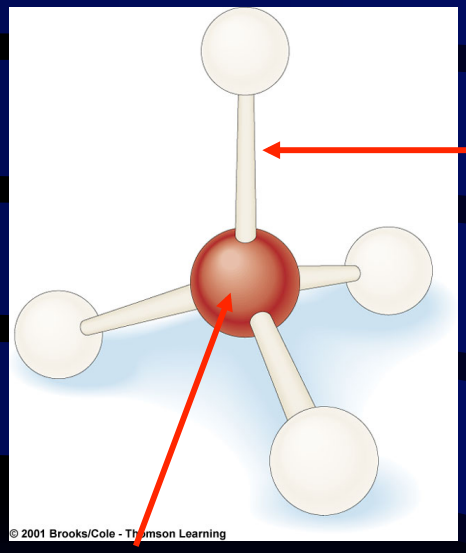
- ***Question: How many electrons does it take to complete carbon's second energy level?***
- ***4***
- ***Question: In the formation of carbon dioxide (CO_2) how does carbon bond with oxygen?***
- ***Carbon shares 2 electrons with each oxygen atom (2 double covalent bonds)***
- ***What would be the chemical formula for carbon chloride (tetra)?***
- ***CCl_4 ; 4 single covalent bonds***



Carbon – The Element of Life

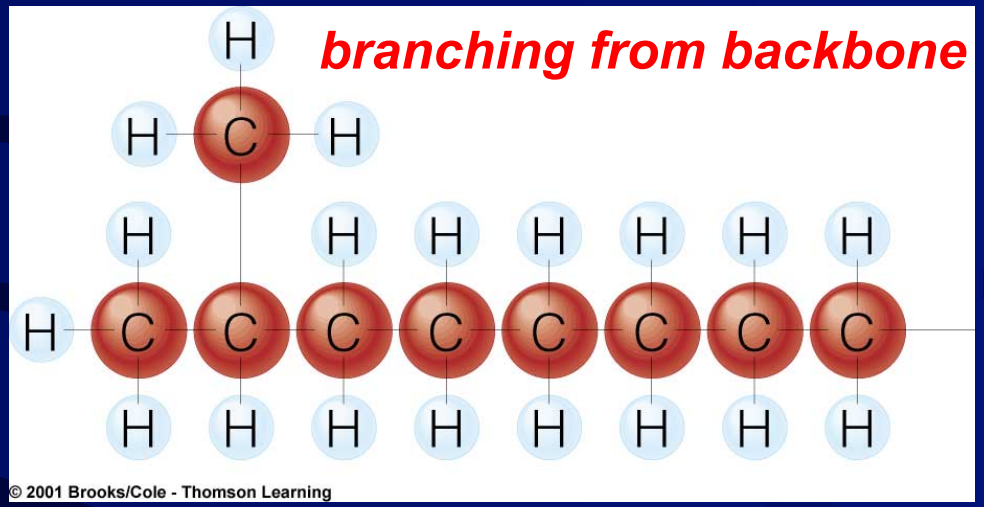


Carbon can bond in a variety of different ways!



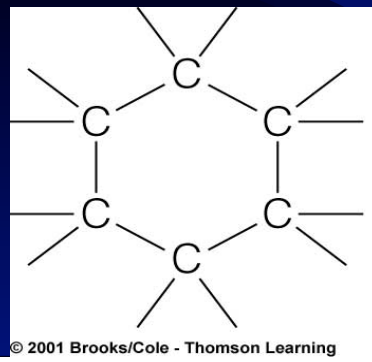
Single covalent bond

Carbon atom



branching from backbone

carbon backbone



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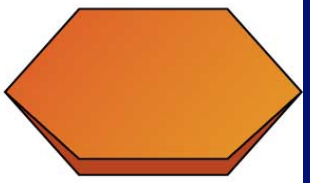


6 carbon ring

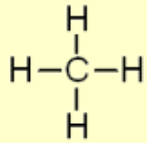
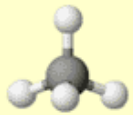
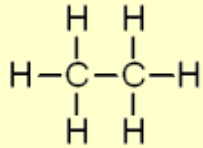
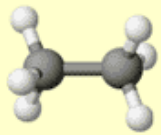
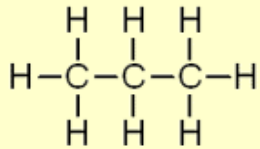
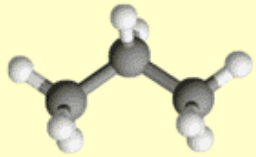
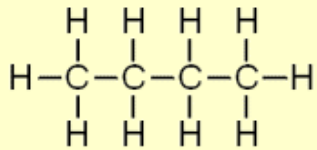
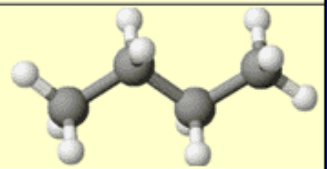
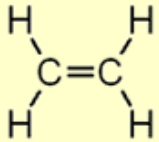
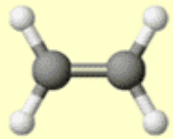
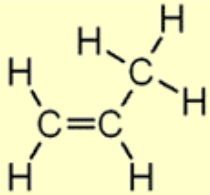
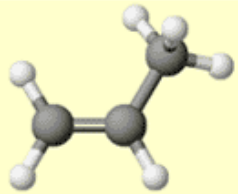
Hydrocarbons are molecules that have only hydrogen atoms attached to the carbon backbone.

Here are just a few examples of some common hydrocarbons:

- Methane - CH_4.....the methyl group CH_3
- Ethane - C_2H_6.....the ethyl group C_2H_5
- Propane - C_3H_8.....the propyl group C_3H_7
- Butane - C_4H_{10}.....the butyl group C_4H_9
- Octane - C_8H_{18}.....the octyl group C_8H_{17}

- ***Long chains of hydrocarbons provide fuel for our power plants, barbeques, lighters, automobiles, and trucks, and are found in living organisms.***

The Story of Hydrocarbons

methane CH_4		
ethane C_2H_6		
propane C_3H_8		
butane C_4H_{10}		
ethene C_2H_4		
propene C_3H_6		

Atoms or molecules that covalently bond to a carbon backbone are known as functional groups.

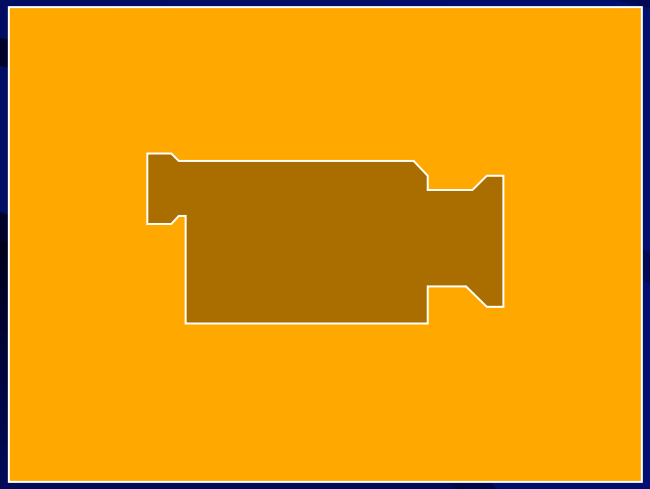
- 1. Methyl-(CH_3)… found in fats oils, waxes
- 2. Hydroxyl- (-OH)…sugars and alcohol
- 3.Aldehyde- (-CHO).. ….sugars
- 4. Ketone- (-C=O)……sugars
- 5.Carboxyl- (HOC=O) ..sugars, fats, amino acids
- 6. Amino- (-NH_3)…amino acids and proteins
- 7. Phosphate- (-PO_4)…phospholipids, DNA, RNA
- 8. Sulfhydryl- (-S-H)…some proteins

•Why do alcohols and sugars easily dissolve in water?

•ANS: Water easily forms hydrogen bonds with OH.

NOTE: These add distinct properties, such as: solubility and chemical reactivity to the complete molecule.

List some unique characteristics of hydrocarbons from the following video



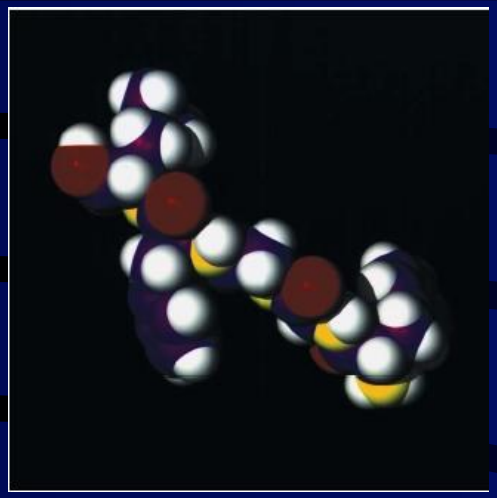
Biochemistry

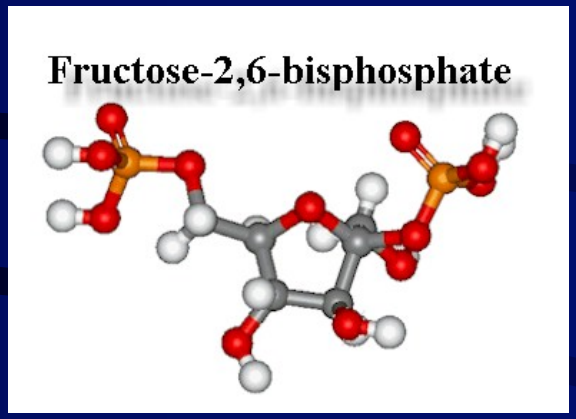
- Many carbon chains fold back upon themselves to form flexible rings.
- The arrangement of these rings can encourage various types of bonding.
- Flexible and rigid bonding arrangements are the starting point for three-dimensional shapes and functions of organic compounds.
- Single carbon bonds are flexible while double and triple bonds are rigid.

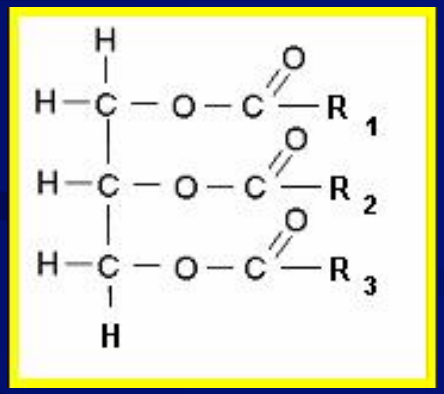
Question: How do cells use carbohydrates, fats, proteins, & nucleotides for building all the organic compounds?

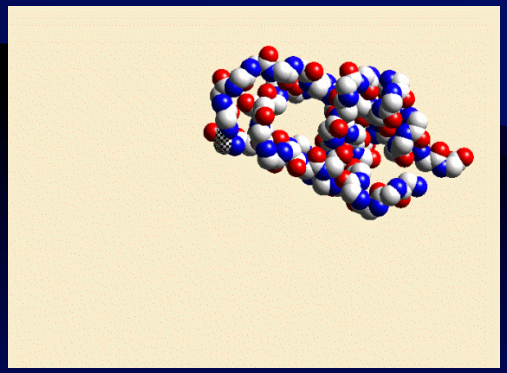
They use energy and need the help of enzymes (these help metabolic reactions happen faster).

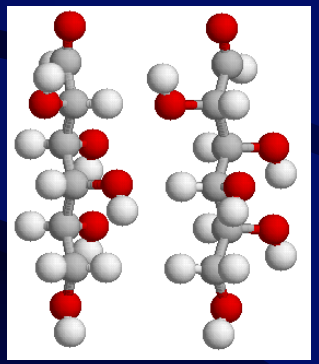
Carbon Molecules

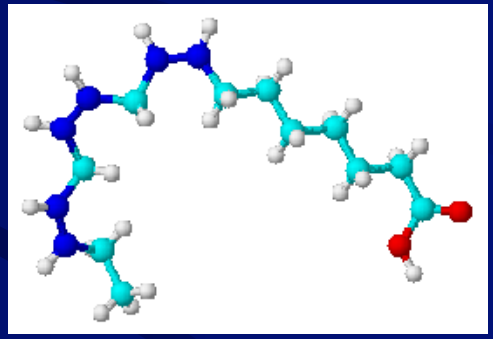












Protein

Carbohydrates

Fats

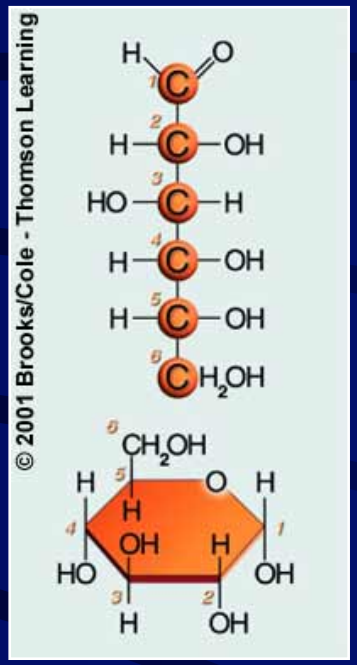
5 Classes of Chemical Reactions in Biochemistry

- ***1. Functional-group transfer- The transfer of one functional group to another molecule.***
- ***2. Electron Transfer – One or more electrons stripped from one molecule are donated to another molecule.***
- ***3. Rearrangement - The conversion of one organic compound to another.***
- ***4. Condensation – Two or more small molecules combine to form a larger molecule.***
- ***5. Cleavage -A large molecule is split into two or more smaller ones.***

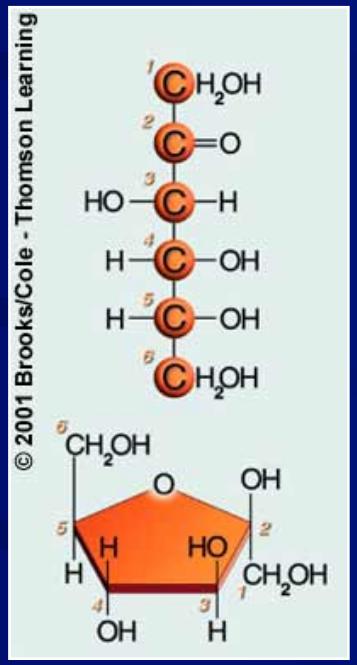
A Typical Condensation Reaction

Formation of a sucrose molecule (a disaccharide) from two simple sugars, glucose and fructose (monosaccharides).

glucose



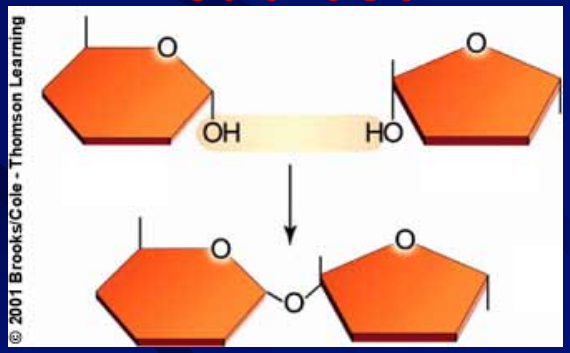
fructose



Notice that for these two molecules to be joined, a water molecule must be liberated. That's why we call this a condensation reaction!

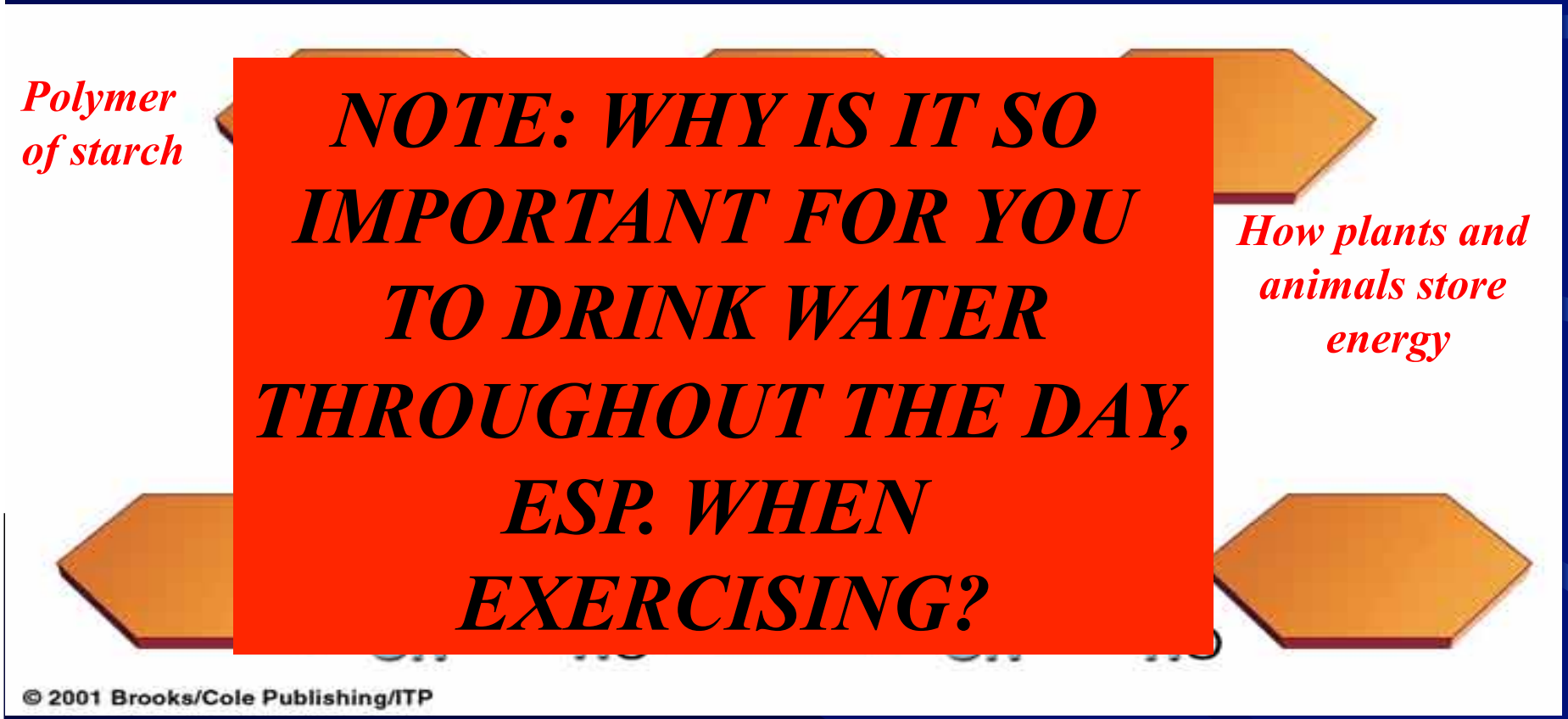
IT IS RAINING OUT!

sucrose



+ H_2O

A cleavage reaction is also known as <u>hydrolysis</u> and is the opposite of a condensation reaction!



NOTE: WHY IS IT SO IMPORTANT FOR YOU TO DRINK WATER THROUGHOUT THE DAY, ESP. WHEN EXERCISING?

Notice that in this reaction, molecules of water (hydro) are required to split (lysis) a large molecule (a polymer) into smaller ones (monomers).

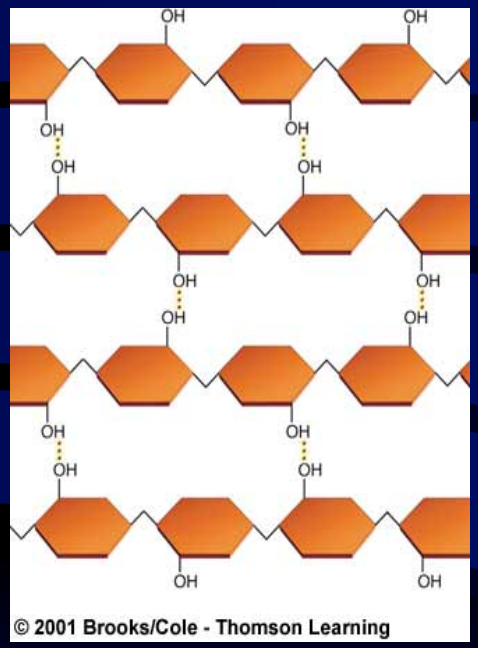
A final word on condensation and cleavage:

- Condensation - When two "monomers" bond together releasing one molecule of water during the process:
- $C_6H_{12}O_6 + C_6H_{12}O_6$ ----> $C_{12}H_{22}O_{11} + H_2O$
- Cleavage (hydrolysis) -When water molecules are used to break a large molecule (polymer) into smaller ones (monomers):
- $C_{12}H_{22}O_{11} + H_2O$ ----> $C_6H_{12}O_6 + C_6H_{12}O_6$

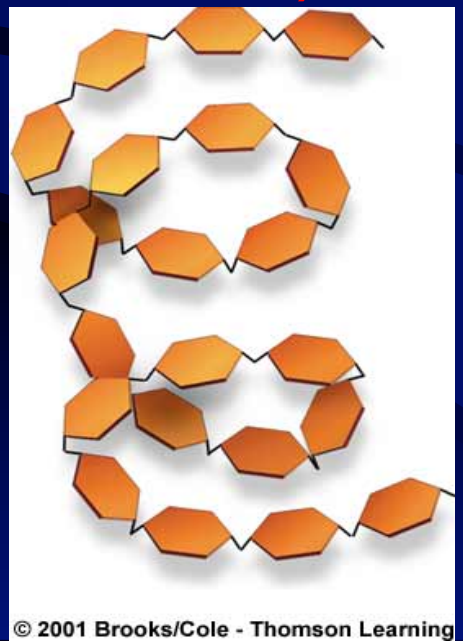
NOTE: Why when running a marathon do athletes very seldom have to urinate during the race??

The four carbon-based macromolecules found in living organisms:

cellulose (a carbohydrate)



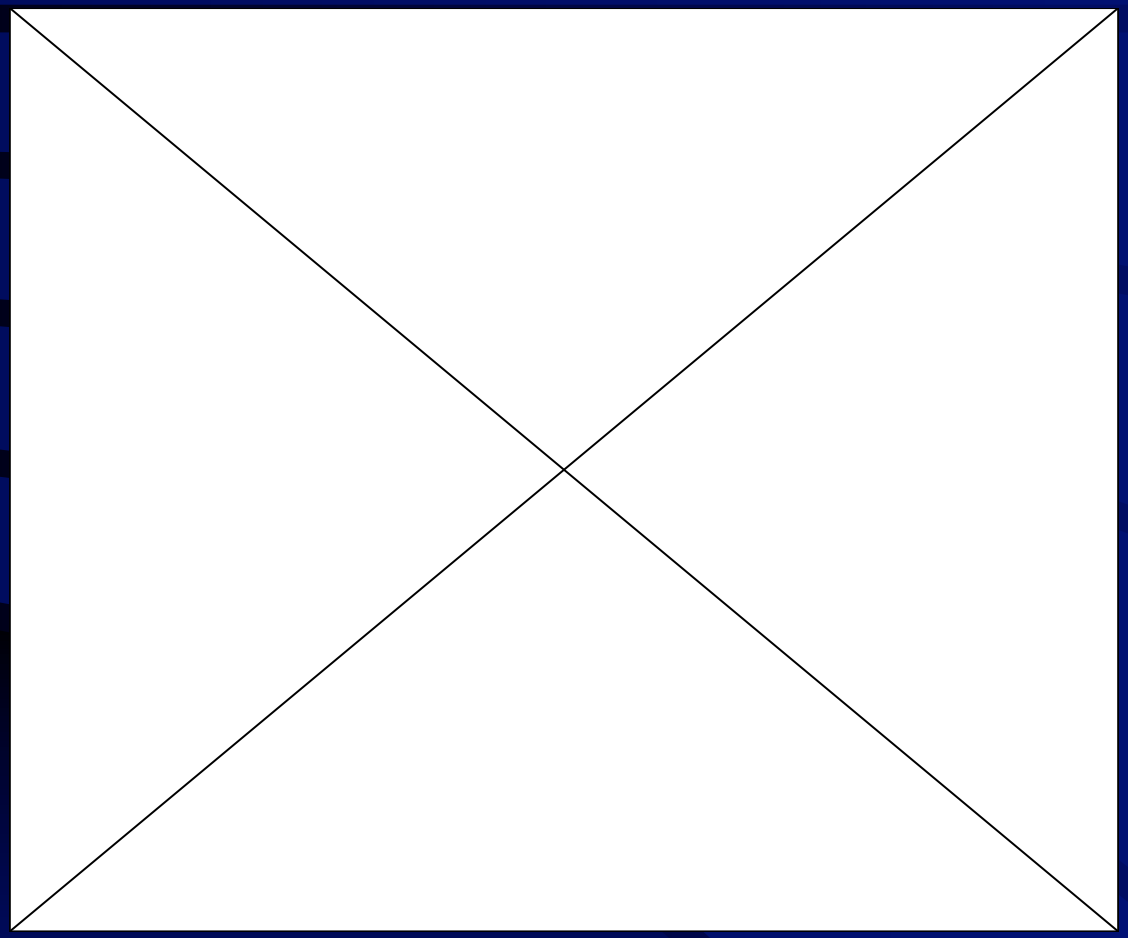
amylose (a carbohydrate / starch)



- 1. Carbohydrates- sugars and starches.
- 2. Lipids- fats, oils and waxes.
- 3. Proteins - meats, eggs, soy.
- 4. Nucleic Acids- building blocks for DNA.
  - *Ribose*
  - *Deoxyribose*

Both of these are mono saccharides

What are CARBOHYDRATES?

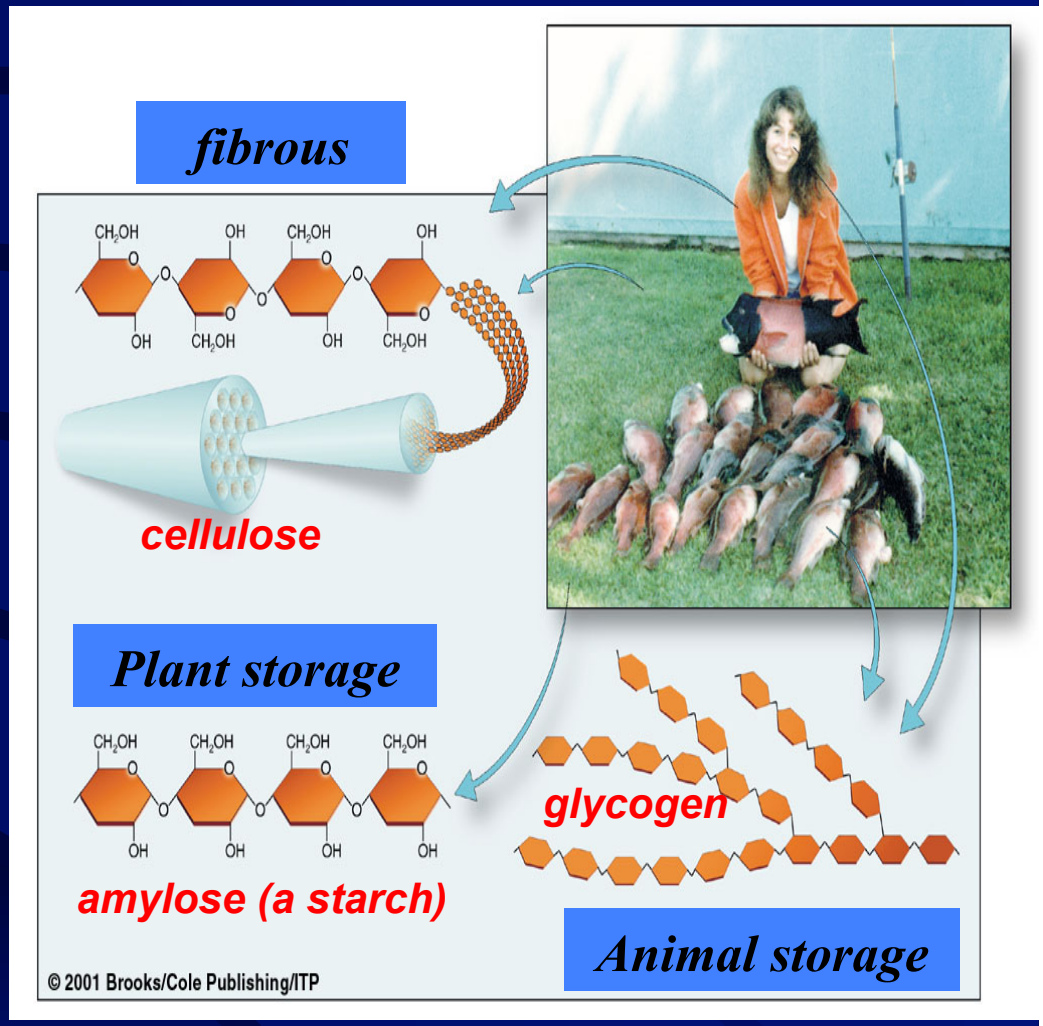


CARBOHYDRATES

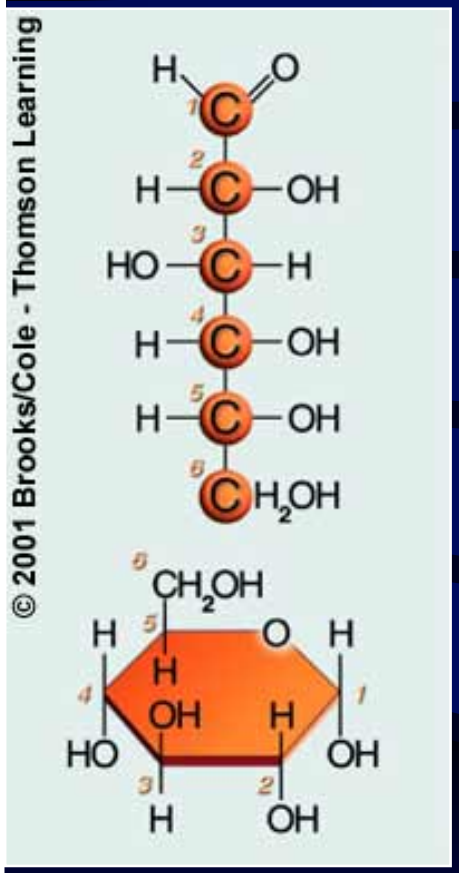
Composed of ***C, H, & O***, with a ***2:1 ratio of H to O.***

These are either simple sugars or molecules composed of two or more simple sugars.

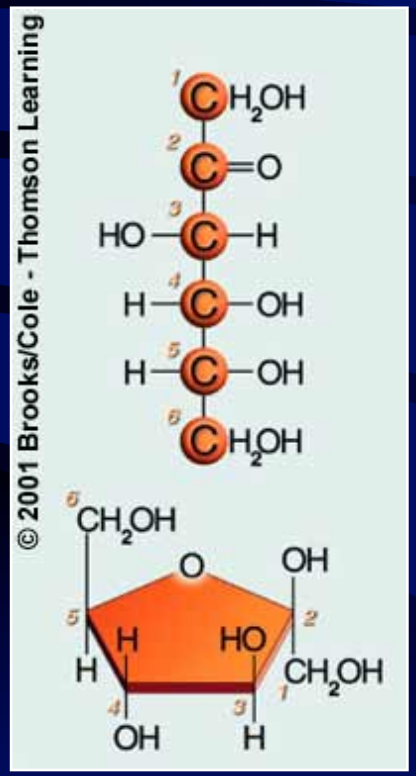
- Used by cells for ***structural materials*** or sources of ***energy***.
  - ***There are 3 types of carbohydrates:***
    - ***1. Monosaccharides***
    - ***2. Disaccharides (also known as Oligosaccharides)***
    - ***3. Polysaccharides***



Monosaccharides



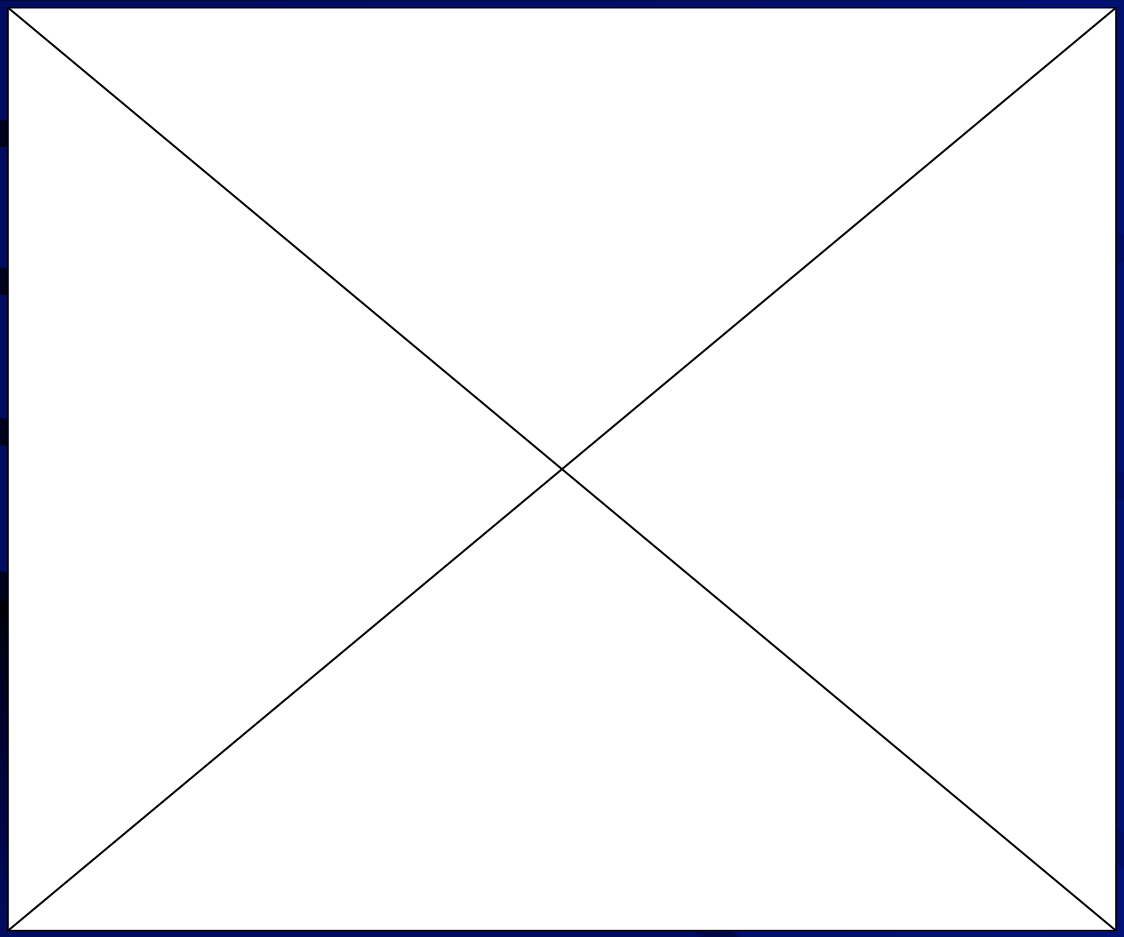
glucose



fructose

- "Saccharide" means sugar.
- "Mono" means one, so a monosaccharide is one sugar unit or ***a simple sugar***.
- Generally made of 5 or 6 carbons formed into a ring.
- Examples: glucose, fructose, ribose, deoxyribose
- How many carbons make up each molecule?
- 6 carbon atoms are called ***HEXOSES***
- How are these molecules different?
- ***The arrangement of their atoms is different***

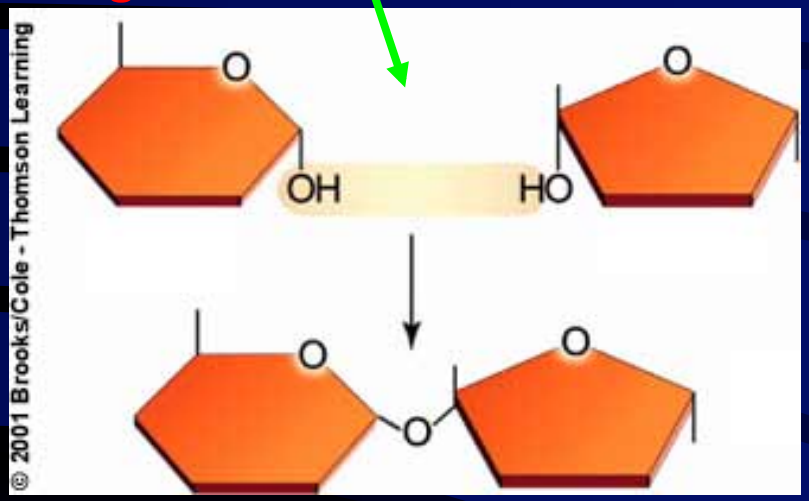
Disaccharides



Disaccharides & Oligosaccharides

NOTE: what type of reaction is this???

glucose + ***fructose***



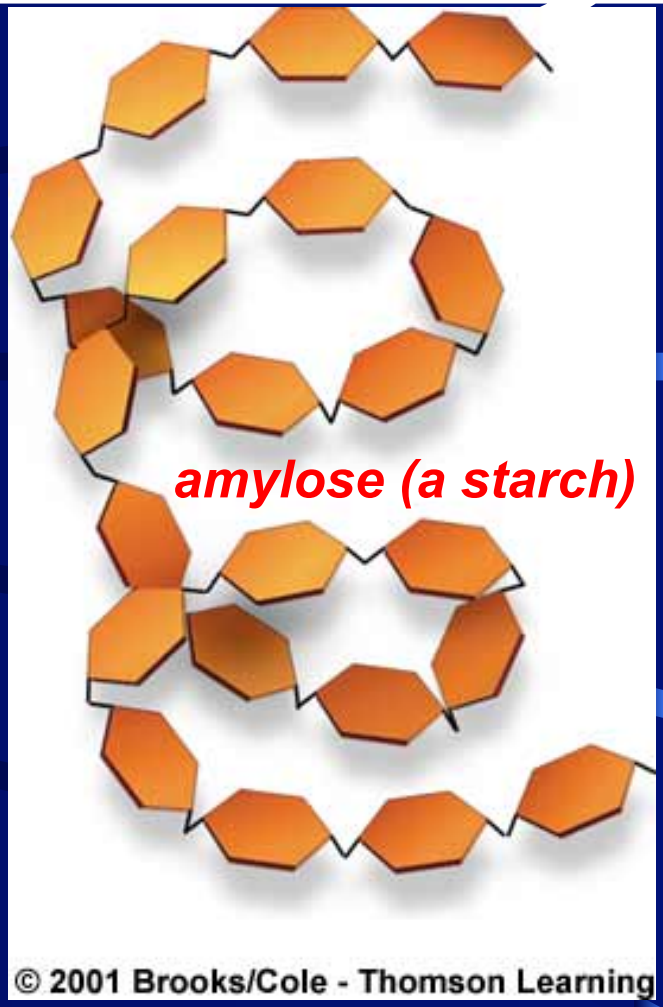
sucrose

- ***Most plentiful sugar in nature.***
- ***Why do plants transport carbo's as sucrose?***

- An oligosaccharide is a molecule made up of ***two or more*** monosaccharides bonded together.
- Another name for an oligosaccharide with only two sugar units is a disaccharide.
- Examples: ***sucrose, lactose, maltose.***

Polysaccharides

- Long chains of monosaccharides bonded together are called polysaccharides.
  - Examples: starch, glycogen, cellulose, chitin (see next slide).
- Found in cell walls as long chains that can be tightly bundled for strength.



Question: What process is used to break these starches down in monosaccharides that allow cells to use them for energy?

Hydrolysis a cleavage reaction.

In what form do animal cells store monosaccharides?

Glycogen

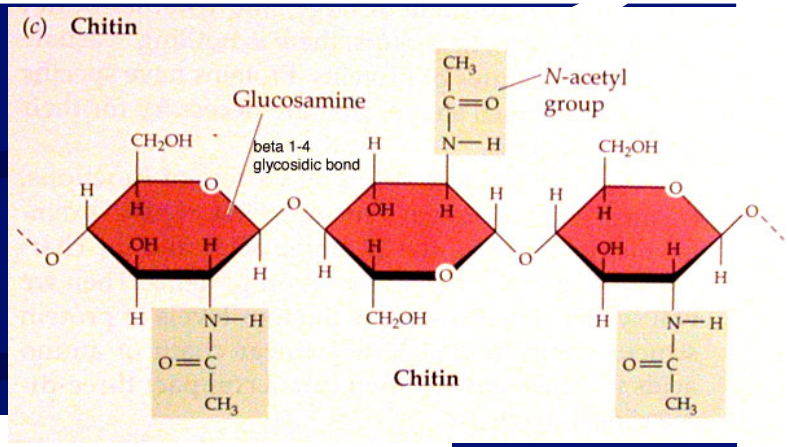
Why do athletes carbo load before strenuous exercise?

To increase energy storage

Where is glycogen stored in the body?

Muscles and liver

The main component of the external skeletons of insects, arachnids (like this tick) and crustaceans is a polysaccharide known as chitin.

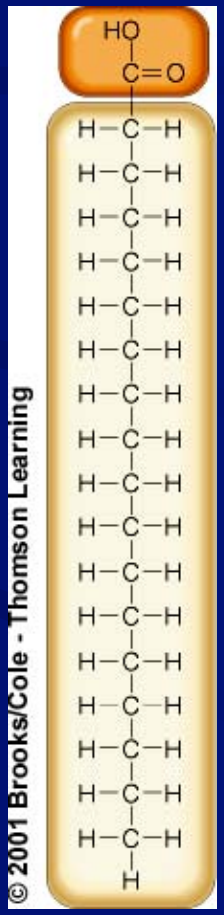


Fats

Fats: Energy-producing nutrients

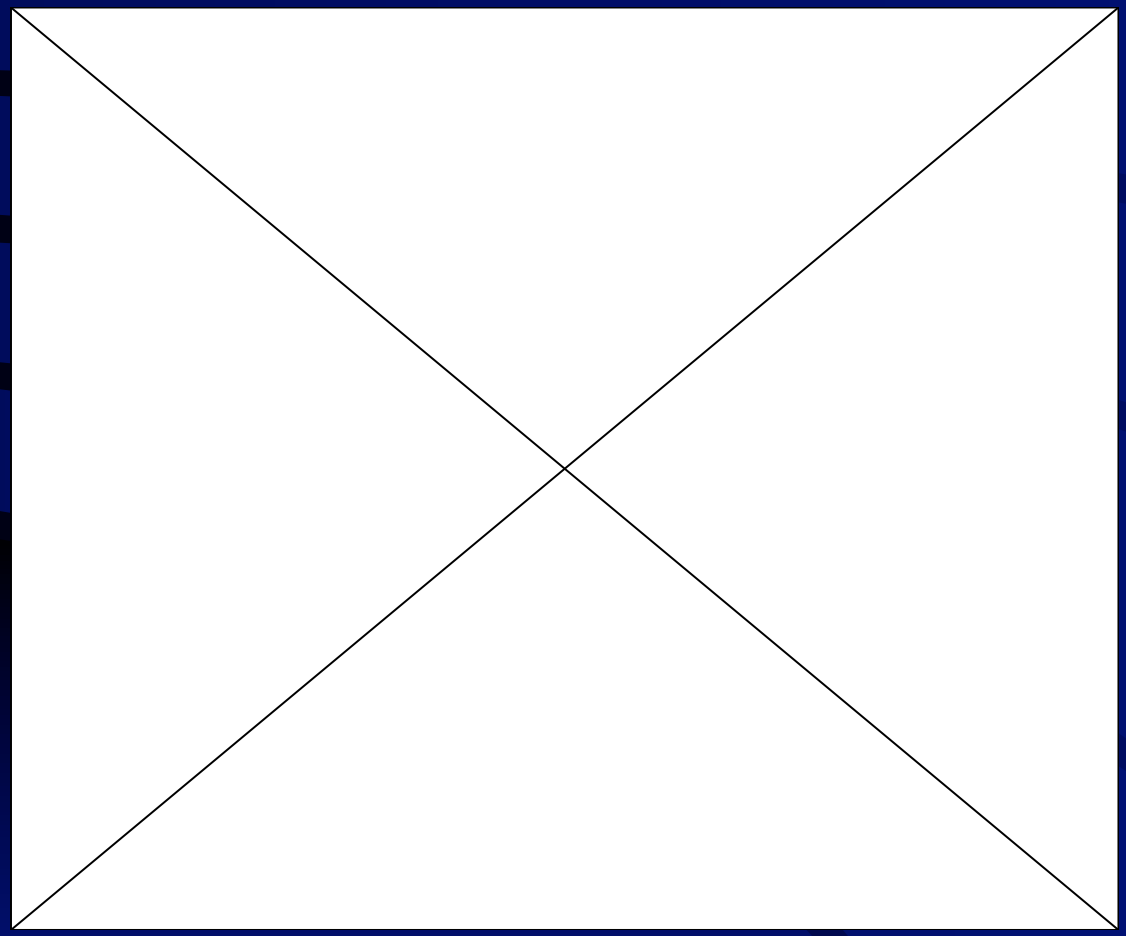
The second type of carbon-based molecules found in living things are LIPIDS.

- Lipids serve as the main reservoir of stored energy in living organisms.
- They are also a major component of cell membranes.
- The basic building block of a lipid is the "fatty acid", like the one shown here.
- Do fats dissolve in water? They do dissolve in non-polar substances, like alcohol.



stearic acid

Fatty Acids



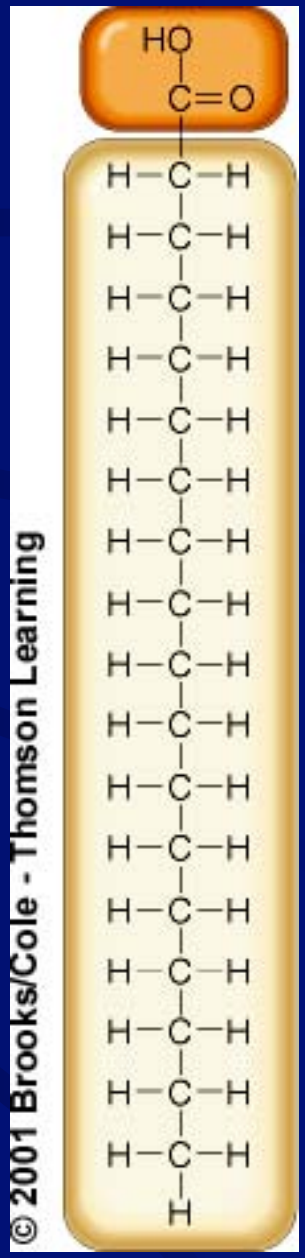
Fatty Acid Structure

- A fatty acid is a ***hydrocarbon***.
- It is made from a long chain of carbon atoms which form the "***backbone***" of the molecule; ***fatty acid tail***.
- It has a carboxyl functional group at one end.
  - ****Remember that a carboxyl group is –COOH!***

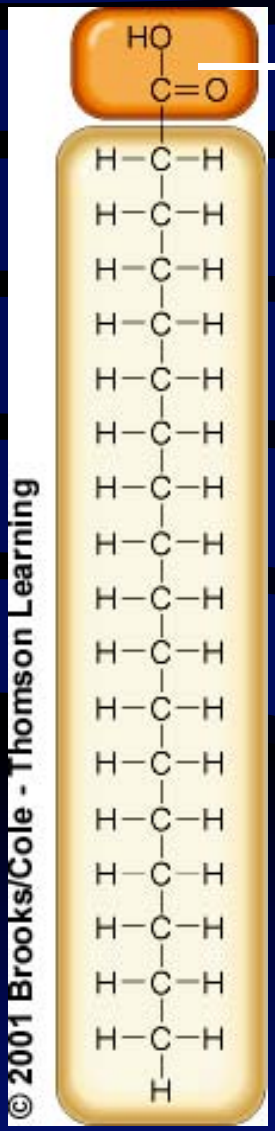
Question: Is this saturated or unsaturated fat?

See the next slide!!!!!!!

Carboxyl group



Types of fatty acids

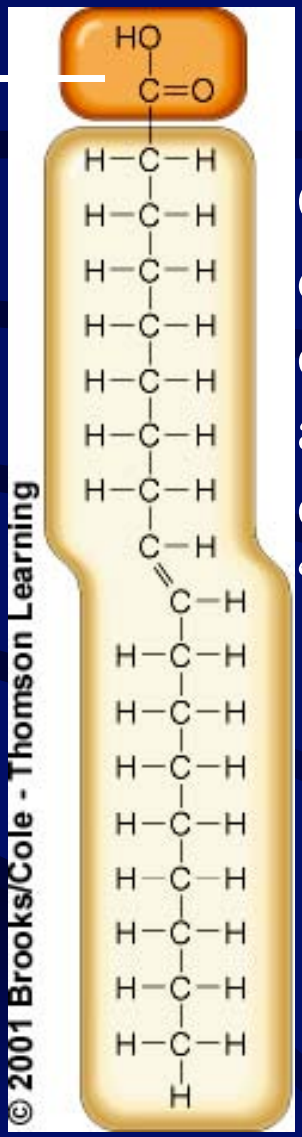


Carboxyl group

Fatty acids are stretched out, like "tails".

When a fatty acid has only single bonds, it's said to be "saturated".

Saturated

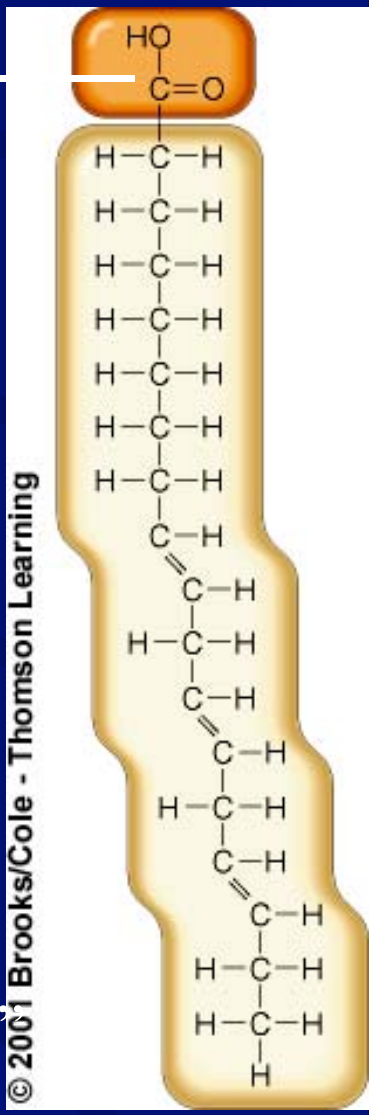


Carboxyl group

One or two double bonds causes the fatty acid to be called "unsaturated".

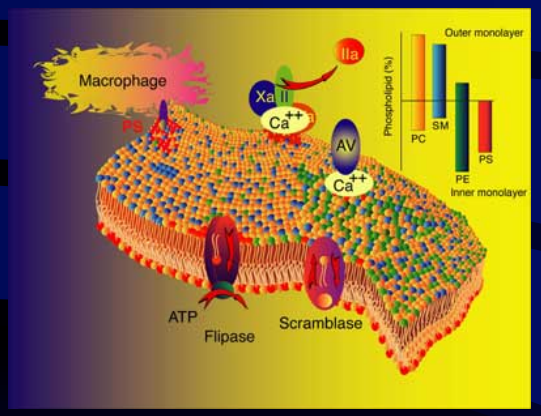
More than two double bonds makes the fatty acid "polyunsaturated".

Unsaturated



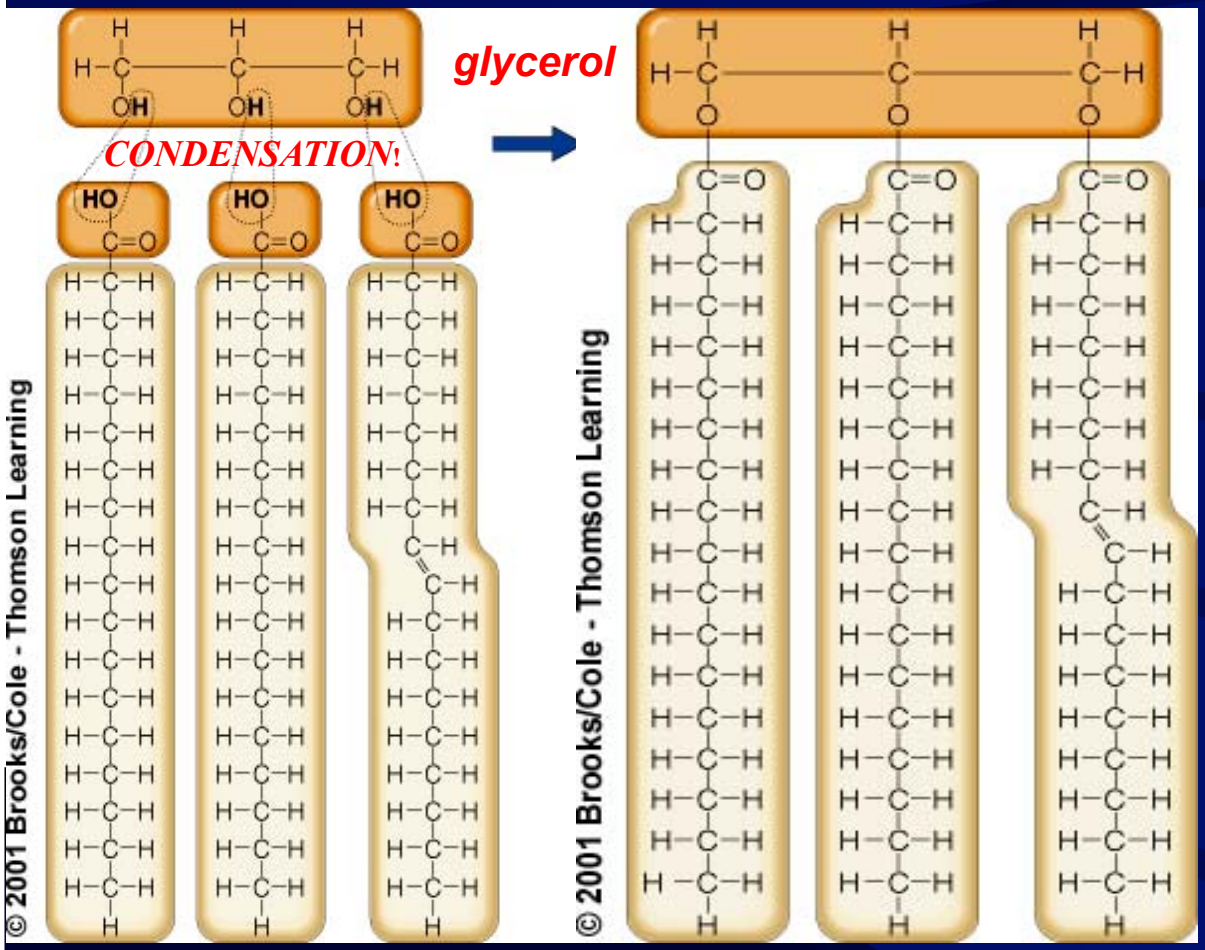
Polyunsaturated

We will look at 4 main types of lipids:



- 1. Neutral fats (or triglycerides)
- 2. Phospholipids
- 3. Waxes
- 4. Sterols
  - ***Plant sterols are also known to block cholesterol absorption sites in the human intestine thus helping to reduce cholesterol in humans.***
  - ***In humans sterols act to provide important signals and metabolic communications eg. circadium rhythms, blood clotting.***

Neutral Fats (triglycerides)



three fatty acids

triglyceride

+ $3H_2O$

- Butter, lard & oils are examples.
- Neutral fats are composed of 3 fatty acid chains bonded to a glycerol molecule.
- In order to combine these molecules, condensation must occur!

Is there an example of an unsaturated above? Why? What about the amount of hydrogen in an unsaturated fat? Which fat packs easier, saturated or un?

Any fatty acid tail with a kink.

Less due to the kink.

Saturated packs easier.

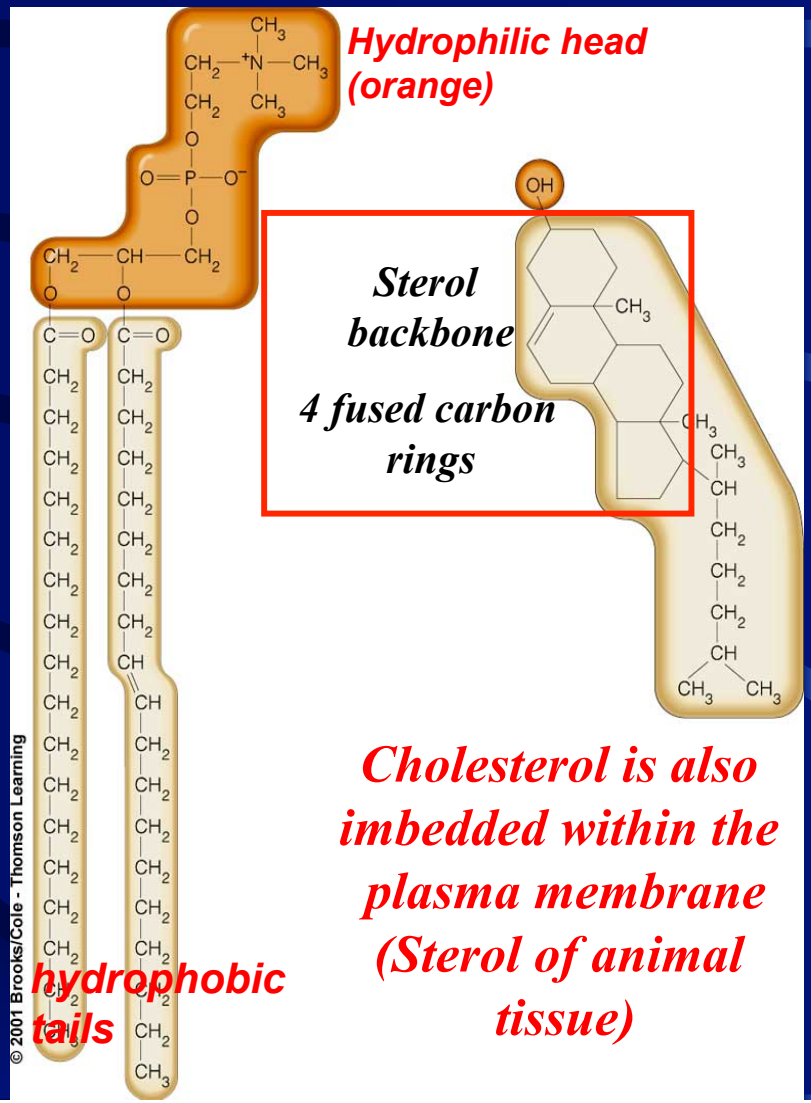
Did You Know…

- Gram for gram, triglycerides yield more than twice as much energy as carbohydrates!
- Energy is released when bonds are broken & triglycerides have far more bonds than carbs do!
- Some vertebrates (like penguins) store thick layers of triglycerides in adipose tissue for insulation!

The second type of lipid molecule is the phospholipid.

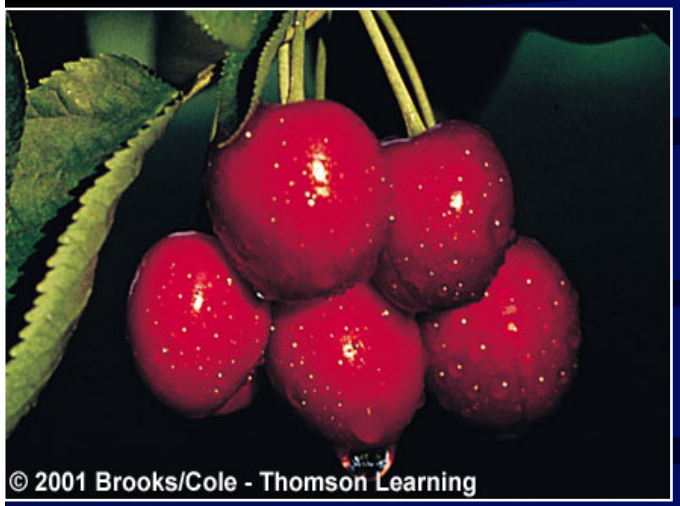
- Phospholipids are made of two fatty acid chains bonded to a glycerol molecule and a phosphate group.
- This causes the molecule to have a polar head (PO_4) and two nonpolar tails.
- This is the main component of the cell membrane.

Question: Why is the hydrophilic head so important in the plasma membrane of cells?



Cholesterol is also imbedded within the plasma membrane (Sterol of animal tissue)

The third type of lipids are waxes.



Why do these cherries have water drops on them?

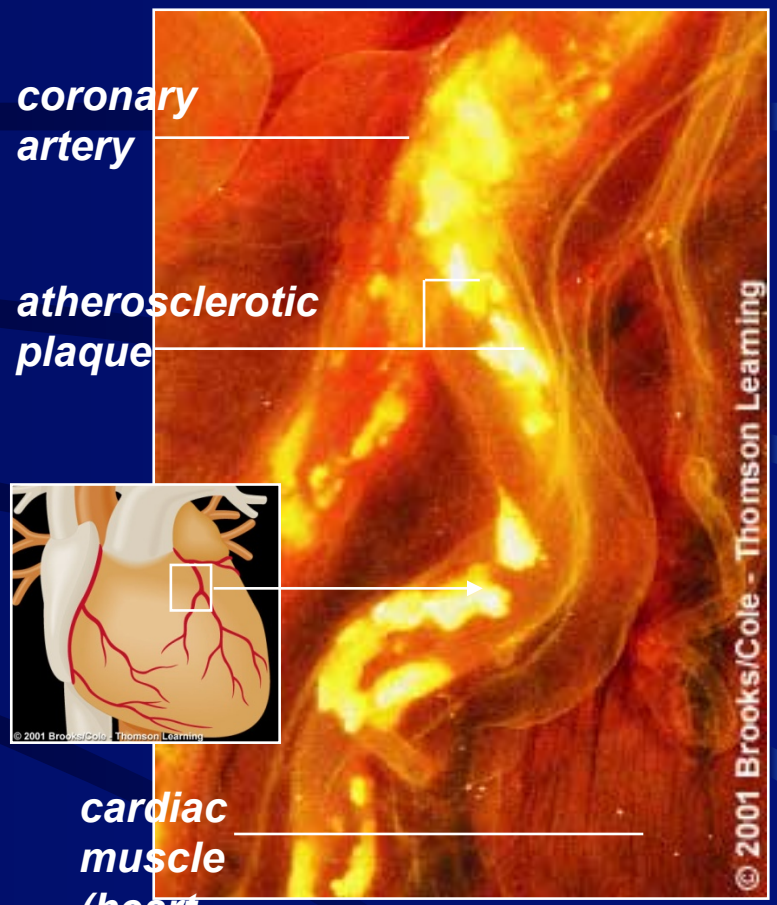
How do these ducks keep their feathers dry?

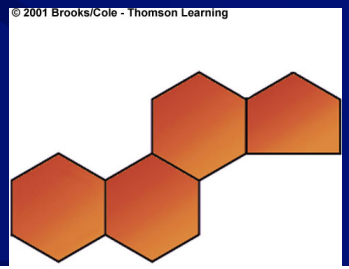
- Waxes have a long chain of fatty acids tightly packed and linked to a long-chain alcohol or carbon ring.
- Waxes repel water and are commonly secreted by vertebrates for hair and feathers and skin.
- They lubricate the skin and make it pliable.
- Waxy coverings over leaves and fruit prevent excessive water loss.

In many animals, like cockroaches, they can secrete a waxy substance through glands.

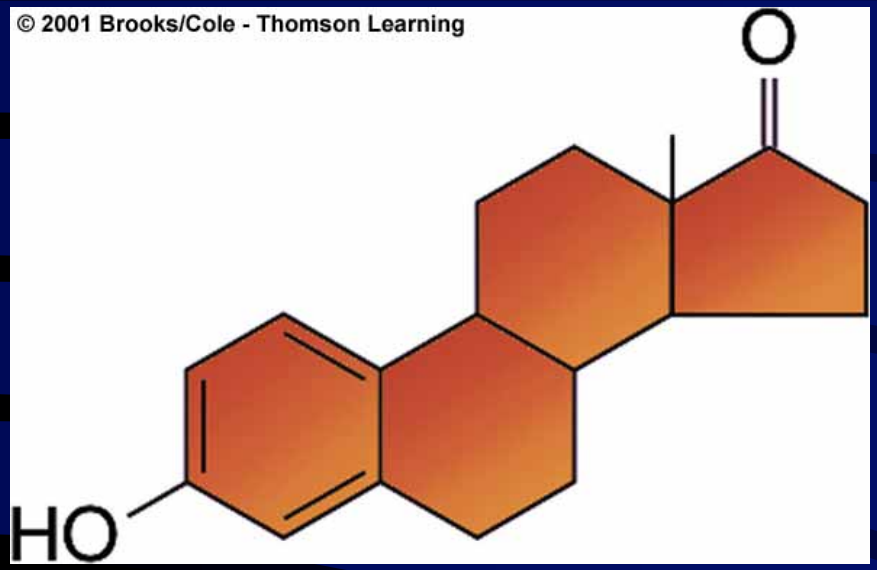
Sterols are the fourth type of lipids

- These lipids have ***no fatty acid tails***, instead having a rigid backbone of ***four-fused carbon rings.***
- Example: cholesterol (found in animal tissue.)
- Sterols are the building blocks of ***steroids*** and ***hormones*** that determine sexual traits in humans.
- Vitamin D and bile salts found in the ***liver*** come from cholesterol.





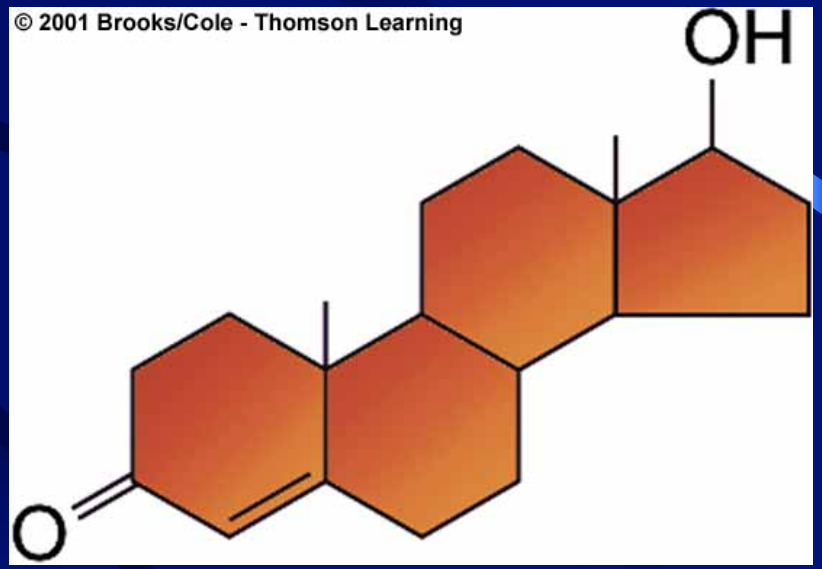
Two very common sterols



ESTROGEN

What is the identifying factor that determines that these two pictures are sterols?

TESTOSTERONE

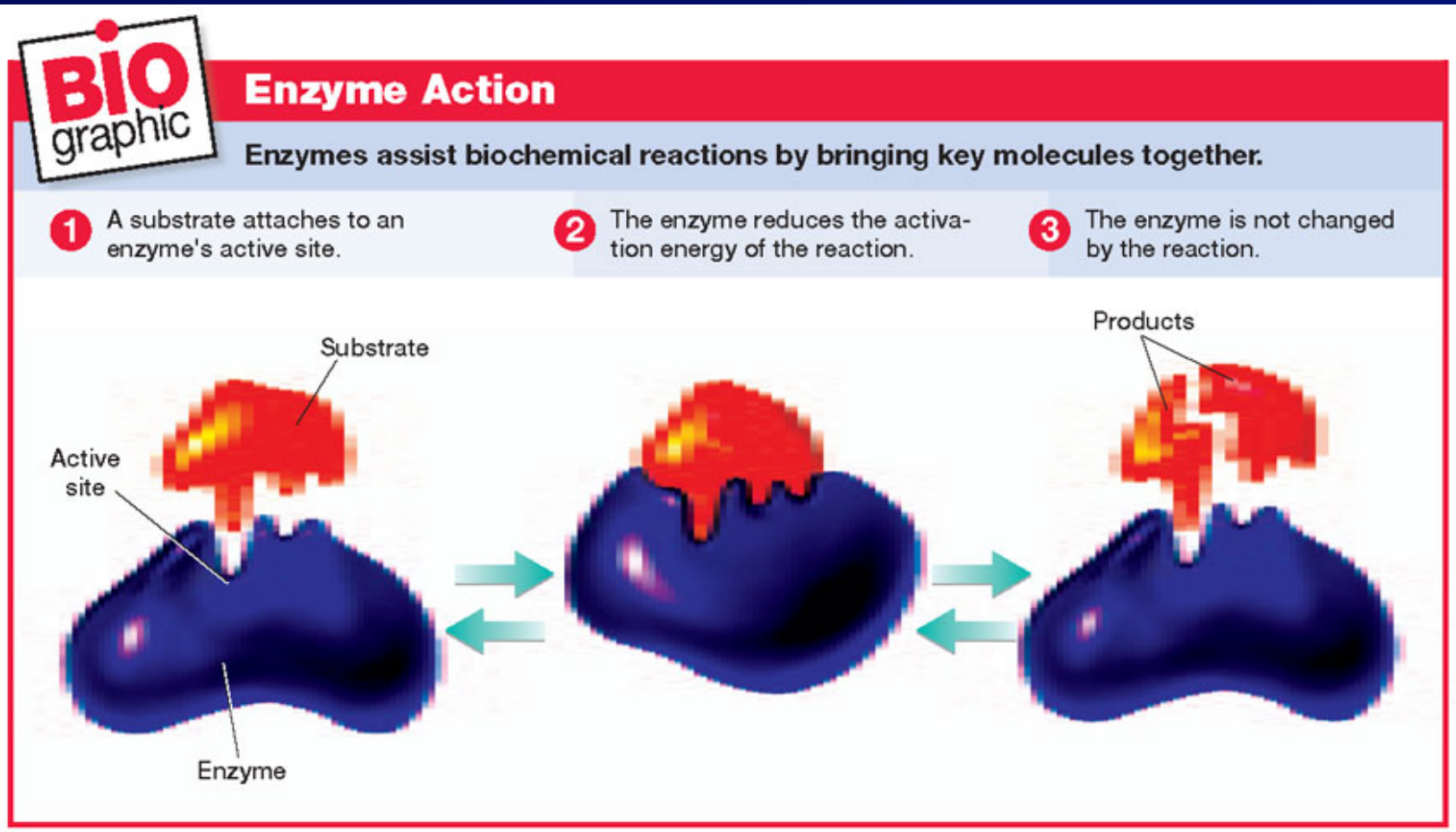


4 Carbon Rings

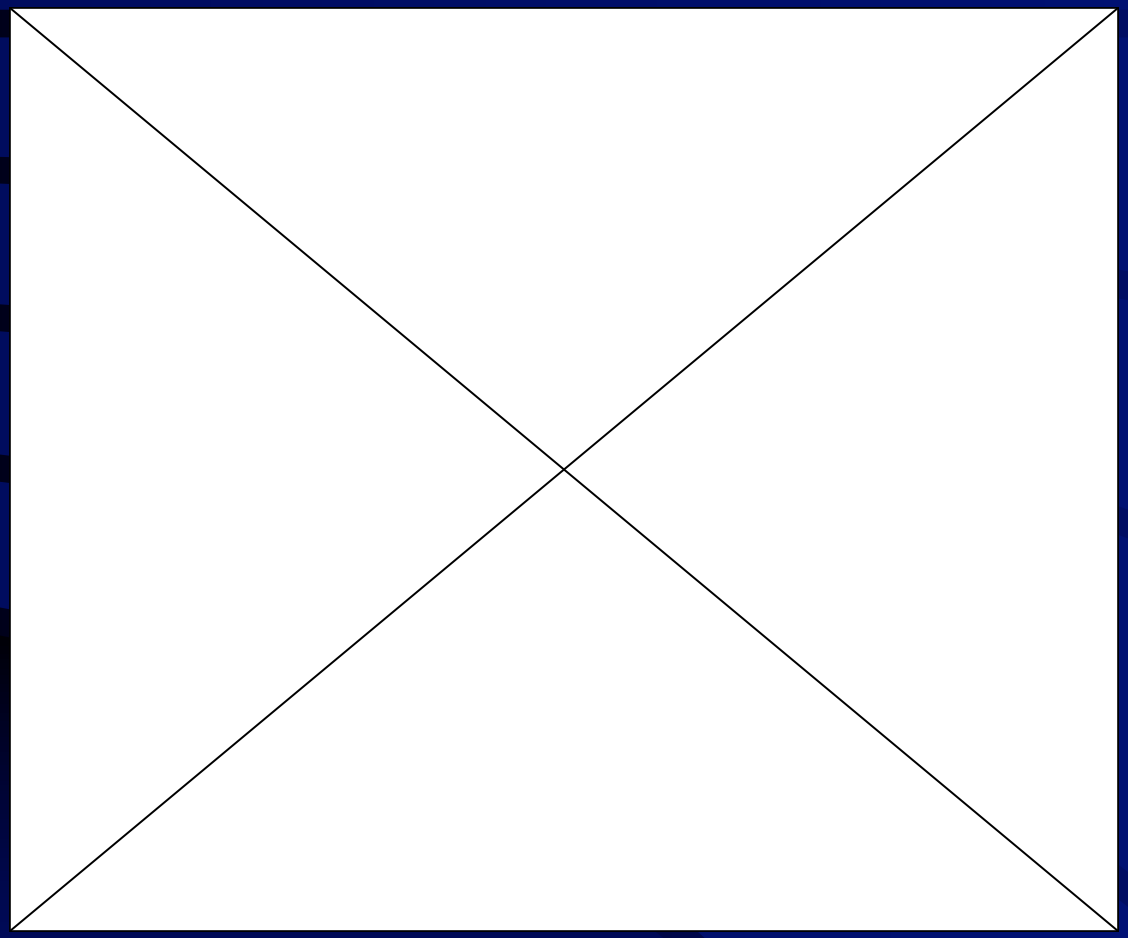
The third type of carbon-based macromolecules found in living organisms are PROTEINS.

- Proteins are the most diverse biological molecules of life!
  - ***Examples: Structural proteins (muscles, feathers, cartilage), steroids, hormones (used as signals for change in cell activity).***
  - ***Makes up enzymes, a class of proteins that make metabolic events proceed much faster than normal.***
  - ***Antibodies are made of proteins.***
  - ***Make up storage and transport agents.***
- The basic structural unit of a protein is the amino acid.
- Amino acids are monomers bonded by condensation to form long polymer chains called polypeptides (proteins).

Enzyme Activity

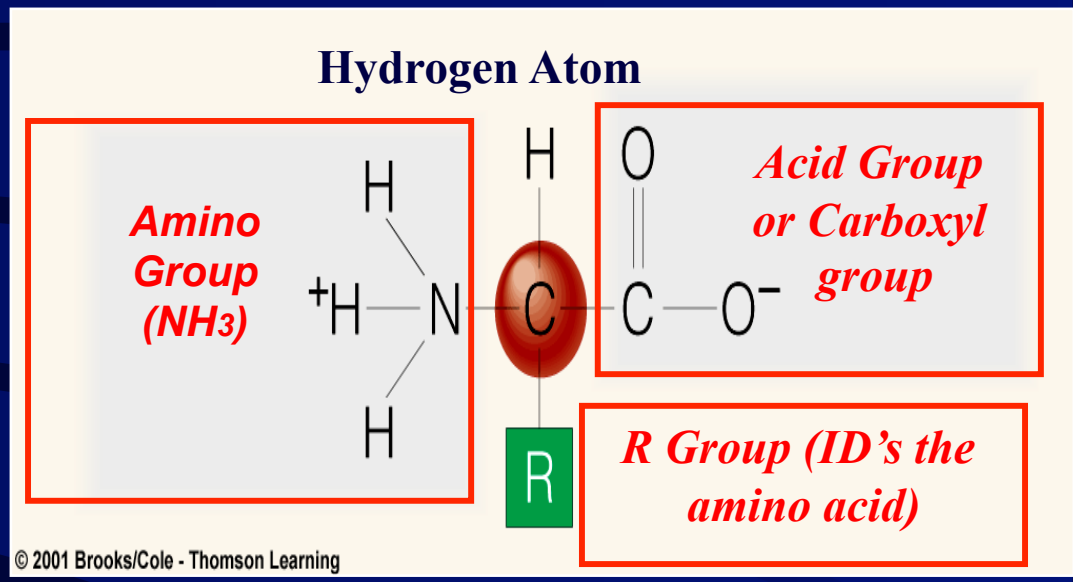


Amino Acid



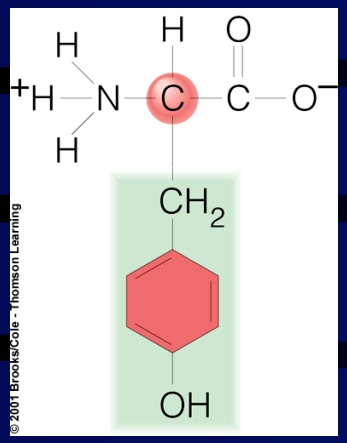
The Structure of An Amino Acid

- All amino acids are made of 4 things:
  - An amino group
  - An acid group or carboxyl group
  - A hydrogen atom
  - One or more atoms called an "R" group.

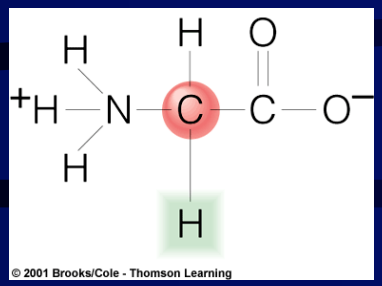


The only thing that makes one amino acid different from other amino acids is what is attached at the "R" group spot.

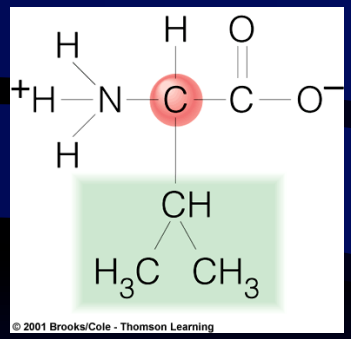
The Structure of Amino Acids



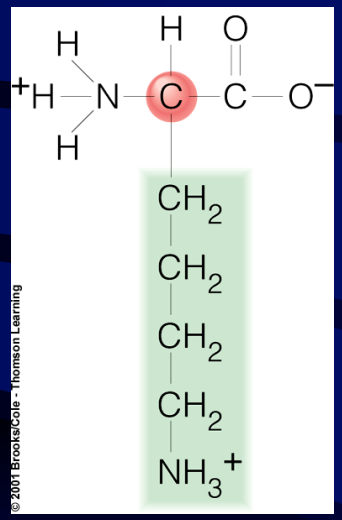
tyrosine (tyr)



glycine (gly)



valine (val)



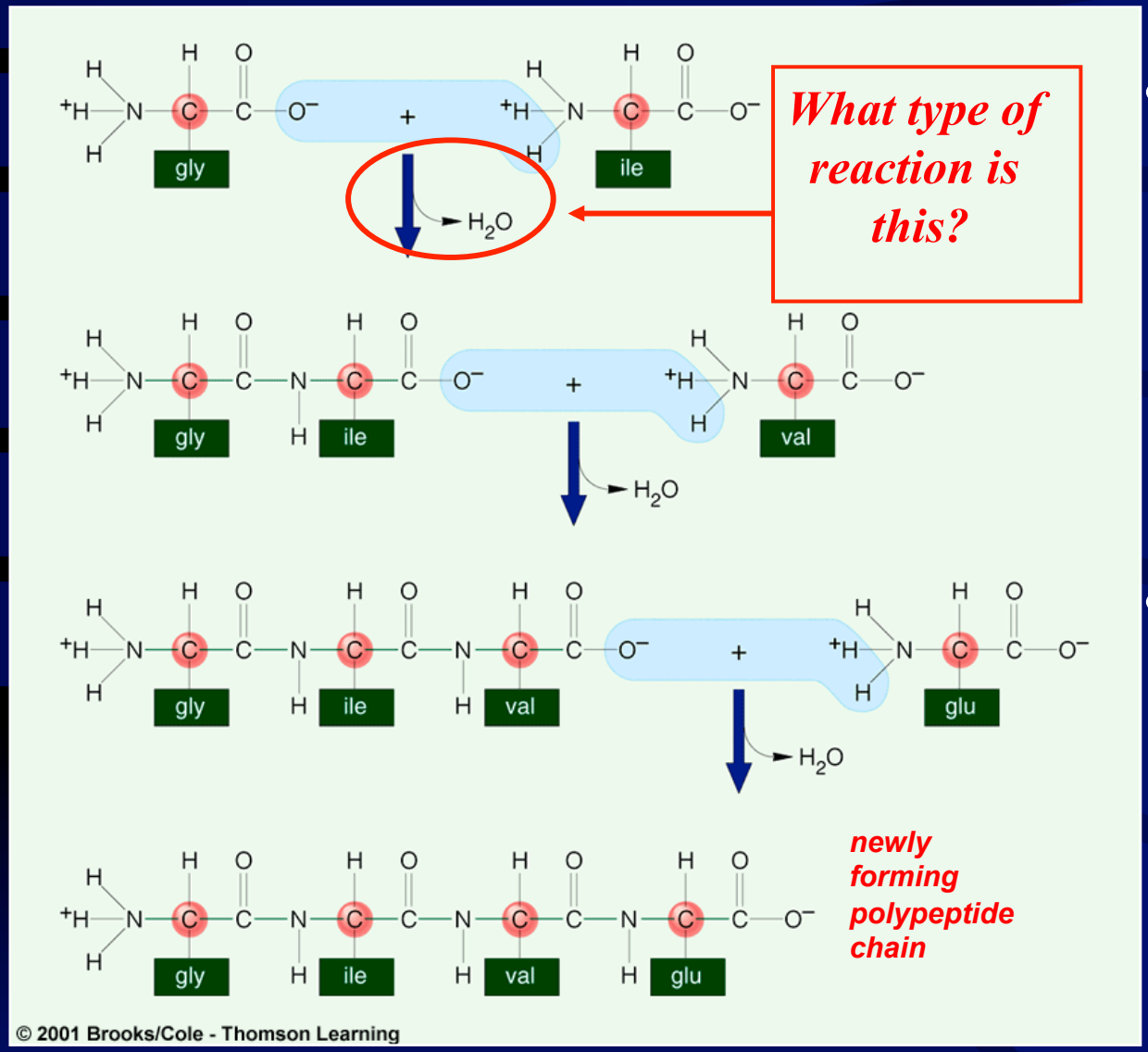
lysine (lys)

- Notice that the only difference between these amino acids is their "R" groups (in green).
- There are 20 different amino acids.
- When amino acids are linked together (by condensation), you have a protein!
- Amino acids are connected to each other by peptide bonds.
- The sequence of amino acids determines which type of protein is produced.

Question: What determines the sequence of amino acids to build the correct protein?

DNA

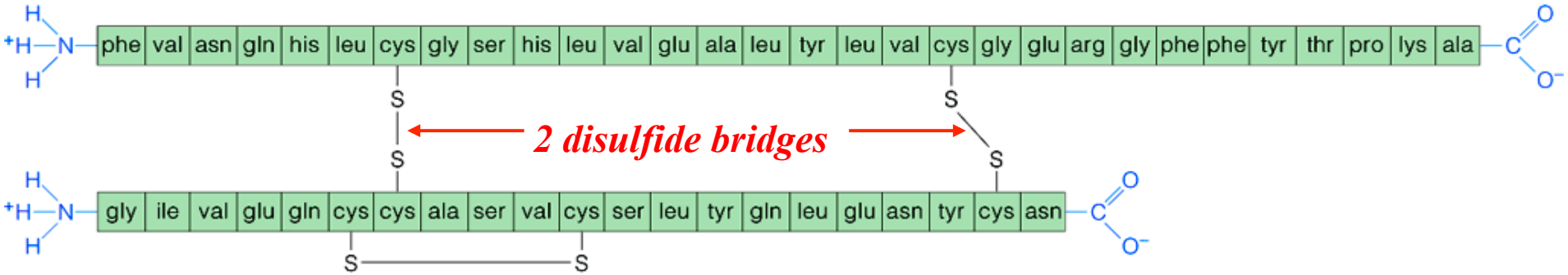
The Construction of a Protein



- Each time an amino acid is joined to the chain, a water molecule is lost (condensation)
- Three or more amino acids in a chain create a "polypeptide"

PROTEIN ORGANIZATION:
http://www.stolaf.edu/people/giannini/flashanimat/proteins/protein%20structure.swf

Three-Dimensional Protein Structure



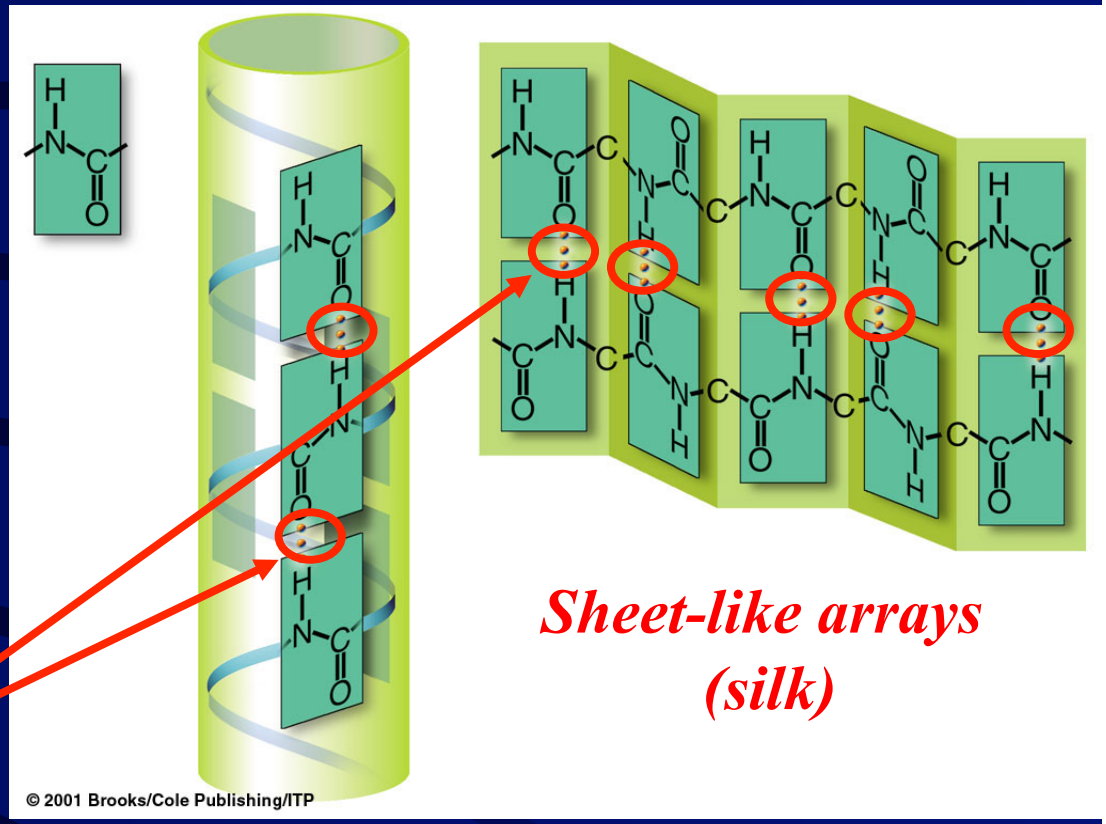
- ***A chain of amino acids represents the primary structure of a protein.***
- ***What is insulin?***
  - ***Pancreatic hormone that lowers glucose levels in the blood by causing cells to take up glucose.***
  - ***Promotes protein & fat synthesis***
  - ***Inhibits protein conversion to glucose.***
  - ***What happens if there is not insulin production?***
    - ***Cells starve even though blood glucose is high.***
    - ***The body will breakdown fats and produce ketones.***

*How many water molecules were liberated by condensation to produce the shorter polypeptide strand?

Answer: 20 (1 water molecule between each amino acid that is bonded)

Secondary Protein Structure

- When amino acids group together to form coils or sheets, the secondary structure of proteins is demonstrated.
- The tiny dots in this picture represent weak hydrogen bonds.

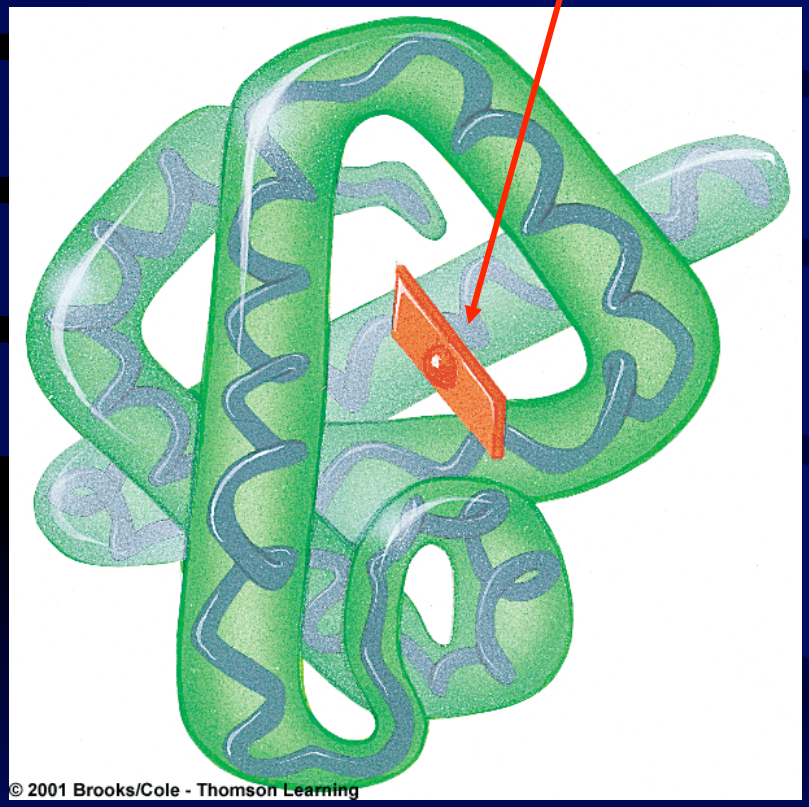


Sheet-like arrays (silk)

Helical coil

Note: HYDROGEN bonds between the amino acids of the Primary Structure allow 'bending' to permit a Secondary Structure.

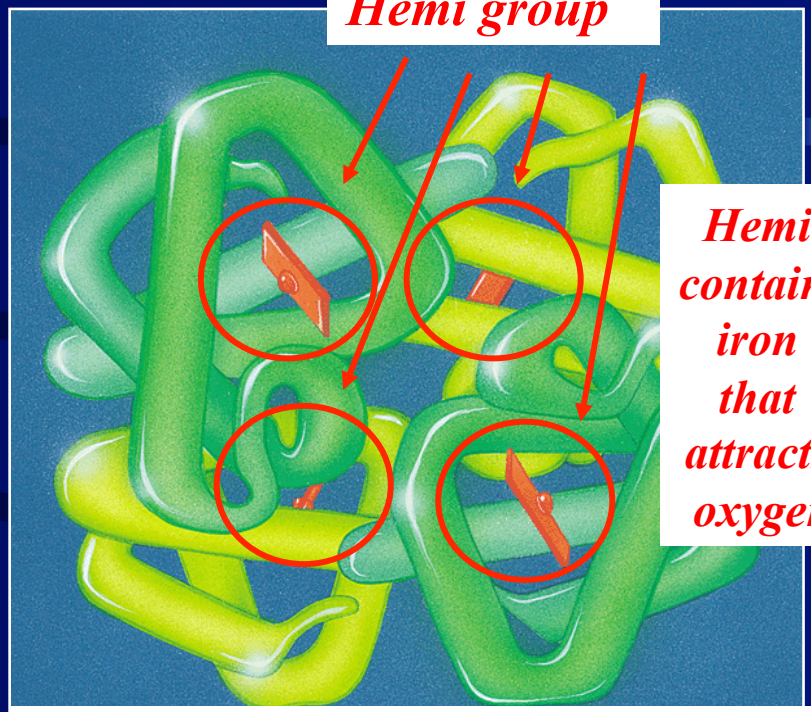
Tertiary Protein Structure



- When the "R" groups of a coiled polypeptide interact with one another to form a ***twisted or folded shape***, the protein shows its ***tertiary*** structure, as shown here.

Quaternary Protein Structure

- When two or more polypeptide chains are incorporated into a protein, the ***quaternary*** structure is demonstrated.
- 2 types of Quaternary Protein Structures:
  - ***Globular***
  - ***fibrous***
- Examples of quaternary proteins: ***hemoglobin*** (in ***blood***, seen here), ***keratin*** (in ***hair*** and ***fur***), ***collagen*** (***skin, bone, tendons, cartilage, blood vessels, heart valves, corneas***).

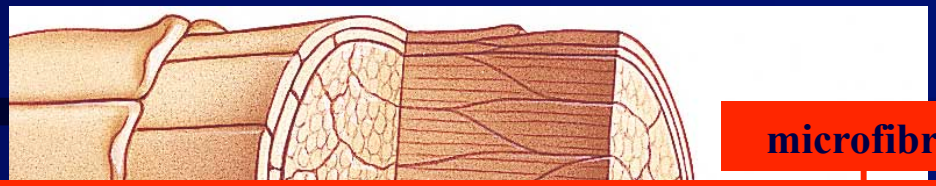


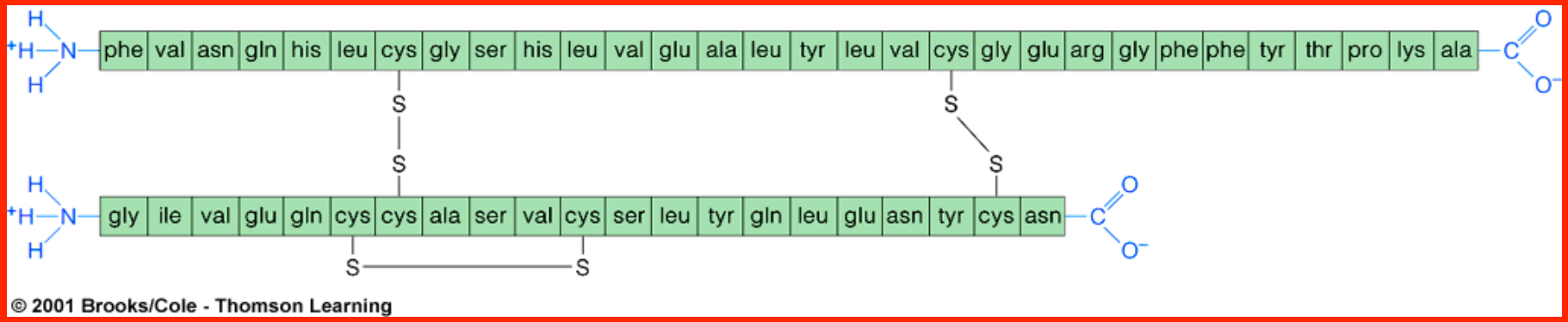
Denaturation: the breaking of weak protein bonds or any large molecule which disrupts its 3D shape. (caused by pH & temperature)

*Did you know that collagen is the most common animal protein?

Hair – A Closer Look

Hair is developed from modified skin cells

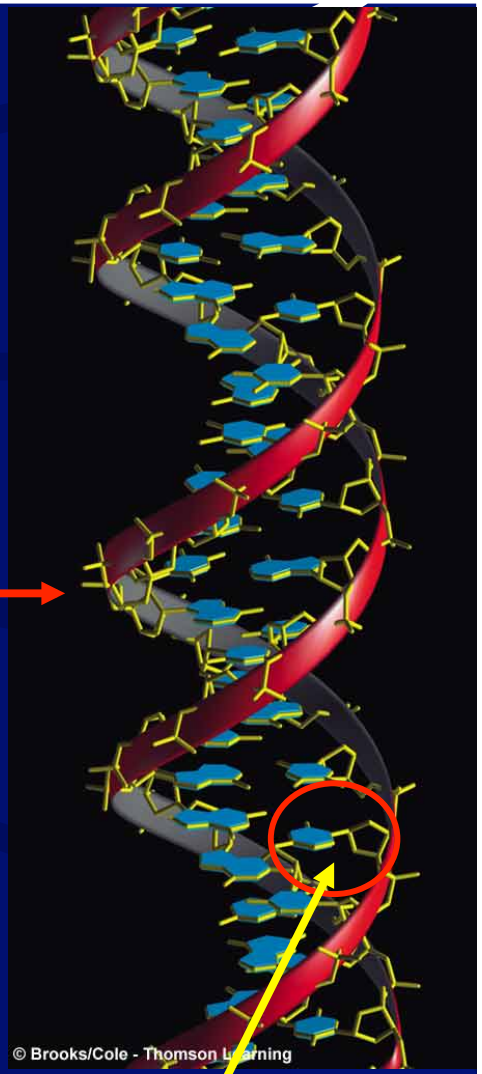


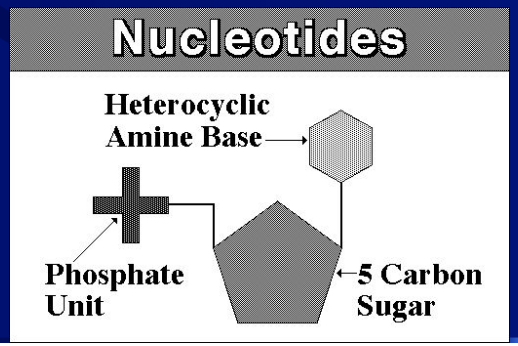


Hair is wrapped around curlers and their polypeptide chains are held into new positions while chemicals cause disulfide bridges to be broken while new bridges are formed between 2 keratin chains.

The fourth type of carbon-based molecules found in living organisms are ***NUCLEIC ACIDS***.

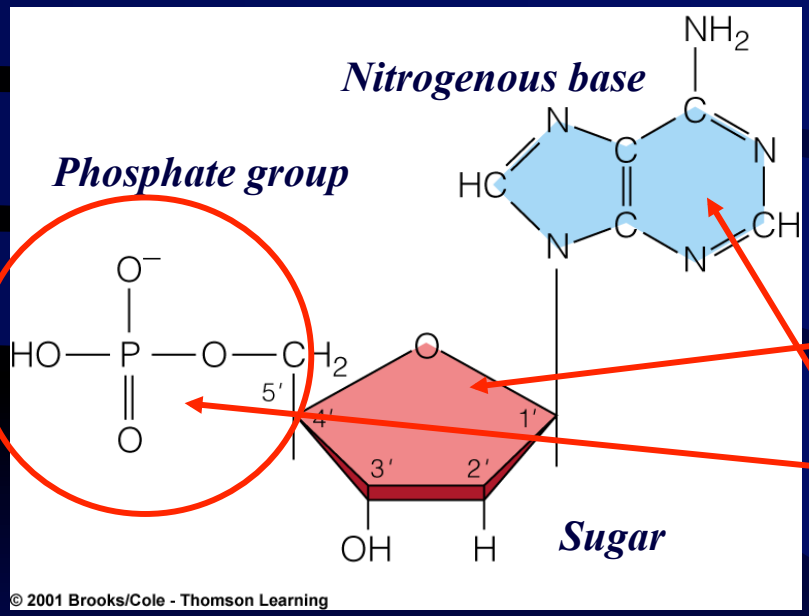
- Play major roles in metabolism.
- Two important nucleic acids are:
  - DNA (deoxyribonucleic acid)
  - RNA (ribonucleic acid)
- ***RNA*** molecules are long and ***single*** stranded.
- DNA molecules are long, double stranded and ***helical*** in shape.
- ***Nucleotides*** are the building blocks of nucleic acids.





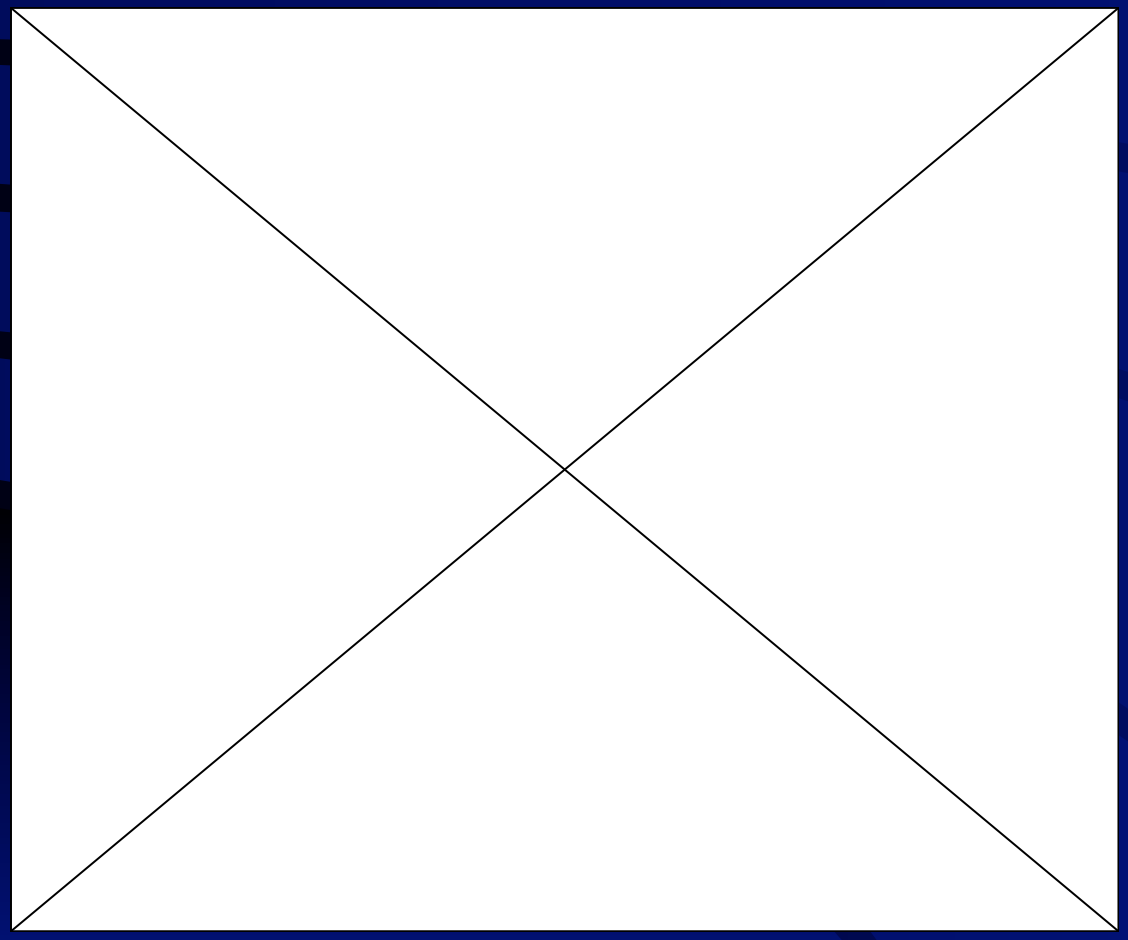
The Structure of a Nucleotide

A nucleotide



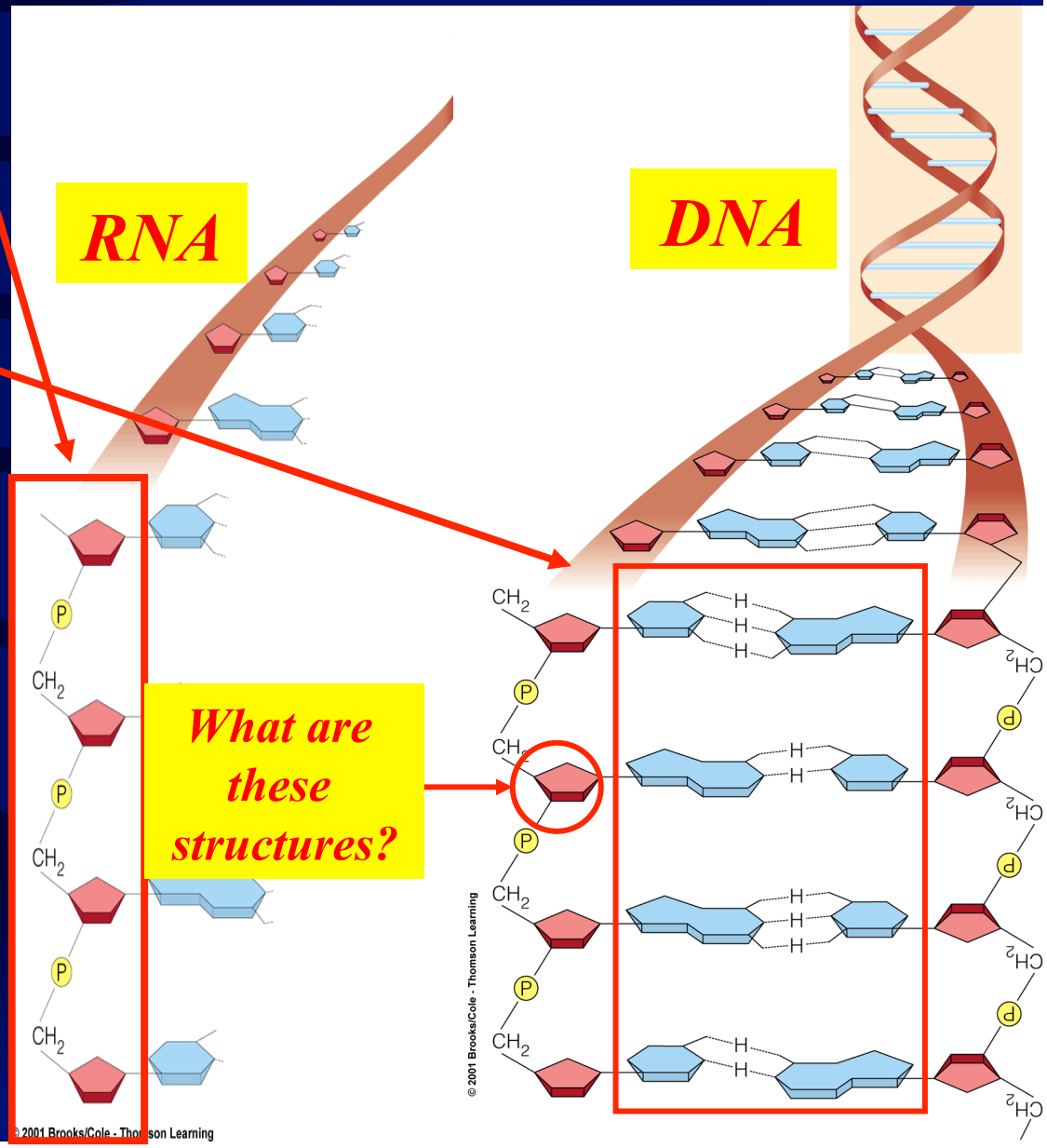
- Nucleotides are the ***monomers*** that make up complex nucleic acid ***polymers*** like DNA and RNA.
- ***Nucleotides are made of three things:***
  - A ***ribose*** or ***deoxyribose sugar*** (in orange)…
  - A ***phosphate group*** (in white) and…
  - A ***nitrogenous base*** (in blue).

Nucleic Acids



DNA and RNA

- *These two molecules are essential for survival!*
- ***Sugars & phosphates** form the "backbone" of both molecules.*
- ***Nitrogenous bases** form the "rungs" of the DNA ladder.*
- *DNA **forms genes and chromosomes** which direct the entire chemistry of the cell.*
- *RNA is produced from DNA and **directs the production of proteins within the cell.***
- *Used in coenzymes; enzyme helpers by transferring H atoms and electrons.*



RNA Molecule