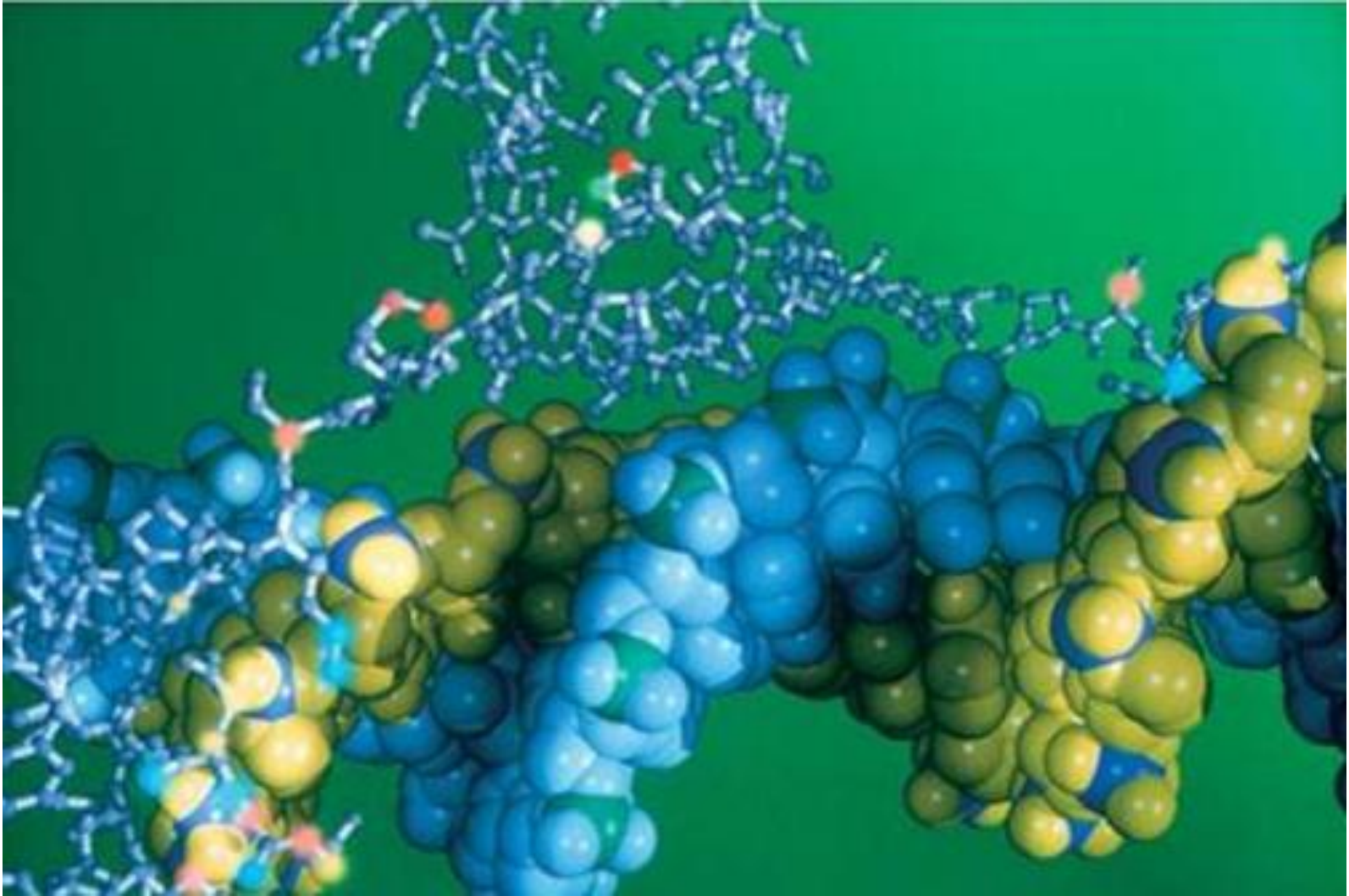


The Chemical Building Blocks of Life

Chapter 3



- Biological Molecules - Macromolecules
 - Carbohydrates
 - Transport and Energy Storage
 - Nucleic Acids - INFORMATIONAL
 - DNA and RNA (and ATP)
 - Proteins
 - Structure, functions -and Denaturation
 - Lipids - Hydrophobic
 - Fats and Phospholipids

Carbon – a party animal



- carbon bonded to other carbon molecules, or other types of atoms

- Hydrocarbons consist of carbon and hydrogen.

- Covalent bonds store considerable energy.

Why so versatile?

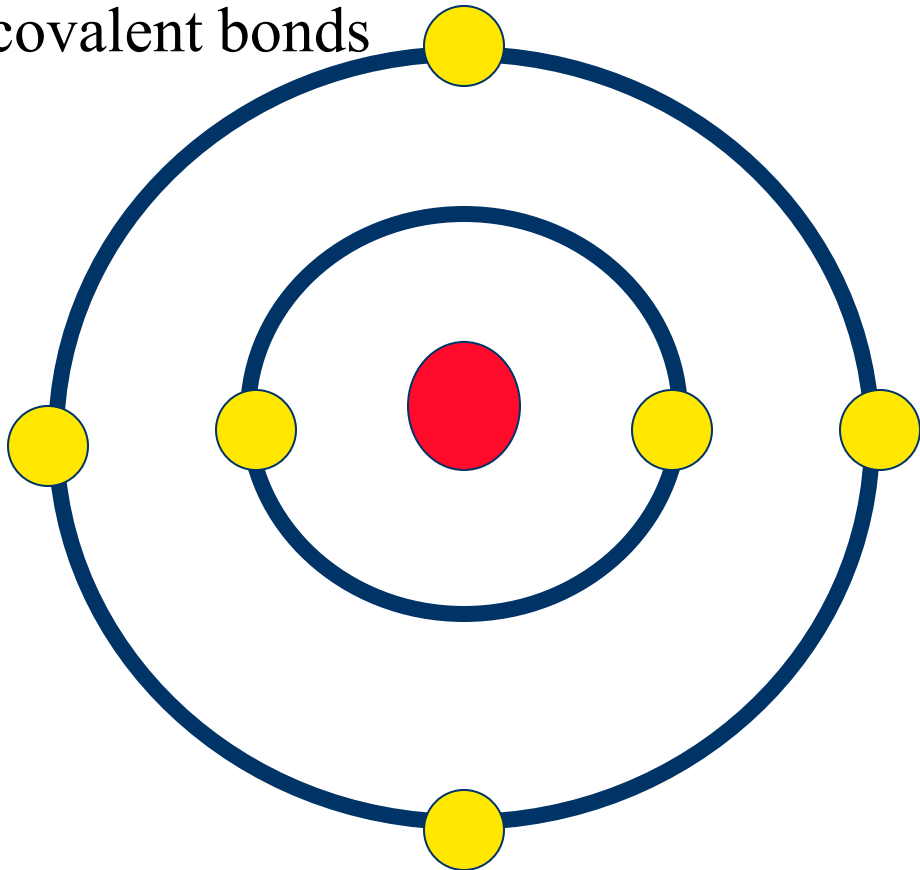
- 6 electrons, 2 in 1st -4 in 2nd

Why so stable?

shares electrons - four covalent bonds

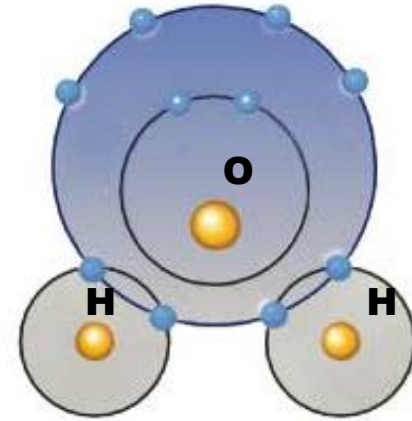
tetravalence

large
complex
stable

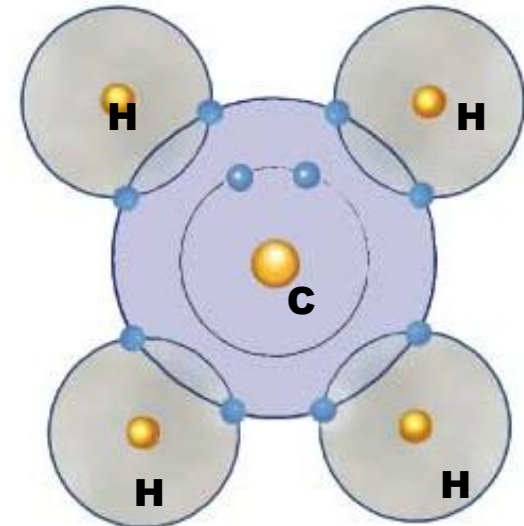


Polar versus Nonpolar Covalent Bonds

- Water is polar
- Methane, CH_4 , is nonpolar
- carbon-
charges are symmetric



•• electrons



silicon based life forms?
WHY???



element - substance that cannot be broken down to other substances by chemical reactions.

92

Fig. 2.8

1 H																	2 He
3 Li	4 Be															9 F	10 Ne
11 Na	12 Mg															17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104	105	106	107	108	109	110								
(Lanthanide series)		58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu		
(Actinide series)		90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr		

- Each element - unique atoms

Biological Molecules

- Functional groups
 - specific groups of atoms attached to carbon backbones
 - retain definite chemical properties

—specific groups of atoms attached to carbon backbones

Act as units

Specific chemical properties

Functional Group	Structural Formula	Example
Hydroxyl	—OH	$\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{OH} \end{array}$ Ethanol
Carbonyl	$\begin{array}{c} \text{C} \\ \\ \text{O} \end{array}$	$\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}=\text{O} \\ \quad \\ \text{H} \quad \text{O}-\text{H} \end{array}$ Acetaldehyde
Carboxyl	$\begin{array}{c} \text{O} \\ // \\ \text{C} \\ \backslash \\ \text{OH} \end{array}$	$\begin{array}{c} \text{H} \quad \text{O} \\ \quad // \\ \text{H}-\text{C}-\text{C} \\ \quad \backslash \\ \text{H} \quad \text{OH} \end{array}$ Acetic acid
Amino	$\begin{array}{c} \text{H} \\ \\ \text{N} \\ \\ \text{H} \end{array}$	$\begin{array}{c} \text{O} \quad \text{H} \\ \quad \\ \text{HO}-\text{C}-\text{C}-\text{N}-\text{H} \\ \quad \\ \text{CH}_3 \quad \text{H} \end{array}$ Alanine
Sulfhydryl	—S—H	$\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{HO}-\text{C}-\text{C}-\text{S}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array}$ β-mercaptoethanol
Phosphate	$\begin{array}{c} \text{O}^- \\ \\ \text{O}-\text{P}-\text{O}^- \\ \\ \text{O} \end{array}$	$\begin{array}{c} \text{O} \quad \text{O} \quad \text{H} \quad \text{O} \\ \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{O}-\text{P}-\text{O}^- \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{O}^- \end{array}$ Glycerol phosphate
Methyl	$\begin{array}{c} \text{H} \\ \\ \text{C}-\text{H} \\ \\ \text{H} \end{array}$	$\begin{array}{c} \text{O} \quad \text{O} \quad \text{H} \\ \quad \quad \\ \text{O}^- - \text{C} - \text{C} - \text{C} - \text{H} \\ \\ \text{H} \end{array}$ Pyruvate

always acidic

always basic

- **1000's of macromolecules**

Macromolecules.

proteins

nucleic acids

lipids

carbohydrates



Vary:

- **among cells same individual**
- **more among unrelated individuals**
- **even more between species**

macromolecules

- assembled the same
- chain of small molecules -
polymers
polys (many) meros (parts)

assembled from monomers

“organic” molecules molecules of life

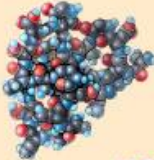

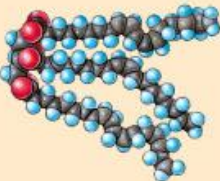

- Proteins - “WORKER” MOLECULE
- Nucleic acids, nucleotide – DNA, RNA ATP
- Lipids - MEMBRANES
- Carbohydrates – FUEL, STRUCTURE

- diversity - combinations
 - 40-50 common monomers
 - rarer ones



– 26 letters in alphabet

Table 3.1 Macromolecules

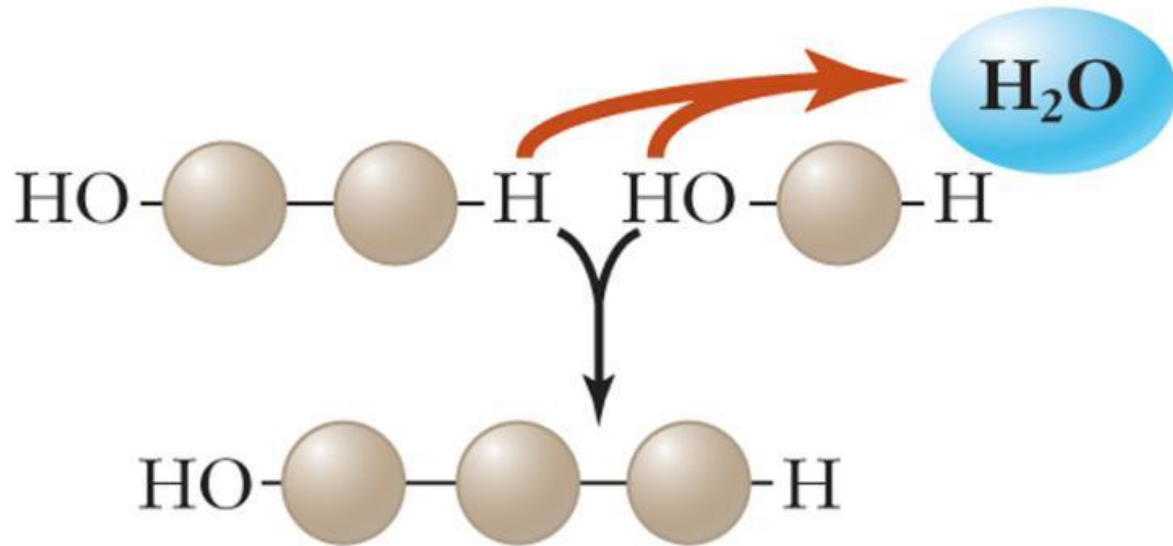
Macromolecule		Subunit	Function	Example	
PROTEINS		Functional	Catalysis; transport	Hemoglobin	
Structural		Amino acids	Support	Hair; silk	
NUCLEIC ACIDS		DNA	Encodes genes	Chromosomes	
RNA		Nucleotides	Needed for gene expression	Messenger RNA	
LIPIDS		Fats	Glycerol and three fatty acids	Energy storage	Butter; corn oil; soap
Phospholipids		Glycerol, two fatty acids, phosphate, and polar R groups	Cell membranes	Lecithin	
Prostaglandins		Five-carbon rings with two nonpolar tails	Chemical messengers	Prostaglandin E (PGE)	
Steroids		Four fused carbon rings	Membranes; hormones	Cholesterol; estrogen	
Terpenes			Long carbon chains	Pigments; structural	Carotene; rubber
CARBOHYDRATES					
Starch, glycogen		Glucose	Energy storage	Potatoes	
Cellulose	Glucose	Cell walls	Paper; strings of celery		
Chitin	Modified glucose	Structural support	Crab shells		

- How? covalent bonds
- **condensation reaction**
 - **dehydration reaction**
 - hydroxyl group
 - hydrogen

requires
energy
aided
by enzymes

Fig. 3.4.a

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



a. Dehydration synthesis

- **REVERSE -hydrolysis**

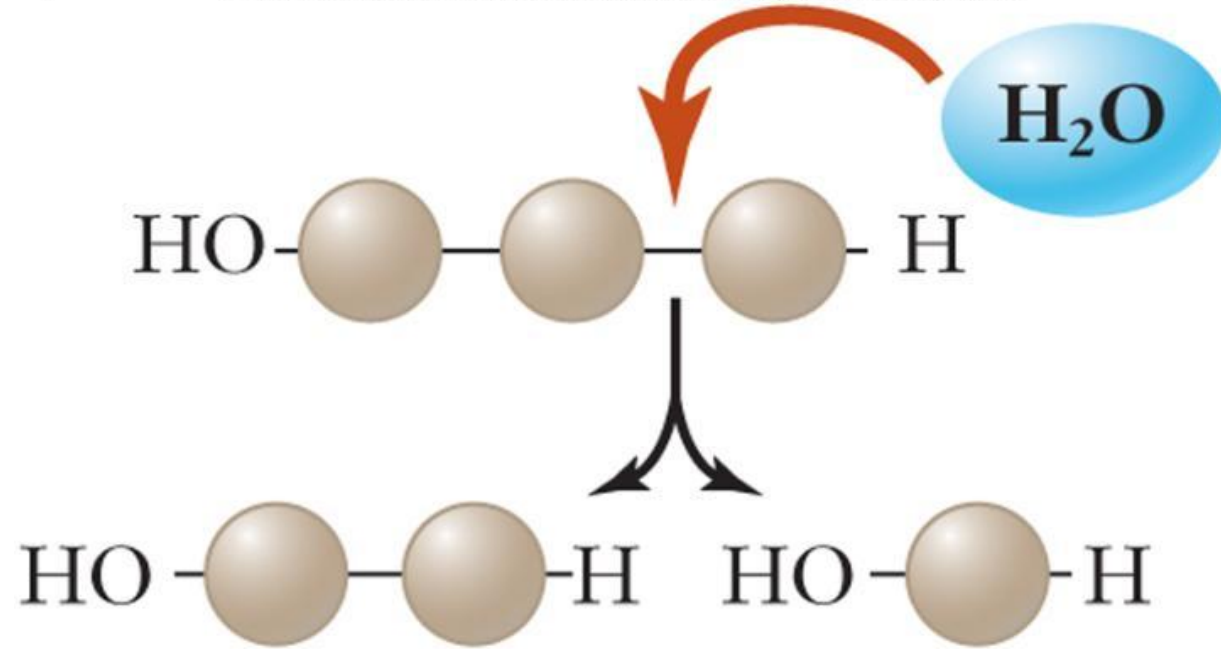
- hydrogen and hydroxyl group attaches where a covalent bond used to be

- digestive process, guided by enzymes.

CONSUMES water

Fig. 3.4.b

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



b. Hydrolysis

Figure 3.3


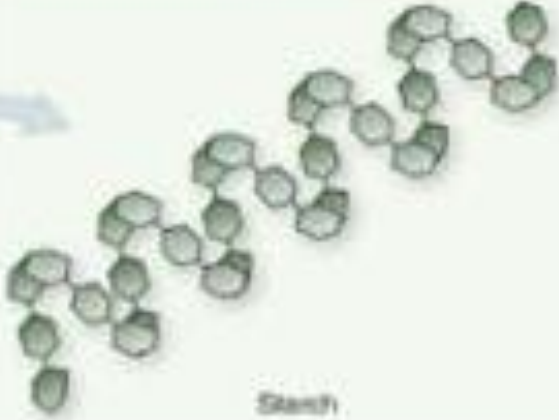
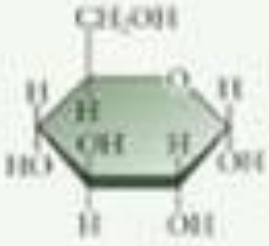


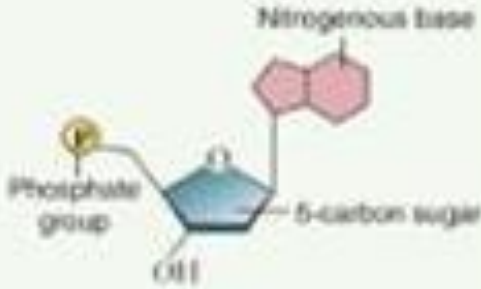
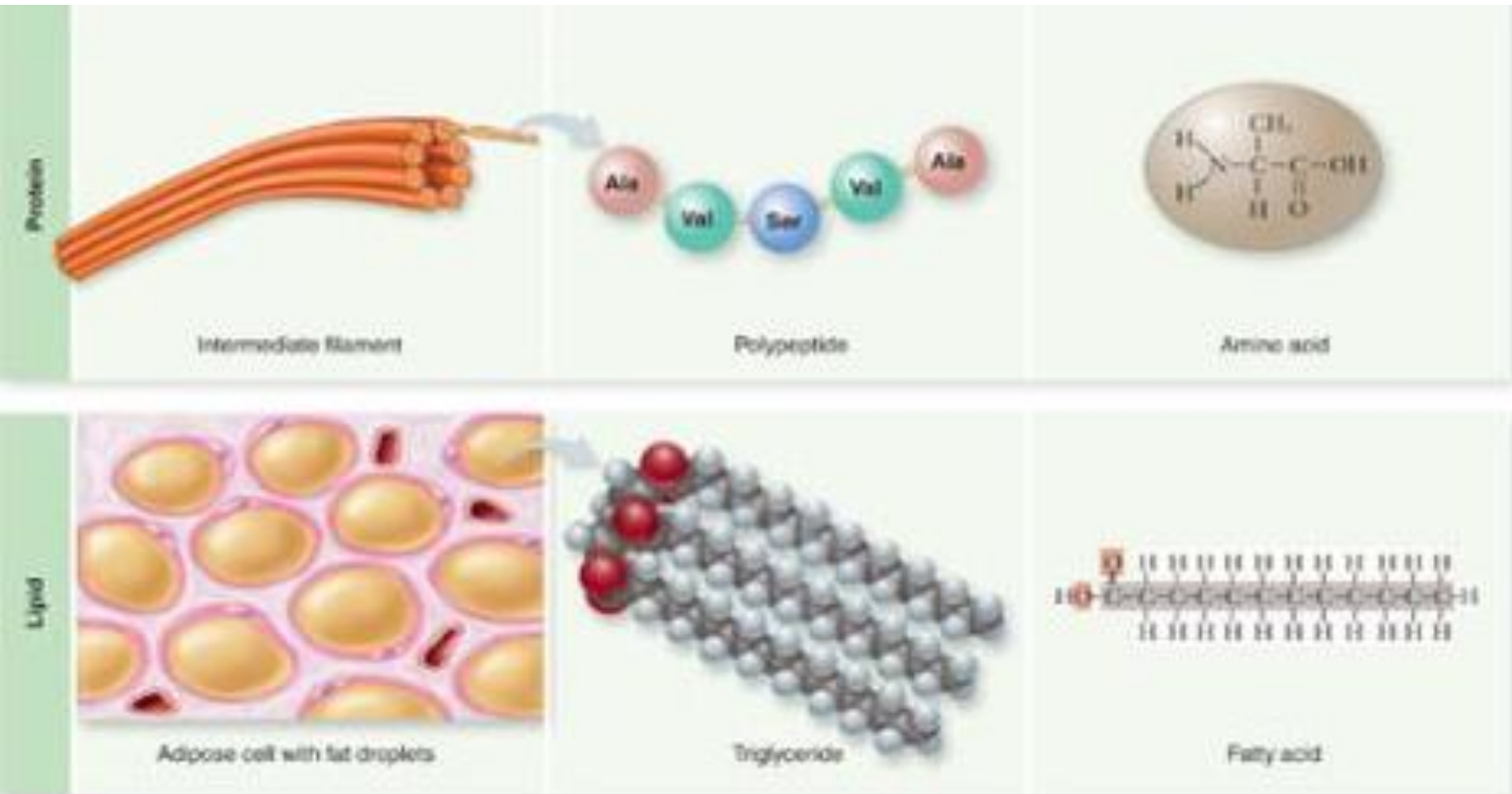
	Cellular Structure	Polymer	Monomer
Carbohydrate	 <p>Starch grains in a chloroplast</p>	 <p>Starch</p>	 <p>Monosaccharide</p>
Nucleic Acid	 <p>Chromosome</p>	 <p>DNA strand</p>	 <p>Nucleotide</p>

Figure 3.3



Carbohydrates: carbon + water

(Hydrate of carbon – C , H₂O)

- usually end in *-ose*
- contain hydroxyl functional group –
OH- allows carbs to dissolve in water
- WHY? Oxygen atom is electronegative and
draws electrons (water is polar)

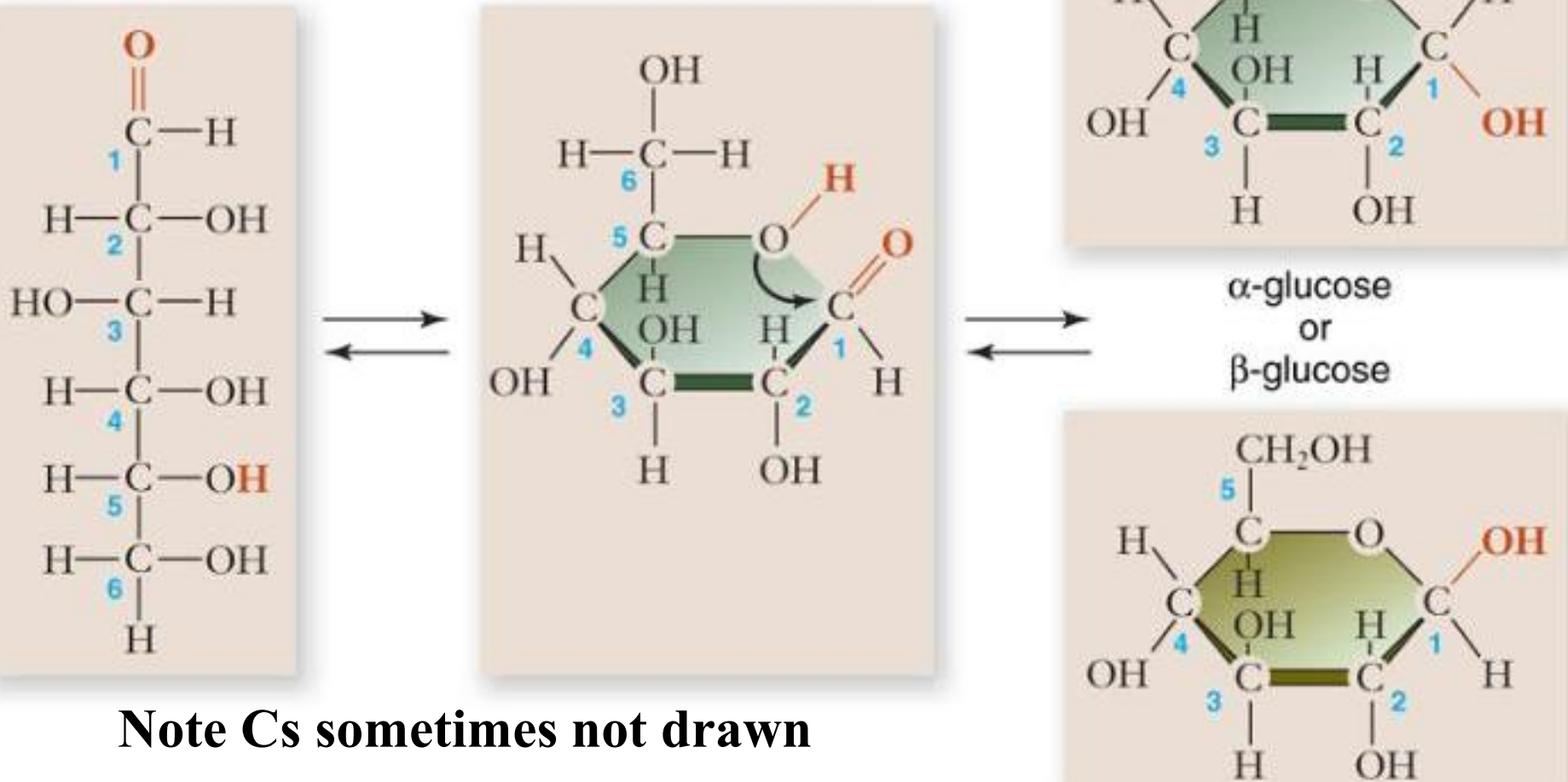
Carbohydrates

- sugars and their polymers
 - Monosaccharides -simple sugars
 - Disaccharides - double sugars-two monosaccharides
 - Polysaccharides - polymers of monosaccharides.

Shapes result in different behaviors

Ring formation is favored IN SOLUTION
(equilibrium)

You must be able to draw a glucose ring!!!



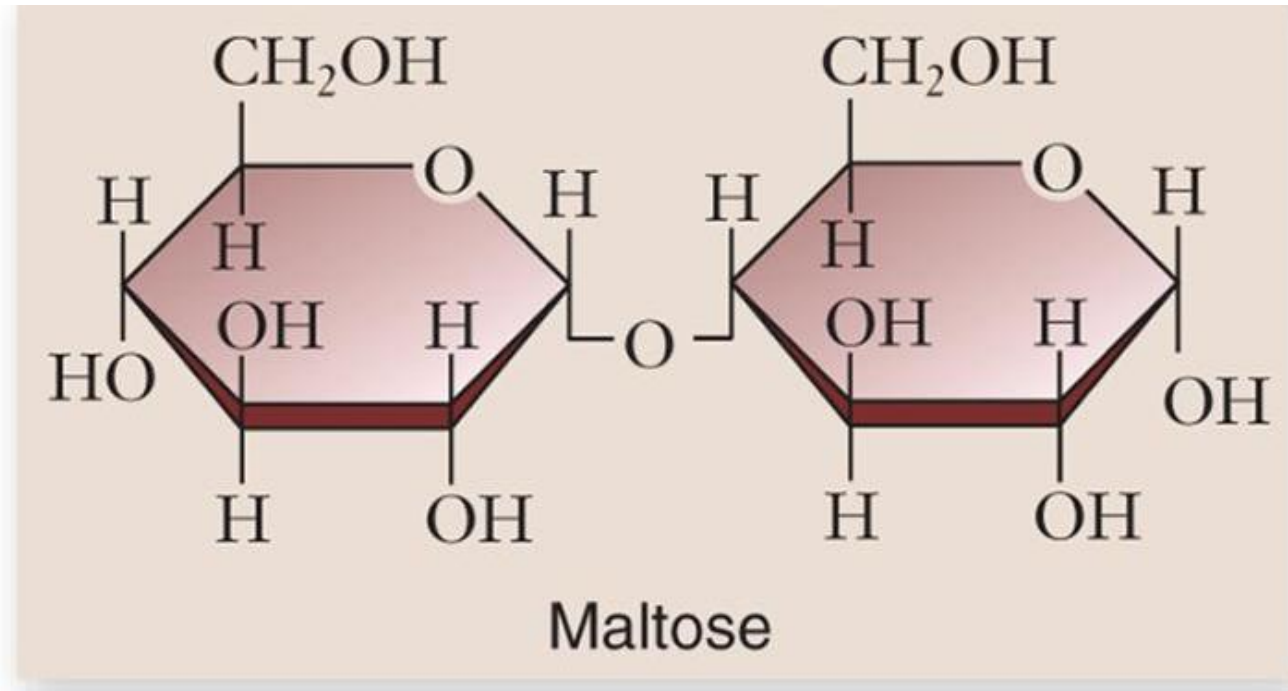
- sugars dissolve in water

maltose USES

water

molecule to

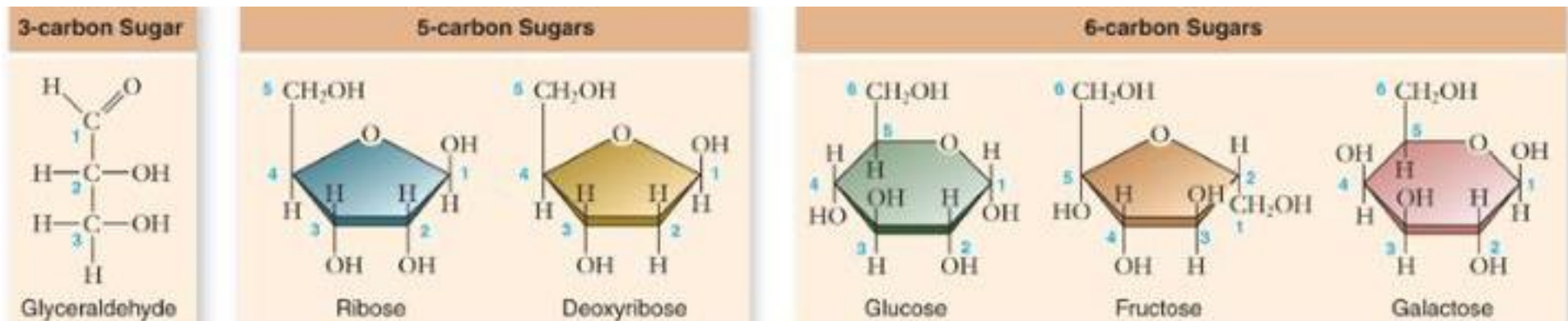
split



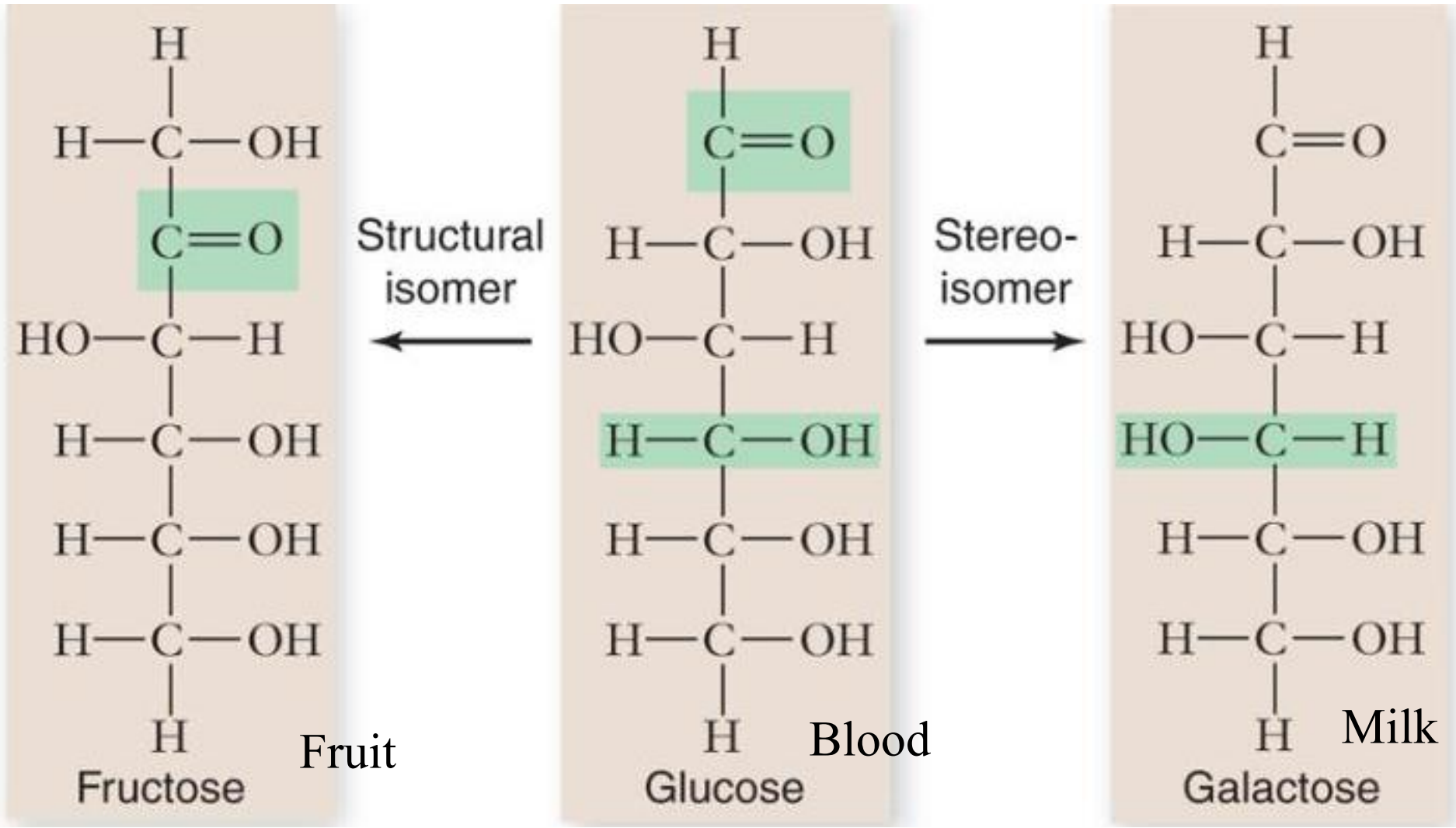
yields 2 glucose

reaction called?? **HYDROLYSIS**

- Monosaccharides classified by # of carbons
 - 6 carbon sugars – hexoses (Glucose)
 - 5 carbon backbones - pentoses
 - 3carbon sugars - trioses



Monosaccharides may be isomers (same elements, different arrangement)



Same chemical groups
Different carbon atoms

Same chemical groups
Different orientations

- Sugar skeletons raw material for synthesis of
 - amino acids
 - fatty acids

- Sugar not used immediately - fuel or structure
 - disaccharides or polysaccharides

polysaccharides (**COMPLEX CARBS**)

starch, glycogen, cellulose, chitin

- **Starch** -storage (glucose monomers)
- starch can be hydrolyzed to release glucoses (energy)
- mouth (enzyme activity)

Carbohydrate Transport

- Plants store starch



- Animals store glucose - **glycogen**
 - highly branched WHY?

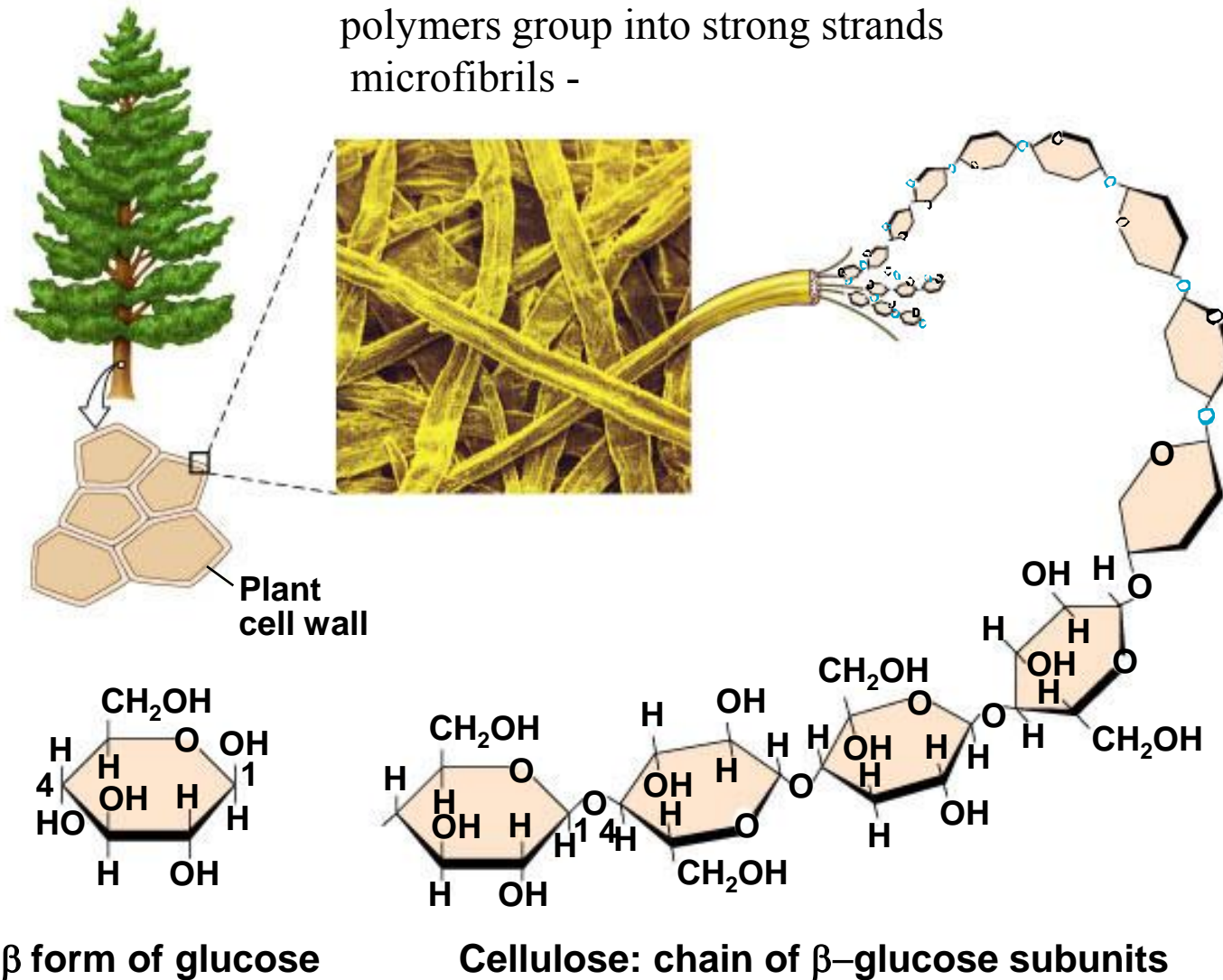
Branching is important in biology!!

- stored in liver and muscles
- one day supply



carbo loading is glyco loading

Structural Carbohydrates

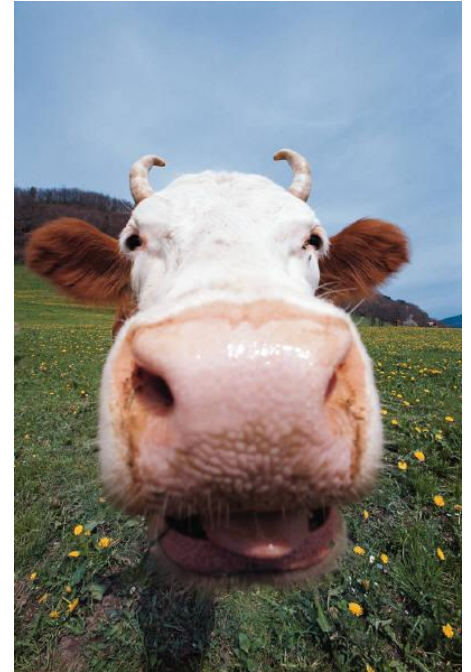


- **Cellulose** - most abundant bioorganic macromolecule on earth!

- enzymes digest starch (hydrolyze) – but not cellulose!

– eliminated “insoluble fiber”

- abrades the intestinal walls
- stimulates secretion of mucus



- microbes digest cellulose (cellulase enzymes)
- cows and termites - symbiotic relationships with bacteria and protozoa

Structural Carbohydrates

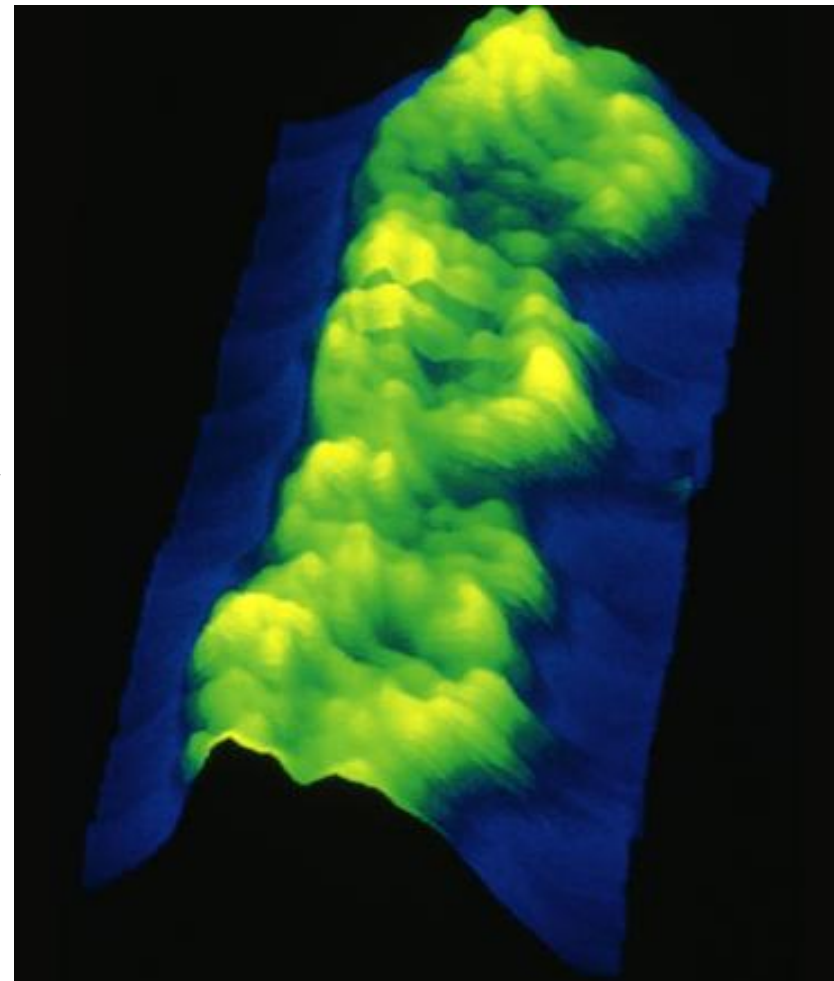
- structural polysaccharide
chitin
- exoskeletons (insects, spiders, and crustaceans)
 - cellulose with nitrogen appendage on each glucose.
- cell walls of many fungi

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



Nucleic Acids - Informational Polymers

- amino acid sequence of polypeptide are programmed by **genes**
- DNA
 - Encodes information used to assemble proteins.
- RNA
 - Reads DNA-encoded information to direct protein synthesis.



store and transmit genetic information

- 2 kinds: **ribonucleic acid (RNA)**
deoxyribonucleic acid (DNA)
- DNA directs own replication
- RNA synthesis
 - protein synthesis

inheritance

- DNA -> mRNA -> protein-> physical traits

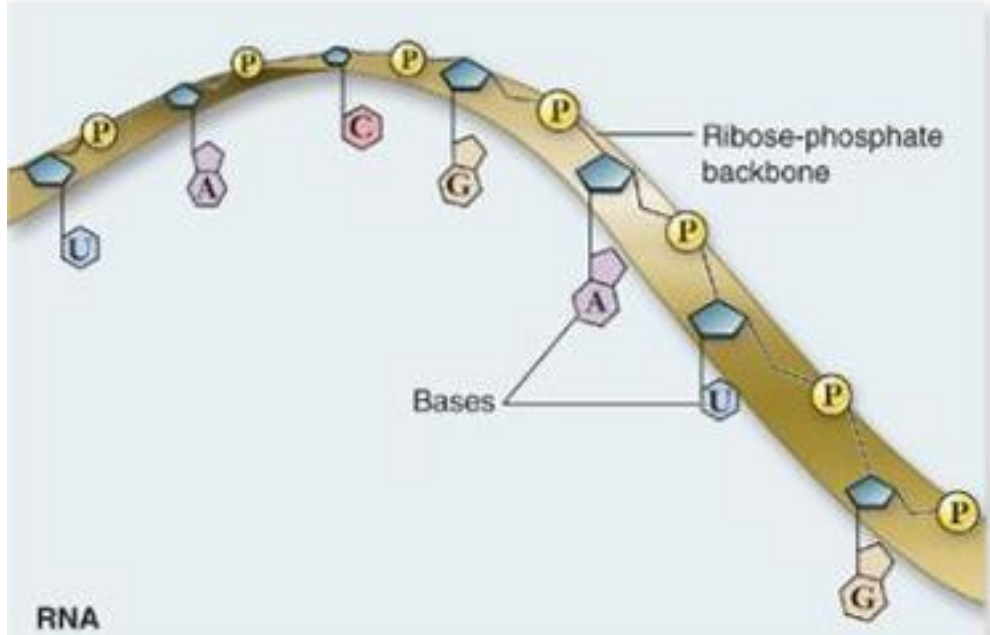
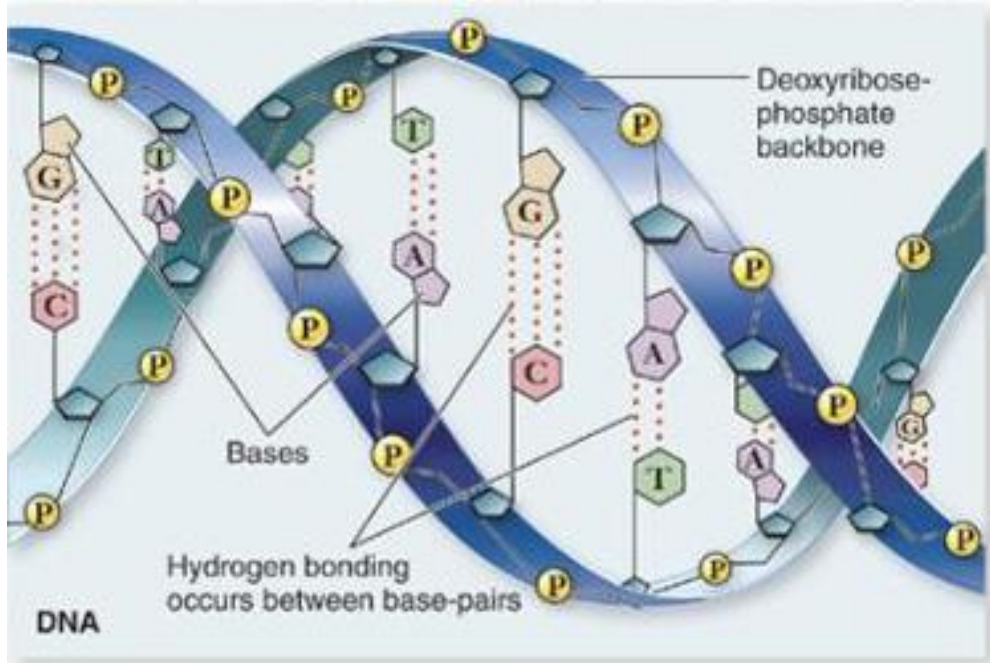
- Protein synthesis occurs in ribosomes

- eukaryotes

DNA in nucleus

ribosomes in cytoplasm

- mRNA is
go between

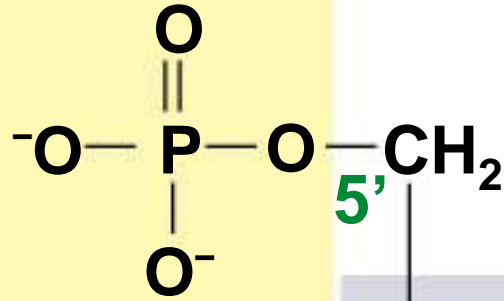


- Each nucleotide consists of three parts:
 - nitrogen base
 - pentose sugar
 - phosphate group

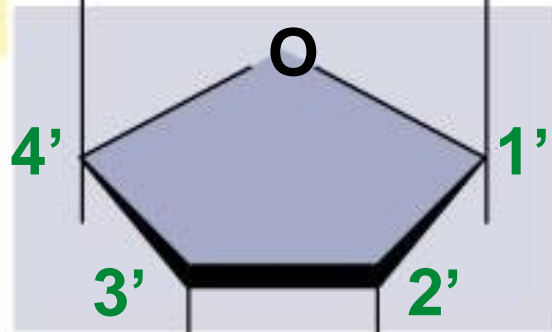
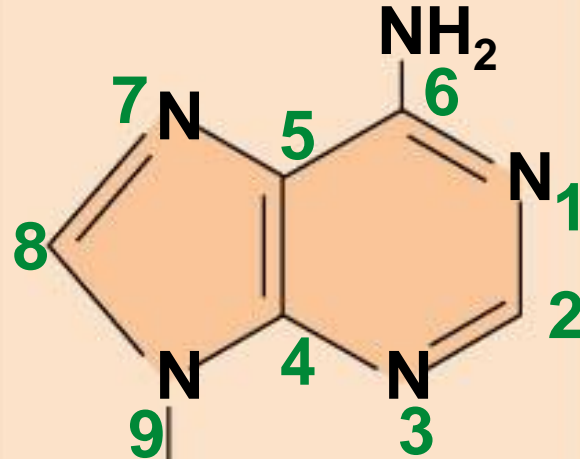
DNA = deoxyribonucleic acid

deoxy ribose sugar
phosphate group
nitrogenous base

Phosphate group



Nitrogenous base



OH in RNA

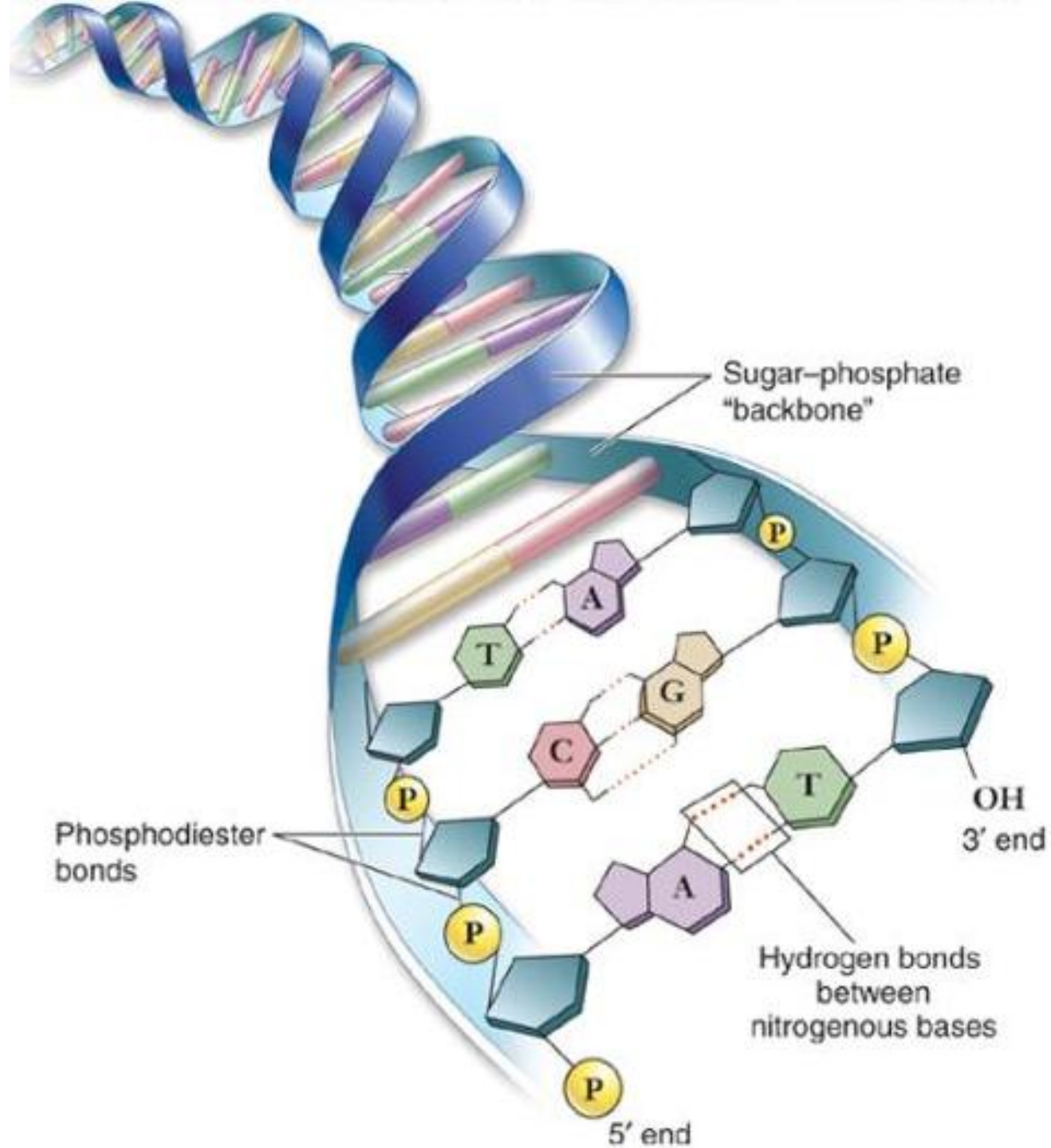
H in DNA

OH R

Sugar

some bases are compatible, some are not

- DNA
 - Adenine (A) pairs with Thymine (T)
 - Guanine (G) with Cytosine (C).
- if we know one sequence, we know the other
- *complementary*



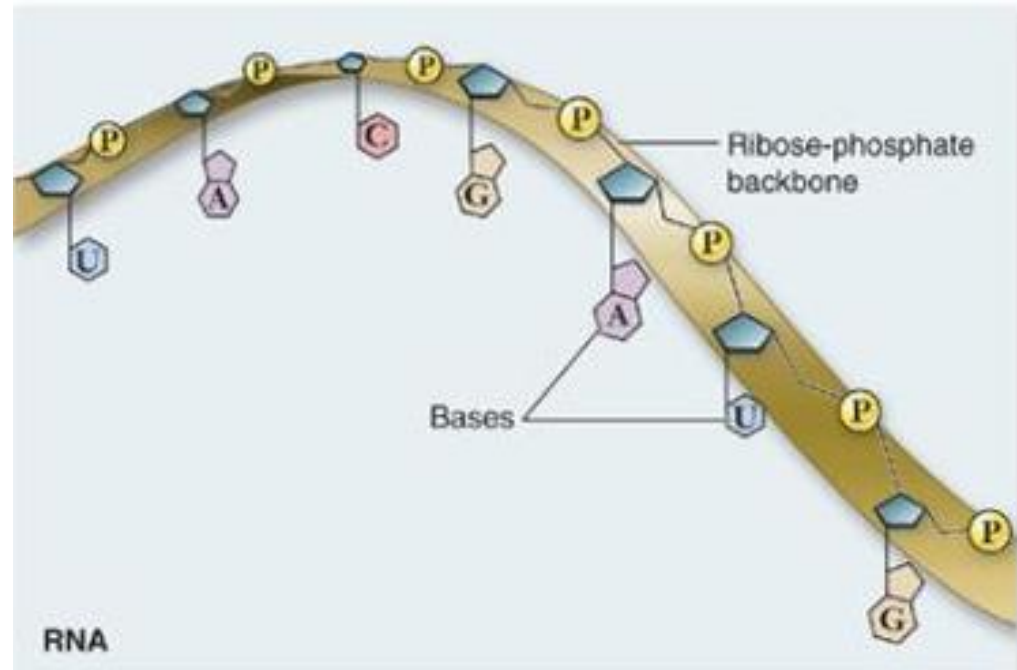
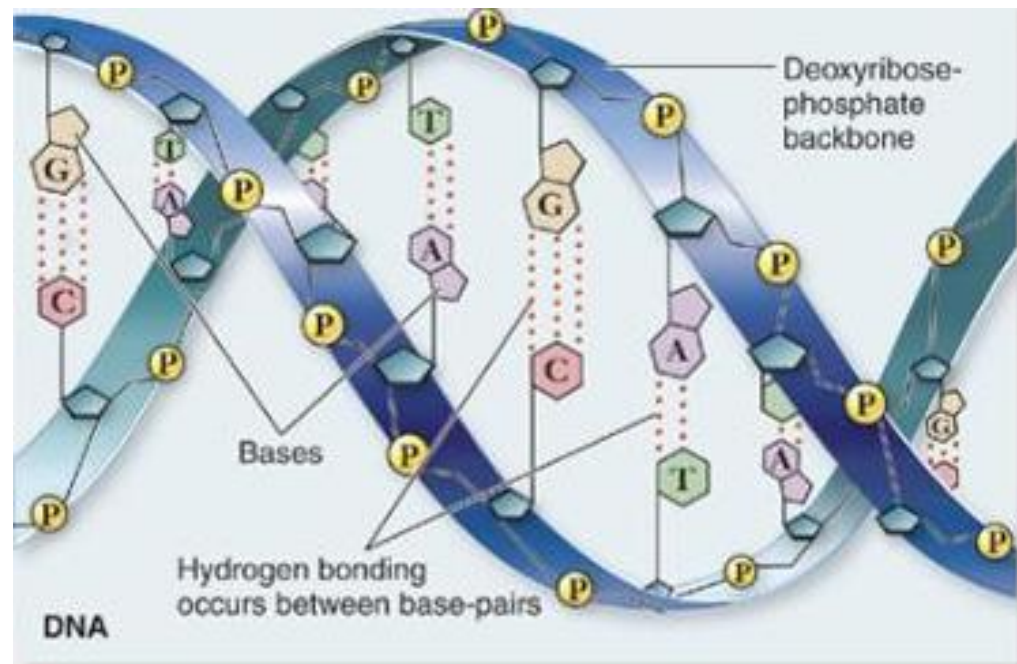
.RNA exists as a single stand.

-contains ribose instead of deoxyribose

-contains uracil in place of thymine

- RNA - single polynucleotide chain
- DNA - two polynucleotide strands

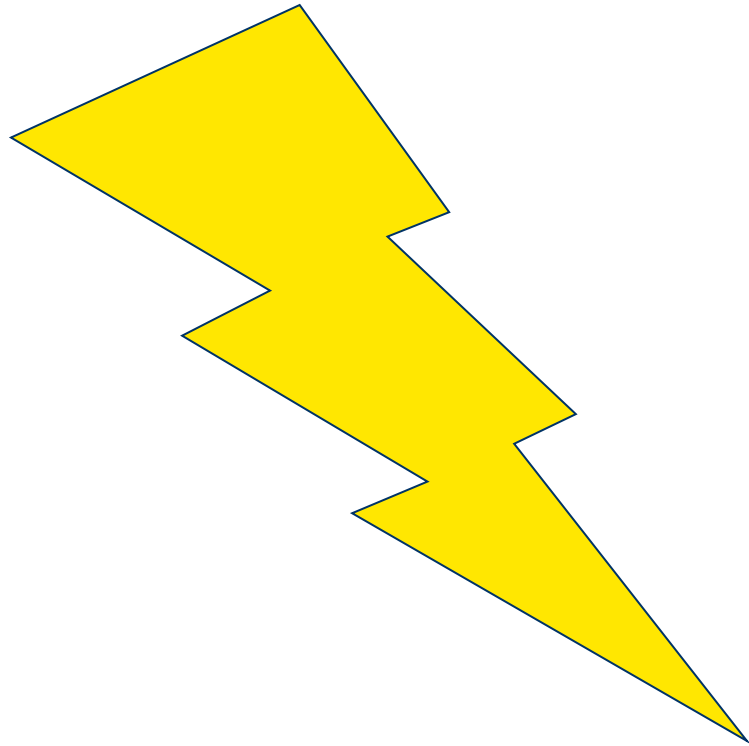
double helix



Nucleic bases

- ATP

- NAD⁺



“organic” molecules molecules of life

- Proteins - “WORKER” MOLECULE
- Nucleic acids, nucleotide – DNA, RNA ATP
- Lipids - MEMBRANES
- Carbohydrates – FUEL, STRUCTURE

● Proteins - everything!

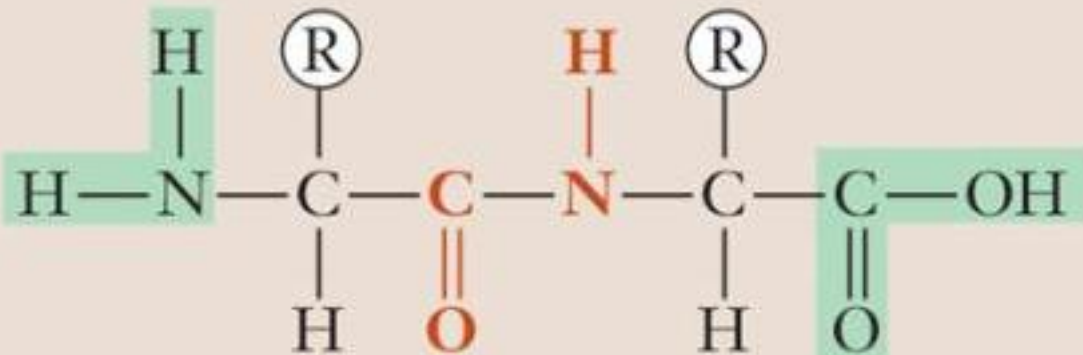
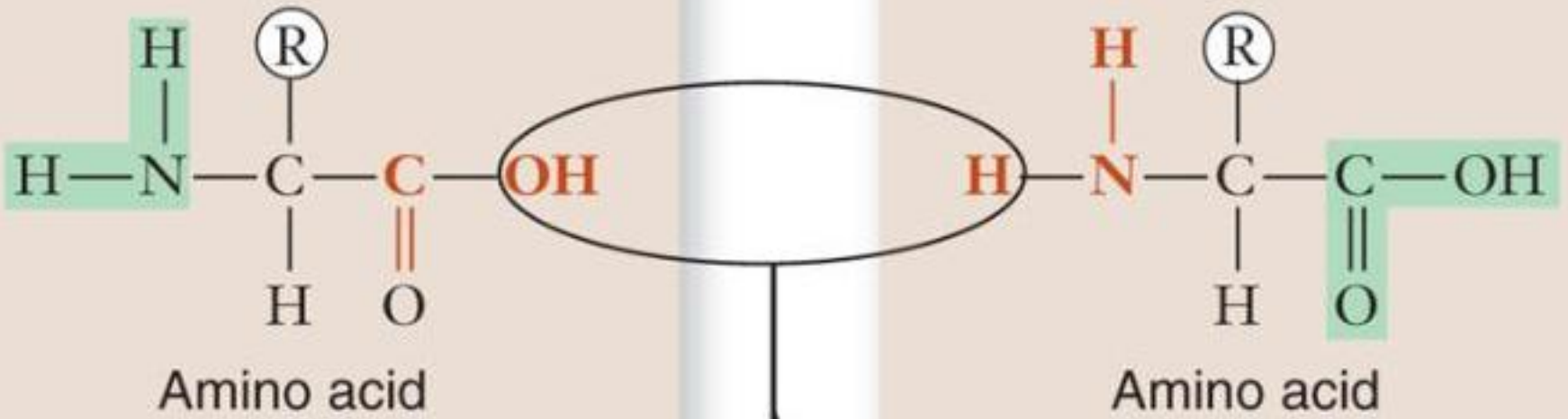
- structural support, storage, transport of other substances, intercellular signaling (receptors, some hormones) , movement, defense against foreign substances (antibodies).
- also enzymes (catalysts) - selectively accelerate chemical reactions

TABLE 3.2

The Many Functions of Protein

Function	Class of Protein	Examples	Examples of Use
Enzyme catalysis	Enzymes	Hydrolytic enzymes	Cleave polysaccharides
		Proteases	Break down proteins
		Polymerases	Synthesize nucleic acids
		Kinases	Phosphorylate sugars and proteins
Defense	Immunoglobulins	Antibodies	Mark foreign proteins for elimination
	Toxins	Snake venom	Blocks nerve function
	Cell surface antigens	MHC proteins	"Self" recognition
Transport	Circulating transporters	Hemoglobin	Carries O ₂ and CO ₂ in blood
		Myoglobin	Carries O ₂ and CO ₂ in muscle
		Cytochromes	Electron transport
	Membrane transporters	Sodium-potassium pump	Excitable membranes
		Proton pump	Chemiosmosis
Support	Fibers	Glucose transporter	Transports glucose into cells
		Collagen	Forms cartilage
		Keratin	Forms hair, nails
Motion	Muscle	Fibrin	Forms blood clots
		Actin	Contraction of muscle fibers
		Myosin	Contraction of muscle fibers
Regulation	Osmotic proteins	Scrum albumin	Maintains osmotic concentration of blood
	Gene regulators	<i>lac</i> repressor	Regulates transcription
	Hormones	Insulin	Controls blood glucose levels
		Vasopressin	Increases water retention by kidneys
Storage	Ion binding	Oxytocin	Regulates uterine contractions and milk production
		Ferritin	Stores iron, especially in spleen
		Casain	Stores ions in milk
		Calmodulin	Binds calcium ions

- most structurally complex molecules
 - complex three-D shape “conformation”
- constructed from set of 20 monomers
 - **amino acids**
- Linked by covalent PEPTIDE bonds
- protein = one or more polypeptides folded and coiled into a specific conformation.
- **Polypeptides - chains of amino acids**

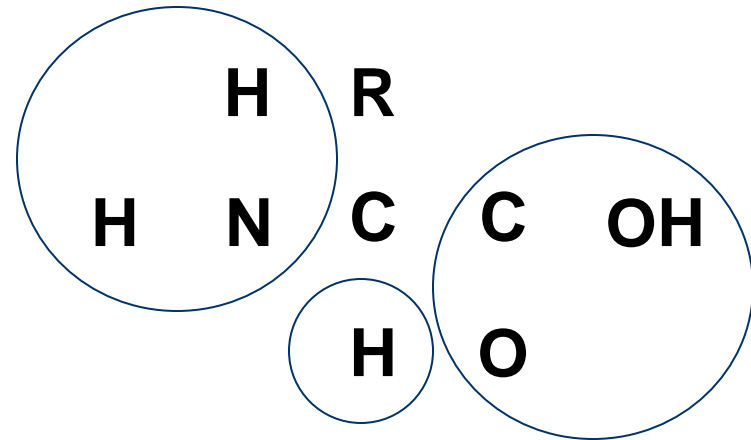


Dipeptide

Polypeptide Chain

Amino Acids

- amino group (-NH₂)
- carboxyl group (-COOH)
- hydrogen atom



R group –unique properties

- all bonded to a central carbon atom (alpha)

- **Amino acids** PAGE 47

- “R” group or side chain

- R group differences = 20 different amino acids

- 20 common amino acids - 5 classes based on side groups

- nonpolar amino acids

- polar uncharged amino acids

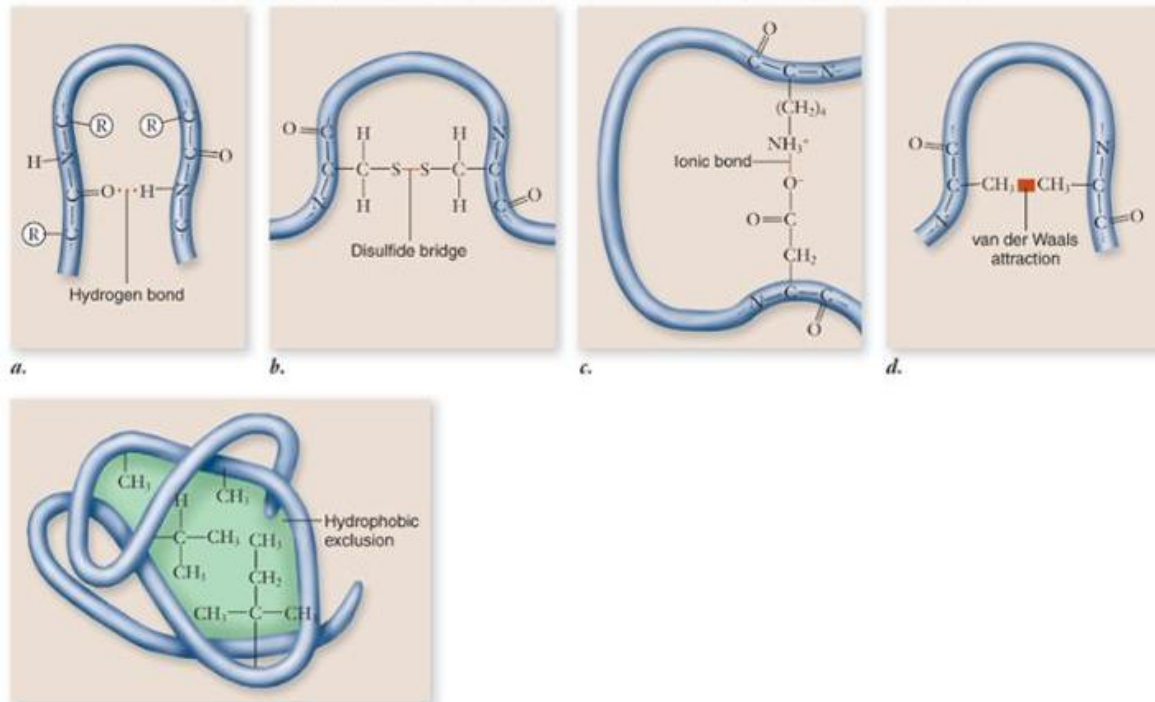
- charged amino acids

- aromatic amino acids

- special-function amino acids

function depends on conformation

- precisely twisted, folded, and coiled
- order of amino acids determines 3D conformation



- folding occurs spontaneously ??? (emergent)

X RAY DIFFRACTION

- levels of structure:

1. Primary

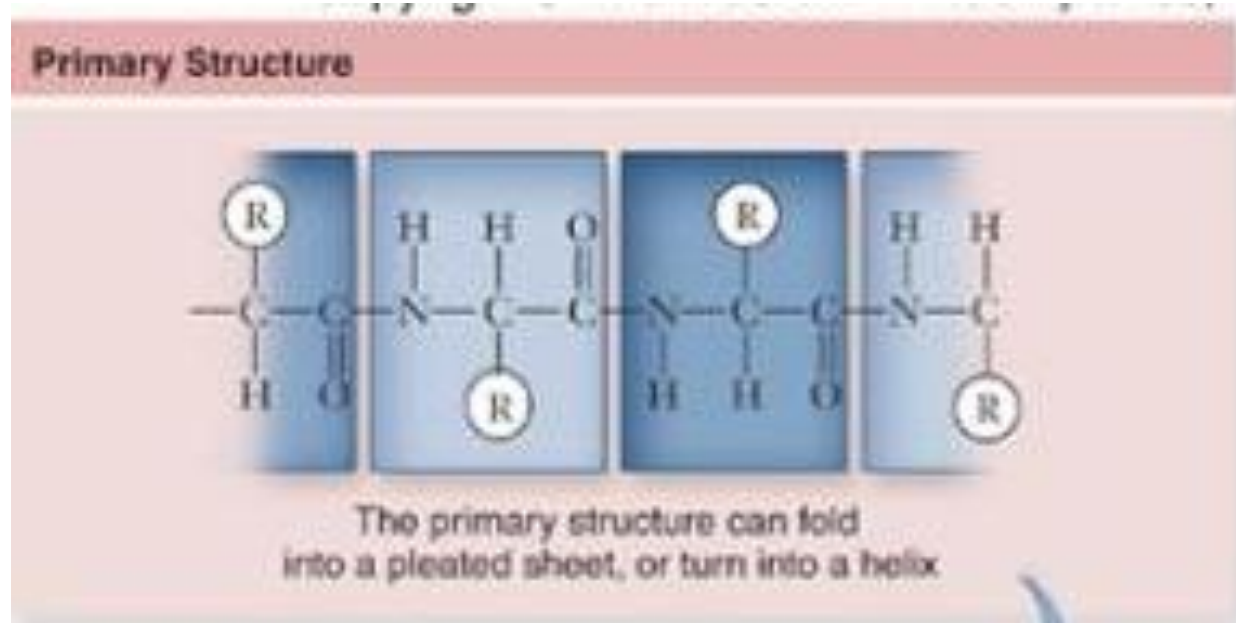
2. Secondary (motifs)

3. Tertiary - organize folding within polypeptide (domains)

4. Quarternary - two or more polypeptides join to form a protein.

Protein Structure

- Protein function is determined by its shape.
 - Protein structure
 - primary - specific amino acid sequence

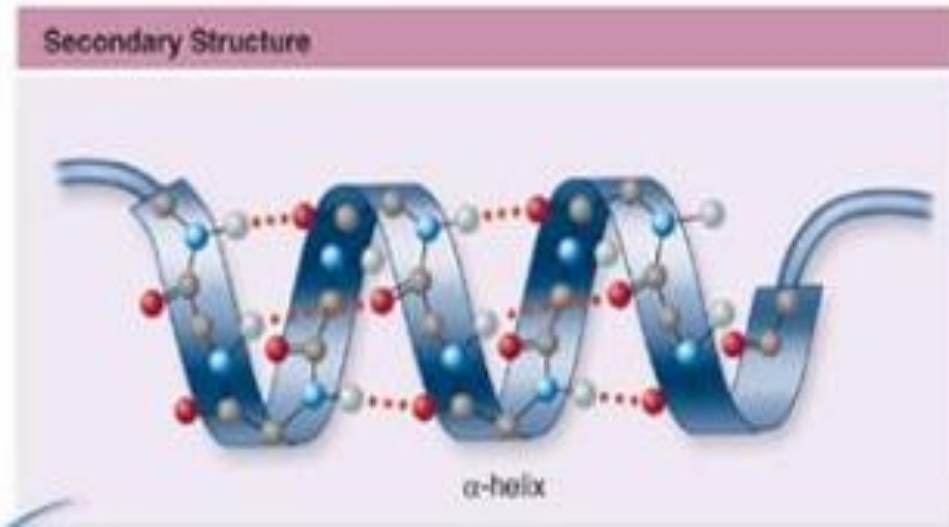
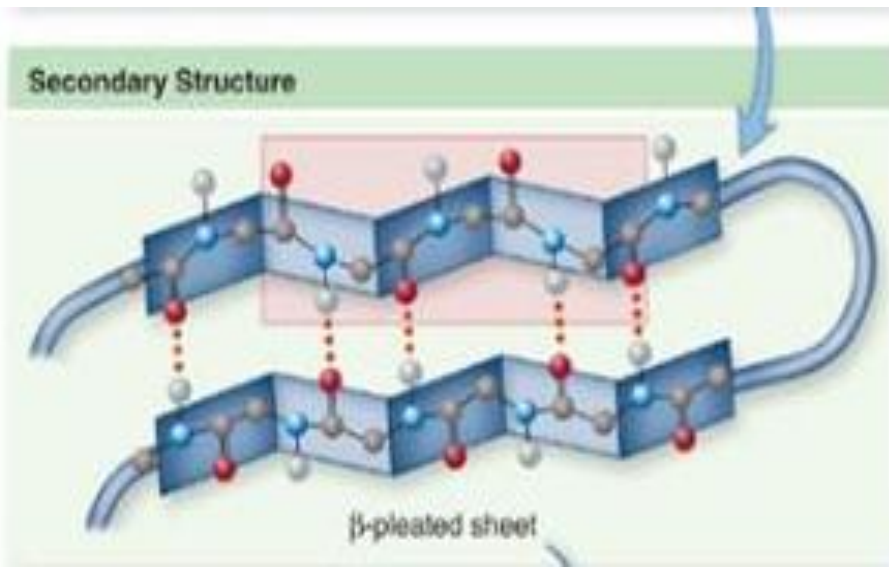


LINKED BY PEPTIDE BONDS (join carboxyl and amino groups)

Protein Structure

- secondary - folding of amino acid chains
- motifs - characteristic folds or creases
 - supersecondary structure

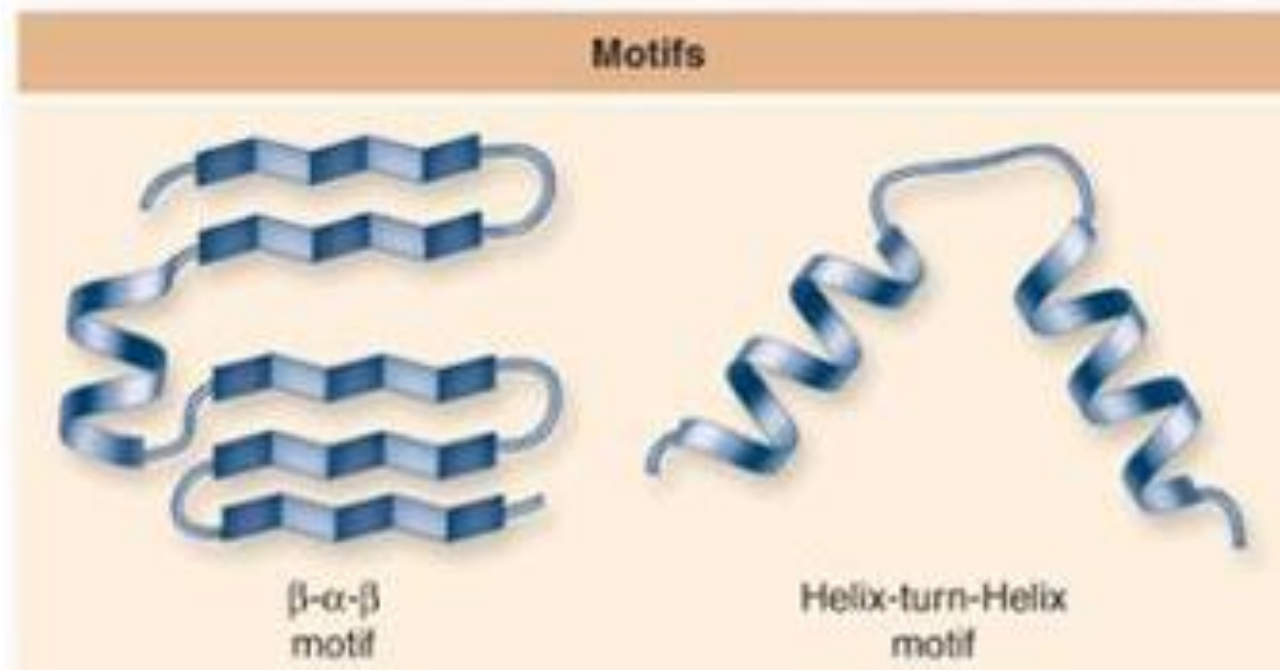
- **secondary structure** - from hydrogen bonds along polypeptide backbone
 - Typical shapes :
 - 1) coils (an alpha helix)
 - 2) folds (beta pleated sheets)



motifs - folds or creases

-supersecondary structure

“recurring theme” -meaning???



- silk - beta pleated sheets (secondary)
 - LOTS of hydrogen bonds



Tertiary Structure

(superimposed on secondary)

*hydrophobic

interaction —

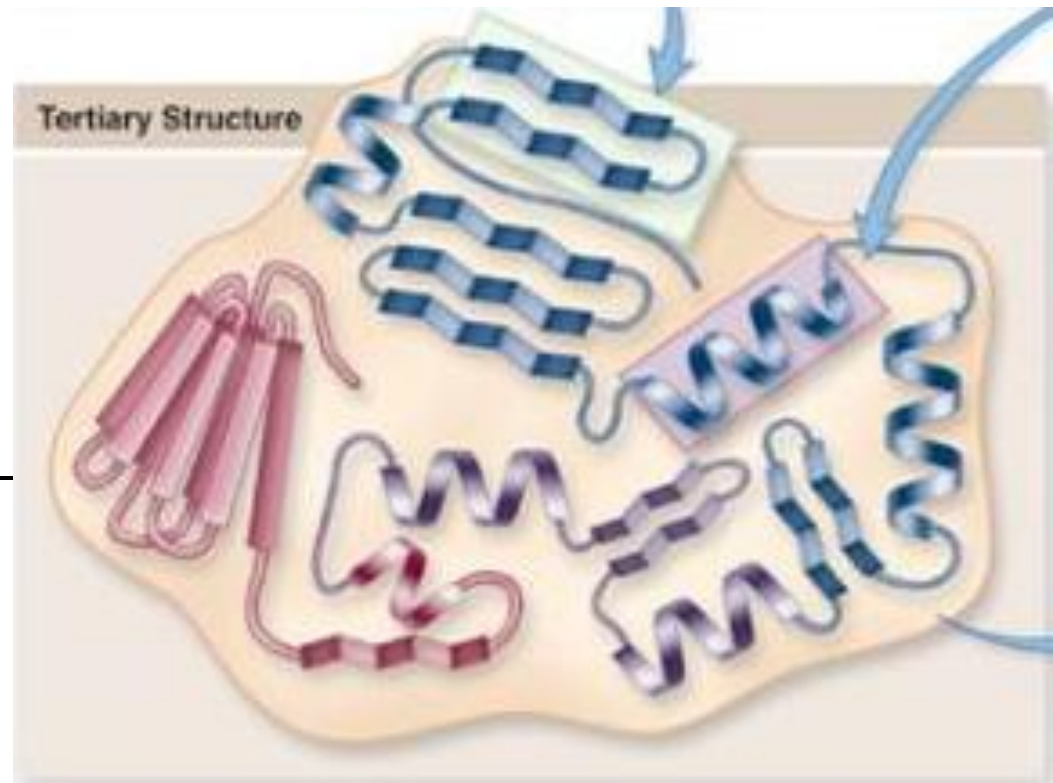
water molecules exclude
non-polar substances

*hydrogen bonds —

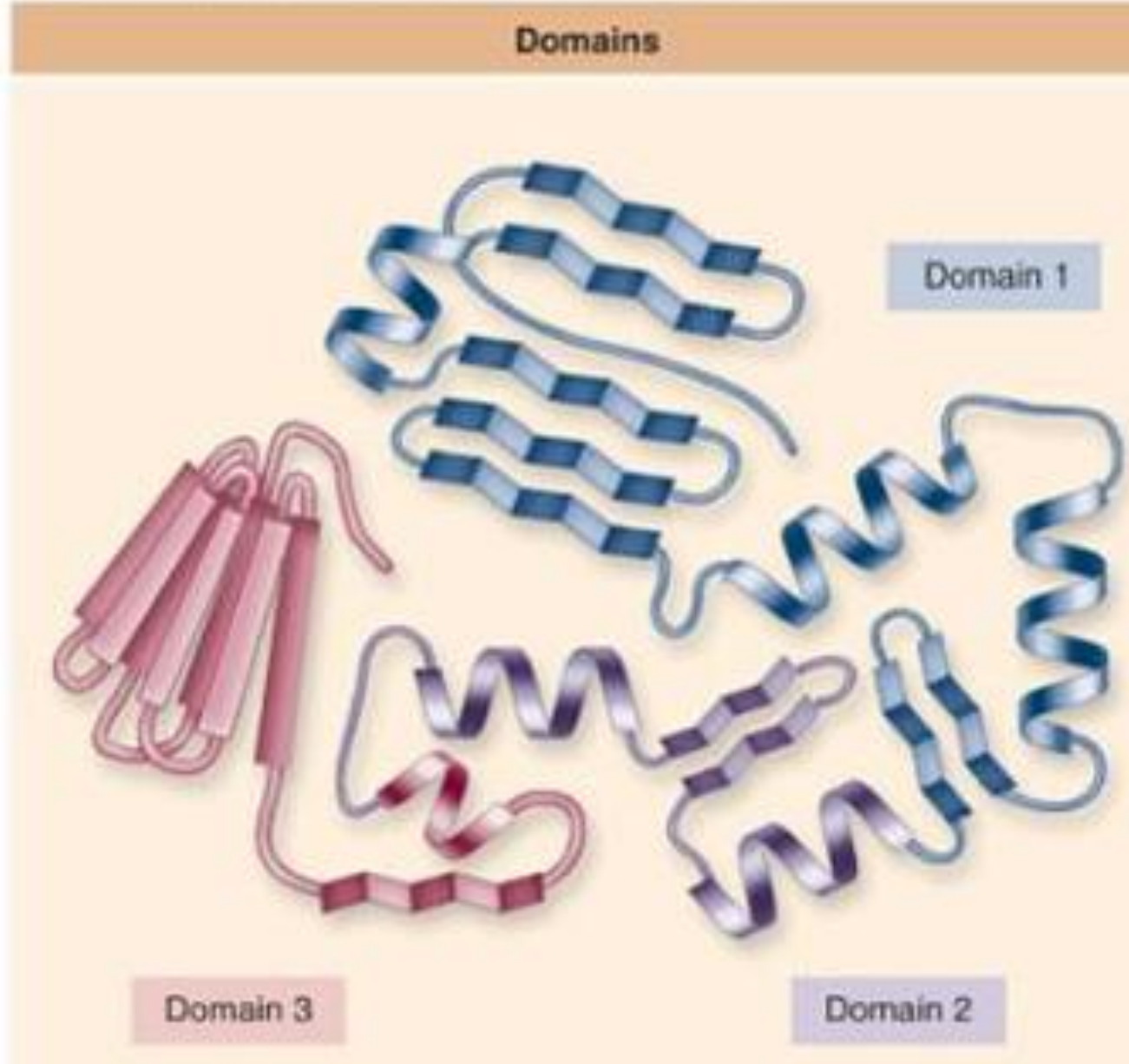
stabilize

*disulfide bridges

strong, covalent bonds



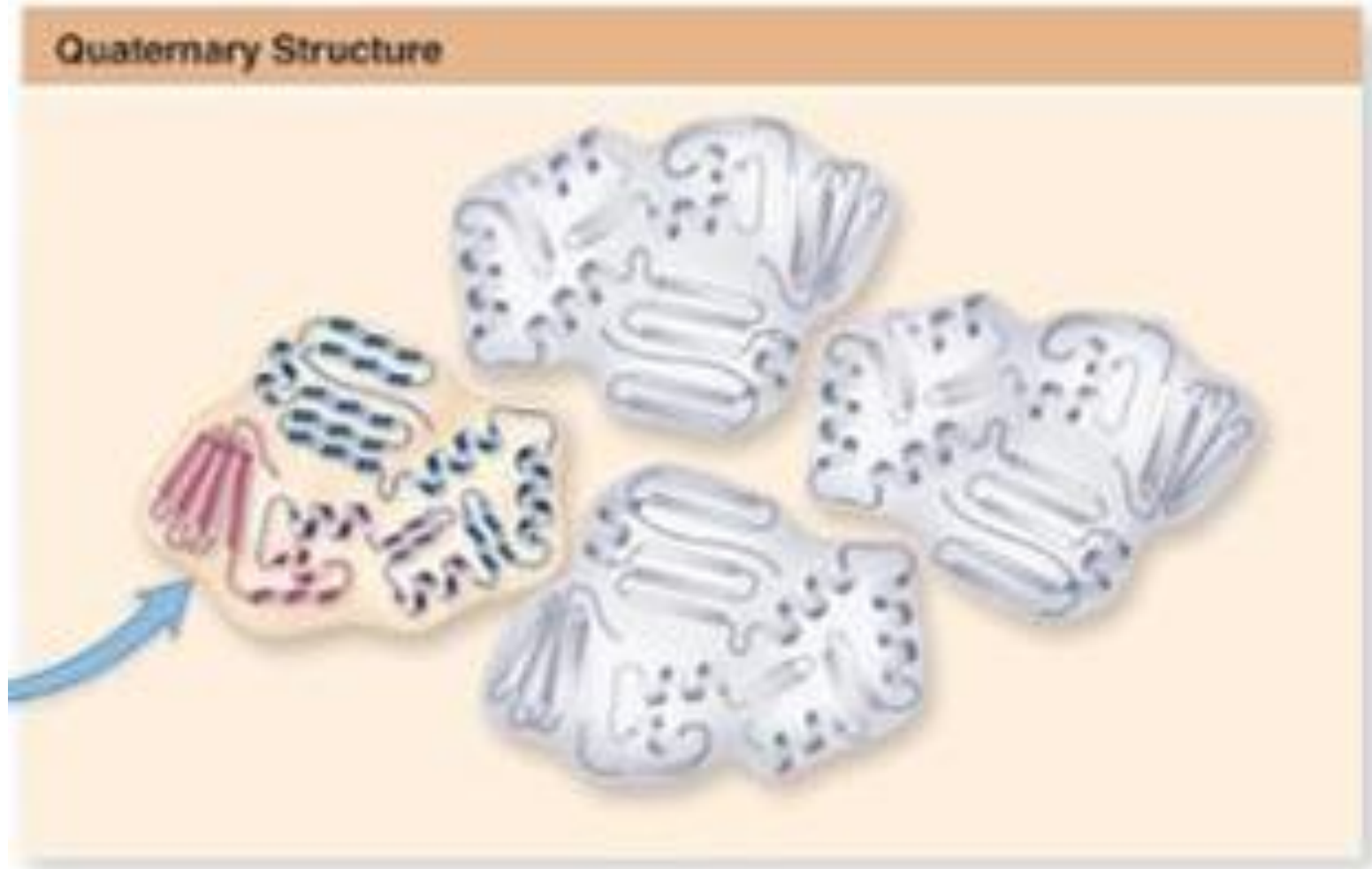
Domains



Domains -separate functions

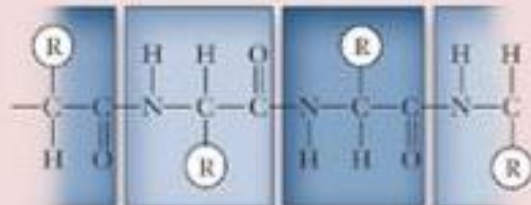
Quaternary structure: interactions between subunits

2 or more chains form protein



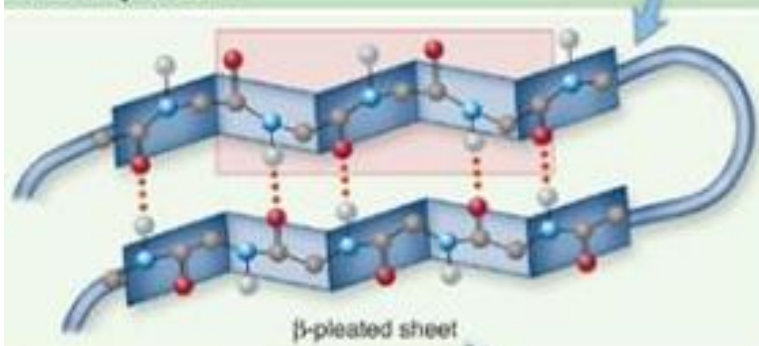
FUNCTIONAL – (disruption stops function – sickle cell)

Primary Structure

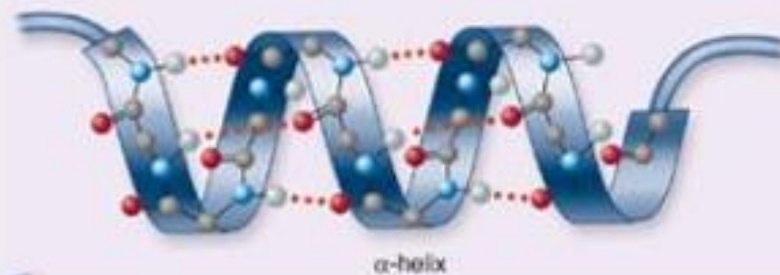


The primary structure can fold into a pleated sheet, or turn into a helix.

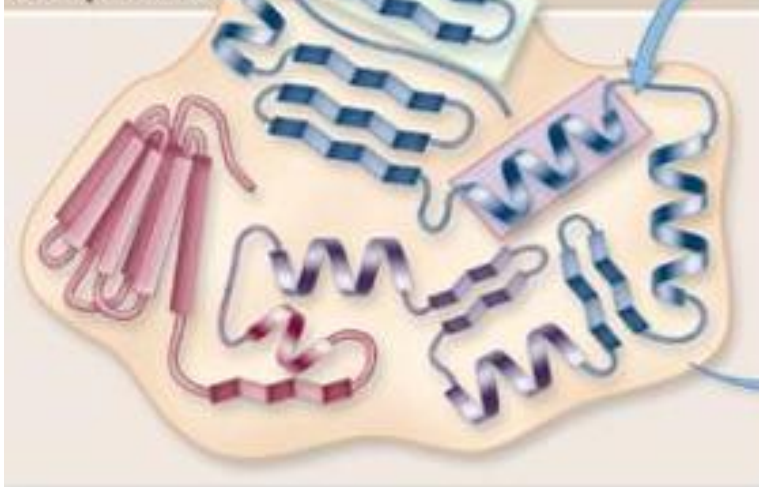
Secondary Structure



Secondary Structure



Tertiary Structure



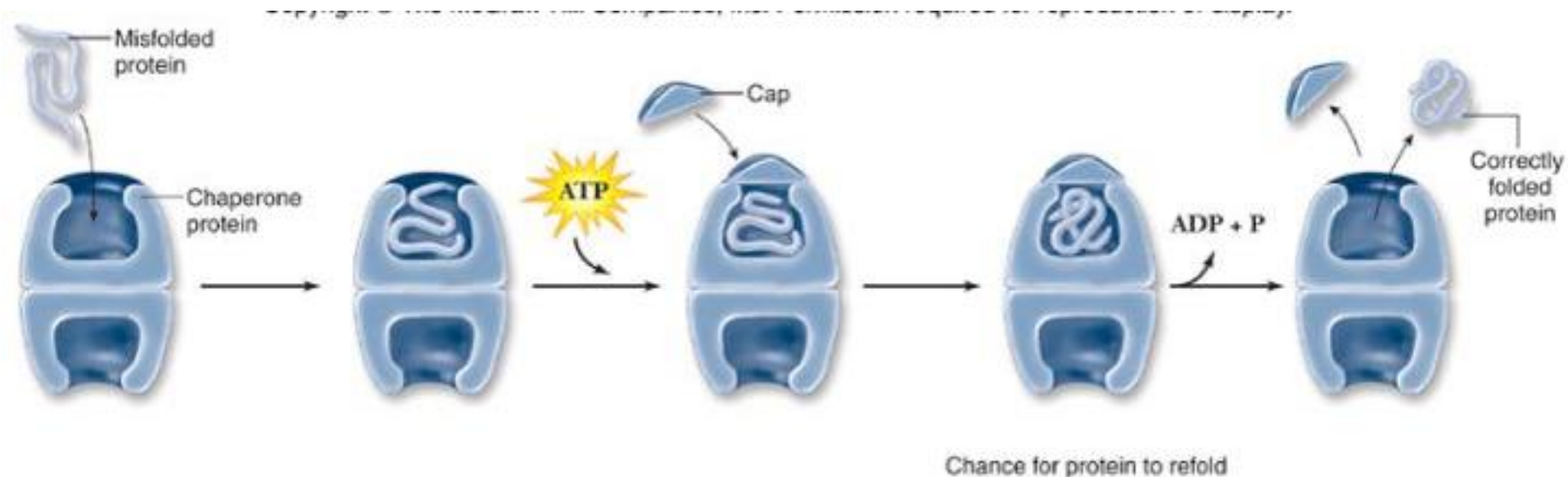
Quaternary Structure



Chaperone Proteins

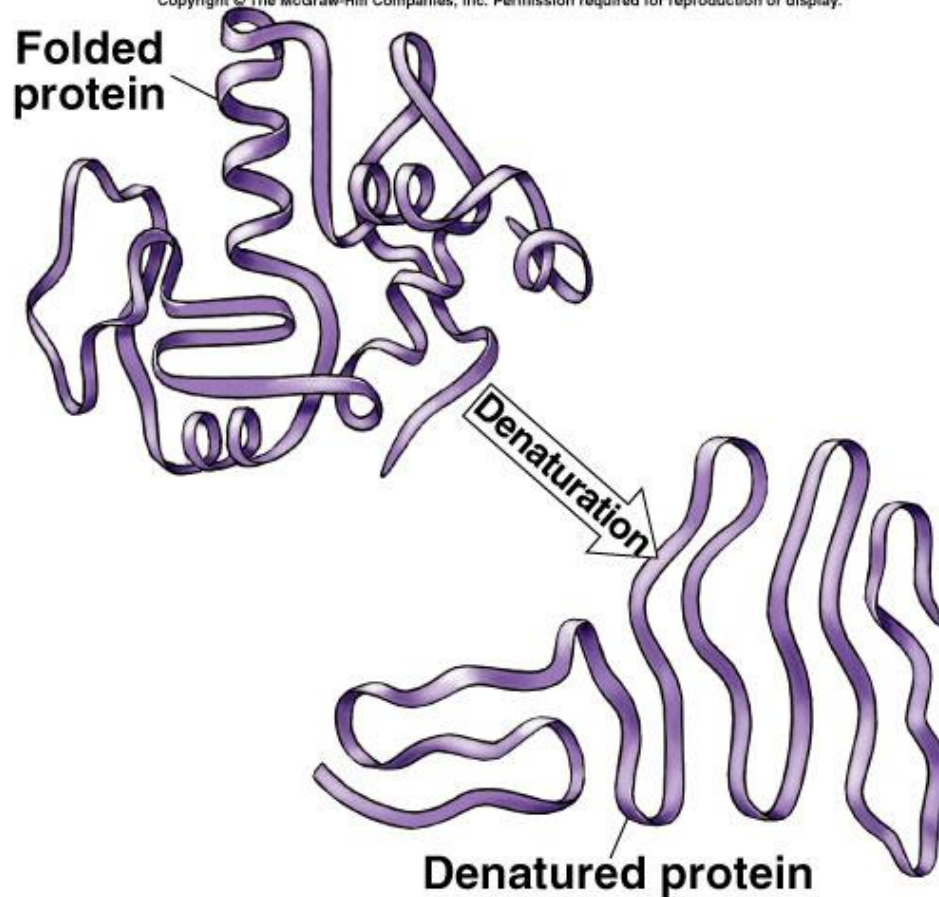
“shock” proteins

- Chaperone proteins are special proteins that help new proteins fold correctly.
 - Chaperone deficiencies may play a role in facilitating certain diseases.



proteins can come undone!

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



Denaturation -some can return, some cannot

Cystic fibrous? Alzheimer's Disease

- unravel or **denature** in response to environment
- pH
- salt concentration (ionic)
- temperature
- other factors

- disrupt hydrogen bonds, ionic bonds, disulfide bridges

protein folding “problem”

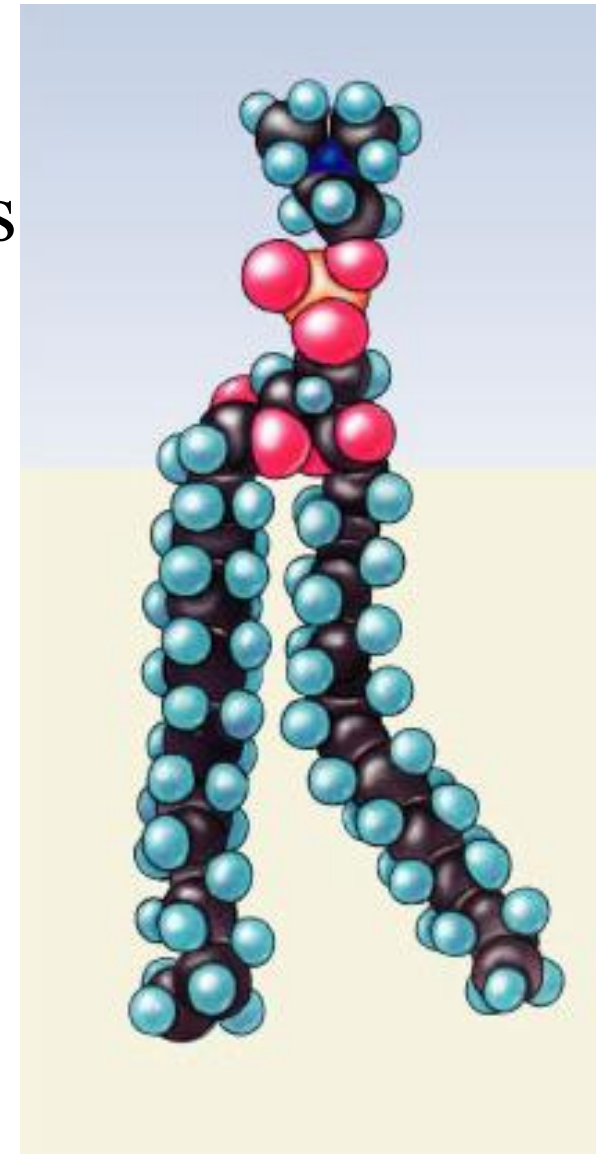
- 100,000 proteins – know AA sequences
- 10,000 – 3 D shapes
- But what are the rules??

Lipids

- Fats, oils, cholesterol, hormones
 - CARBON
 - HYDROGEN
 - OXYGEN

“CONTAINERS” FOR LIFE - Membranes
WHY? INSOLUBLE IN WATER

also store energy, provide insulation

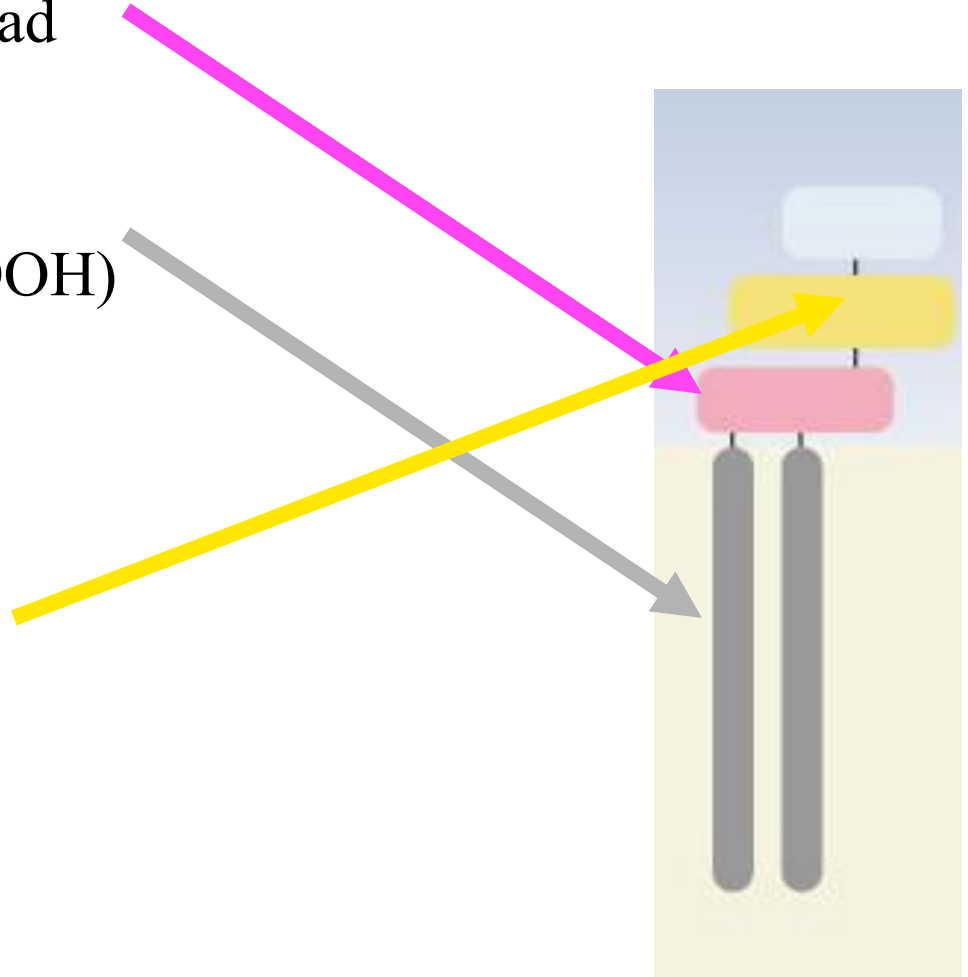


Lipids – not polar - do not dissolve in H₂O

Glycerol - 3 carbon alcohol head

Fatty acids - long carbon tail
ending in carboxyl group (COOH)

Phosphate group -on glycerol

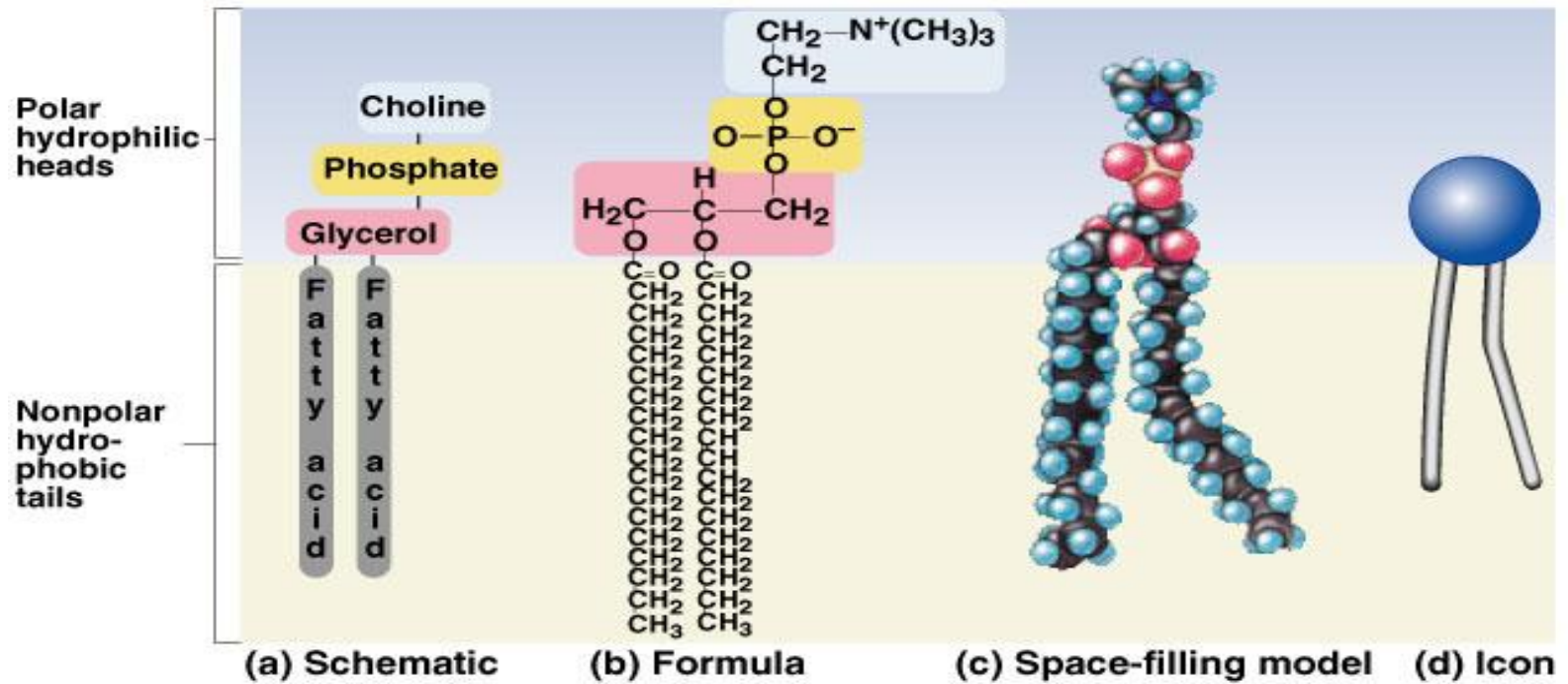


carbon
hydrogen
oxygen
PLUS phosphorous and nitrogen

Hydrophilic (polar) head

Tails CH bonds - non-polar

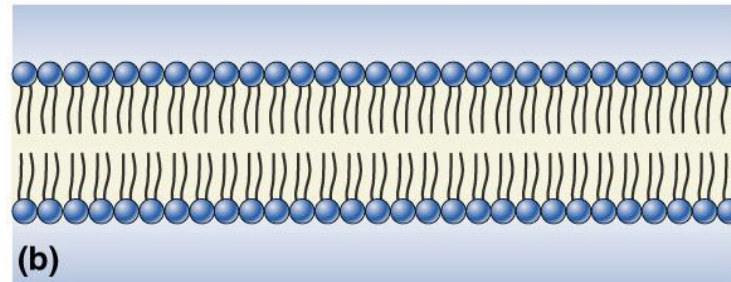
Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



Lipids

- Fats - glycerol and fatty acids
 - Glycerol - one 3 carbon alcohol
 - Fatty acids - long carbon skeleton ending in carboxyl group (-COOH)

- Phospholipids
 - (MEMBRANES)



- Steroids

– linked together **avoiding water**

saturated fats - linked to heart disease

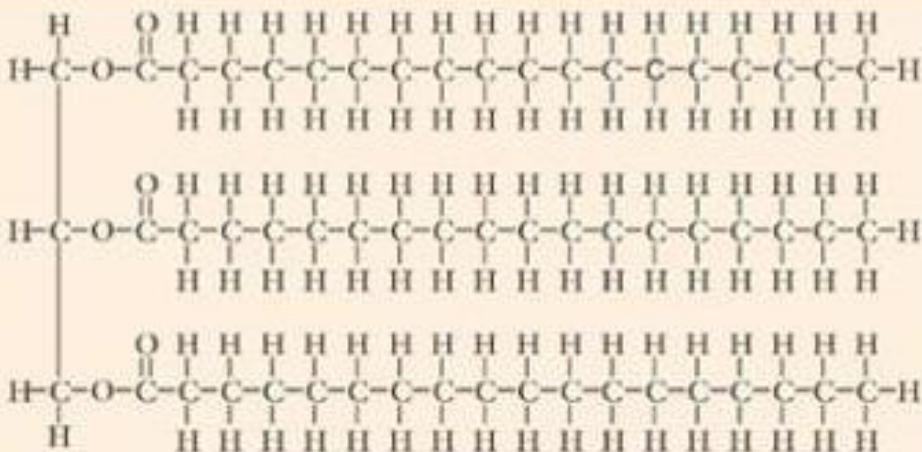
(more than cholesterol from diet)

- meat
- dairy products
- chocolate

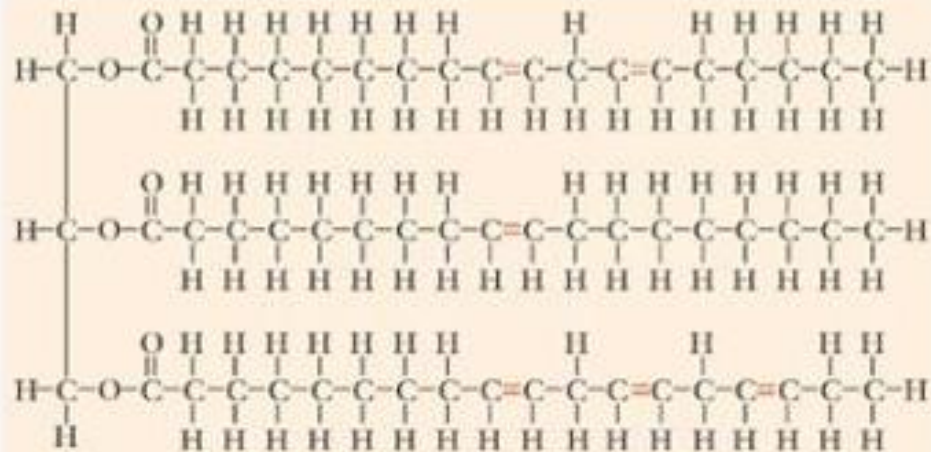
but - great way to store energy

WHAT ARE THEY SATURATED WITH???

Structural Formula



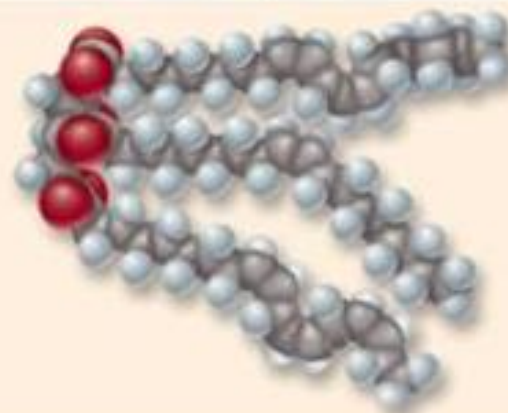
Structural Formula



Space-Filling Model



Space-Filling Model

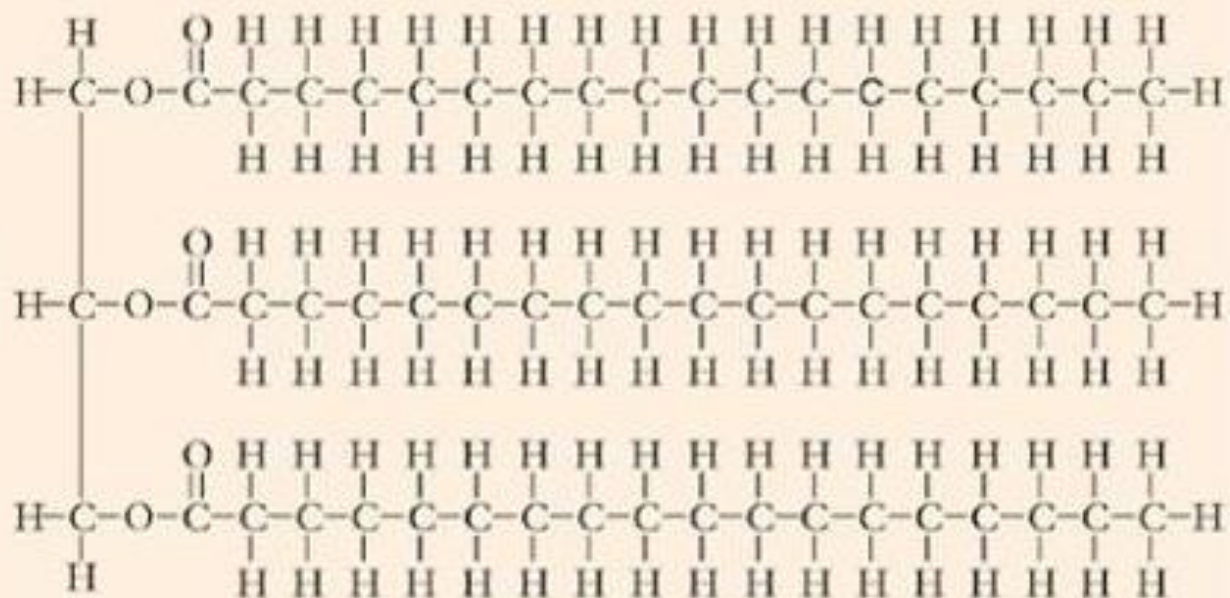


SATURATED – no kinks – Lard, butter
“saturated” with hydrogen atoms

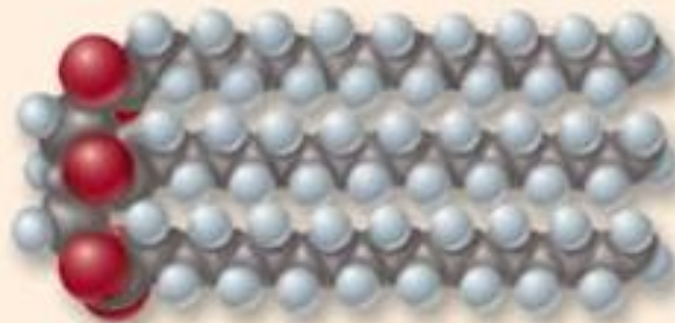
mono unSATURATED –
one double bond – not saturated with H

poly un SATURATED –
more than one double bond – not saturated
room to take on hydrogen – plant and fish oil

Structural Formula



Space-Filling Model



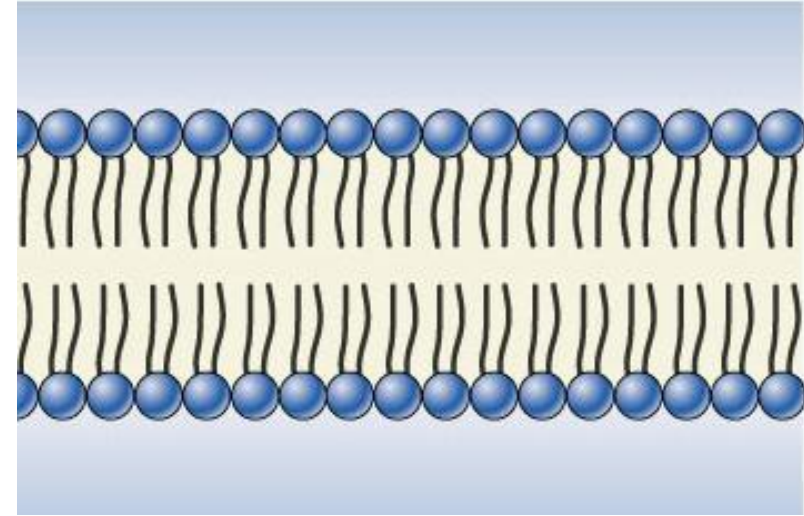
“hydrogenation” -hydrogen is added into oil
oil gets “saturated”

Why Are Fats Storage Molecules?

- highest density of calories.
 - Carbohydrates—4 calories/gram
 - Proteins—4 calories/gram
 - Fats—9.3 calories/gram
- consume more calories than you use
- no matter what type
- converted and stored in the **most efficient**
(densest) form — fat



- **MORE LIPIDS**



- **Phospholipids**

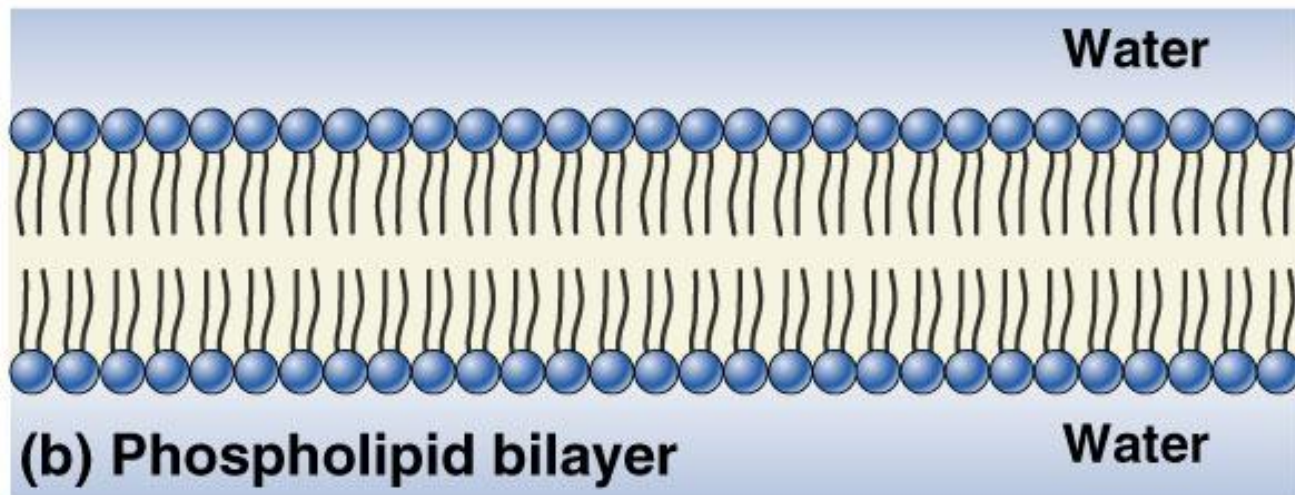
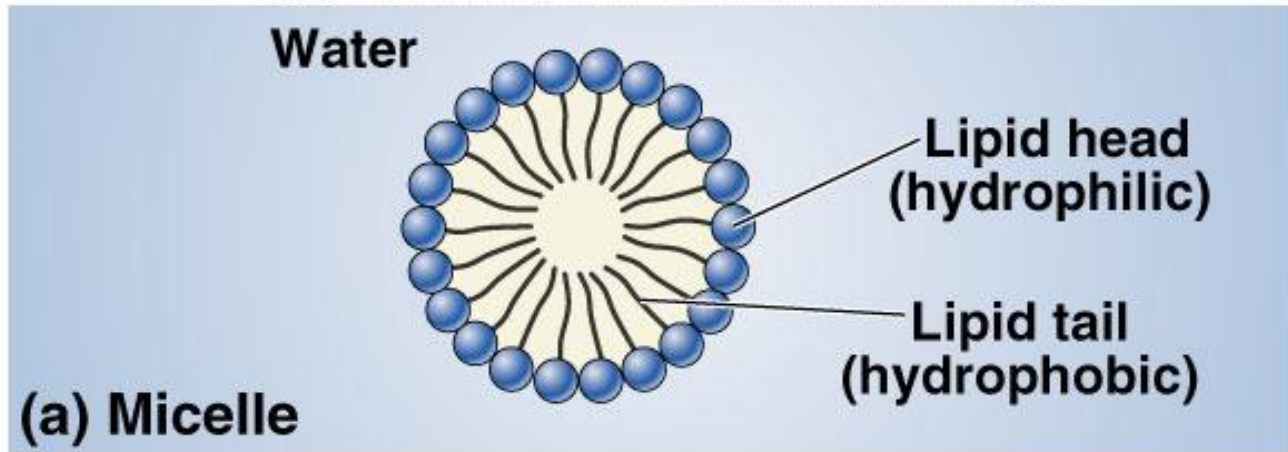
- cell membranes

- Not polymers - linked together because they avoid water

- Dual Nature—Fatty-acid tails are hydrophobic, but phosphate head is charged and hydrophilic.

Phospholipids - only 2 fatty acid tails
3rd hydroxyl group linked to phosphate

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



“organic” molecules molecules of life

- Proteins - “WORKER” MOLECULE
- Nucleic acids, nucleotide – DNA, RNA ATP
- Lipids - MEMBRANES
- Carbohydrates – FUEL, STRUCTURE