BO101

Topic: Biomolecules: part 1 (30-04-21)

Chemical basis of life

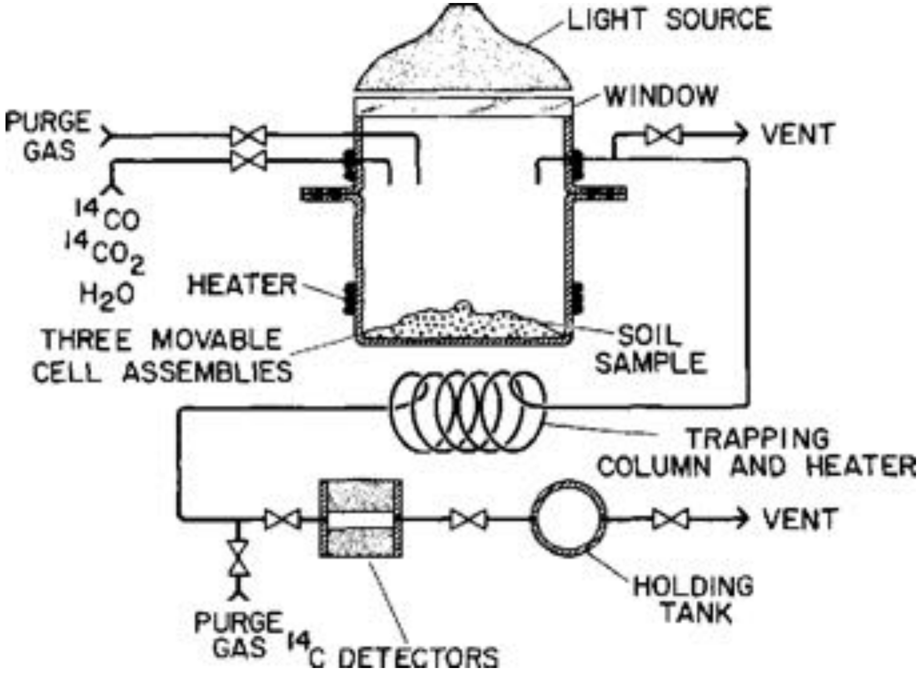
- Carbon, Hydrogen, Oxygen, Nitrogen, Phosphorus and Sulfur are the most abundant elements in living things (97%).
- Most biomolecule consists of atoms joined by covalent bonds
- Other important chemical bonds include ionic bonds, Hydrogen bonds and van der Waals interactions.

O OXYGEN	Required for cellular respiration; present in most organic compounds; component of water
C CARBON	Forms backbone of organic molecules; each carbon atom can form four bonds with other atoms
H HYDROGEN	Present in most organic compounds; component of water; hydrogen ion (H^+) is involved in some energy transfers
N NITROGEN	Component of proteins and nucleic acids; component of chlorophyll in plants
Ca CALCIUM	Structural component of bones and teeth; calcium ion (Ca^{2+}) is important in muscle contraction, conduction of nerve impulses, and blood clotting; associated with plant cell wall
P PHOSPHORUS	Component of nucleic acids and of phospholipids in membranes; important in energy transfer reactions; structural component of bone
K POTASSIUM	Potassium ion (K^+) is a principal positive ion (cation) in interstitial (tissue) fluid of animals; important in nerve function; affects muscle contraction; controls opening of stomata in plants
S SULFUR	Component of most proteins
Na SODIUM	Sodium ion (Na^+) is a principal positive ion (cation) in interstitial (tissue) fluid of animals; important in fluid balance; essential for conduction of nerve impulses; important in photosynthesis in plants
Mg MAGNESIUM	Needed in blood and other tissues of animals; activates many enzymes; component of chlorophyll in plants
Cl CHLORINE	Chloride ion (Cl^-) is principal negative ion (anion) in interstitial (tissue) fluid of animals; important in water balance; essential for photosynthesis
Fe IRON	Component of hemoglobin in animals; activates certain enzymes

Chemical basis of life

- Because the different isotopes of a given element have the same chemical characteristics, they are essentially interchangeable in molecules.
- Molecules containing radioisotopes are usually metabolized and localized in the organism in a similar way to their nonradioactive counterparts, and they can be substituted.
- Radioisotopes such as ^{3}H (tritium), ^{14}C, and ^{32}P are extremely valuable research tools used, for tracing biochemical pathways.

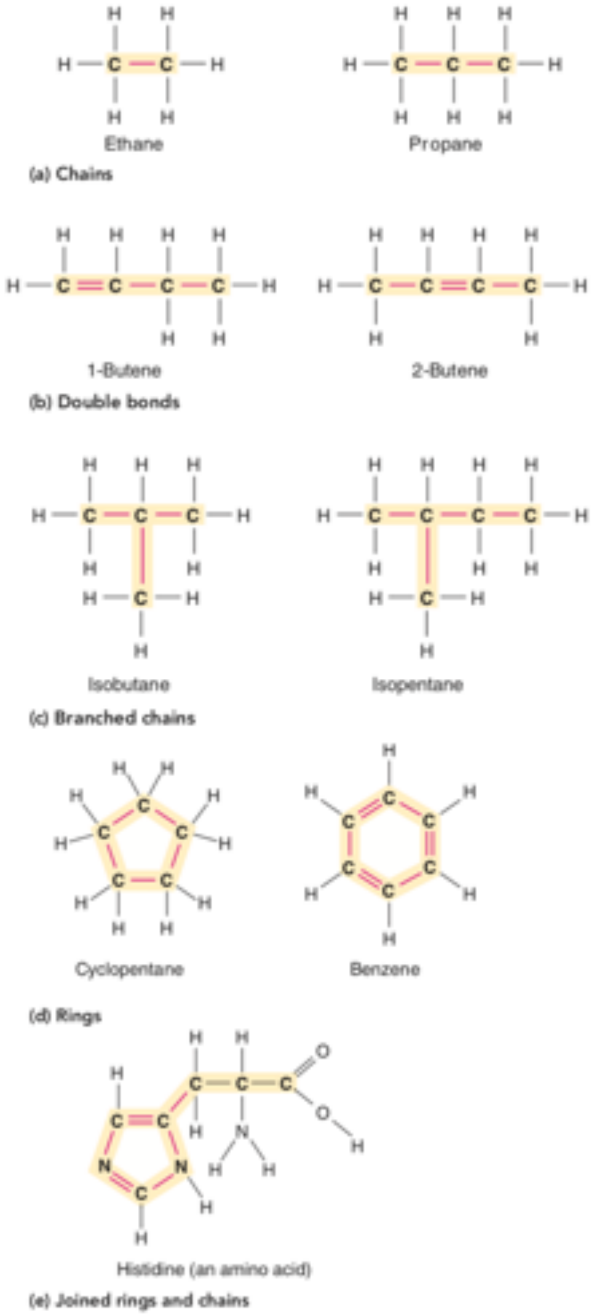
Biological experiments of the Viking Mars lander



Why Carbon?

Carbon has unique properties that allow the formation of the backbones of the large, complex molecules essential to life

1. Carbon atom can form total of 4 covalent bonds; each bond can link it to another carbon atom or to an atom of **Nitrogen, Hydrogen, Oxygen**.
2. Carbon-to-carbon bonds are strong; yet, they are not so strong that it would be impossible to break them.
3. Carbon-to-carbon bonds can form single bond, double bond, triple bond, with <u>different shape</u>. The shape of a molecule is important in determining its biological properties and function. Carbon atoms can produce a wide variety of 3-D molecular shapes



The FOUR Classes of Large Biomolecules

All living things are made up of four classes of large biological molecules:

1. **Carbohydrates**
2. **Lipids**
3. **Protein**
4. **Nucleic Acids (DNA & RNA)**

Large Biomolecules are called Macromolecules

Made of large number of molecules composed of thousands of *covalently* bonded atoms

Organic compounds (biomolecules)

- Organic compounds can be **monomers** or **polymers**

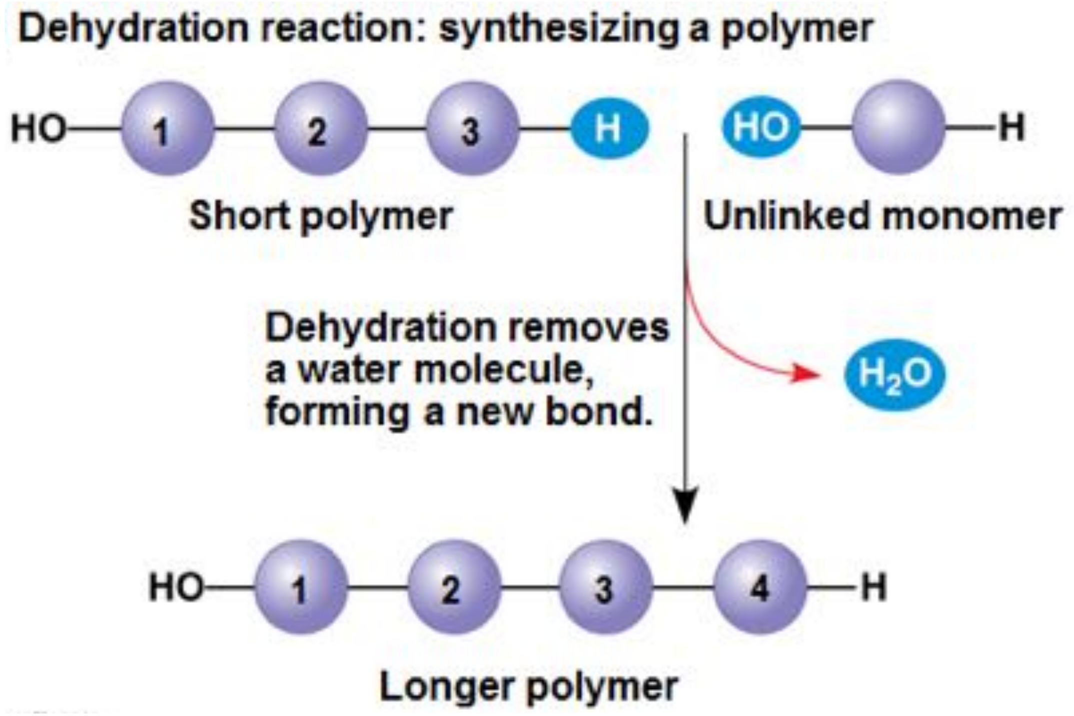
- Carbon atoms directly join with one another or other atoms to form large molecules

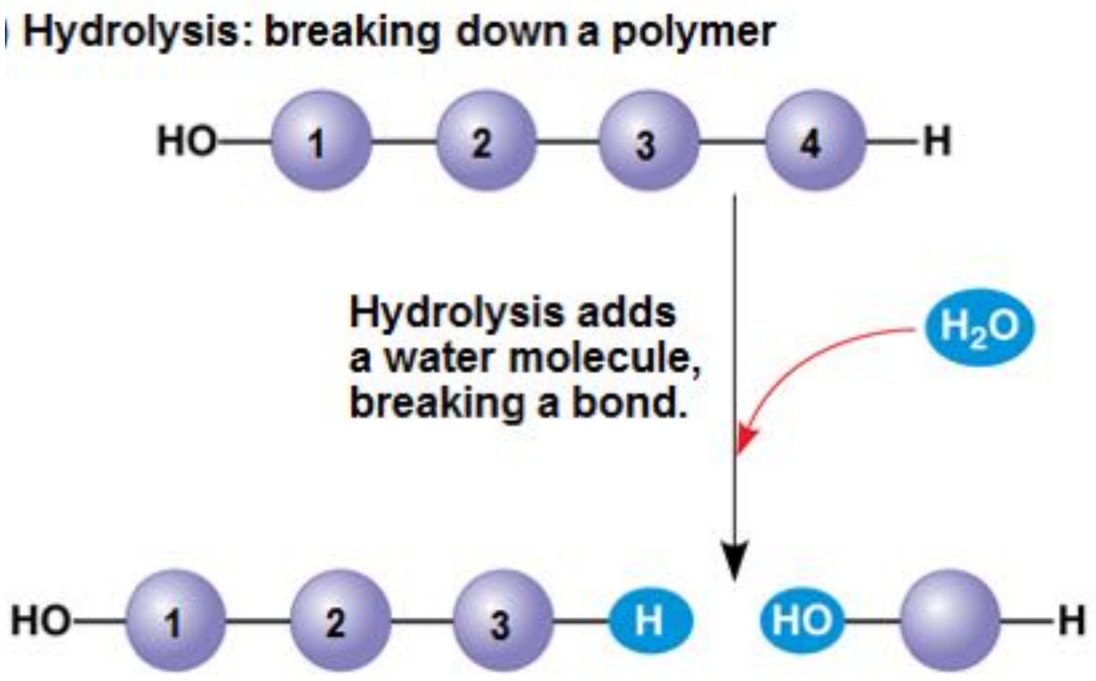
  Example: lipids

- Monomers can be joined by dehydration that are **polymers**
  - **Example:** Carbohydrates, Proteins, Nucleic acids

The synthesis and breakdown of polymers

- **Condensation reaction joins** two monomers together
- Condensation through the loss of a water molecule is dehydration





- **Hydrolysis reaction** disassembles polymers to monomers by a reaction that is reverse of the dehydration reaction

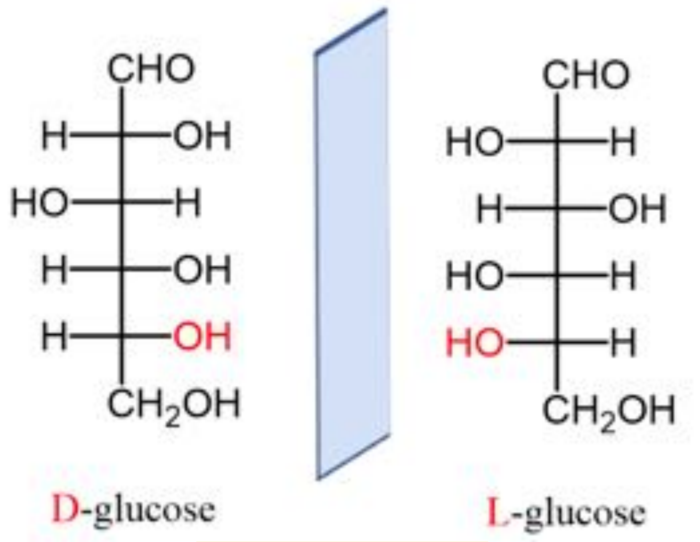
Carbohydrates

- **Carbohydrates** are the polymers of sugars
- C, H, O
- The simplest monomer of carbohydrates are *monosaccharides* (single sugars)

- A *disaccharide* is formed form two monosaccharides

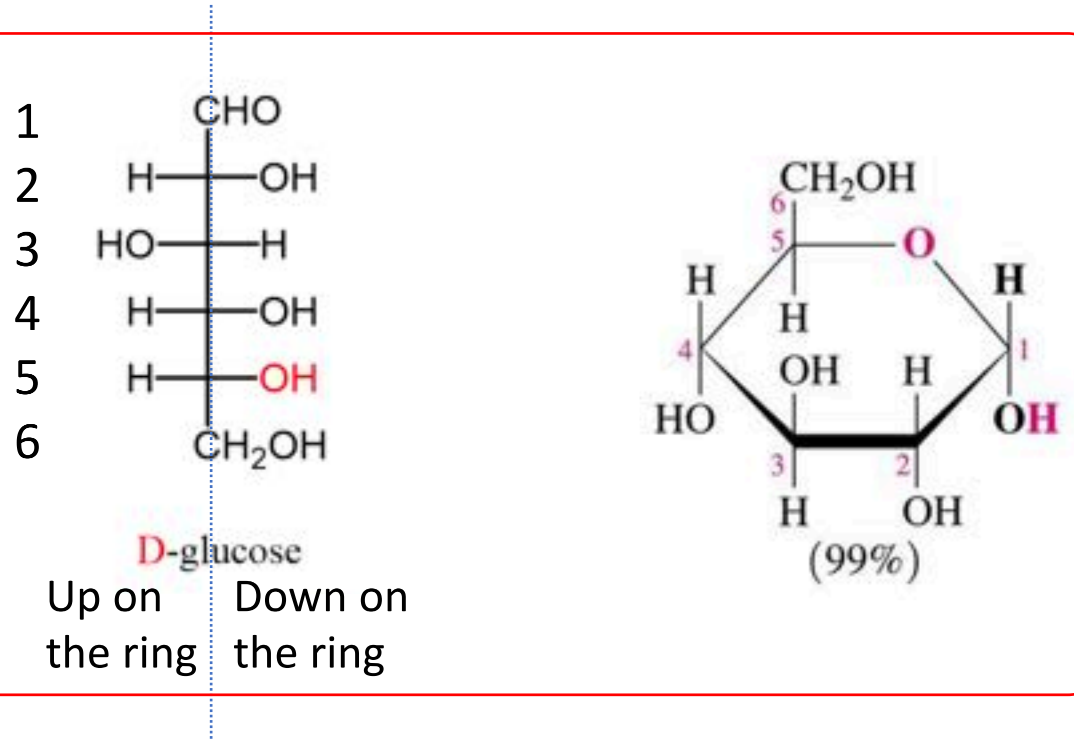
- Carbohydrate macromolecules are *polysaccharides*, polymers composed of many sugar building blocks

Monosaccharide: Glucose



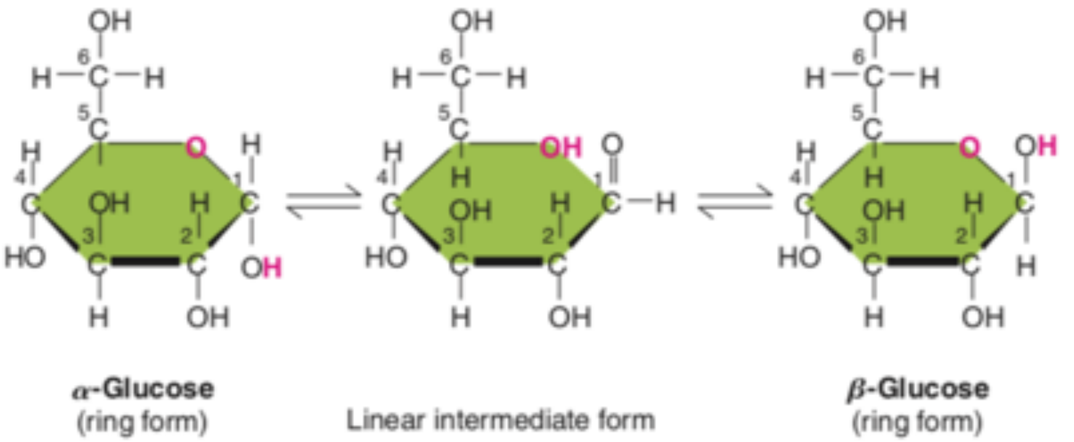
Enantiomers

All biological sugars are D enantiomer
What does this suggest about the evolution of sugars?



Glucose in solution typically exists as a ring of five carbons and one oxygen.

Monosaccharide: Glucose



When dissolved in water, glucose undergoes a rearrangement of its atoms, forming one of three possible structures: 2 ring structure and and 1 open structure

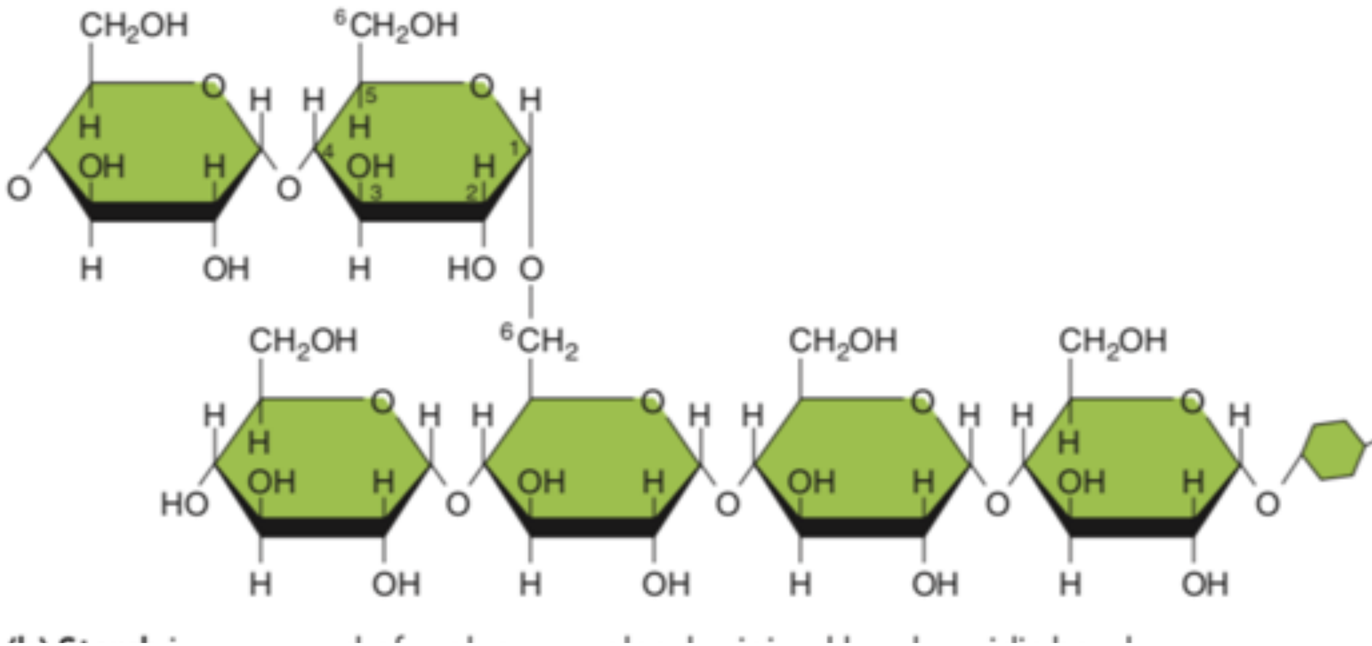
- When glucose forms a ring, two isomeric forms are possible, α-glucose and β-glucose
- The differences between α-glucose and β-glucose: in α-glucose, the -OH group on the 1st carbon is present on the same side as that of the CH_2OH group

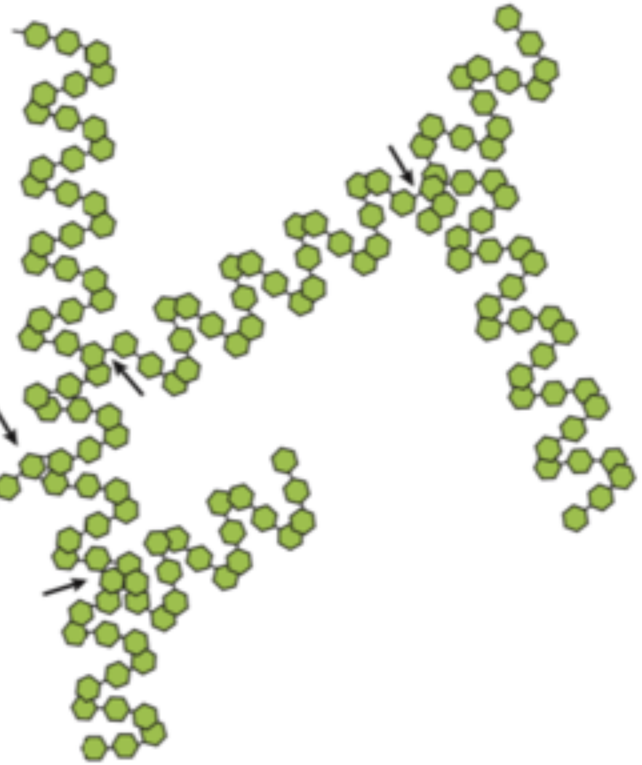
Polysaccharides

- When α-glucose molecules are joined chemically to form a polymer starch is formed.

- When β-glucose molecules are joined to form a polymer cellulose is formed.

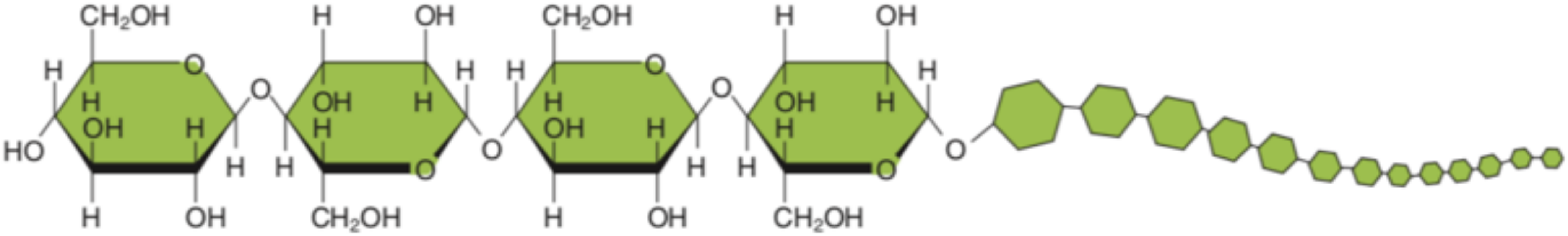
Polysaccharides





Starch: branched polymer of α-glucose molecules

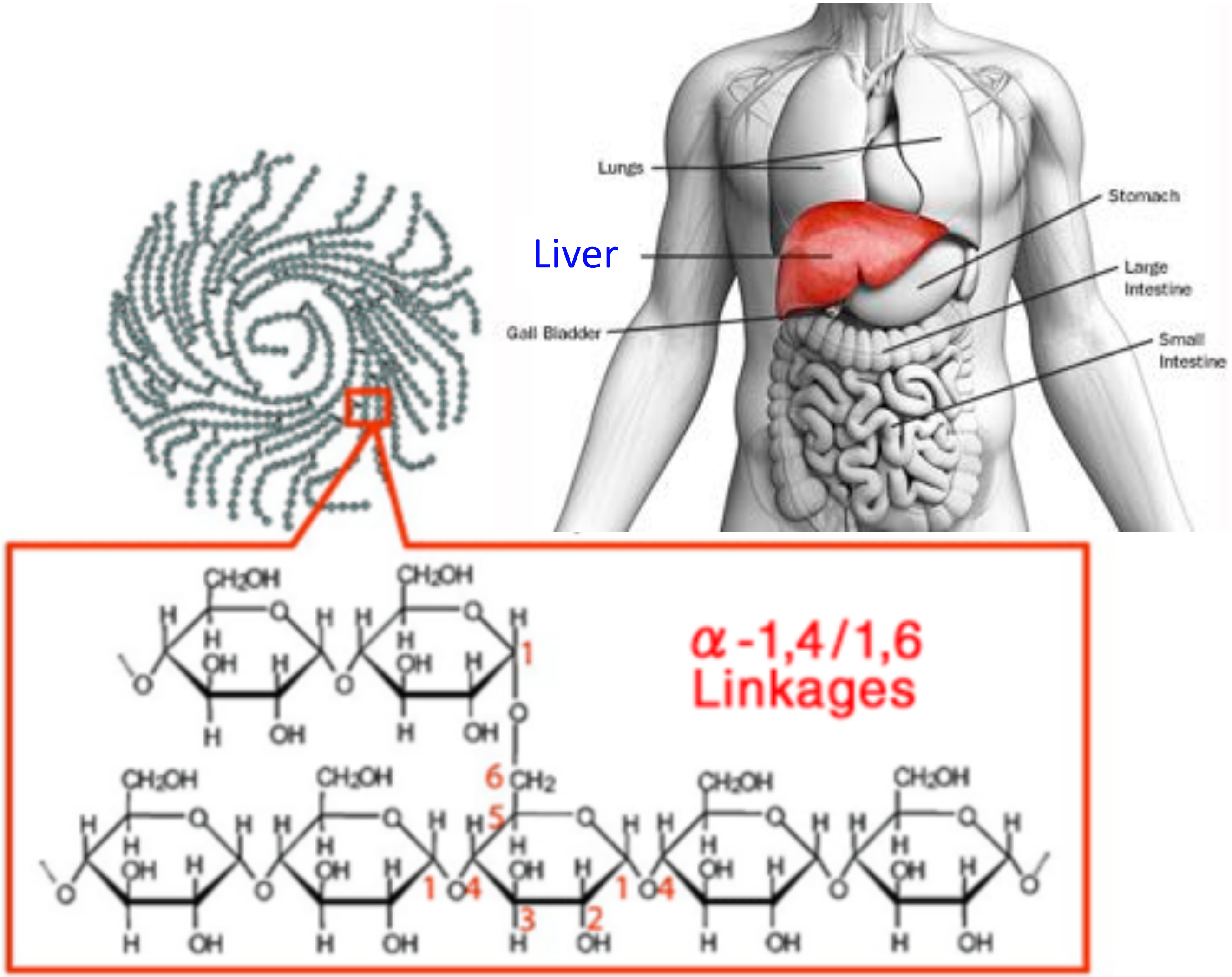
Polysaccharides



Cellulose: unbranched polymer of β-glucose molecules

Polysaccharides

- **Glycogen** is a storage polysaccharide in animals
- Polymer of α-glucose
- This covalent bond is called a **glycosidic linkage**
- Humans store glycogen in **liver** & **muscle** cells



In the human diet, carbohydrates constitute approximately half the total caloric intake, yet only 1% of body weight is carbohydrate.

- Most of the carbohydrates in the human diet are **used as fuel** to **supply the energy** requirements of the organism.
- The amount of energy: 4 calories in a gram of carbohydrate or protein. 9 calories in a gram of fat.
- Thus, carbohydrate contributes relatively little to the weight of the body.

Lipids

- **Lipids** are the one class of large biological molecules that <u>do not form polymers</u>
- C, H, O (sometimes N, P)

- Lipids Are **Hydrophobic** (no affinity for water) because they consist mostly of **hydrocarbons**

Biologically important lipids are classified into:

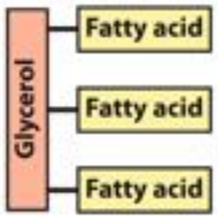
1. Energy storage lipids: fat
2. structural lipids: phospholipid
3. sterols

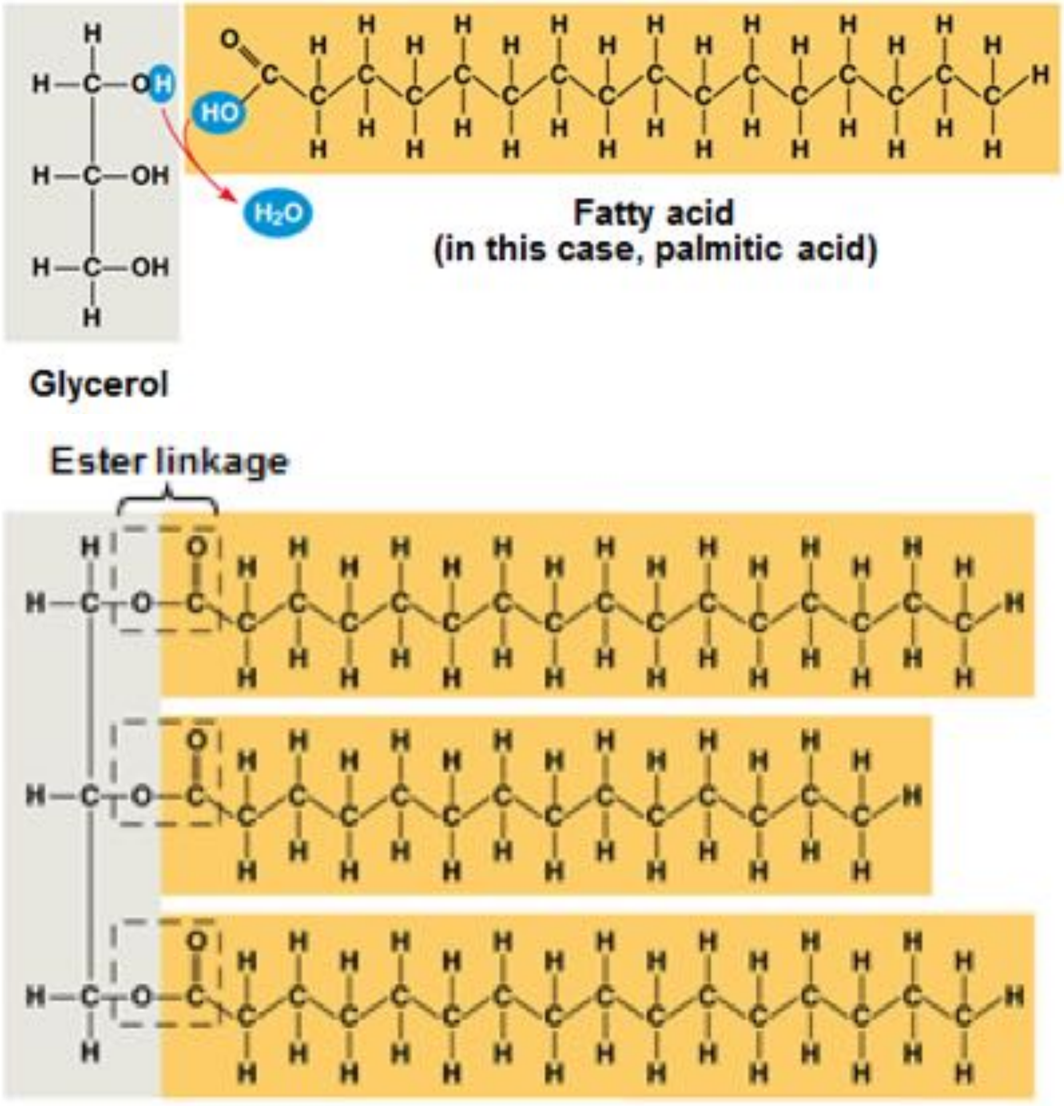
Storage lipids

- **Fats** are made from two types of molecules: **glycerol** & **fatty acids**
- Glycerol has 3 hydroxyl groups

- **Fatty acid** consists of a carboxyl group attached to <u>long carbon chain</u>
- **Three** fatty acids joins the hydroxyl group of the glycerol via **ester linkage (**via dehydration)

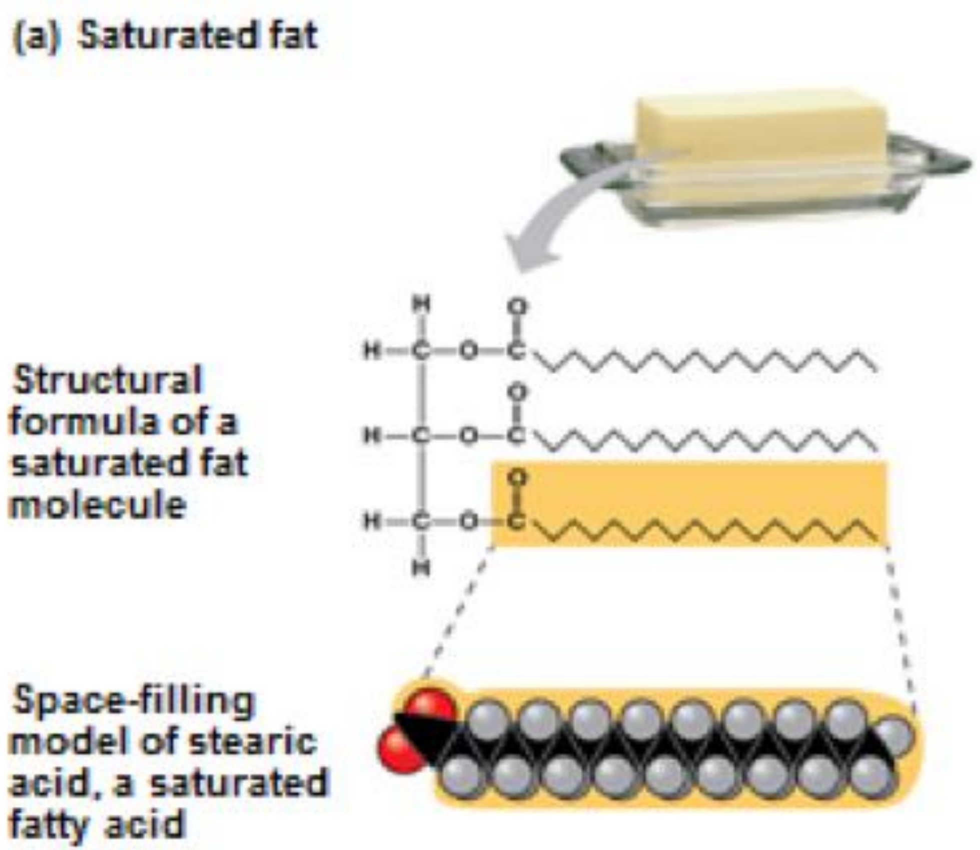
- AKA **triacylglycerol** or **triglyceride**





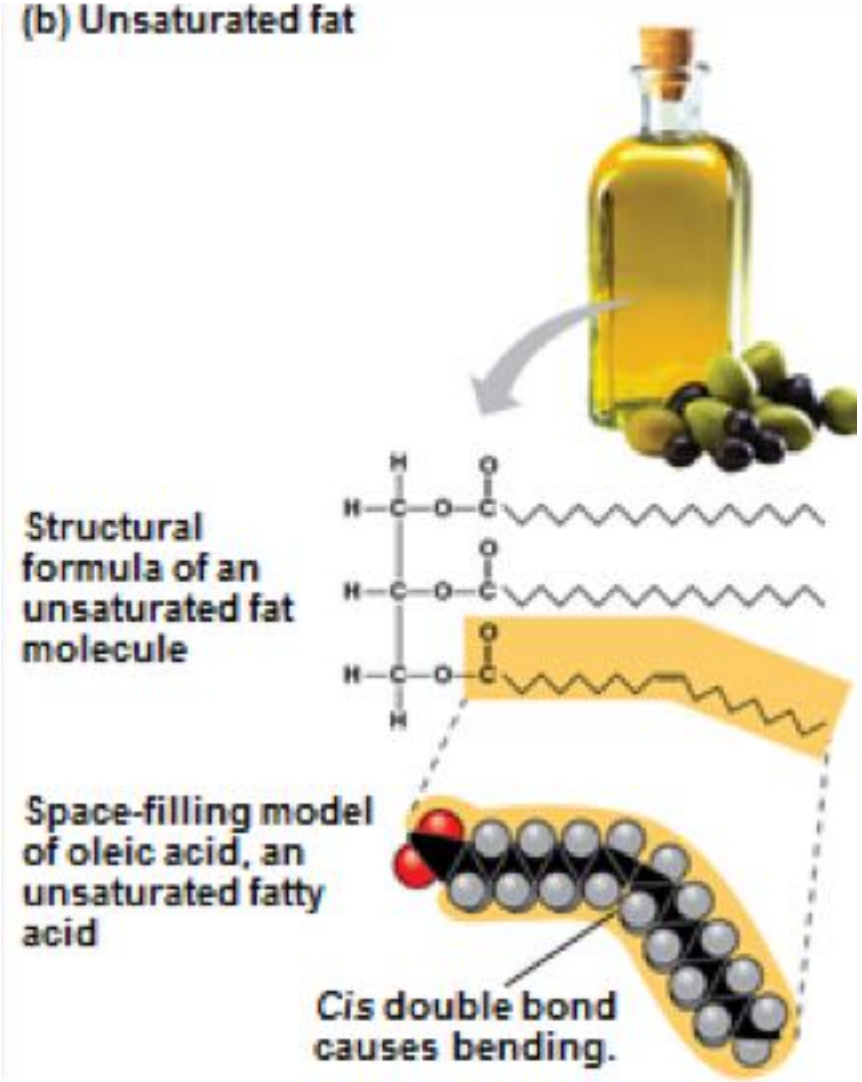
Storage lipids: Fat

- Most animal fats are saturated (butter)
- **Saturated fatty acids** have the maximum number of hydrogen atoms possible and *no double bonds*
- Fully saturated fatty acids, molecules **can pack together tightly** in arrays, with atoms all along their lengths in **van der Waals contact** with the atoms of neighboring molecules.
- More thermal energy in needed to disorder these arrays of saturated fatty acids, they have higher melting points & solid in room temperature

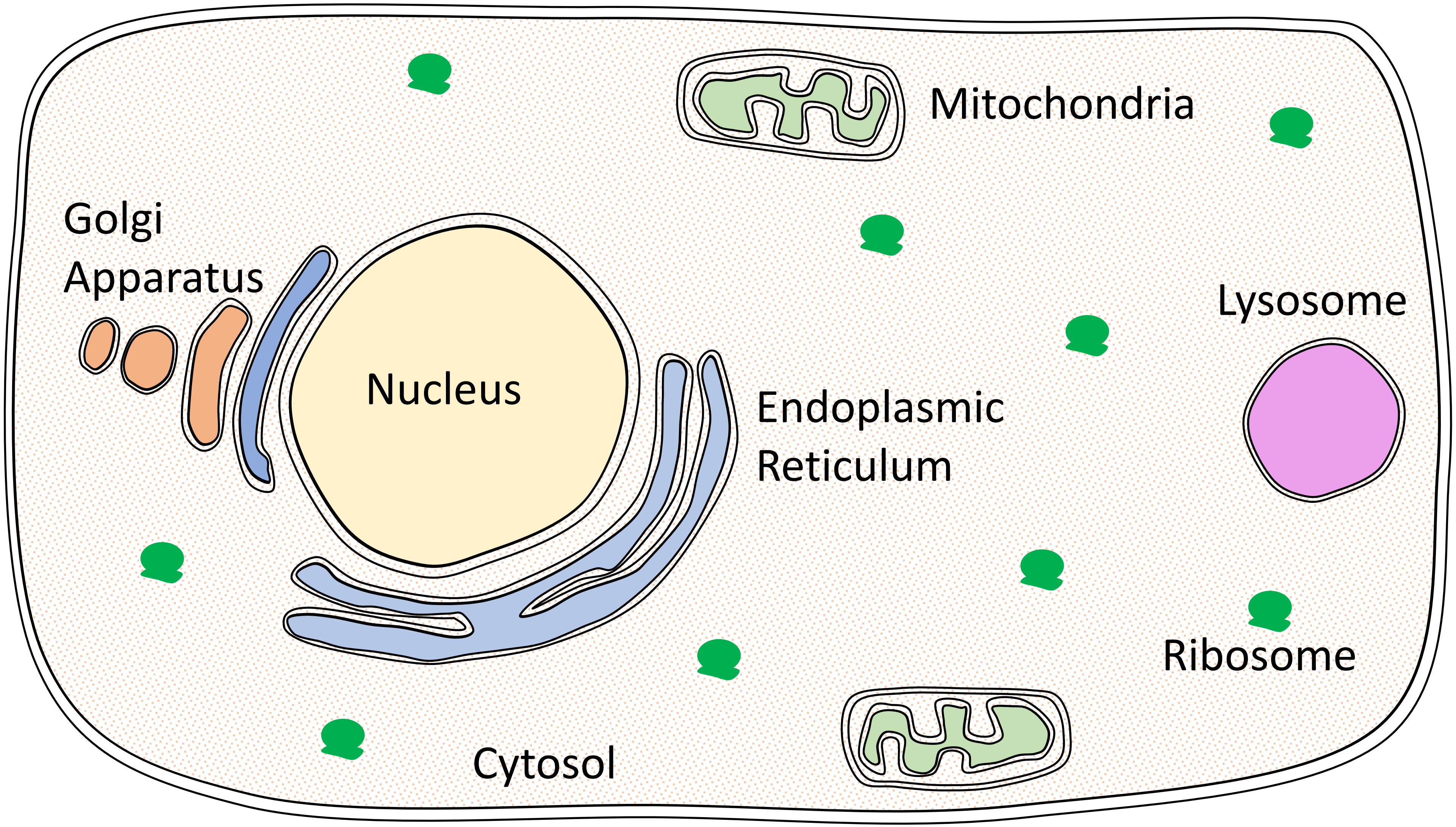


Storage lipids: oil

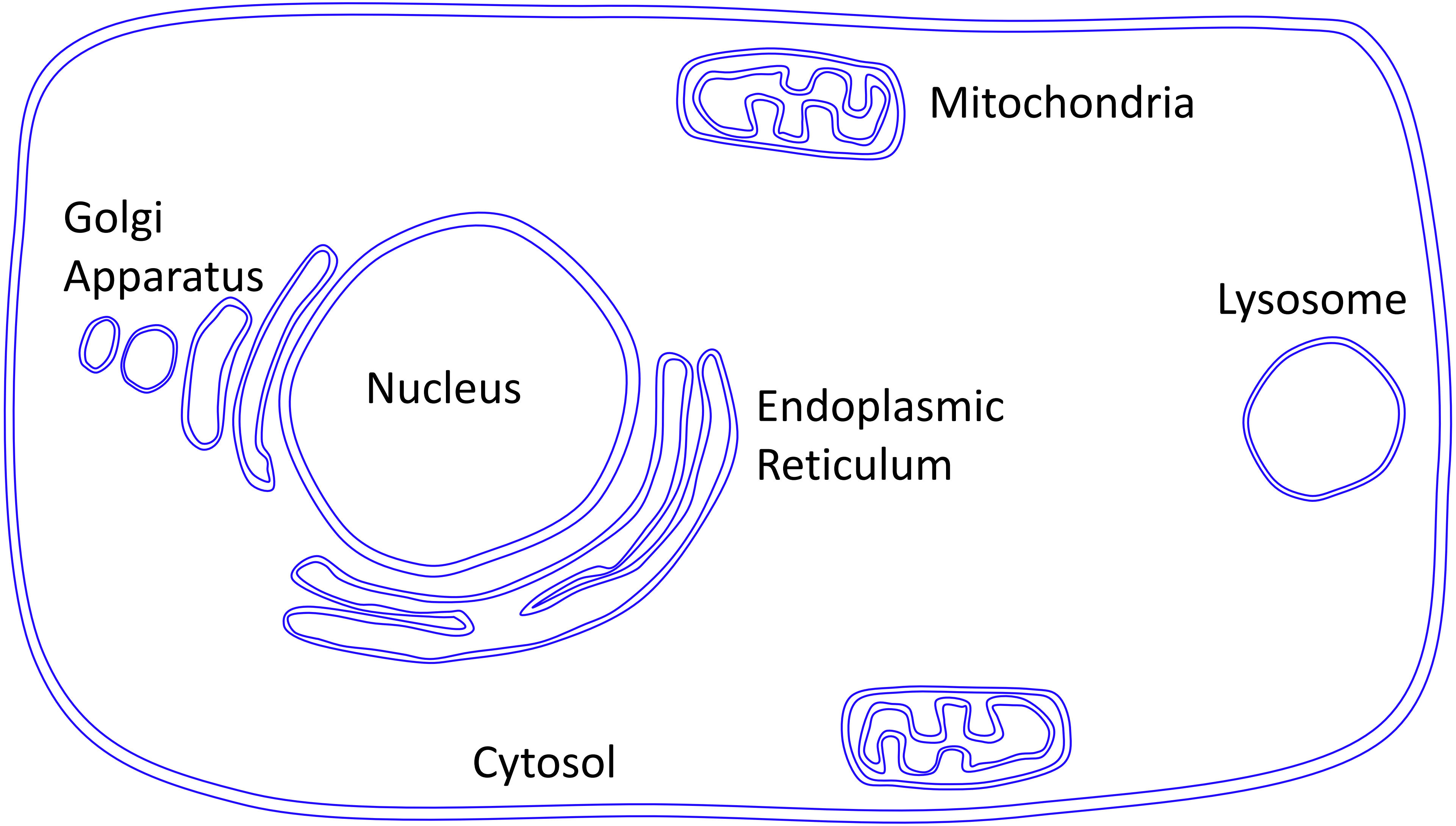
- Oils are made from unsaturated fatty acids
- Liquid at room temperature
- Plant fats and fish fats are usually unsaturated
- **Unsaturated fatty acids** have *one or more double bonds*
- Because less thermal energy is needed to disorder these poorly ordered arrays of unsaturated fatty acids, they have lower melting points than saturated fatty acids of the same chain length



Structural lipid: cell membrane

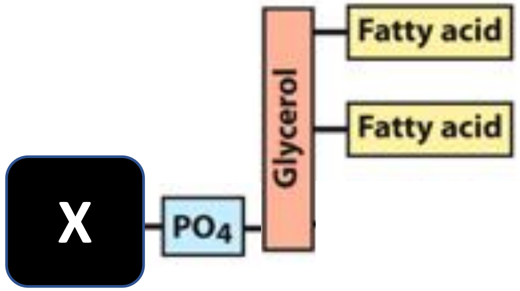


Structural lipid: cell membrane

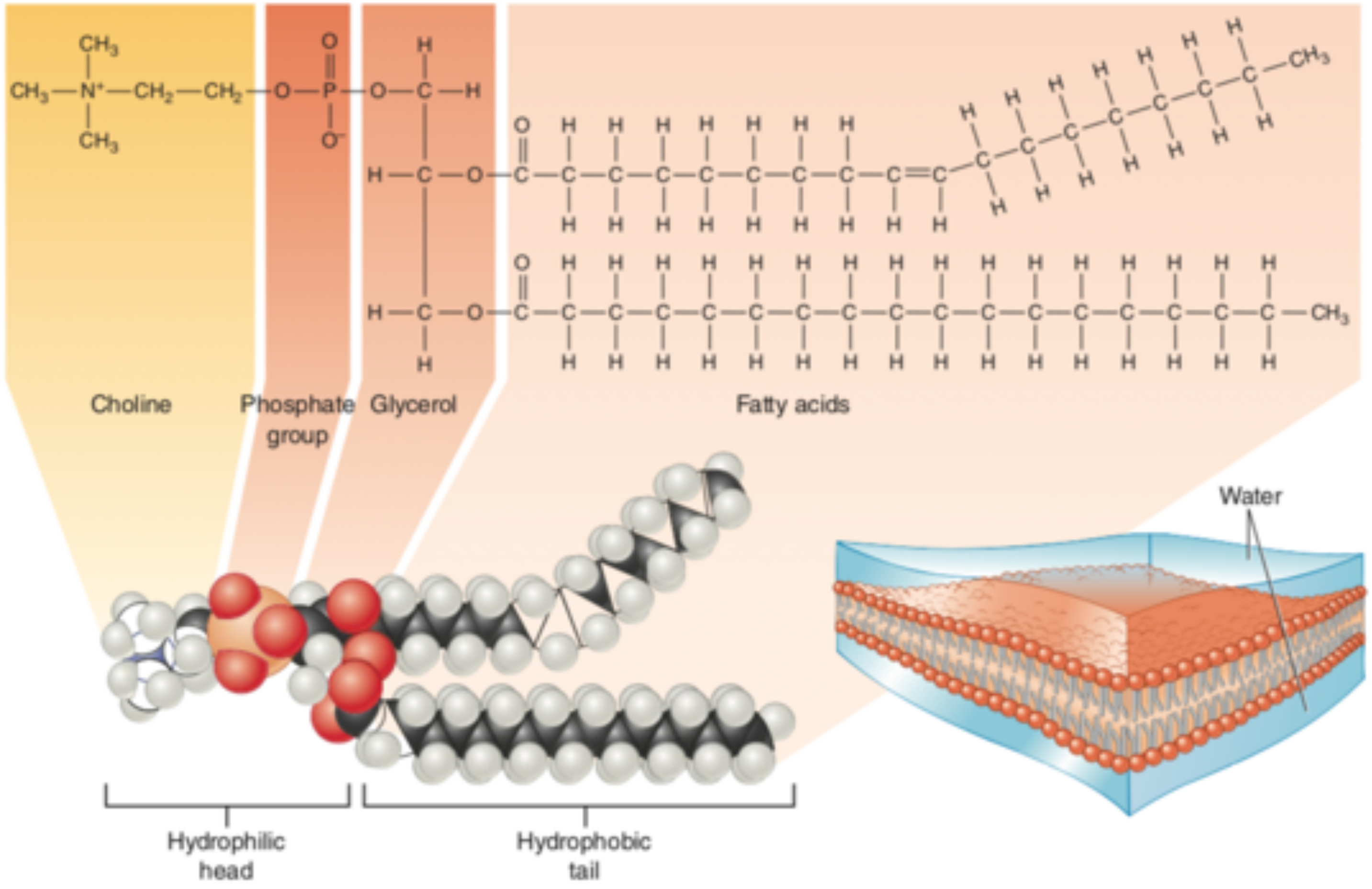


Structural lipid: cell membrane

Varies between the tissue →

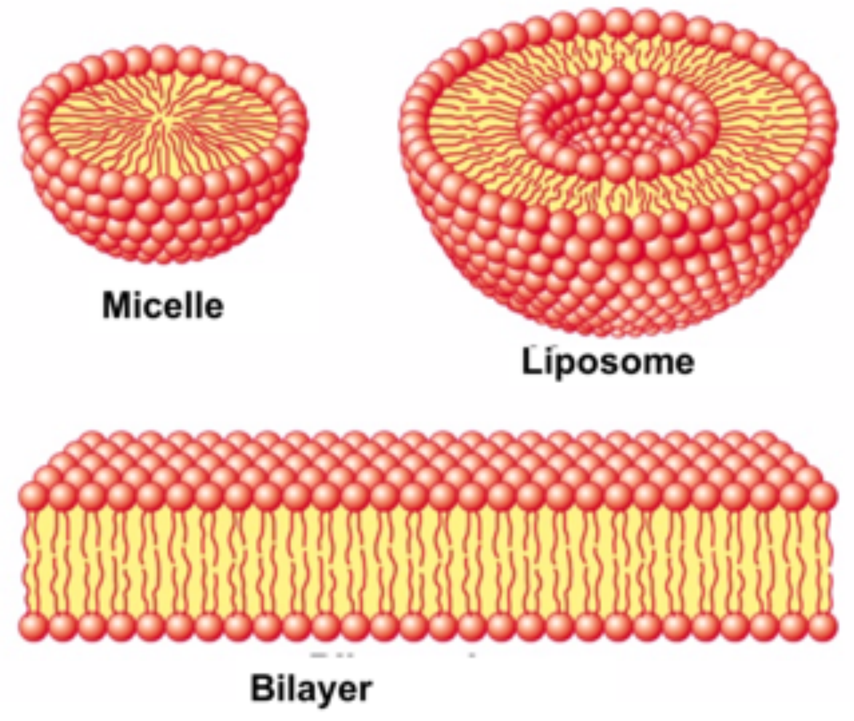


- The central feature of structural lipids are **amphipathic**
- <u>one end of the molecule is **hydrophobic**, the other end is **hydrophilic**</u>
- **Phospholipids** form all biological membranes

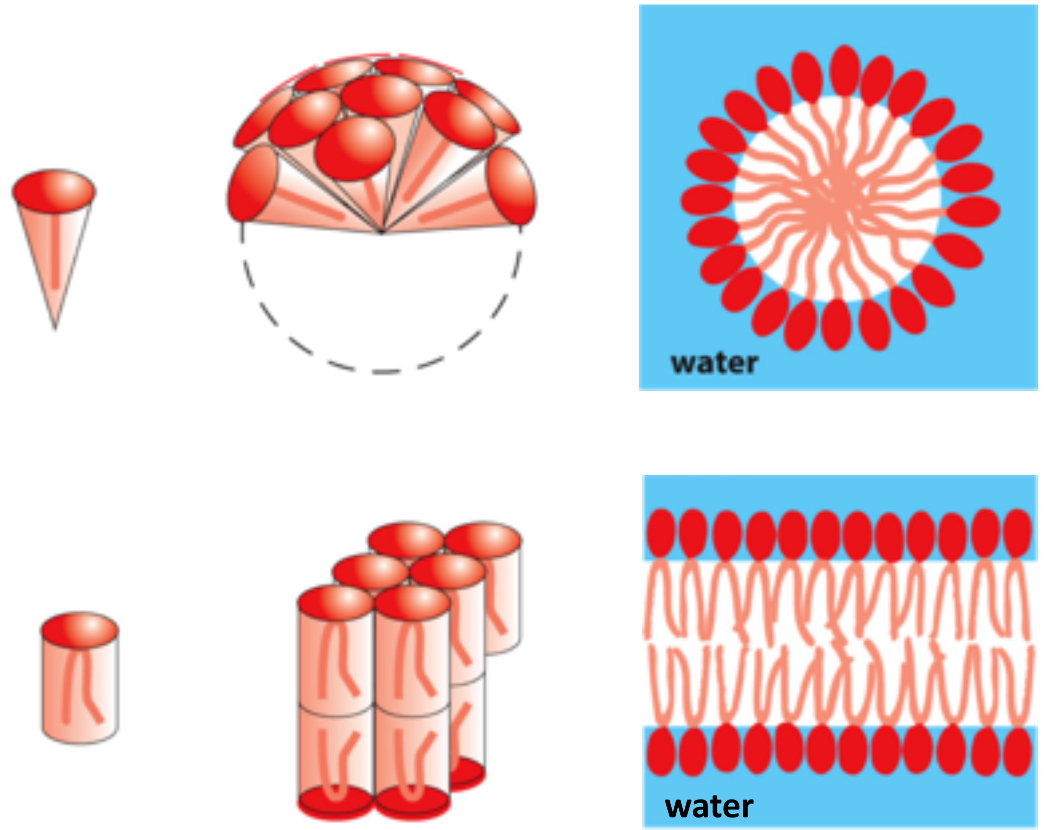


Basic characteristics of structural lipids

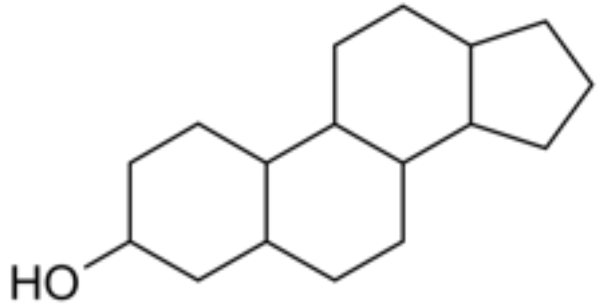
- Phospholipids spontaneously form 3 types of structures in water



- Shape of the Phospholipid molecules determine their packing and structure



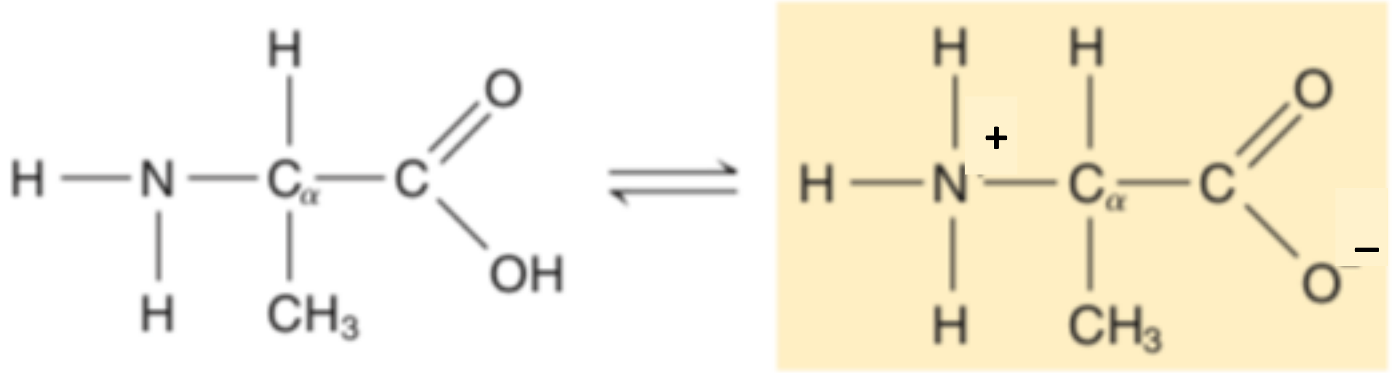
Sterols



- **Sterols** are lipids characterized by a carbon skeleton consisting of four fused rings
- **Cholesterol**, an important sterol, is a component in animal cell membranes
- The overall length of the molecule is similar to a 16-carbon fatty acid chain.
- In addition to their roles as membrane constituents, sterols serve as precursors for a variety of biologically important molecules.
- Example: **Steroid hormones, Vitamin D, Bile acids** etc.

Proteins

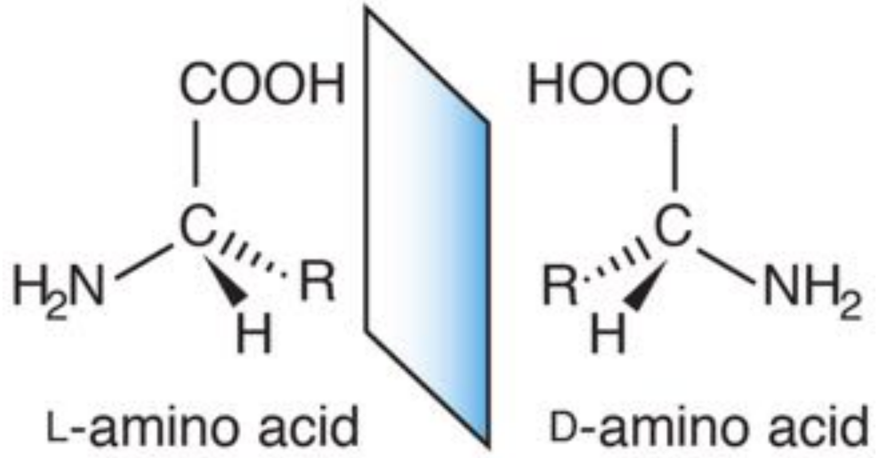
- Proteins are polymers of amino acids
- C, H, O, N, S
- **Amino acids**, have an amino group (—NH_2) and a carboxyl group (—COOH) bonded to the same asymmetrical carbon atom.
- Amino acids in solution at neutral pH possess a positive charge at one end and a negative charge at the opposite end.



Ionized form

Amino acids

- Each amino acid could potentially exist as one of two possible enantiomers, known as the D-form and the L-form
- All biological amino acids are L-amino acids
- What does this suggest about the evolution of proteins?

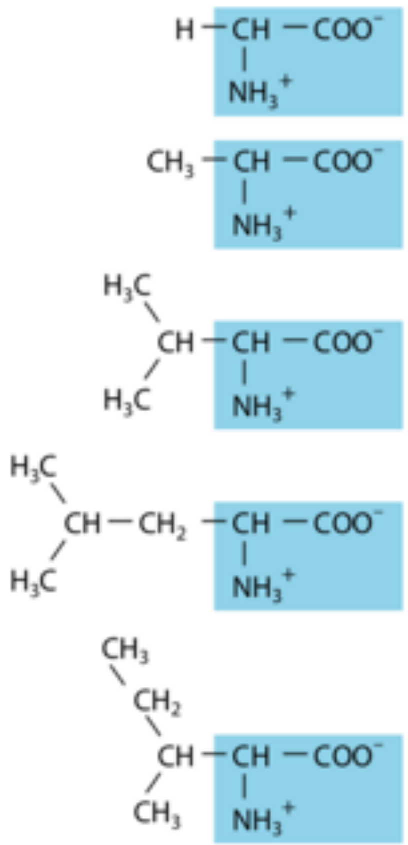


Enantiomers

Twenty amino acids

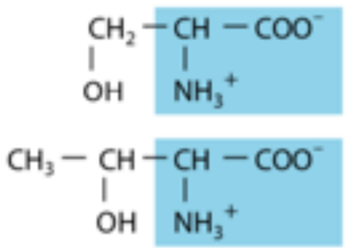
With Aliphatic Side Chains

Glycine	Gly [G]
Alanine	Ala [A]
Valine	Val [V]
Leucine	Leu [L]
Isoleucine	Ile [I]



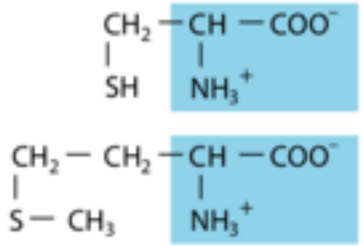
With Side Chains Containing Hydroxylic (OH) Groups

Serine	Ser [S]	
Threonine	Thr [T]	
Tyrosine	Tyr [Y]	See below.



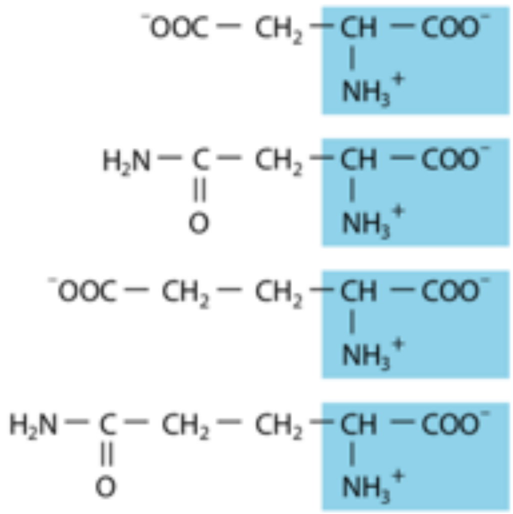
With Side Chains Containing Sulfur Atoms

Cysteine	Cys [C]
Methionine	Met [M]

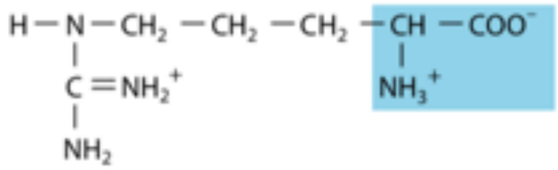
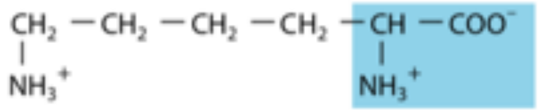
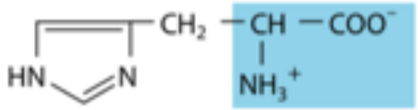
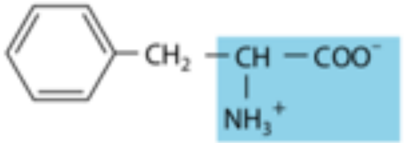
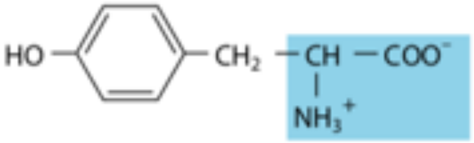
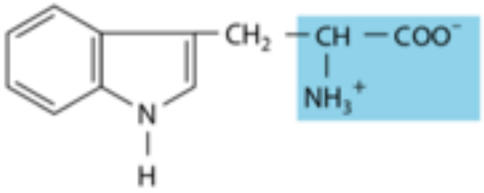
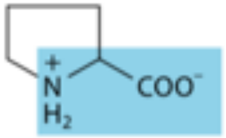


With Side Chains Containing Acidic Groups or Their Amides

Aspartic acid	Asp [D]
Asparagine	Asn [N]
Glutamic acid	Glu [E]
Glutamine	Gln [Q]



Twenty amino acids

With Side Chains Containing Basic Groups		
Arginine	Arg [R]	
Lysine	Lys [K]	
Histidine	His [H]	
Containing Aromatic Rings		
Histidine	His [H]	See above.
Phenylalanine	Phe [F]	
Tyrosine	Tyr [Y]	
Tryptophan	Trp [W]	
Imino Acid		
Proline	Pro [P]	

Abbreviations of twenty amino acids

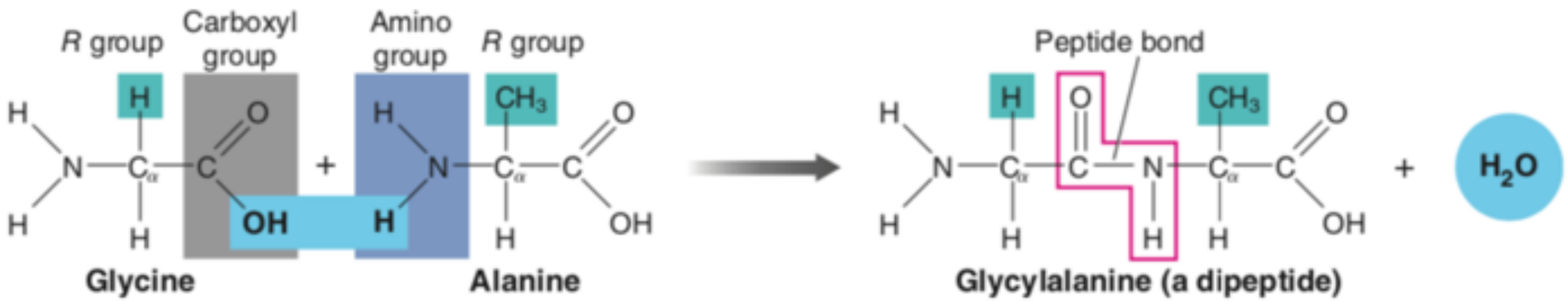
AMINO ACID		
Aspartic acid	Asp	D
Glutamic acid	Glu	E
Arginine	Arg	R
Lysine	Lys	K
Histidine	His	H
Asparagine	Asn	N
Glutamine	Gln	Q
Serine	Ser	S
Threonine	Thr	T
Tyrosine	Tyr	Y

AMINO ACID		
Alanine	Ala	A
Glycine	Gly	G
Valine	Val	V
Leucine	Leu	L
Isoleucine	Ile	I
Proline	Pro	P
Phenylalanine	Phe	F
Methionine	Met	M
Tryptophan	Trp	W
Cysteine	Cys	C

Need to memorize

Peptide bonds

- Two amino acids are joined by ***peptide bond***



- Multiple amino acids join together to form proteins

Linear orders of amino acids can make a huge number of proteins

Consider a peptide with two amino acids

AA1 – AA2

20 x 20 = 400 different molecules

AA1 – AA2 – AA3

The number of distinct proteins containing *n* amino acids = 20^{n}

20 x 20 x 20 = 8000 different molecules

For 100 amino acid protein the # of possibilities are: $20^{100} = 1.27x10^{130}$

The actual number of proteins is much low; Why?→ **Ramachandran Plot**

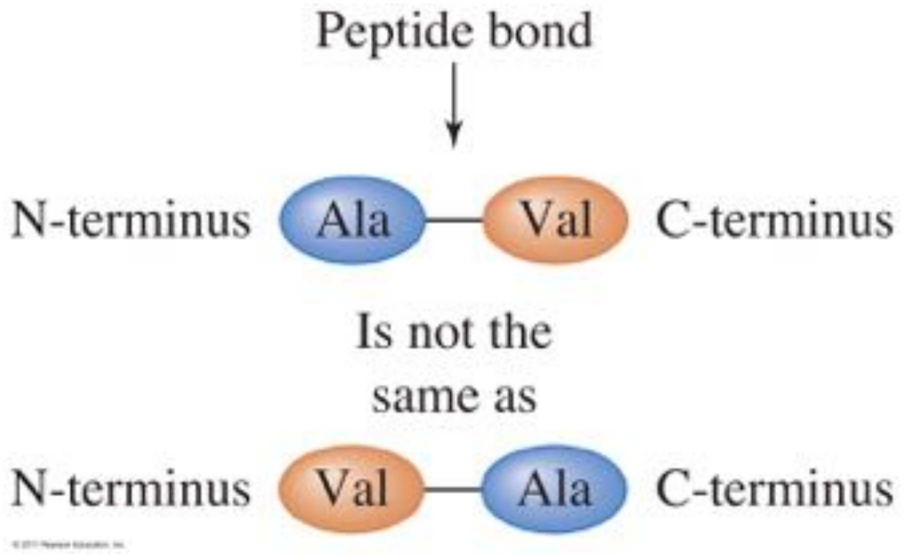
Primary structure of proteins

- The order or sequence of amino acids in a protein chain are important in determining its **structure and function**.
- Arranging amino acids in a different order creates different protein
- For example, *angiotensin II* (blood pressure regulating protein) sequence:

Asp—Arg—Val—Tyr—Ile—His—Pro—Phe

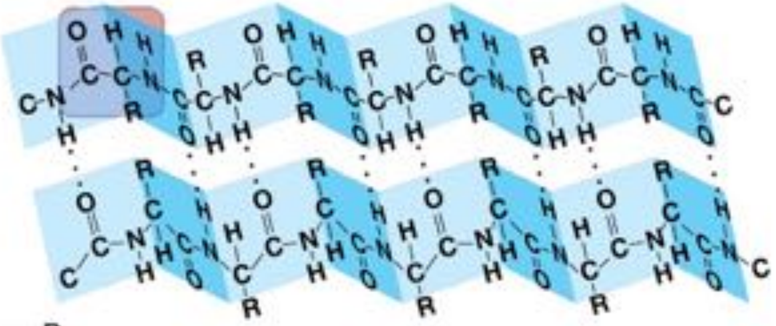
- Any other order of amino acids in this peptide would result in a peptide that would not function as angiotensin II.

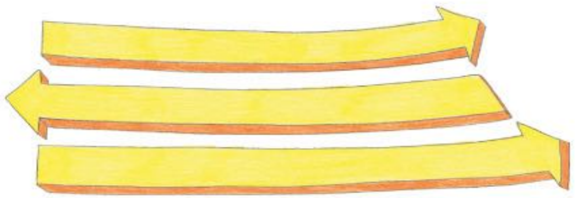
edit ≠ diet ≠ tide ≠ tied



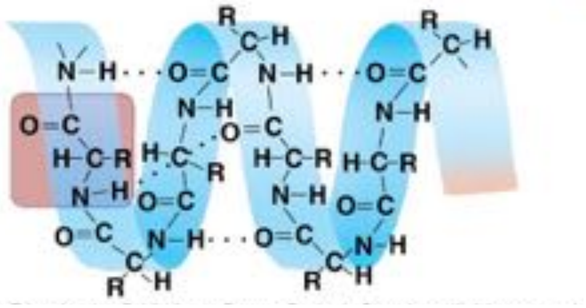
Secondary structure of proteins

- α **helix** or β **sheet** or **random coil**
- **Based on the sequence of amino acids (primary structure) protein might fold like a helix or sheet**
- **Stabilized by** Hydrogen bond between the N-H of a peptide bond to the C=O of another peptide bond (R groups are not involved)





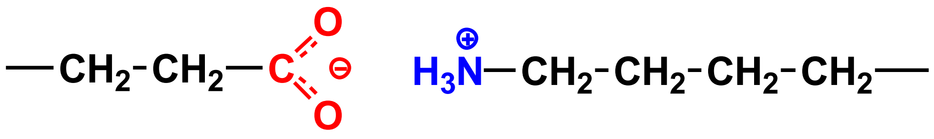
β sheet



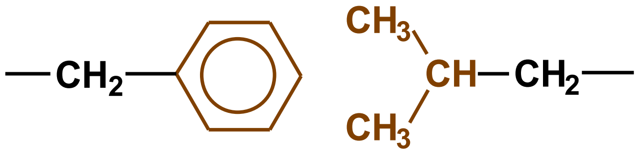
α helix

Tertiary structure of proteins:

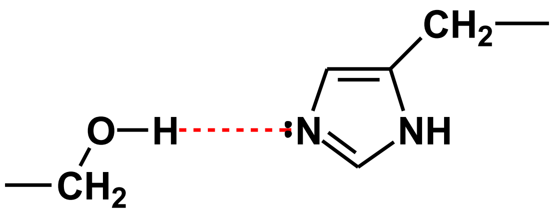
Non-covalent bonds between side-chains guide the overall conformation



Ionic bonding ("salt bridge")



Van der Waals interactions

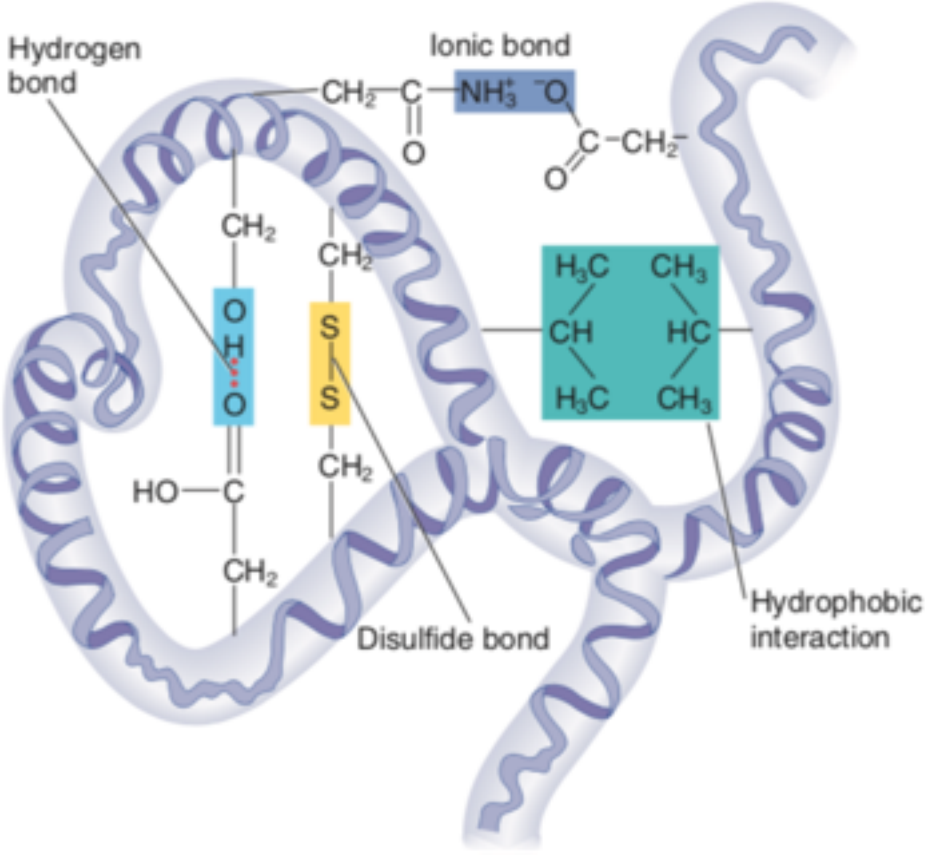


Hydrogen bonding

Tertiary structure of proteins:

Chemical bonds that hold the parts of the protein molecule in the designated shape:

- Hydrogen bonds
- ionic bonds,
- hydrophobic interactions,
- disulfide bonds



Three levels of protein structure

Primary

Secondary

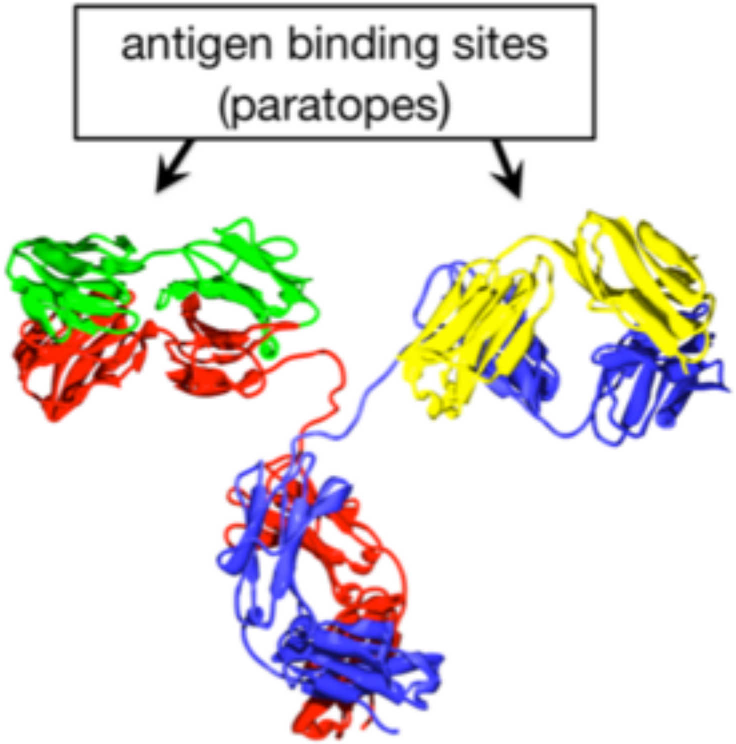
α helix **β sheet**

Tertiary.

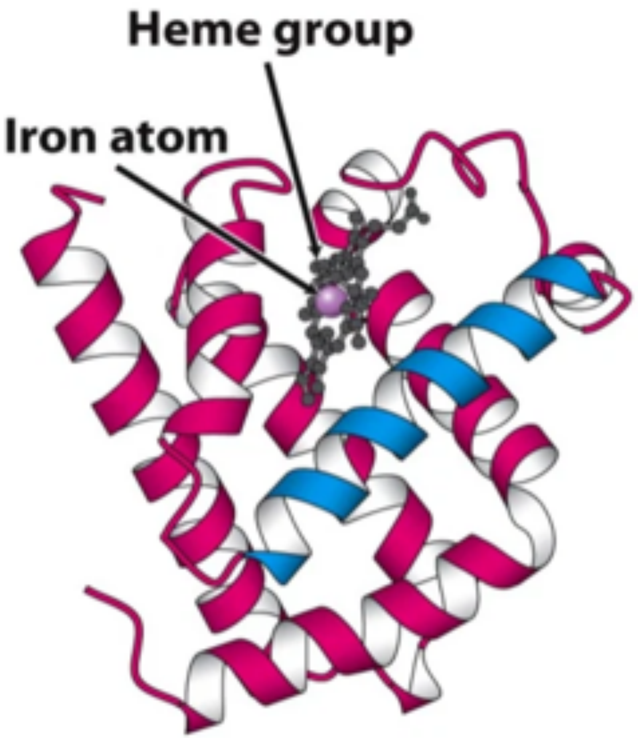
3-dimensional structure of proteins

- Proteins are classified into groups based on their three-dimensional shape.
- ***Globular proteins*** are <u>spherical </u>structures that are soluble in an aqueous environment. Example: **Hemoglobin** in blood
- ***Fibrous proteins*** are <u>long, thread-like </u>structures that have high helical content. Keratins, in hair, nails
- ***Membrane proteins*** are part of Biological membrane

Globular proteins



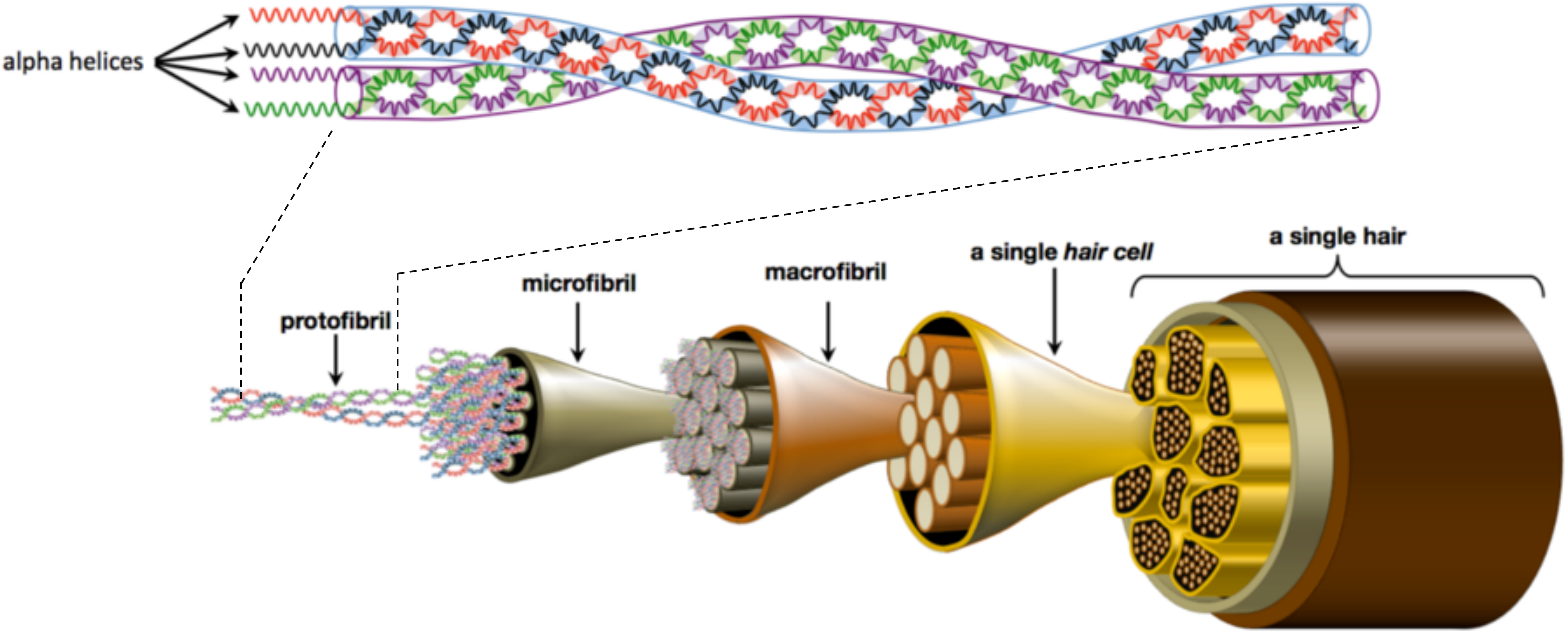
ANTIBODY



HEMOGLOBIN

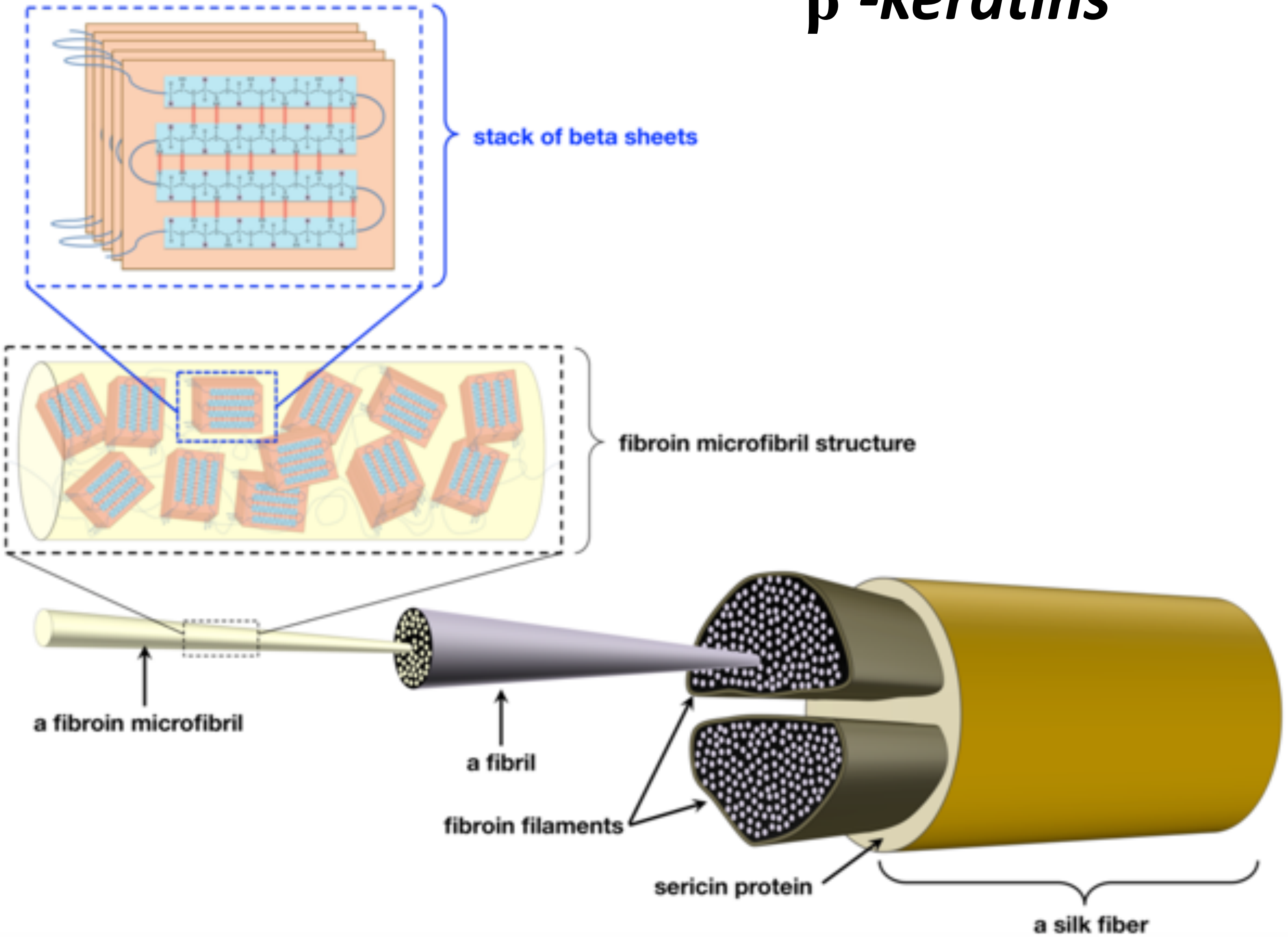
Fibrous proteins

α-keratins



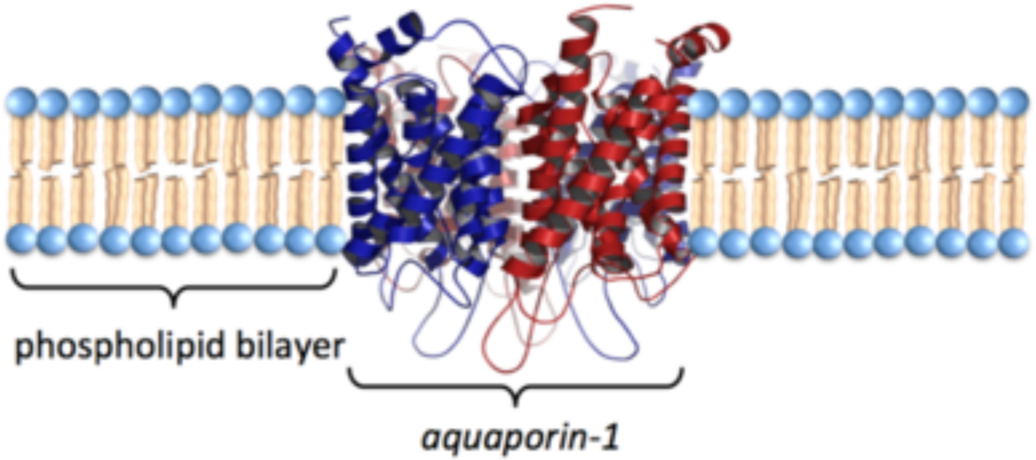
Fibrous proteins

β *-keratins*



Membrane proteins

- Membrane proteins extend **through the membrane**
- They form membrane **channel** and **pump** across the membrane bilayer
- Example: *aquaporins*



- *Aquaporin* facilitate the transport of water molecules in and out of cells.

Questions

1. All proteins contain the

(A) Same 20 amino acids

(B) Different amino acids

(C) 300 Amino acids occurring in nature

(D) Only a few amino acids

2. Which of the following statement(s) are CORRECT about <u>primary</u> structure of proteins?

A. It refers to alpha-helix

B. It refers to amino acid sequence

C. It refers to hydrogen bonding between proteins

Questions

3. What is the single letter abbreviation of this tetrapeptide "Aspartic acid-Glutamic acid-Alanine-Aspartic acid"

A. REAR

B. DEAD

C. AGAG

4. How many tetra-peptides can be made with 20 amino acids?

A. 400

B. 8000

C. 10^9

D. None of the above

Questions

5. The synthetic process by which monomers are covalently linked is

(a) hydrolysis

(b) isomerization

(c) condensation

(d) glycosidic linkage

(e) ester linkage

6. Saturated fatty acids are so named because they are saturated with

(a) hydrogen

(b) water

(c) hydroxyl groups

(d) glycerol

(e) double bonds