

(a) A ribbon model (b) A space-filling model (c) A wireframe model

Ch. 3b: The Structure and Function of Macromolecules

You Must Know

- The role of **dehydration synthesis** in the formation of organic compounds and **hydrolysis** in the digestion of organic compounds.
- How the sequence and subcomponents of the four groups of organic compounds determine their properties.
- The cellular functions of carbs, lipids, proteins, and nucleic acids.
- How changes in these organic molecules would affect their function.

You Must Know

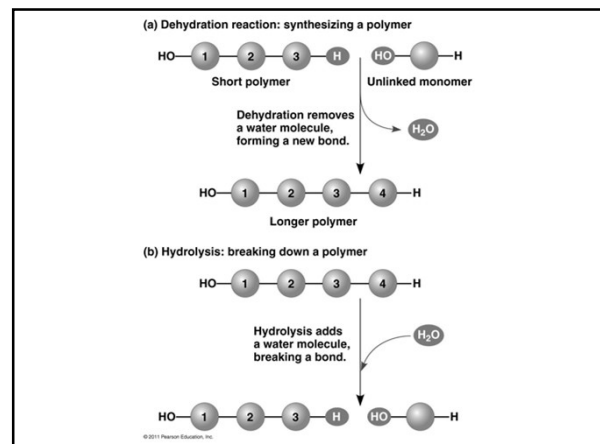
- The 4 structural levels of proteins and how changes at any levels can affect the activity of the protein.
- How proteins reach their final shape (**conformation**), the **denaturing** impact that heat and pH can have on protein structure, and how these changes may affect the organism.
- Directionality influences structure and function of polymers, such as nucleic acids (5' and 3' ends) and proteins (amino and carboxyl ends).

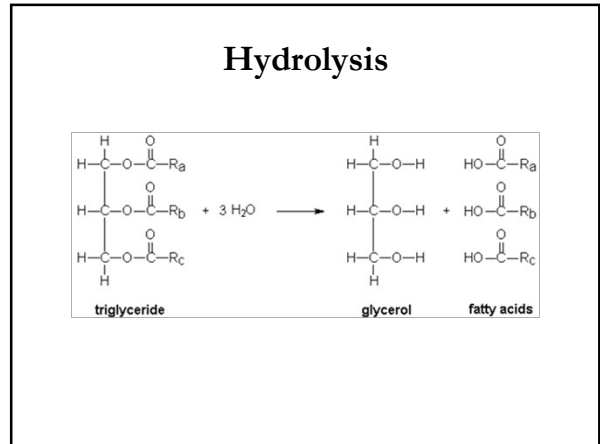
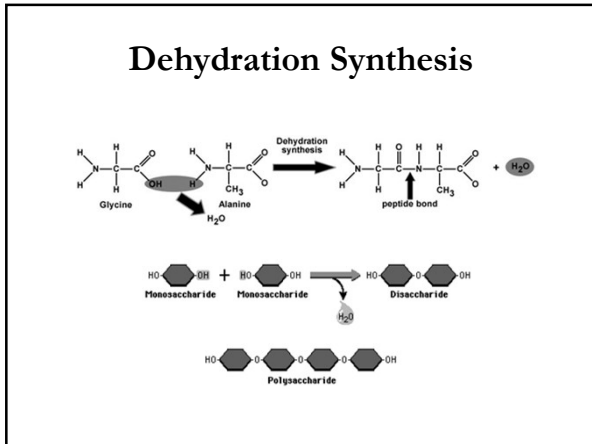
Monomers	Polymers	Macromolecules
<ul style="list-style-type: none"> Small organic Used for building blocks of polymers Connects with condensation reaction (dehydration synthesis) 	<ul style="list-style-type: none"> Long molecules of monomers With many identical or similar blocks linked by covalent bonds 	<ul style="list-style-type: none"> Giant molecules 2 or more polymers bonded together

ie. amino acid → peptide → polypeptide → protein

smaller → larger

Dehydration Synthesis (Condensation Reaction)	Hydrolysis
Make polymers	Breakdown polymers
Monomers → Polymers	Polymers → Monomers
$A + B \rightarrow AB$	$AB \rightarrow A + B$
<input type="text"/> + <input type="text"/> → <input type="text"/> + H ₂ O	<input type="text"/> + H ₂ O → <input type="text"/> + <input type="text"/>





- ## I. Carbohydrates
- **Fuel** and **building material**
 - Include simple sugars (fructose) and polymers (starch)
 - Ratio of 1 carbon: 2 hydrogen: 1 oxygen or CH₂O
 - monosaccharide → disaccharide → polysaccharide
 - Monosaccharides = monomers (eg. glucose, ribose)
 - Polysaccharides:
 - Storage (plants-starch, animals-glycogen)
 - Structure (plant-cellulose, arthropod-chitin)
- } Differ in position & orientation of glycosidic linkage

The structure and classification of some monosaccharides

Triose: three-carbon sugar (C₃H₆O₃)

Glyceraldehyde
An initial breakdown product of glucose in cells

Pentose: five-carbon sugar (C₅H₁₀O₅)

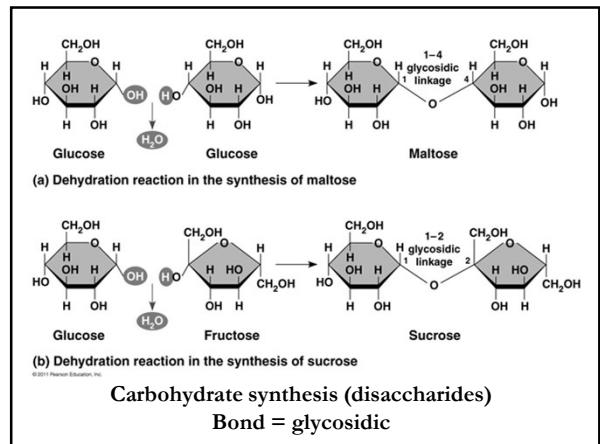
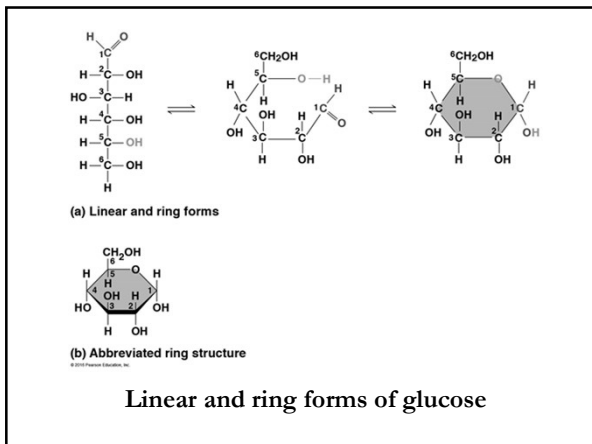
Ribose
A component of RNA

Hexoses: six-carbon sugars (C₆H₁₂O₆)

Glucose
Energy sources for organisms

Fructose
Energy sources for organisms

An OH group is attached to each carbon except one, which is double bonded to an oxygen (carbonyl).



Polysaccharides Cellulose vs. Starch

Two Forms of Glucose: α glucose & β glucose

(a) α and β glucose ring structures

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Cellulose vs. Starch

- Starch = α glucose monomers
- Cellulose = β glucose monomers

(b) Starch: 1-4 linkage of α glucose monomers

(c) Cellulose: 1-4 linkage of β glucose monomers

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Storage polysaccharides of plants (starch) and animals (glycogen)

(a) Starch

(b) Glycogen

(c) Cellulose

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Structural polysaccharides: cellulose & chitin (exoskeleton)

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IV. Lipids

- Structure: Greasy or oily nonpolar compounds
- Functions:
- Energy storage
- Membrane structure
- Protecting against desiccation (drying out).
- Insulating against cold.
- Shock-absorbers.
- Regulating cell activities by hormone actions.

IV. Lipids

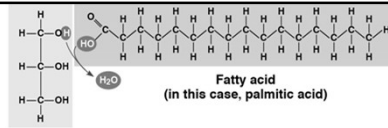
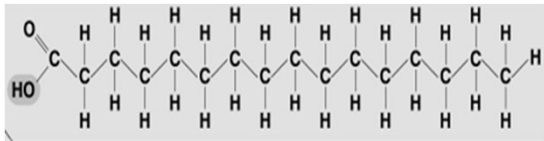
- Fats (triglyceride):** store energy
 - Glycerol + 3 Fatty Acids
 - saturated, unsaturated, polyunsaturated
- Steroids:** cholesterol and hormones
- Phospholipids:** lipid bilayer of cell membrane
 - hydrophilic head, hydrophobic tails

Hydrophilic head

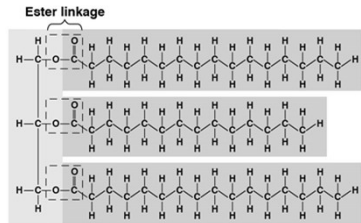
Hydrophobic tail

1. Structure of Fatty Acids

1. Long chains of mostly carbon and hydrogen atoms with a -COOH group at one end.
2. When they are part of lipids, the fatty acids resemble long flexible tails.



(a) One of three dehydration reactions in the synthesis of a fat



(a) Saturated fat

Structural formula of a saturated fat molecule

Space-filling model of stearic acid, a saturated fatty acid

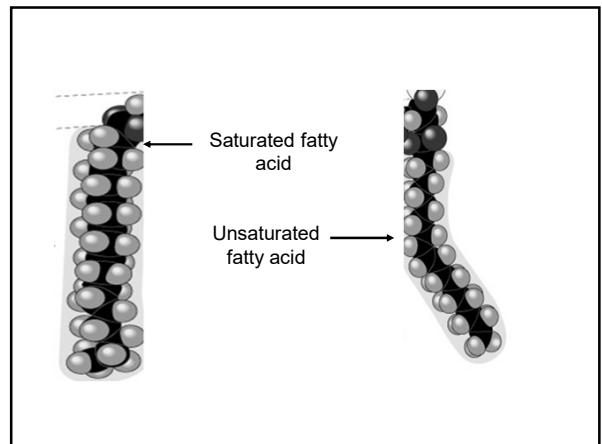
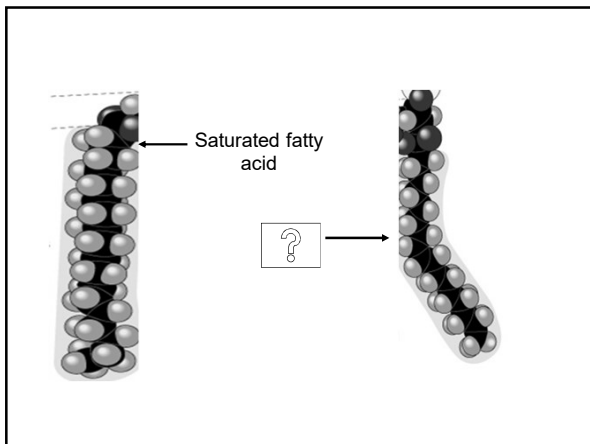
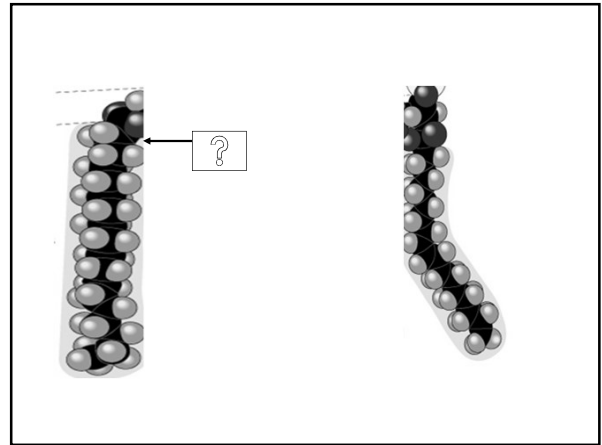
(b) Unsaturated fat

Structural formula of an unsaturated fat molecule

Space-filling model of oleic acid, an unsaturated fatty acid

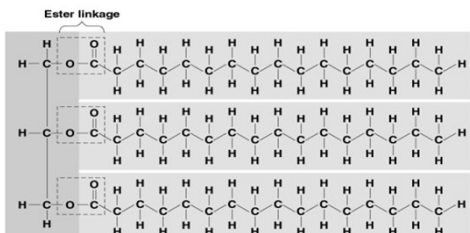
Cis double bond causes bending.

Saturated	Unsaturated	Polyunsaturated
"saturated" with H	Have some C=C, result in kinks	
In animals	In plants	
Solid at room temp.	Liquid at room temp.	
Eg. butter, lard	Eg. corn oil, olive oil	



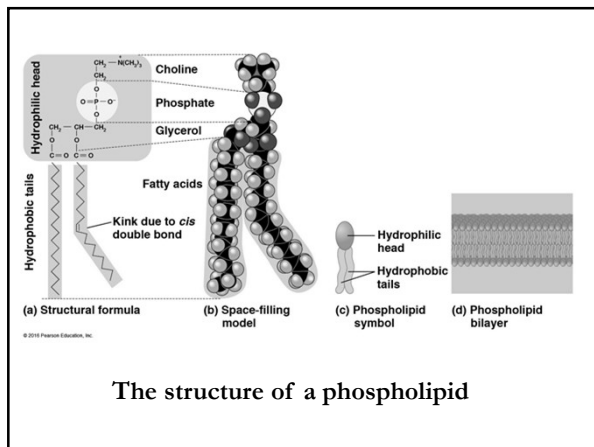
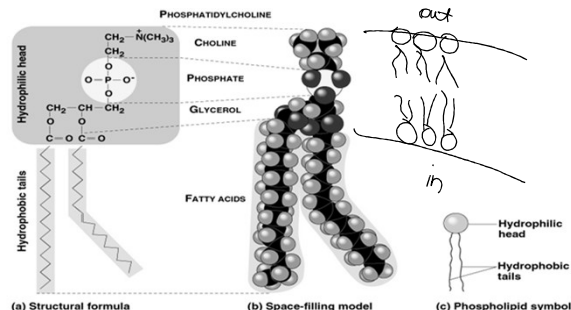
2. Structure of Triglycerides

1. Glycerol + 3 fatty acids
2. 3 ester linkages are formed between a hydroxyl group of the glycerol and a carboxyl group of the fatty acid.

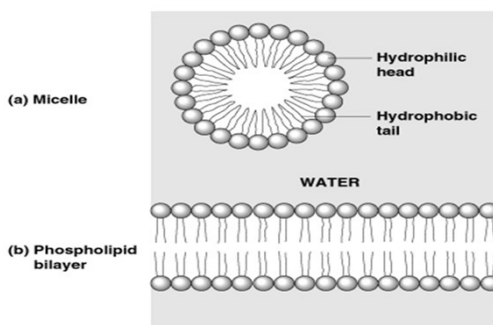


3. Phospholipids

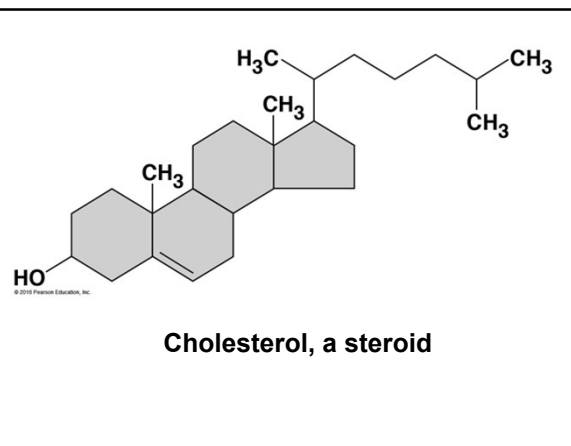
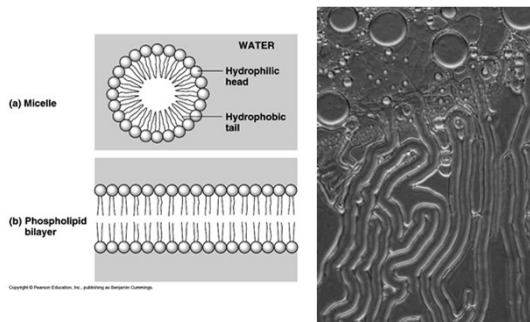
1. Structure: Glycerol + 2 fatty acids + phosphate group.
2. Function: Main structural component of membranes, where they arrange in bilayers.



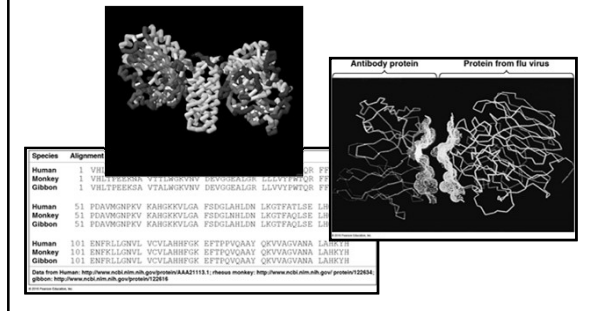
Phospholipids in Water



Hydrophobic/hydrophilic interactions make a phospholipid bilayer

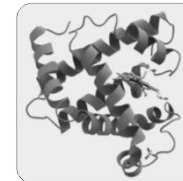


Proteomics: Analysis of proteins and sequences



I. Proteins

- “Proteios” = first or primary
- 50% dry weight of cells
- Contains: C, H, O, N, S



Myoglobin protein

Protein Functions (+ examples)

- Enzymes (lactase)
- Defense (antibodies)
- Storage (milk protein = casein)
- Transport (hemoglobin)
- Hormones (insulin)
- Receptors
- Movement (motor proteins)
- Structure (keratin)

Overview of protein functions

<p>Enzymatic proteins</p> <p>Function: Selective acceleration of chemical reactions</p> <p>Example: Digestive enzymes catalyze the hydrolysis of bonds in food molecules.</p>	<p>Defensive proteins</p> <p>Function: Protection against disease</p> <p>Example: Antibodies inactivate and help destroy viruses and bacteria.</p>
<p>Storage proteins</p> <p>Function: Storage of amino acids</p> <p>Examples: Casein, the protein of milk, is the major source of amino acids for baby mammals. Plants have storage proteins in their seeds. Ovalbumin is the protein of egg white, used as an amino acid source for the developing embryo.</p>	<p>Transport proteins</p> <p>Function: Transport of substances</p> <p>Examples: Hemoglobin, the iron-containing protein of vertebrate blood, transports oxygen from the lungs to other parts of the body. Other proteins transport molecules across membranes, as shown here.</p>

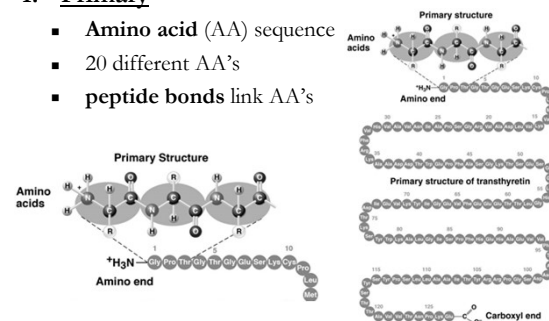
Overview of protein functions

<p>Hormonal proteins</p> <p>Function: Coordination of an organism's activities</p> <p>Example: Insulin, a hormone secreted by the pancreas, causes other tissues to take up glucose, thus regulating blood sugar concentration.</p>	<p>Receptor proteins</p> <p>Function: Response of cell to chemical stimuli</p> <p>Example: Receptors built into the membrane of a nerve cell detect signaling molecules released by other nerve cells.</p>
<p>Contractile and motor proteins</p> <p>Function: Movement</p> <p>Examples: Motor proteins are responsible for the undulations of cilia and flagella. Actin and myosin proteins are responsible for the contraction of muscles.</p>	<p>Structural proteins</p> <p>Function: Support</p> <p>Examples: Keratin is the protein of hair, horns, feathers, and other skin appendages. Insects and spiders use silk fibers to make their cocoons and webs, respectively. Collagen and elastin proteins provide a fibrous framework in animal connective tissues.</p>

Four Levels of Protein Structure

1. Primary

- Amino acid (AA) sequence
- 20 different AA's
- peptide bonds link AA's



Amino Acid

- **R group** = side chains
- **Properties:**
 - hydrophobic
 - hydrophilic
 - ionic (acids & bases)
- “amino” : $-NH_2$
- “acid” : $-COOH$

Side chain (R group)

α carbon

Amino group **Carboxyl group**

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Nonpolar side chains; hydrophobic

Side chain (R group)

Glycine (Gly or G) Alanine (Ala or A) Valine (Val or V) Leucine (Leu or L) Isoleucine (Ile or I)

Methionine (Met or M) Phenylalanine (Phe or F) Tryptophan (Trp or W) Proline (Pro or P)

Polar side chains; hydrophilic (sometimes classified as nonpolar)

Serine (Ser or S) Threonine (Thr or T) Cysteine (Cys or C) Tyrosine (Tyr or Y) Asparagine (Asn or N) Glutamine (Gln or Q)

Electrically charged side chains; hydrophilic

Acidic (negatively charged)

Aspartic acid (Asp or D) Glutamic acid (Glu or E)

Basic (positively charged)

Lysine (Lys or K) Arginine (Arg or R) Histidine (His or H)

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Peptide bond

New peptide bond forming (releasing H_2O)

Side chains

Backbone

Amino end (N-terminus) **Peptide bond** **Carboxyl end (C-terminus)**

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Four Levels of Protein Structure (continued)

2. Secondary

- Gains 3-D shape (folds, coils) by **H-bonding**
- **Alpha (α) helix**, **Beta (β) pleated sheet**

Secondary Structure

α helix **Hydrogen bond**

β pleated sheet **β strand** **Hydrogen bond**

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Basic Principles of Protein Folding

- A. Hydrophobic AA buried in interior of protein (hydrophobic interactions)
- B. Hydrophilic AA exposed on surface of protein (hydrogen bonds)
- C. Acidic + Basic AA form salt bridges (ionic bonds).
- D. Cysteines can form disulfide bonds.

Four Levels of Protein Structure (continued)

3. Tertiary

- Bonding between **side chains** (R groups) of amino acids
- H bonds, ionic bonds, disulfide bridges, hydrophobic interactions, van der Waals interactions

Hydrogen bond

Disulfide bridge

Hydrophobic interactions and van der Waals interactions

Ionic bond

Polypeptide backbone

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Four Levels of Protein Structure (continued)

4. Quaternary

- 2+ polypeptides bond together

Hemoglobin: Shows α subunit, β subunit, Heme, and Iron.

Collagen: Shows a triple helix structure.

amino acids \rightarrow polypeptides \rightarrow protein

(a) Primary structure: Val - Gly - Ser - Leu

(b) Secondary structure: β Pleated sheet, α Helix

(c) Tertiary structure

(d) Quaternary structure

Hydrogen bonding (ionic & H) can create asymmetrical attractions

Chaperonins assist in proper folding of proteins

Chaperonin (fully assembled): Hollow cylinder, Cap

Steps of Chaperonin Action:

- 1 An unfolded polypeptide enters the cylinder from one end.
- 2 The cap attaches, causing the cylinder to change shape in such a way that it creates a hydrophilic environment for the folding of the polypeptide.
- 3 The cap comes off, and the properly folded protein is released.

- Protein **structure and function** are sensitive to chemical and physical conditions
- Unfolds or **denatures** if **pH** and **temperature** are not optimal

Normal protein $\xrightarrow{\text{Denaturation}}$ Denatured protein

Denatured protein $\xrightarrow{\text{Renaturation}}$ Normal protein

change in structure = change in function

	Primary Structure	Secondary and Tertiary Structures	Quaternary Structure	Function	Red Blood Cell Shape
Normal	1 2 3 4 5 6 7	Normal β subunit	Normal hemoglobin	Proteins do not associate; each carries oxygen.	Normal red blood cells are full of individual hemoglobin proteins. 5 μ m
Sickle-cell	1 2 3 4 5 6 7	Sickle-cell β subunit	Sickle-cell hemoglobin	Hydrophobic Interactions between proteins lead to aggregation; oxygen carrying capacity reduced.	Fibers of abnormal hemoglobin deform red blood cell into sickle shape. 5 μ m

X-ray crystallography used to determine the 3-D structure of proteins

Technique: X-ray source, X-ray beam, Crystal, Diffracted X-rays, Digital detector, X-ray diffraction pattern

Results: 3D model of the protein structure

Genomics: Analysis of genes and genomes

II. Nucleic Acids

Function: store hereditary info

DNA	RNA
<ul style="list-style-type: none"> • Double-stranded helix • N-bases: A, G, C, <i>Thymine</i> • Stores hereditary info • Longer/larger • Sugar: deoxyribose 	<ul style="list-style-type: none"> • Single-stranded • N-bases: A, G, C, <i>Uracil</i> • Carry info from DNA to ribosomes • tRNA, rRNA, mRNA, RNAi • Sugar: ribose

Nucleotides: monomer of DNA/RNA

Nucleotide = Sugar + Phosphate + Nitrogen Base

(a) Polynucleotide, or nucleic acid

(b) Nucleotide

Nucleotide

phosphate

5-C sugar

Nitrogenous base { A - T, G - C }

Deoxyribose (in DNA) Ribose (in RNA)

(c) Nucleoside components

SUGARS

Deoxyribose (in DNA) Ribose (in RNA)

NITROGENOUS BASES

Pyrimidines

Cytosine (C) Thymine (T, in DNA) Uracil (U, in RNA)

Purines

Adenine (A) Guanine (G)

Information flow in a cell: DNA → RNA → protein

1 Synthesis of mRNA

2 Movement of mRNA into cytoplasm

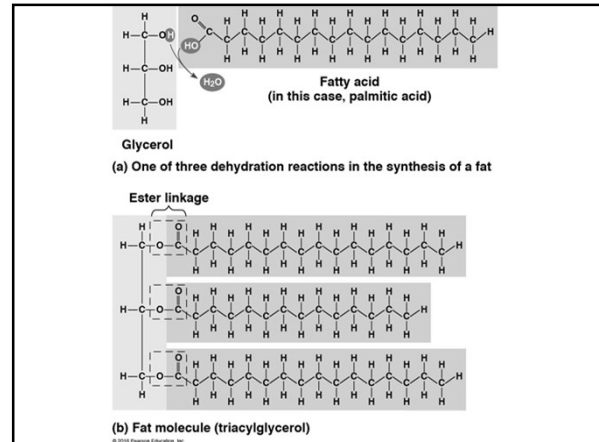
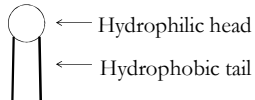
3 Synthesis of protein

Polypeptide

Amino acids

IV. Lipids

- A. Fats (triglyceride):** store energy
 - Glycerol + 3 Fatty Acids
 - saturated, unsaturated, polyunsaturated
- B. Steroids:** cholesterol and hormones
- C. Phospholipids:** lipid bilayer of cell membrane
 - hydrophilic head, hydrophobic tails



(a) Saturated fat

Structural formula of a saturated fat molecule

Space-filling model of stearic acid, a saturated fatty acid

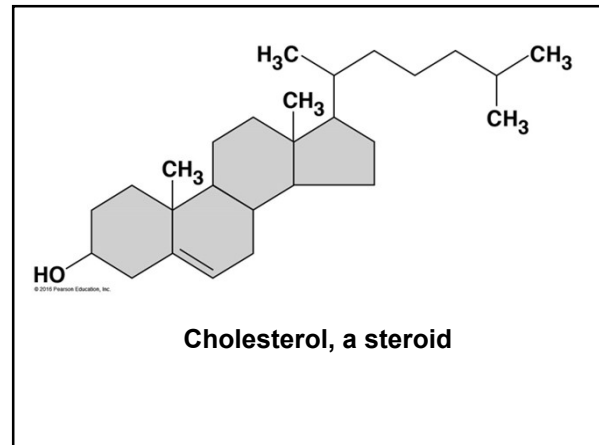
(b) Unsaturated fat

Structural formula of an unsaturated fat molecule

Space-filling model of oleic acid, an unsaturated fatty acid

Cis double bond causes bending.

Saturated	Unsaturated	Polyunsaturated
"saturated" with H	Have some C=C, result in kinks	
In animals	In plants	
Solid at room temp.	Liquid at room temp.	
Eg. butter, lard	Eg. corn oil, olive oil	



(a) Structural formula

(b) Space-filling model

(c) Phospholipid symbol

(d) Phospholipid bilayer

The structure of a phospholipid

Hydrophobic/hydrophilic interactions make a phospholipid bilayer

(a) Micelle

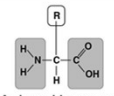
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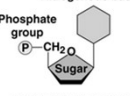


Hydrophilic head

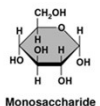
Hydrophobic tail




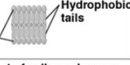

(b) Phospholipid bilayer

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Components	Examples	Functions
 <p>Amino acid monomer (20 types)</p>	<ul style="list-style-type: none"> Enzymes Structural proteins Storage proteins Transport proteins Hormones Receptor proteins Motor proteins Defensive proteins 	<ul style="list-style-type: none"> Catalyze chemical reactions Provide structural support Store amino acids Transport substances Coordinate organismal responses Receive signals from outside cell Function in cell movement Protect against disease

Components	Examples	Functions
 <p>Nucleotide monomer</p>	<p>DNA: </p> <ul style="list-style-type: none"> Sugar = deoxyribose Nitrogenous bases = C, G, A, T Usually double-stranded <p>RNA: </p> <ul style="list-style-type: none"> Sugar = ribose Nitrogenous bases = C, G, A, U Usually single-stranded 	<p>Stores hereditary information</p> <p>Various functions in gene expression, including carrying instructions from DNA to ribosomes</p>

Components	Examples	Functions
 <p>Monosaccharide monomer</p>	<p>Monosaccharides: glucose, fructose</p> <p>Disaccharides: lactose, sucrose</p> <p>Polysaccharides:</p> <ul style="list-style-type: none"> Cellulose (plants) Starch (plants) Glycogen (animals) Chitin (animals and fungi) 	<p>Fuel; carbon sources that can be converted to other molecules or combined into polymers</p> <ul style="list-style-type: none"> Strengthens plant cell walls Stores glucose for energy Strengthens exoskeletons and fungal cell walls

Components	Examples	Functions
 <p>Glycerol</p>	<p>Triacylglycerols (fats or oils): glycerol + three fatty acids</p>	<p>Important energy source</p> 
 <p>Phospholipid</p>	<p>Phospholipids: glycerol + phosphate group + two fatty acids</p>	<p>Lipid bilayers of membranes</p>  <p>Hydrophilic heads</p> <p>Hydrophobic tails</p>
 <p>Steroid backbone</p>	<p>Steroids: four fused rings with attached chemical groups</p>	<ul style="list-style-type: none"> Component of cell membranes (cholesterol) Signaling molecules that travel through the body (hormones)